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T2-TRACMIS – A Type 2 Fuzzy Logic Traffic Management Information System for the Coordination of Vehicular Traffic

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ABSTRACT

The current challenges of traffic control and management and the limitations imposed on vehicular traffic have continued unabated. In this paper, a software framework called T2-TRACMIS is proposed as a possible solution to the traffic congestion problem. The framework proposed in this paper is a Type-2 Fuzzy Logic Traffic Management and Information System. The proposed framework introduced a modification to the Karnik Mendel (KM) switch-point algorithm which reduces the run-time of the T2-TRACMIS. Simulations are performed using real-time traffic data obtained from the Rumuokoro traffic circle, Rivers State, Nigeria; the simulations compare the performance of the original KM with the modified KM (modKM) on the basis of mean-of-mean run times and the predicted fuzzy states of the standard KM and modKM compared to an expectation state. From the results, the MODKM showed better performances than the standard one.

Keywords – Karnik Mendel, switch point algorithm, Expectation state, Type-2 Fuzzy Logic, Traffic Congestion, Traffic circles

1. INTRODUCTION

Traffic congestion is a recurrent problem peculiar to large cities and towns and represents one of the core problems faced with large modern cities. In Nigeria, and Port-Harcourt City in particular, the alarming rate of traffic jams has made the Government embark on emergency road reconstruction and building demolishing exercises leading to increased government expenditure and displacement of persons. Traffic congestion is also the primary cause of long queues and lost man-hours in everyday business activity. n order to tackle the problem of traffic congestion, the traffic light control system has been the fundamental solution approach in the transportation sector.

Other approaches include the use of a Government sponsored monitoring teams, for instance LAWMA in Lagos and TIMARIV in Port-Harcourt City. Such approaches try to use the method of forced compliance or impounding of vehicles and fines on defaulters are charged with high fees plus mental test. In order to improve the task of traffic control, modern soft-computing and hardware tools and devices have been developed and integrated into existing traffic light control systems by researchers and industry experts. Some of these tools include the use of embedded systems, fuzzy logic and neuro-fuzzy systems, Global Position System (GPS) monitoring and the use of geographic information system (GIS) software. However, by far the most used and well researched approach remains Fuzzy Logic.

Fuzzy Logic has been applied in several ways and is very important Artificial Intelligence (AI) techniques that allow human based reasoning to be integrated in a computing environment. Fuzzy Logic permits vagueness and degrees of uncertainty into the system solution space thereby accounting for a global prediction on the feature data. In road transportation sector, fuzzy logic has been applied widely and proved to be useful means of improving traffic flow. A type-2 fuzzy system has recently attracted attention as a candidate fuzzy technique for short-term traffic forecasting (Li et al, 2015).Type-2 fuzzy logic is powerful in handling uncertainties, including uncertainties in measurements and data used to calibrate the parameters, This work seeks to extend the already rich body of knowledge in this area. In this study, we implement some novel theories and ideas that leverage Type-2 fuzzy models for traffic congestion and management.

2. STATEMENT OF PROBLEM

Traffic management is one of the major problems in many metropolitan cities around the world. The traffic problem can affect the economy, slow down the processes of development, reduce the production rate cost, and daily performance index. There are several causes that can create traffic problem in a big city. Among them increasing number of vehicles, shortage of sufficient roads and highways, and traditional traffic light system. All of these factors can create traffic congestion in the intersection but among them traditional traffic light system is one of the major factors.

Traffic signals are common features of urban areas throughout the world, controlling number of vehicles. Their main goals are improving the traffic safety at the intersection, maximizing the capacity at the intersection and minimizing the delays which are indeed a pain in the neck for traffic management agencies; but the proper and timely coordination of vehicular traffic light systems is essential if there must be progress in the traffic sector.

3. OBJECTIVE

The objective of this research study is to develop a modified version of a type fuzzy network using Gaussian membership function for traffic congestion management and to compare a modification of the switch-point algorithm of existing Karnik-Mendel interval type-2 (IT2) fuzzy technique with a modified version. The developed tool will be applied to field data obtained from the East-West and North-South axis of the Rumuokoro traffic circle located in Rivers State

4. RELATED WORK

Traffic control and management is a well-researched topic that keeps on evolving as the demand for better control policies arise. And as such, there is always diversity in the nature of solutions used by the various researchers. In Siuli Roy et al, (2011), road traffic congestion monitoring and measurement using active RFID and GSM Technology. This is an intelligent Traffic Congestion Monitoring & Measurement System called TrafficMonitor to monitor and measure the road traffic congestions using probe vehicle.

