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Evaluating the Emission of CO_2 at Traffic Intersections with the Purpose of Reducing Emission Rate, Case Study: The University of Nigeria, Nsukka

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Abstract

Traffic congestion is a major problem around the world that results in slower speeds, increased trip time and a longer queuing of vehicles. The production and use of fuels for vehicles results in emissions of greenhouse gases (GHSs), besides carbon dioxide, which include methane and nitrous oxide. Traffic lights that wirelessly keep track of vehicles could reduce journey time and fuel consumption thereby reducing carbon emissions. In view of the importance of vehicles as an emitter of GHGs, namely CO_2, with the growing concern about climate change, this paper aims to explore the emission of CO_2 from vehicles at a traffic intersection for the purpose of reducing emission rate. Realising this reduction, points to the implementation of an Advanced Traffic Management System (ATMS) with Wireless Sensor Networks (WSNs) on the road network of a region will be discussed. With such a technology, a region can experience lower queue lengths at an intersection and therefore lower CO_2 emission surrounding the area. The University of Nigeria, Nsukka (UNN) is used as a case study in exploring this phenomenon which over the years has seen a drastic increase on the amount of cars on the campus area. With the assumption that an ATM system with WSNs is deployed on the UNN campus area, the paper looks into the traffic dynamics that makes it possible to evaluate CO_2 emission at traffic light intersections to ensure a cleaner environment. Throughout the paper, it will be made clear that with the relevant equation of CO_2 emission and the arrival time per vehicle, CO_2 emission rate can be evaluated at a traffic intersection depending on the volume of cars at the intersection. With such evaluation, further analysis can be made on ways to actually reduce CO_2 emission and techniques for implementation with an ATM system.

Keywords

CO2 emission; Traffic Dynamics; Intersection; Arrival Times; Wait Times

1. Introduction

Over the years, The University of Nigeria, Nsukka (UNN) has seen an ever-increasing traffic demand which, as a result, has brought in problems of congestion and air pollution. The pollution issue results from exhaust gases emitted from the combustion of fuel released into the atmosphere through the pipes of motor vehicles. Consequently, the emissions from these cars are the primary causes to the greenhouse effect and a main contribution to air pollution (UCS, n.d.). Additionally, due to the increase in the number of vehicles, the university has seen an increase of congestion particularly at the intersection of road networks where cars mainly experience "stop and go" traffic of usually long queue lengths. This further augments air pollution where vehicles are emitting more at stagnant positions on the campus area for a considerable amount of time.

The solution in reducing these greenhouse gases from vehicles and therefore decrease the congestion at intersections is an effort towards the implementation of an Advanced Traffic Management System (ATMS) through the deployment of smart traffic lights with Wireless Sensor Networks (WSNs). With such a system, traffic conflict will be minimised and queue lengths will be shortened through optimum and more efficient traffic signalling switch control. This, by all means, will cut down vehicle journey times, reduce waiting times, and consequently reduce the amount of gases emitted at a closed area on the campus.

This paper aims to explore the emission of CO_2 from vehicles at a traffic intersection for reducing emission rate. In order to realise the reduction level of the greenhouse gas at the crossroads, it is assumed that The University of Nigeria has implemented an ATM system with WSNs to manage traffic flow in the region. A study by Chinedu & Nathan (2014) provides such implementation where it focuses on the deployment approach on a region where no existing infrastructure is in place such as the UNN campus area.

1.1. Existing Works

Works on the use of WSNs for the monitoring and control of traffic flows have been pursued at different levels. Goel, Ray & Chandra (2012) provided work on an adaptive traffic signal system with WSN technology. The proposed system was designed to give a clear way for emergency vehicles on the road to reach their destination. The system involved a traffic intersection that was smart enough to manage traffic flow anytime an emergency vehicle needed to pass through. Although actual implementation was not pursued, the work provided a great insight into the use of WSNs for a smart traffic light system.

Yousef, Al-Karaki & Shatnawi (2010) also presented an adaptive traffic control system using WSNs but this time actual new techniques were provided for the controlling of traffic flow sequences. These techniques were dynamically adaptive to traffic conditions on both single and multiple intersections. The proposed system involved the usage of a WSN to instrument and control traffic signals roadways, and an intelligent traffic controller developed to control the operation of the traffic infrastructure supported by the WSN. This work gave a real deep insight and understanding on the design and traffic control algorithm for the proposed smart control lighting system.

