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Intelligent Traffic Management System to Improve Mobility at Ayigya, a Commuter City in Ghana

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***Abstract**: The issue of vehicular traffic congestion is faced by most road users all over the world, including Ghana. The complications intensify day in and day out, especially in most urban areas, due to development and urbanization. The exponential increase in road users awakens concern for an effective road transportation system to convey people and goods from one place to another. In an attempt to mitigate the effect of the problem, a system based on a statistically programmed lighting sequence was introduced. This technique served its purpose for some time and was realized to be inefficient because it controlled traffic flow by assigning a fixed amount of green light time to each phase of traffic, which meant that green light time was sometimes given to lanes even when there was no conflicting traffic. The persistent nature of the problem requires the need for an intelligent traffic management system to effectively coordinate the flow of vehicles through the available road network. The proposed system works based on priority queuing, where green and red phases are dynamically assigned to lanes depending on the present traffic volume. The proposed system uses two methods of counting to determine the highest lane count. They are the Digital Vehicle Counting (DVC) and the Manuel Vehicle Counting (MVC) methods. An effective detection zone of sixty meters is declared away from the traffic intersection. The values produced by both counting methods are fed to the Traffic Phase Router (TPR) for comparison. The lane with the highest vehicle counts from both counters is given the chance to leave the intersection. The proposed system was designed using Simulation of Urban Mobility (SUMO) software. Results obtained after the simulation showed that the proposed system performed better than the existing system based on the Key Performance Indicators (KPIs) used.*

***Keywords**: Digital Vehicle Counting (DVC), Intelligent Traffic Management System (ITMS), Manual Vehicle Counting (MVC), Traffic Phase Router (TPR).*

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I. INTRODUCTION

A. Overview

The current traffic management system deployed in Ghana is based on fixed time allocation which is unable to acclimatize to changes in traffic demands, as a result creating unnecessary delays at the intersection [1][15][16]. The inability of the existing traffic management system to cope with large volumes of traffic on inadequate road infrastructures results in huge congestion and prolonged waiting times [1] [5][17][18][19]. This suggests that one of the effective ways to manage traffic flow is to introduce automation or intelligence to roadside infrastructure [3] [4]. The main objective of this project was to design an Intelligent Traffic Management System (ITMS) that effectively manages traffic at an isolated intersection by dynamically assigning priority to lanes depending on the immediate traffic demand. The proposed system comprises two techniques that aid in counting vehicles within a declared effective detection area which is sixty meters away from the traffic intersection. The vehicle counts from both technologies for each lane are fed into the Traffic Phase Router for comparison so that the lane with the highest vehicle counts from both counters is given priority to leave the traffic intersection. The proposed system is limited to coordinating traffic flow at an isolated intersection with its efficiency being tested in a virtual simulating environment.

B. Literature Review

Transportation by road undoubtedly is one of the regular and widely used means of throughout the country. The need to transport people, goods, and other items is on the rise, leaving massive congestion on many urban roads, creating discomfort for commuters, increasing fuel consumption and emissions, contributing to air pollution and climate change [1], as well as decreasing economic productivity, among others [2] [6]. Various methods, designs, and projects in that regard have been developed to reduce the effect of this problem. In [7] infra-red sensors were used to collect traffic data and fed to a microcontroller. The system was easy to implement, with priority given to emergency vehicles, however, the sensors were unable to differentiate between pedestrians and other objects from vehicles, hence they may not be entirely reliable.

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[8] Combined ultrasonic sensors and GSM technology to control traffic flow at an isolated intersection. The system consumes less power but periodic checking of accuracy and precision is required for effective operation.

[9] This paper proposes a system that combines a Wireless Sensor Network (WSN) and fuzzy logic for real-time traffic monitoring. The system is, however, not flexible and has lots of complex computations.

[10] Propose the use of pneumatic tube sensors. Inaccuracy in axle count when truck and bus volumes are high causes a great defect in the system.