The concept of probe vehicle has come up in recent times for collecting real time traffic data. This approach provides an easy platform to analyze the traffic movement and congestion pattern. The congestion detection algorithm is based upon calculation of vehicular speed over a stretch of road and the average waiting time of vehicles at road-crossing. In one research by Reinartz et al (2009), detection of traffic congestion in optical remote sensing imagery has been considered to resolve the traffic congestion problem; the volume of traffic and other factors like traffic speed, road occupancy, and traffic density were experimented. In Posawang et al, (2009), a road traffic congestion classification using neural networks has been investigated and compared with an existing model. Their objective was to determine road traffic congestion levels based on real imagery data and web surveys obtained from the field. The web surveys were based on road user's perception of traffic congestion levels – flow, heavy and jam. From their simulations, they reported a percentage classification accuracy of 94.999% with a Root mean square error (RMSE) of 0.1583 which was an improvement of 12.5% over the Occupancy Ratio (OR) technique - an existing model used in the Bangkok road traffic system. Salehi et al (2014) proposed an autonomous multi-agent traffic light control system based on the fuzzy logic.

Their system employed image processing techniques to derive the real time parameters (road traffic density and queue length) for adaptively adjusting the delay (time) switch settings of the traffic lights display control. Their field domain was an emergency schedule algorithm for a two-junction 4-way road network with wireless sensors mounted at strategic distances from the junctions. In their work, however, only the red and green traffic lights were considered. Li et al (2006) were albeit the first to practically investigate the feasibility of T2 fuzzy logic systems in Traffic light control systems. They described a T2 fuzzy inference system for short-term road forecasting using historical and real time information for rules construction in the context of flow and occupancy levels. Such systems can account for the large FOU desirable in processes requiring a wide variation of site-specific explanatory factors. From their simulation experiments the authors were able to report a Root Mean relative error (RMRE) of about 12% and 5% for occupancies and flows respectively. Castillo et al (2012) indicate that T2 fuzzy set can be efficiently manage large amount of uncertainties it has three dimensional memberships. Perhaps with T2 FLC it has better performance but the performance is largely affected by the quality of the fuzzy rules and it is difficult to determine optimal performance of membership functions of T2 FLC.

Timotheou et al (2013) suggested some of the ways traffic congestion can be improved so as to increase the capacity of the existing traffic infrastructure including specifically the traffic signal control (TSC). Traffic-Monitor System (TMS), a system for road traffic congestion monitoring, detection and measurement has been proposed in (Mandal et al 2011) for studying and analyzing traffic mobility in congestion prone roads. Their system used the Radio-Frequency Identification Module (RFIM) and Global System Mobile (GSM) techniques. Parameters such as trip times, waiting time and congestion levels were measured and computed. While using a system such as TMS can give better insight into the task of descriptive (linguistic) measurements – an approach well suited for fuzzy-like inference systems, a lot still remains to be done in the area of linguistic MF and meta-formulator rules.

Zhang et al, (2014), proposed a hierarchical fuzzy rule base (HFRB) for short-term traffic congestion prediction. The system was optimized using genetic algorithms (GAs) to reduce the dimensionality in variables i.e. prune the number of variables needed for road traffic forecasts. The system specifically used the GA for ranking and selecting important variables. However, the use of GA may still incur overhead due to long training times to evolve a possible global solution and this is not desirable in real time road traffic decongestion/planning scenarios. Thus, simpler reductionist approaches are still desired.

5. METHODOLOGY

5.1 Proposed System

The proposed traffic congestion control and management system called here as TRACMIS-2 is based on the interval type-2 fuzzy inference system (IT2-FIS). Its architecture includes additional functions (context data) and is captured in Fig1. These context functions include:

- Occupancy level
- Vehicle-type
- Emergencies and
- Route-mapping.