In contrast to the previous sources where conventional WSNs were used with known sensing methods, Professor Al Bovik, (2017) presented a Wireless Visual Sensor Network scheme for the management of urban traffic flow. The approach was an innovative method into the way traffic flow can be controlled with the use of a complex visual sensor network that can automatically or semi-automatically deliver information on traffic flow more resourcefully. The proposal also represented an incredible opportunity into fast-forward technological innovations in many areas that include video acquisition and processing over wide geographic areas by smart cameras; and the integration of the information learned between cameras to reach aggregate understanding of the complex (traffic) scenes. Although complex, the technological proposals will have incalculable impact on society, the economy, and the fragile environment, when implemented.

Unlike previous literature and the subsequent sources of Toepfer, Chervakova, Goetze, Hutschenreuther, Nikolić & Dimitrijević (2015), Collotta, Salerno & Scata (2012) and Zhou, Cao, Zeng & Wu (2010) where deep insights were given on a traffic control system with WSNs, this paper attempts to exploit the realization of the ATM system for the conceptual evaluation of CO_2 emission at traffic intersections. It will be presented that through the relevant equations of CO_2 emission and arrival time per vehicle, CO_2 emission can be evaluated at a traffic intersection depending on the volume of cars at the intersection. With such assessment, further scrutiny can be made to reduce CO_2 emission with the implementation of an ATM system.

1.2. Overview of the Study

Consider the scenario of Fig. 1 where there is a traffic intersection with four external approaches.

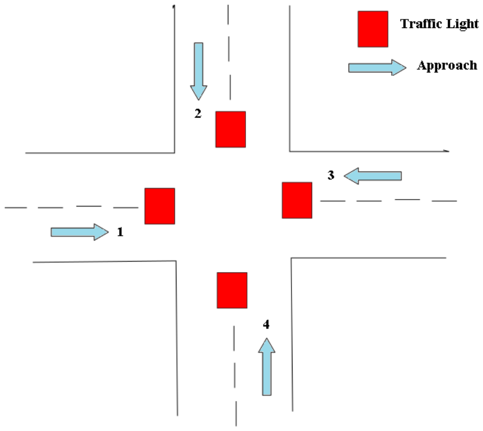

Figure 1. TrafficIntersection with approaches

Directions 1 and 3 are opposite each other and so share the same green times, whereas directions 2 and 4 share the same signaling times. For simplicity, each direction consists of a single lane and turning lanes are not considered (David 2009), (Shih 2013).

A network of sensors and traffic lights are deployed to make up the ATM system as shown in Fig. 2.

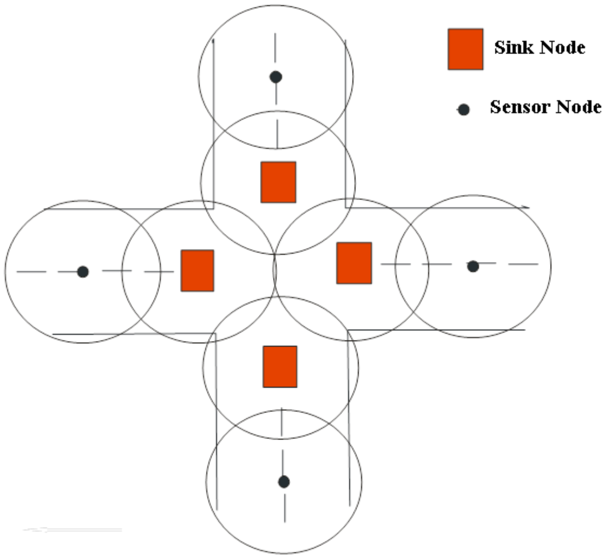

Figure 2. ATM system with WSNs.

As observed from Fig. 2, traffic lights are deployed for each external approach and sensor nodes, connected through the overlap of their coverage, are placed on each approach path where the node closest to the traffic light (sink node) is connected in the same way.