[14] Proposed the use of piezo-electric sensors which obtain data by converting mechanical energy into electrical energy. The system is quite simple to install, and piezo-electric sensors are highly compatible with the pavement, however operation over long cables may introduce noise into the system.

The system in [13] adapt to sudden changes in traffic demand thereby enhancing high throughput at intersections; nevertheless, it consumes much power and has high operational cost. The systems proposed in [11] gives a much more accurate count as compared to the other commonly used techniques but it is very expensive to implement.

[12] Assures fast and reliable communication between vehicles but it cannot be installed in rural areas with no internet connection.

C. Data Collection

Data were collected at the Ayigya traffic intersection in three sections during specific working hours of the day. These included the morning, afternoon, and evening sections. During data collection, so much importance was attached to the morning and evening rush sections, where roads were usually busy due to office activities commencing and ending, respectively, in and around those times. Data collection in the morning section started from 6 a.m. to 8 a.m., in the afternoon section from 12 p.m. to 1 p.m., and in the evening section from 5 p.m. to 7 p.m. The selected intersection for data collection was considered at various random intervals, with the necessary deductions made to give a meaningful traffic pattern. Table 1 below shows the data collected at the Ayigya traffic intersection.

Table 1. Data Collection

Location	Session	Arrival (Average No. of Vehicles per hour)	Departure (Average No. of Vehicles per hour)
Tech Junction-to-Top High	MORNING	45	60
Bomso-to-Ayigya	MORNING	20	30
Tech Junction-to-Top High	AFTERNOON	35	50
Bomso-to-Ayigya	AFTERNOON	24	29
Tech Junction-to-Top High	EVENING	40	55
Bomso-to-Ayigya	EVENING	25	32

II. PROPOSED SYSTEM

The proposed system comprises two techniques that aid in counting vehicles within the effective detection area. They are the Digital Vehicle Counting (DVC) technique and the Manual Vehicle Counting (MVC) technique. The effective detection zone serves as a focal area where system operations are based, so vehicles outside this area are ignored. The idea is to consider a particular area close to the intersection and extend it to the entire lane. Of course, if the detection area is less congested or free of traffic, the entire lane can also be assumed to be so. The detection area is defined as being sixty meters away from the traffic intersection. The Digital Vehicle Counter serves as the primary mode for counting vehicles and consists of four cameras, one for each lane. Each camera is responsible for monitoring and capturing vehicles within the detection zone. The camera captures the traffic scene in frames, which are used to generate a vehicle count. The values obtained from each lane are compared, and the highest vehicle count is passed to the traffic phase router. The traffic phase router, after taking the highest count, waits to compare it with the highest value obtained from the manual vehicle counting process to decide the next line of action. The manual vehicle counter serves as the secondary counting method. It consists of a road tube sensor that is laid in a groove cut into the road surface at both the entry and exit points of the detection zone. It maintains a constant burst of air pressure along the tube. When a vehicle drives over the tube, the pressure exerted closes an air switch, which produces an electrical signal. This enables the sensor to detect the entry and exit of vehicles. A count is obtained by dividing the number of axles that pass over the sensors by two. The final vehicle count is determined by subtracting the number of vehicles that left the detection area from those that entered. The final count is then compared with the result attained from the digital vehicle counting process. The next step after the vehicle counting process is assigning priority based on the count. This step is achieved with the help of the traffic-phase router. The highest lane count for both counters (i.e., the DVC and MVC) is placed in variables MAX 1 and MAX 2, respectively, and serves as input to the TPR. The TPR, upon receiving the counts, compares the values. If the value in MAX 1 is greater or equal to that in MAX 2, MAX 1 is considered the highest value, and green phase time is assigned to that lane. However, if MAX 2 is greater than MAX 1, the opposite occurs, and priority is given to the desired lane for vehicles to exit the intersection. Fig 1 below explains the algorithm used by the TPR to assign green phase time.