One important advantage of the proposed system over the existing one is in the use of a modified Karnik-Mendel algorithm to speed-up the TRACMIS data processing. This is described in the results and implementation section

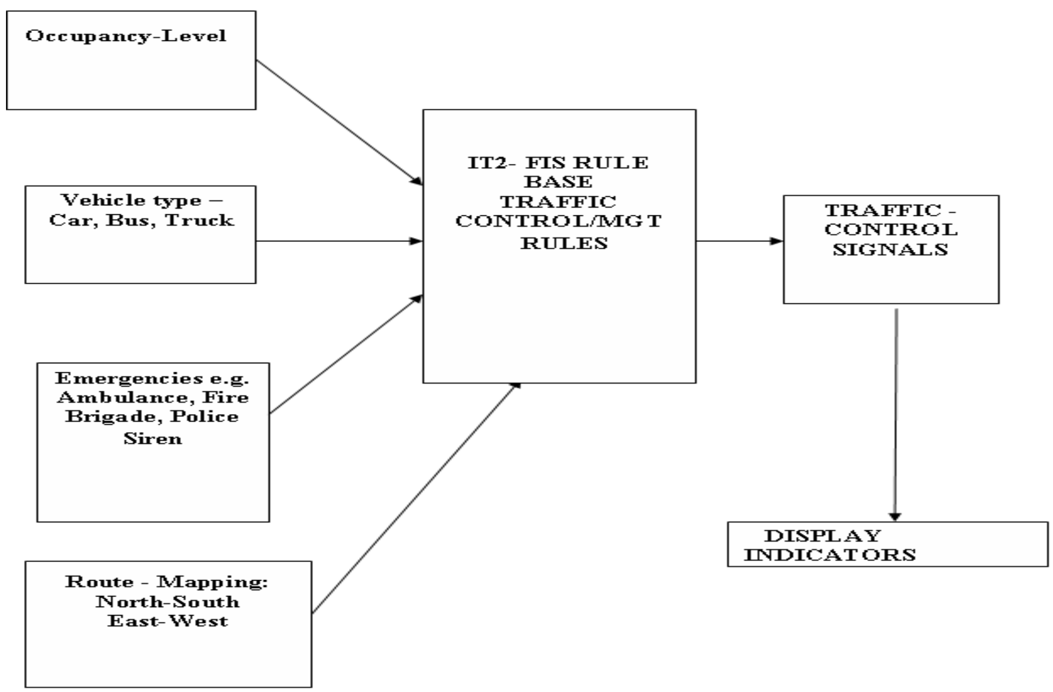

Fig.1: Proposed Systems Design Architecture

5.2 Use case model of proposed system

In order to model a typical scenario of the proposed T2-FS Traffic control and management system, a use case diagram is used. The diagram in Fig.2 includes use cases for describing possible scenarios and actors for executing one or more of these scenarios.