From Fig. 2, it can be seen that the system is made up of clusters of WSNs where the traffic lights are the cluster heads and sensor nodes are candidates of the cluster network. The candidates essentially detect vehicle activity and send relevant information such as the arriving, waiting, and departing times of motor vehicles to the corresponding cluster head. The traffic lights can then determine queue lengths for each approach and react accordingly. The primary goal of the network will be to determine the traffic signaling switch times that will minimize the average delay of vehicles at the intersection. A base station, deployed externally from the system can be used to manage all traffic lights.

2. Traffic Dynamics with CO_2 Effect

As mentioned in Section 2, the ATM system with WSNs measures the queue length of each path approach, detects, and estimates the volume of traffic. The goal of the system, as previously stated, is to determine the traffic signaling switch times that minimizes the average delay of vehicles at the intersection. It is understood that the longer cars wait at an intersection, which therefore increases the queue length because more cars are arriving in time, the more CO_2 is being emitted in that closed area surrounding the intersection. Since vehicles are static during the red phase of a signaling light, the focus of analyzing the amount of CO_2 emitted per vehicle is on that red stage of the traffic light where cars are delayed and more are arriving at the intersection.

2.1. Analysis on Emission of CO_2 at Traffic Intersections

At any given time and during motion, vehicles are emitting CO_2 which is proportional to their travel time (seconds), travel distance (m), and acceleration energy (m^2/s^2) as modeled by the following equation by Guan, Sengupta, Krishnan & Bai (2008) and Li & Shimamoto (2011).

$$E_{CO_2} = 0.3K_C T + 0.028K_C D + 0.056K_C A_{ee} \tag{1}$$

$$A_{ee} = \sum_{k=1}^{K} \sigma_k ({v^2}_k - {v^2}_{k-1}) \tag{2}$$

Where:

E_{CO2}= CO2 emissions (g);

K_C= Coefficient between gasoline consumption and CO2 emissions (g/cc);

D = Travel distance (m);

T = Travel time for the distance D (seconds);

A_{ee}= Acceleration Energy Equivalent (m^2/s^2);

v_k = The speed at time k (m/s);

σ_K= When accelerating, this equals 1; otherwise, it equals 0.

Applying equation 1 to the condition of vehicle motion at an intersection implies that A_{ee}=D=0. Therefore, equation 1 is simplified to:

$$E_{CO_2} = 0.3K_C T \tag{3}$$

Equation 3 is the relationship that is used in describing emission at the red phase of the signaling light where cars are on standby waiting to continue with their journey.

It is understood that the waiting time for all vehicles at the queue of the red phase are different. This is because cars are arriving at subsequent times to the queue which as a result defines the amount of emission per vehicle. To get an idea of the individual amount of CO_2 emitted by each vehicle at the red stage is to imply that the red phase has a length of (t_2-t_1) where t_1 is the start of the red signal and t_2 is the end of the signal getting ready to turn to green. Therefore, let q_{wait}=$q_{wait}(t_1,t_2)$. If $j \le q_{wait}$ or $q_{wait}(t_1) \le j \le q_{wait}(t_2)$ which represents the position in the queue of a vehicle waiting, then at the beginning of the red phase, the wait time of the j^{th} vehicle in the queue is:

$$t_2 - at_j \tag{4}$$

Where is the arrival time of the j^{th} vehicle (David, 2009), (Shih, 2013). To be precise, determining the arrival times for each vehicle is the key in defining the total amount of CO_2 emitted at the intersection area.

2.2. Arrival Time

For a more realistic approach, it is assumed that cars are arriving to an intersection randomly and unrelated. This makes the Poisson distribution process a more suitable model for arrivals in which in the process, inter-arrival times follow the exponential distribution with the probability density function (pdf) of Yates & Goodman (2005):

$$f(x) = \lambda e^{-\lambda x} u(x) \tag{5}$$

Where λ is the arrival rate in vehicles per minute per approach, and u(x) is the unit step function. The step function is required because negative inter-arrival times are impractical (David, 2009).

