Integration of Data Analytics in the Development of a DTAT-Based Smart Traffic Control System

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Abstract— *Traffic congestion is a global phenomenon. A good number of major cities in the world experience heavy vehicular traffic. Unfortunately, current smart traffic control systems do not utilize data analytics which is an aspect of Artificial Intelligence. This paper proposes the integration of data analytics in the development of a smart traffic control system that is based on Dynamic Time Allocation Technology (DTAT). It adopts a concatenated software development technique which involves object-oriented systems modelling, alongside Cross Industry Standard Process for Data Mining (CRISP-DM) in the development of the DTAT-based smart traffic control system. After applying the two-mentioned modelling patterns to the smart traffic control system, the wait time, go time, and number of vehicles on each road lane were considered the key performance indicators for the performance of the system. Data captured from the KPIs were stored in MySQL database and then imported into Tableau data analytics tool for analysis. Results obtained showed that with the integration of data analytics optimized the general performance of the system as traffic data were better visualized with meaningful insights derived from it, and the condition of traffic could easily be predicted.*

Keywords— *DTAT, Object-Oriented Systems Modelling, CRISP-DM, Data Analytics, A.I*

I. INTRODUCTION

Road traffic congestion is one of the major challenges that has faced most cities in the past and present. It is one challenge that has posed severe negative effects on the environment, the economy, and humans in general [1][2][3]. In 2019, studies suggested that people with respiratory tract diseases such as SARS-CoV-2, COVID-19, etc. are more in urban cities, especially in areas that experience heavy traffic congestion. The rationale behind this is that areas with heavy traffic congestion are exposed to high emission of carbon II oxide (CO) and other toxic gases like chlorofluorocarbons (CFCs) [2][3]. Furthermore, heavy traffic congestion impedes the economic progress of an affected area. In Lagos Nigeria for instance, workers lose about $11 per hour in wages, which amounts to approximately $17,000 daily, due to heavy traffic congestion in the cosmopolitan city [4]. The negative implication of heavy traffic congestion on man and nature is very obvious to state.

Although various projects have been carried out so far to curb the negative effects of heavy road traffic congestions via the implementation of smart systems which comprise the use of cyber-physical devices, much attention has not been given to the utilization of data analytics in making smart traffic control systems more intelligent and effective. As a result, monitoring of the structure and behavior of traffic generated data is given less attention, amounting to the development of traffic signal management systems that are less artificially intelligent.

The main objective of this paper, therefore, is to integrate predictive analytics, an A.I. process, in the development of a DTAT-based smart traffic control system.

The rest of the paper is structured as follows: section 2 is the literature review; section 3 presents materials and method; section 4 describes the system implementation; while sections 5 and 6 present the results and conclusion respectfully.

II. REVIEW OF RELATED LITERATURE

The work in [5] adopted radio frequency identification (RFID), infrared sensors, and GSM in the development of a smart traffic management system. In this work, each vehicle that plied the road had an RFID card attached to it. Although [5] envisaged reducing cost of implementation and maintenance of smart traffic control by adopting the proposed approach, attachment of RFID tags to every vehicle on the road is most likely not cost friendly for cities with high population of vehicles (as applicable in most cases). Nevertheless, the work did not support traffic information sharing mechanism amongst other smart traffic control systems positioned in other locations.

. As reported in [6], the work focused on the application of IoT and a decentralized approach in the development of a smart traffic management system. The work attached RFID tags to vehicles that were referred to as high priority vehicles. These high priority vehicles included; ambulance, fire trucks, etc. Unlike [5] which did not have the capacity of gathering traffic information, [6] made use of cameras that were utilized as sensors for capturing traffic data in real-time. Despite that [6] is more capital intensive than [5] in terms of implementation, the captured data were not subjected to any form analysis which would have been highly instrumental in obtaining more accurate results and making informed decisions.