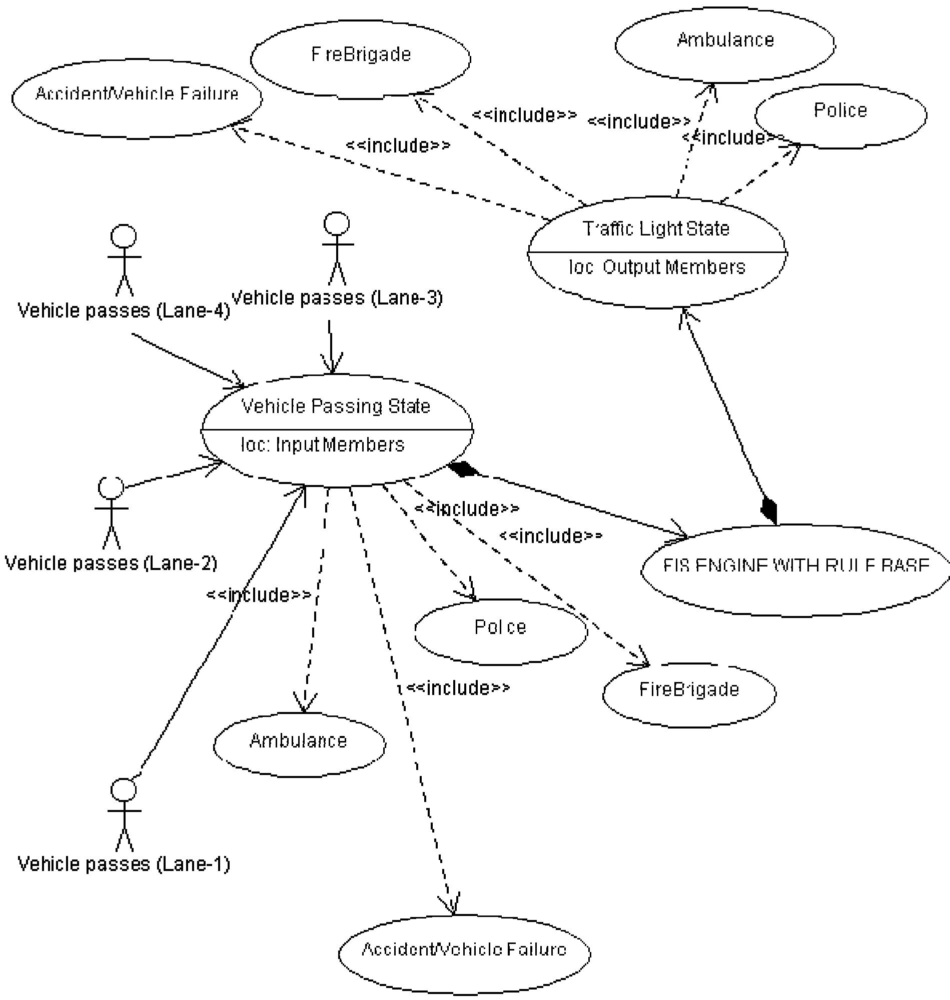

Fig. 2: A Use-case Model of Proposed Traffic Control and Management System

The use case captures 4 key actors denoting vehicle passes for the four lanes under study. Each actor has a dependency on the vehicle passing state use case (VPSU). The VPSU includes four use cases (Ambulance, Police, Vehicle Failure/Accident and Fire Brigade) as input member providers. There is also a strong dependency of the VPSU on the Fuzzy Inference System (FIS) engine use case.

6. RESULTS AND DISCUSSIONS

6.1 Experimental Details

A fuzzy inference system (FIS) system is first implemented using the Type-2 fuzzy logic toolbox function in MATLAB; it is then simulated and tested in the MATLAB-SIMULINK environment to verify the performance of the proposed system. A sample FIS implementation session is as shown in Fig.3. It shows the results of simulation using a RUN Model user dialog block where the user specifies the vehicle type and occupancy level. A sample testing session using the model interface and the experimental data given in the Appendix; the session is captured in Fig.4 when traffic exists and in Fig.5 when there is free-flow.