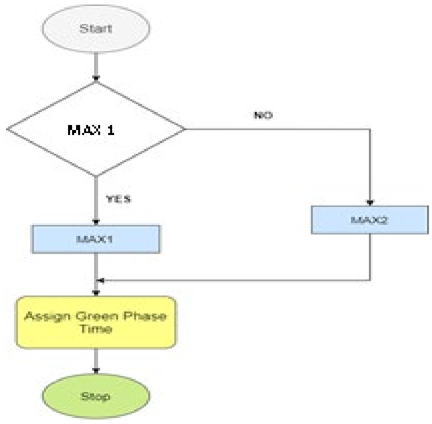

Fig. 1: Algorithm used by the TPR to Assign Green Phase Time

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Below is a flow chart that explains the entire operation of the proposed system.

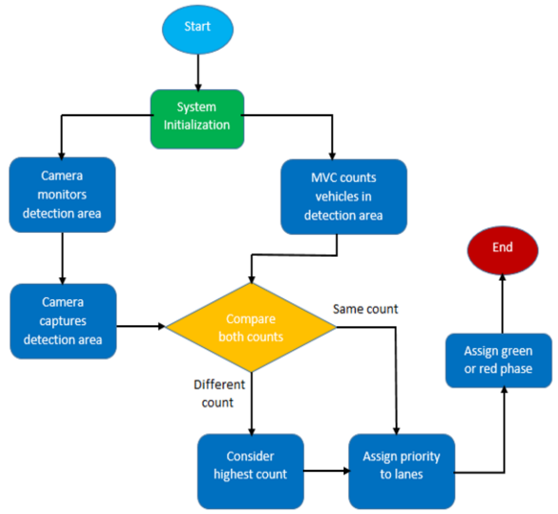

Fig. 2: A Flow Chart of the Proposed System

III. SIMULATION RESULTS

In an attempt to measure the efficiency of both systems, some key performance indicators were considered. They are average vehicular speed, average trip queuing times, and average trip duration. These KPIs serve as the determinants for performance measurements of the systems. Since the goal of this project is to reduce vehicle congestion at an isolated intersection, the KPIs chosen were used to measure traffic congestion and their influence on congestion. Table 2 indicates the chosen KPIs used to outline the performance of both systems.

Table 2. System Key Performance Indicators

Key Performance Indicators	Unit
Average Vehicular Speed	[m/s]
Average Trip Queuing Time	[s]
Average Trip Duration	[s]

A. Average Vehicular Speed

The average vehicle speed is the measure of the speed at which a vehicle moves throughout the network from one point to the next in the simulation. It is expressed in meters per simulation second. This KPI has a significant influence on traffic congestion. Thus, the lower the average vehicle speed throughout the road network, the higher the probability of the occurrence of vehicular traffic congestion, and vice versa. Figure 3 below assesses the performance of both the current and proposed systems in terms of their average vehicular speeds. The blue graph pattern represents the proposed system, with the orange graph pattern representing the current system. The graph below shows that the average vehicle speed for the proposed system is 11.21 meters per second, as opposed to 4.58 meters per second for the current system. This explains that for the same number of vehicles introduced into the network, on average, vehicles in the proposed system drive 6.63 m/s faster as compared to vehicles in the current system. The result obtained primarily means that vehicles in the simulation, on average, would drive at a speed of almost 6 m/s quicker than in the current system. Such a difference is huge and significant for traffic management and analysis.