Equation 5 allows for a response that is instant and because realistically the traffic dynamics of a traffic scenario requires a minimum space between vehicles, the exponential distribution is shifted for a more practical inter-arrival time. Therefore, equation 5 is modified in Luttinen (1996):

$$f(x) = \frac{\lambda}{1-\lambda(space)} e^{-\frac{\lambda}{1-\lambda(space)}(x-space)} u(x-space) \tag{6}$$

Where *space* is the minimum space between vehicles in seconds. Consequently, vehicle arrival times can be generated by the following equation David (2009) & Pang-shi (2013):

$$at_2 = at_1 + space - (\frac{1}{\lambda} - space)\log(\gamma) \tag{7}$$

Where at_2 is the next arrival time; at_1 is the previous arrival time; and $\gamma$is the uniformly distributed random number between 0 and 1 Ramanathan (1993).

3. Evaluation of CO_2 Emission at Intersection

In evaluating the amount of CO_2 emitted, an intersection of the UNN campus area was chosen as determined by Chinedu & Nathan (2016) to carry out the analysis. This is marked with a circle as shown in Fig. 3.

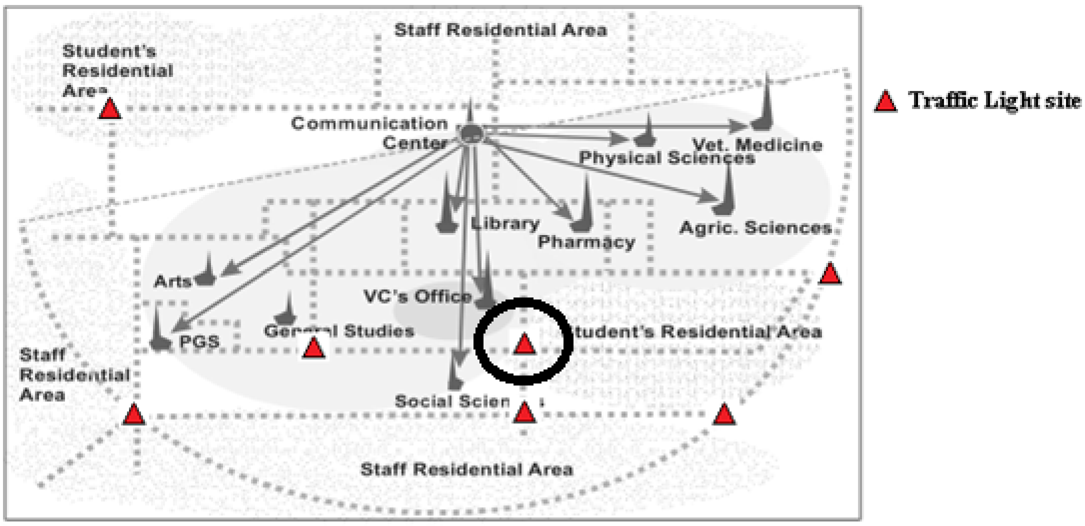

Figure 3. Chosen Intersection

Using Figure 1 as a template, it was observed that the average number of cars arriving per minute at the marked intersection per approach was recorded as shown in Table 1.

Table 1. Volume of Cars per minute for each approach

Approach	Volume of Cars
1	20
2	10
3	15
4	25

The following are the obtained sample results for Approach 1 using the parameters presented in Table 2.