The proposed solution to [7] is based on vehicle-to-infrastructure (V2I) technology. Rather than using RFID tags on the vehicles, as proposed in [5], this work equipped the vehicles with Dashboard Traffic Light (DBTL) sensors that communicate with the traffic light. Although [6] claimed better efficiency as waiting time was reduced to 23%, the typical function of the DBTL is to enable vehicles ascertain the duration of time remaining for a traffic light to change from red to green. This actually could influence the decision of the driver to change route or not (if possible), but it has no

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direct impact on dynamic allocation of time for the road lanes. In fact, the decision of the vehicle drivers is what primarily influences the traffic situation, rather than the traffic control system itself.

In [8], the focus was on the development of a self-powered triboelectric sensor which is composed of nanofibers for smart traffic management systems. The essence of adopting this technology is to achieve high sensitivity and fast response of smart traffic signals. Although this work neither focused on capturing traffic information nor dynamically control the flow of traffic on roads as discussed in [5][6] and [7], it is considered important due to its significance in the power management and sensitivity of the traffic system.

A framework of smart traffic lights which determines the traffic priority of road lanes based on the level of traffic congestion was proposed in [9]. Traffic congestion is assessed by processing images taken by digital cameras which are based on a decentralized computing infrastructure known as fog computing. Although the work used RFID technology to count the number of cars on the road as applicable to [5][6] and [7], account was not given for traffic data generation which consequently made the outcome to be less intelligent.

From the review it is obvious that much attention has not been given to the utilization of data analytics in making smart traffic control systems more intelligent and effective. As a result, monitoring of the structure and behavior of traffic generated data is given less attention, amounting to the development of traffic signal management systems that are less artificially intelligent.

III. MATERIALS AND METHOD

This paper tends to utilize cheap and readily available components in developing the proposed solution. Object-oriented systems modelling [10][11][12][13] and CRISP-DM were adopted as development methodology.

A. Materials

i. Proteus 8 – a simulation software tool developed by Labcenter Electronics [14]. It is used for simulating the operations of the system.

ii. Arduino Uno Microcontroller – an open-source electronic development board that has the capability of accommodating sensors and actuators, as well as executing Embedded-C code which drives operations of the system [15].

iii. Arduino IDE – a software development tool used for writing programs that run on the Arduino board [15].

iv. Torch LDR – light-dependent resistors that represent the number of vehicles on each lane.

v. Traffic Lights – comprising of red, yellow, and green light emitting diodes (LEDs), it is used to represent road traffic signals at each lane of the road.

vi. 7SEG-MPX2-CA-BLUE – digital liquid crystal display (LCD) counter timer mounted alongside each traffic light. It is used for the dynamic display of the traffic flow and wait time of each road lane.

vii. ESP8266 Wi-Fi Module – for transmission of captured traffic signal to MySQL database.

viii. Tableau – a data analytics software tool used for analyzing captured traffic data in order to derive insights and make informed decisions, a fundamental feature of A.I. [16].

B. Methods

The proposed solution is designed and developed using a combined development methodology that incorporates the CRISP-DM framework along with the use of object-oriented systems modeling. This concatenated approach begins with understanding the operational functionalities of the DTAT-based smart traffic control system, applies unified modelling language (UML) techniques in designing the entities, attributes, operations, and relationships that drive the operational flow of the solution, program models are developed and written in Embedded-C language which runs in the Arduino microcontroller, the captured traffic data is then subjected to predictive analytics using the Tableau Data Analytics / Business Intelligence software tool.

(a) The Requirements of the Proposed Solution

i. The system will read the number of vehicles on each road lane.

ii. The system will compare the number of vehicles against each road lane.

iii. The system will dynamically allocate go time, and wait time to different traffic lights situated at four road lanes which intersect at a point.

iv. The system will assign priority to each road lane based on the number of vehicles and wait time, with relation to other lanes.

v. The system will transmit traffic data in real-time to a centralized database.

vi. Stored traffic data should be subjected to predictive analytics using appropriate data A.I. tool.

(b) Use Cases

The Use Cases are presented in Tables 1-3.