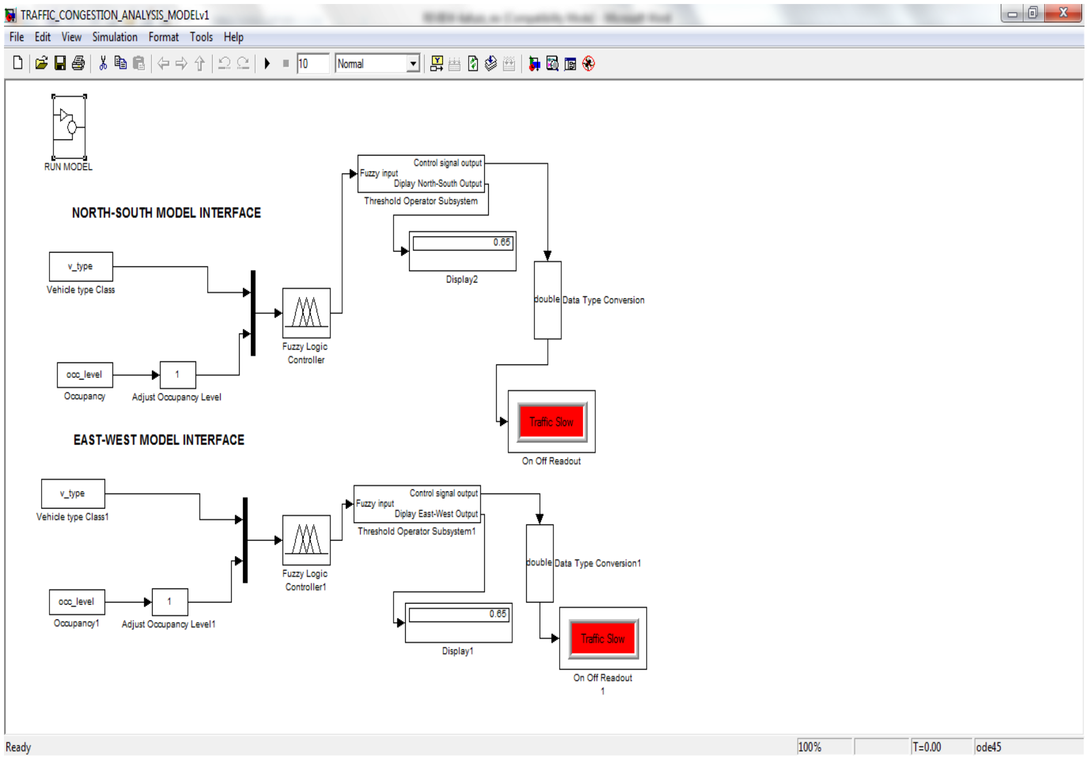

Fig 3: Sample session when Simulating the TRACMIS-2 systems Model

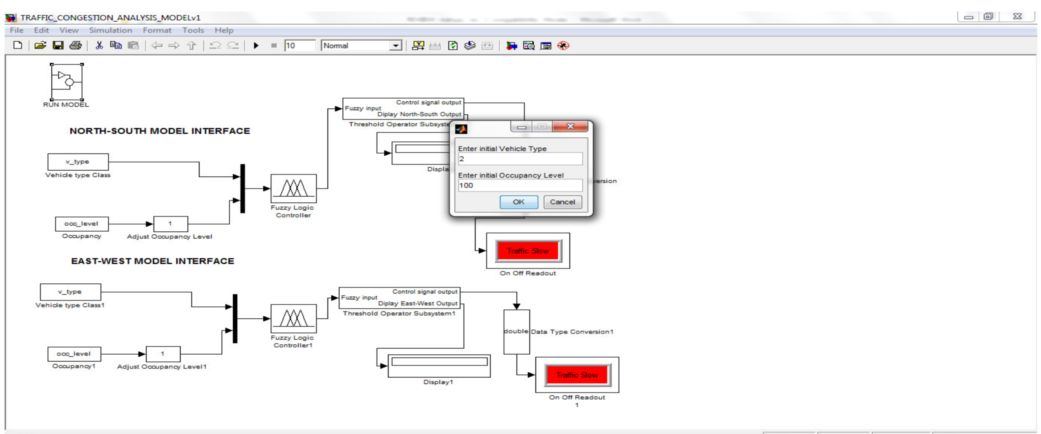

Fig 4: Sample Session when Implementing the TRACMIS-2 FIS System when there is Traffic

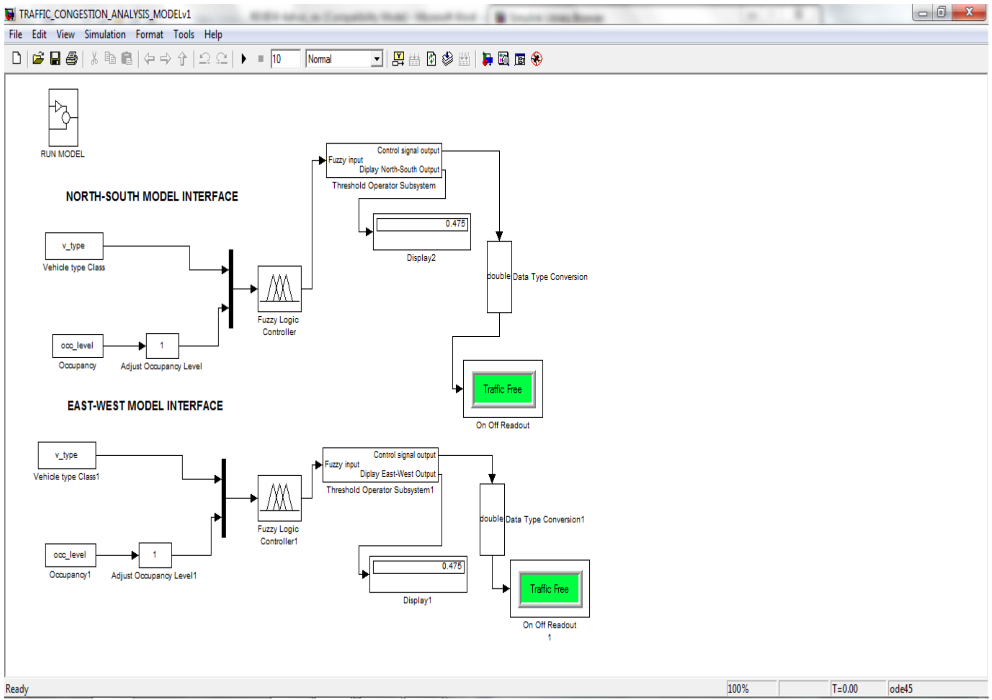

Fig. 5: Sample Session when Implementing the TRACMIS-2 FIS System when Traffic is Free