Table 2. Parameters for Evaluation

K_C	2.31g/cc
t_2	60 seconds

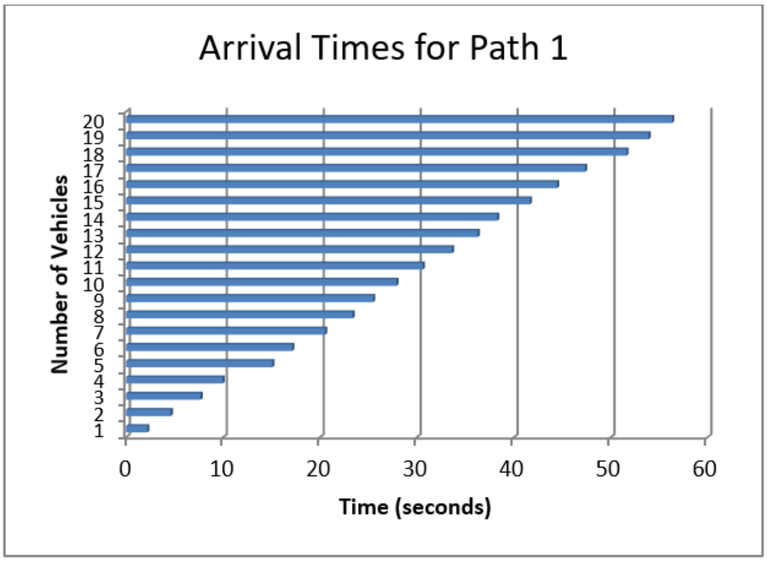

Figure 4. Arrival Time for each vehicle

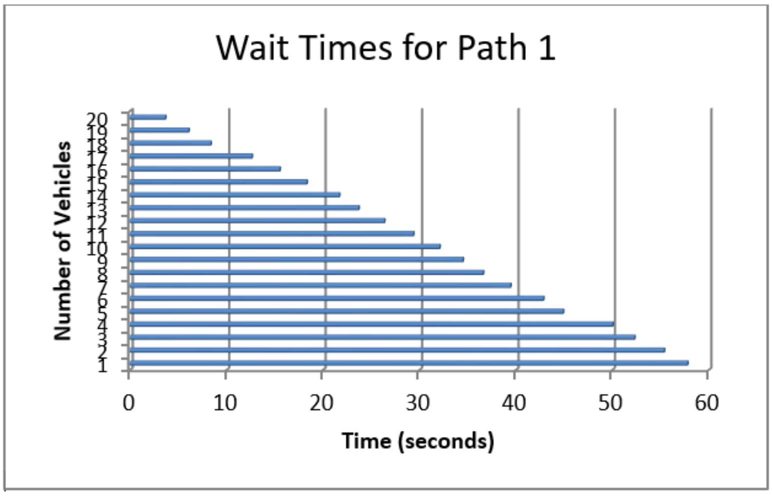

Figure 5. Wait Times for each vehicle for t2=60 seconds

Based on the arrival times of Figure 4 and the wait times of Fig. 5, it was observed that the CO_2 emission per vehicle was directly proportional to the wait times and inversely proportional to the arrival times as expected and as shown in Fig. 6. This meant vehicles arriving subsequently after the first arrival, emitted less CO_2 due because of their lesser wait time. The total amount of CO_2 emitted was recorded as 423.9354 grams for t_2=60 seconds.

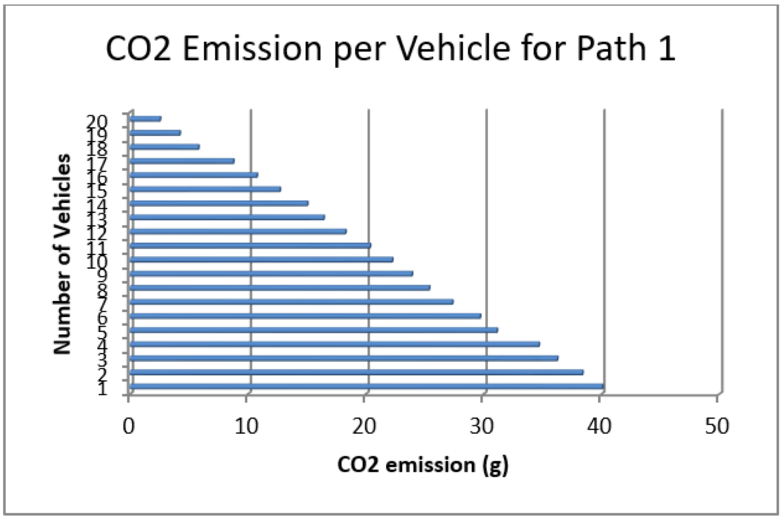

Figure 6. CO2 emission for each vehicle for t2=60 seconds

Observing Figs. 5 and 6, it can be seen that reducing CO_2 emission would essentially mean decreasing length t_2 of the red phase. The following figures provide proof of this conjecture of which t_2 was reduced to 30 seconds.