TABLE 1: Read Number of Cars

#1 Name: Read number of cars	
Brief description: This use case describes the steps taken to read the number of cars in each road lane	
Primary Actor: LDR sensor and Road Lane.	
Precondition:	The traffic control system is turned on and initialized. LDR is ready to pick signals.
Trigger	Vehicles approach the LDR region of the road lane. This is simulated by the turning on of the LDR torch light.
Main Flow	
1. System reads the number of LDRs whose signals are instantaneously altered by change in light intensity for road lanes. 2. System compares the result of a specific lane against other lanes. 3. System records the number of read LDR with instantaneous disruption of signal due to change in light intensity as number of cars.	
Alternative Flow	
If no vehicle disrupts the light intensity read by the LDR: a. System does not read number of vehicle.	
Result	
The number of LDR signals instantaneously disrupted at any given point in time is used to represent the number of vehicles on the road lane.	

TABLE 2: Prioritize Road Lanes

| #2	
Name: Prioritize road lanes and dynamically allocate time	
Brief description:	
This use case describes how the system assigns priority to each road lane and dynamically allocates go time / wait time.	
Primary Actor:	
Traffic Signal, Road Lane	
Precondition:	The number of vehicle on road lanes have been ascertained in relation to one another.
Trigger	No. of vehicles on road lanes are known and system attempts to read the wait time of respective lanes.
Main Flow	
1. System reads the wait time on each road lane.	
2. If road lane is on go time, i.e. moving:	
i. The wait time === 0	
3. Read wait time of each road lane.	
4. Check lane with highest no. of vehicles and wait time.	
5. Assign highest priority to it.	
6. Stop go time for moving lane.	
7. Start counting the wait time.	
8. Allocate go time for the road lane with highest priority.	
Alternative Flow	
If the lane in motion maintains highest no. of vehicles and wait time with respect to other lanes:	
a. The active lane still maintains motion while other lanes wait on the standby.	
Result	
Go time are issued to road lanes with highest priority based on the no. of vehicles on the lane and the wait time.	
#3	
Name: Use Traffic Data for Analytics	
Brief description:	
This use case describes steps involved in carrying out data analytics on traffic data.	
Primary Actor:	
Traffic Data, Tableau Data Analytics Tool.	
Precondition:	Go time and wait time have been issued to respective road lanes based on the no. of vehicles and wait time at a given interval of time.
Trigger	Data regarding the go time, wait time and no. of vehicles of each road lane at given intervals of time, are subjected to Tableau for analysis.
Main Flow	
1. Intervals of three hours are given to gather traffic data.	
2. Data regarding go time, wait time, and no. of vehicles for each road lane are sampled within the stated interval.	
3. Sampled data are then subjected to analytics.	
Result	
Traffic data have been sampled within a specific time interval and subjected to Tableau for analytics.	

(c) Use Case Diagram
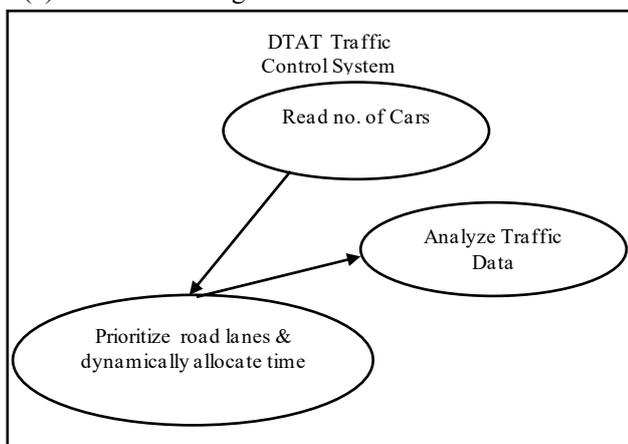
Figure 1: Use Case Diagram of the System

(d) *Conceptual Analysis of the Proposed System*

In taking a critical consideration of the nature of the system with respect to the established requirements and use cases, it is observed that the proposed solution has the following key entities – microcontroller, road lane, traffic light, and traffic information. These are considered key entities with attributes and operations. Furthermore, they are considered entities as they do have state, behaviours, and values [10][11].