6.2 Discussion of Results

In this section, the discussion of results comparing the Karnik-Mendel (KM) technique with a modified version called modKM used in TRACMIS performance evaluation is presented. Due consideration is given to the switch-point and tolerance parameters in the original KM algorithm (see Appendix). A parameter called the mean of mean times (MoMt) is used to describe the accompanying results. The MoMt is computed after several iterative runs at the first (first-mean) and second (second-mean) levels. The results show that refinements to the Karnik-Mendel (KM) switch-point algorithm can indeed lead to improved runtimes (see Tables 1-4). This is handled internally by carefully modifying the switch-point states in the original KM algorithm (see Appendix) and increasing tolerance constraint to appreciable values (a tolerance factor >= 10^{-30} was found adequate). For the North-South simulations the predicted states of both algorithms is clearly distinguishable from Fig.6; however, for the East-West simulations it is not easy to see this difference (see Fig. 7).

Table 1: NORTH-SOUTH USING THE KM METHOD;
Best times and mean of mean times (MoMt) are in bold

s/n	Run-time (s)
1	47.42
2	**38.63**
3	48.27
4	42.37
5	47.81
Mean	**44.90**

Table 2: NORTH-SOUTH USING THE MODIFIED (CUSTOM) METHOD;
Best times and mean of mean times (MoMt) are in bold

s/n	Run-time (s)
1	47.55
2	47.26
3	**43.27**
4	47.08
5	44.60
Mean	**45.95**

Table 3: EAST-WEST USING THE KM METHOD;
Best times and mean of mean times (MoMt) are in bold

s/n	Run-time (s)
1	44.91
2	48.56
3	48.51
4	**44.25**
5	48.54
Mean	**46.95**

Table 4: EAST-WEST USING THE MODIFIED (CUSTOM) METHOD;
Best times and mean of mean times (MoMt) are in bold

s/n	Run-time (s)
1	37.11
2	**36.97**
3	47.32
4	49.47
5	41.16
Mean	**41.16**

Table 5: Predicted Responses (traffic states) at the best runtime (N-S KM vs N-S modKM); Note both the KM and modKM are interval-valued (i.e. of continuous form)

Index No.	Actual	KM	modKM
1	0	0.479	0.479
2	1	0.500	0.500
3	0	0.479	0.479
4	0	0.500	0.500
5	1	1.000	0.852
6	0	0.000	0.002
7	0	0.000	0.021
8	0	0.000	0.007
9	1	1.000	0.814
10	0	0.000	0.074
11	0	0.000	0.004
12	0	0.000	0.001
13	0	0.000	0.002

Table 6: Predicted Responses (traffic states) at the best runtime (E-W KM vs E-W modKM); Note both the KM and modKM are interval-valued (i.e. of continuous form)

Index No.	Actual	KM	modKM
1	1	0.999	0.999
2	0	0.459	0.459
3	1	0.500	0.500
4	1	0.472	0.472
5	1	0.999	0.999
6	0	0.459	0.459
7	1	0.466	0.466
8	0	0.459	0.459
9	1	0.500	0.500
10	0	0.459	0.459
11	0	0.500	0.500
12	1	0.499	0.500
13	0	0.459	0.459