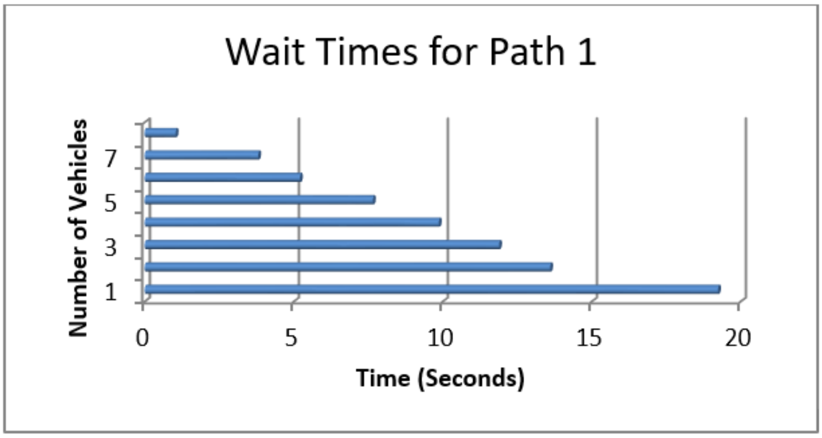

Figure 7. Wait Times for each vehicle for t2=30 seconds

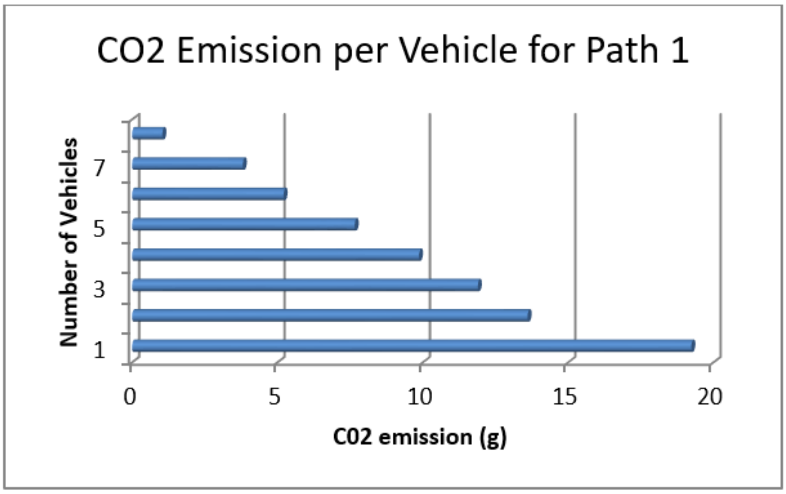

Figure 8. CO2 emission for each vehicle for t2=30 seconds

Observing both Figures 7 and 8**,** it can be seen that shortening the red phase length to 30 seconds produces better results than t_2=60 seconds. First of all, the wait times for all vehicles is reduced and because the red stage length is shortened, this produces smaller queue lengths due to the lesser amount of cars waiting at the intersection. Because wait time is directly proportional to CO_2 emission, the amount of emission of the greenhouse gas has also reduced in comparison to that of t_2=60 seconds. The total amount of CO_2 emitted was recorded to be 72.33712 grams for t_2=30 seconds which is considerable less than the CO_2emitted for the red phase length of 60 seconds.

In applying this analysis for the entire four lane approach of Figure 1, it is safe to say that reducing the red phase length of a traffic signaling switch system is the most optimum way to minimize the average delay of vehicles at the intersection. Through the reduction, queue lengths will be shortened and consequently CO_2 emission and other greenhouse gases will be less at that closed area of the intersection.

4. Conclusion

This paper provides an exploration on the emission of CO_2 from vehicles at a traffic intersection for the purpose of reducing emission rate. The University of Nigeria, Nsukka was used as the case study where it was assumed that an Advanced Traffic Management System with Wireless Sensor Networks was deployed in the campus area. The focus of this exploration was at the red phase of a traffic light where the greenhouse gas of CO_2 is being emitted from vehicles at static positions. It was found out that arrival times and wait times of uncorrelated vehicles was crucial in evaluating the total CO_2 emission at an intersection. Through the evaluation and in an attempt to reduce greenhouse gas emission, the ATM system with WSNs can be fitted with CO_2 detection mechanisms to monitor levels of the greenhouse gas on road networks which can then ensure a cleaner campus environment.

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