The attributes and operations of the identified entities are captured as thus:

Microcontroller
- LDR sensor
- ESP8266 Wi-Fi module
- Embedded-C program
+readRoadVehicle();
+assignGoTime();
+assignWaitTime();
+transmitTrafficData();

Traffic Light
- Go time
- Wait time
+readGoTime();
+readWaitTime();

Road Lane
- No. of Cars (LDR)
- Traffic Signal

Traffic Information
- Road lane
- Time interval
- No. of vehicle
- Wait time
- Go time

(e) Conceptual Class Diagram

Figure 2 presents the conceptual class diagram of the system which shows the interrelationship between entities.
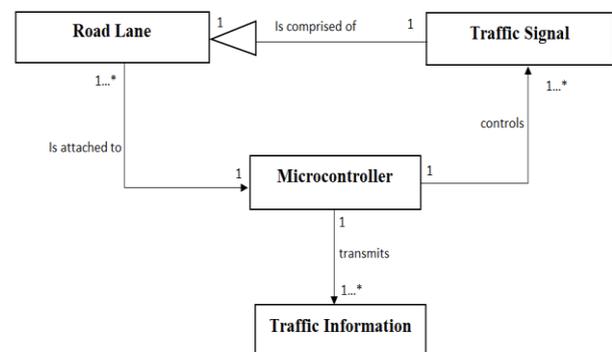

Figure 2: Conceptual Class Diagram of the System

IV. SYSTEM IMPLEMENTATION

The proposed solution was implemented in Proteus simulation environment [14]. In so doing, some of the materials outlined in section 3.0.1 which include – Arduino

Uno, Torch LDR, Traffic Lights, 7SEG-MPX2-CA-BLUE, and ESP8266 Wi-Fi module were used in Proteus to simulate the traffic control system.

Nevertheless, the Embedded-C program which drives the operational functionalities of the microcontroller and consequently the entire system, was programmed using the Arduino IDE. The developed program was then converted into a hexadecimal file format and uploaded into the memory of the Arduino Uno microcontroller in the Proteus simulation environment. Traffic information gathered are the transmitted via the Wi-Fi module and sent to MySQL database for analysis.

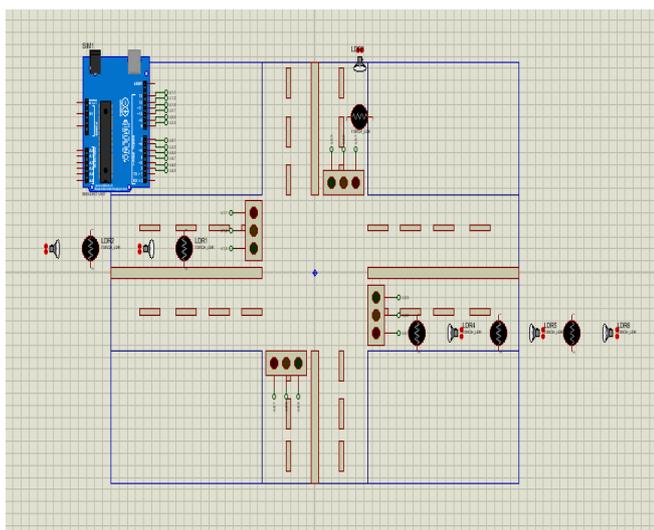An overview of the simulation setup is presented in figure 3.

Figure 3.0 Simulation Setup of the Proposed System

V. RESULTS AND DISCUSSION

A. Results

The number of vehicles, wait time, and go time for the respective road lanes were considered the KPIs upon which the performance of the proposed system was based. Data pertaining the KPIs were captured and sampled every four hours. The tables below show the samples of the results obtained in twelve hours.

TABLE 4: First Sample of the Captured Result

S/N	RL	NV	WT	GT
1.	A	10	108	60
2.	B	4	57	35
3.	C	6	22	20
4.	D	0	0	0
5.	A	8	47	48
6.	B	9	98	55
7.	C	6	12	10
8.	D	4	14	15
9.	A	10	80	65
10.	B	8	39	35
11.	C	2	28	18
12.	D	3	14	18

TABLE 5: Second Sample of the Captured Result

S/N	RL	NV	WT	GT
1.	A	6	97	65
2.	B	7	58	40
3.	C	2	15	12
4.	D	3	8	30
5.	A	9	50	40
6.	B	10	45	40
7.	C	4	38	35
8.	D	3	25	20
9.	A	7	40	52
10.	B	10	70	55
11.	C	4	30	25
12.	D	2	25	18