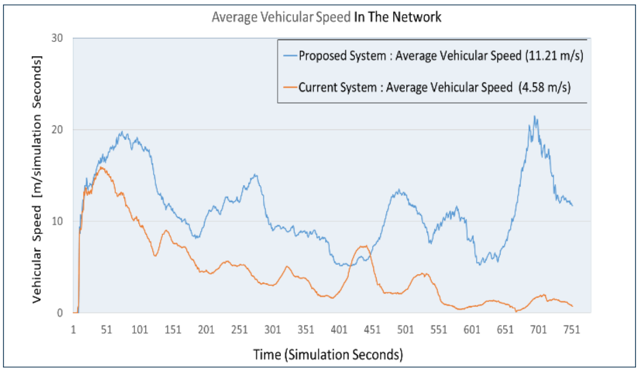

Fig. 3: Average Vehicular Speed

B. Average Trip Queuing Time

The second KPI used for the performance analysis is the average trip queuing time, which actually characterizes the measure of vehicular congestion in the system. It basically represents the time in which a vehicle has to stop and wait on the road network, excluding scheduled or planned stops. In that case, the higher the average trip queuing time, the longer the existence of traffic congestion in the road network, leading to an increase in time loss for a trip, and vice versa. This shows that the average trip queuing time is directly proportional to the trip time loss. The trip queuing time is measured in simulation seconds. Figure 4 below displays the performance of the current and proposed systems in terms of average trip queuing times. The blue graph pattern represents the proposed system, while the orange graph pattern represents the current system. It is realized that the proposed system has an average queuing time of 52.15 seconds as opposed to 68.69 seconds for the current system. This indicates that for the same number of vehicles introduced into the network on average, the proposed system outperforms the current system by 16.54 seconds. This means vehicles in the simulation, on average, would spend at least 16 seconds less queuing on the roads.

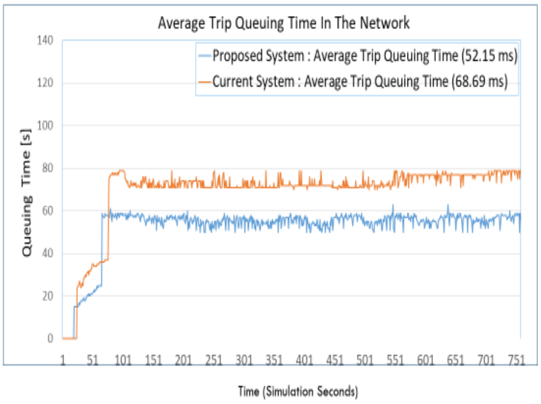

Fig. 4: Average Trip Queuing Time

C. Average Trip Duration

The average trip duration represents the time taken by a vehicle to move from one point to another in the network. The trip duration is also measured in simulation seconds.

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This KPI actually has a direct impact on the average trip queuing time and traffic congestion for both systems. It is seen from t below that the proposed system has an average trip duration of 188.88 seconds as opposed to 249.32 seconds for the current system. This explains that for the same number of vehicles introduced into the network on average, the proposed system performs better than the current system by 60.44 seconds. It further indicates that vehicles in the simulation, on average, would leave the simulation at least 60 seconds faster or earlier than in the current system. The blue graph pattern represents the proposed system, while the orange graph pattern represents the current system.

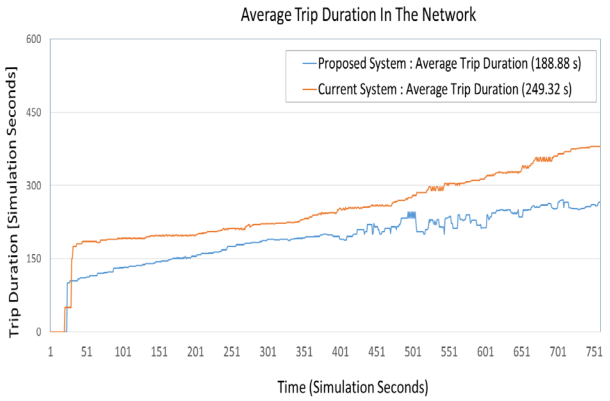

Fig. 5: Average Trip Duration

IV. CONCLUSION

In this project, an intelligent traffic management system that operates based on priority queuing was successfully designed. The system is able to cope with the random nature of traffic. It effectively manages traffic flow at an isolated intersection (bottleneck) by dynamically assigning priority to lanes depending on the present traffic demand. The system was designed in the Simulation of Urban Mobility (SUMO) environment. The simulation results clearly suggested that the proposed system performed better than the existing one with regards to the Key Performance Indicators (KPI's) used.

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