TABLE 6: Third Sample of the Captured Result

S/N	RL	NV	WT	GT
1.	A	9	79	65
2.	B	7	57	40
3.	C	4	30	28
4.	D	6	18	20
5.	A	7	40	45
6.	B	8	55	49
7.	C	3	18	22
8.	D	4	14	15
9.	A	8	67	60
10.	B	7	45	50
11.	C	2	18	20
12.	D	4	16	18

Key:
RL = Road Lane
NV = Number of vehicles
WT = Wait Time (seconds)
GT = Go Time (seconds)

5.2 Discussion

In the process of preparing the captured data for analysis, calculated fields were generated for each of the KPI which represented the mean of each data for a single occurrence, with the number of vehicles (NV) rounded up to the nearest whole number. This is represented in table below.

TABLE 7: Calculated Fields (Mean) of the Captured Data.

S/N	RL	NV	WT	GT
1.	A	8	67.55	53.33
2.	B	8	58.22	44.33
3.	C	4	23.44	21.11
4.	D	3	14.89	17.11

From table 4 above, it could be seen that there is even allocation of go time of traffic signal based on the number of vehicle on each road lane at a given instant. The amount of vehicles and the wait time of these vehicles are the sole determinants of the traffic flow in a certain road lane. Figure 4 is simply a graphical representation of the interrelationship between road lanes and traffic flow with respect to the number of vehicles, wait time, and go time.

The below graph typically represents the interrelation between the KPIs which are the number of vehicles (NV), wait time (WT), and go time (GT) against each road lane. At any point there is an increased number of vehicle in a specific road lane, there is a corresponding increase in the number of wait time which amounts to increased go time to compliment the traffic situation.

From the captured data and presented graph, road lanes A and B are considered to be most congested zone with average number of vehicle of 8, and consequently an average number of wait time of 53.33 and 44.33 seconds respectively.
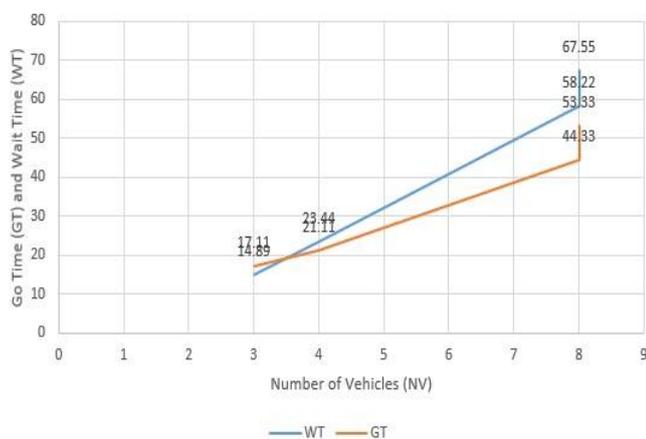

Figure 4: Analytic Graph of Traffic Information for each Road Lane

VI. CONCLUSION

In conclusion, data analytics has been integrated to a DTAT-based smart traffic control system. In so doing, an object-oriented system modeling has been adopted alongside CRISP-DM in the development of the proposed system. Having subjected the KPIs of the proposed solution to predictive analytics using the Tableau Data Science tool, results show that certain road lanes (A and B) have the highest number of vehicles and wait time. With this information, it is obvious that these road lanes have the heaviest traffic flow in the junction of focus. This can be used by other smart traffic control systems to make informed decisions.

However, it is recommended that motion sensors be integrated into the solution in order to sense the speed at which vehicles move in each road lane. This will improve the accuracy of ascertaining the lane with highest traffic flow and that with least traffic flow, a parameter that is very important in allocating go time and wait time to the road lanes.

This work is the first to integrate data analytics in the development of a smart traffic control system that is based on Dynamic Time Allocation Technology (DTAT). It adopts a concatenated software development technique which involves object-oriented systems modelling, alongside Cross Industry Standard Process for Data Mining (CRISP-DM) in the development of the DTAT-based smart traffic control system.

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