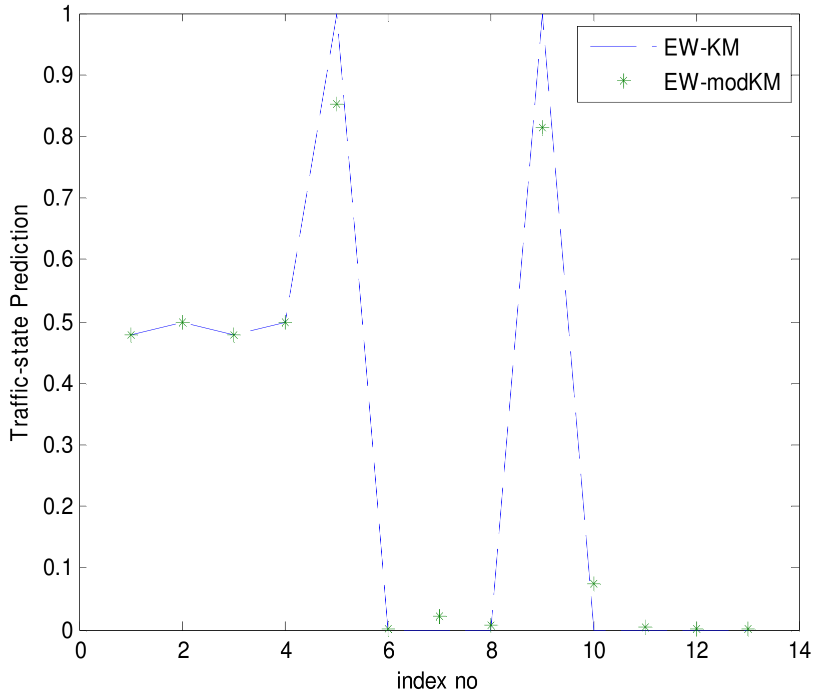

Fig. 6: Continuous (Interval) Plot of Traffic states for the North-South (NS) route

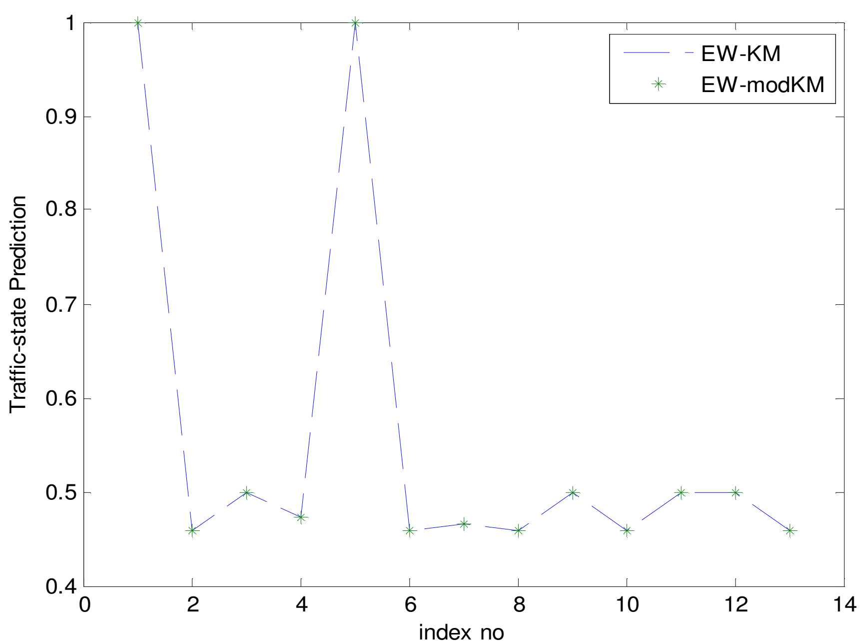

Fig. 7: Continuous (Interval) Plot of Traffic states for the East-West (EW) route

7. CONCLUSION

Traffic congestion is a major challenge for the transportation sector including the road transport users, commuters and road transport authorities. Thus, this challenge presents an active area of study for researchers. In this research study, a Type-2 Fuzzy Logic Management System (TRACMIS) was presented as an option or strategy to solve the problem of traffic congestion control using real-time data obtained from the Rumuokoro axis in Rivers State Nigeria. With reference to the related research in Artificial Intelligence (AI), the Type-2 Fuzzy Logic approach showed very good promises as an effective tool for traffic congestion analysis. It can be observed that a modified Type -2 fuzzy logic control system provides a better performance in terms of improving the safety and efficiency by reducing the waiting delay of vehicles on signals. Less traffic congestion and less waiting time at red traffic lights will reduce the fuel consumption, air pollution, sound pollution, and time and energy waste. In addition the same data set was utilized to ascertain the performance of T2-FIS using a standard Karnik-Mendel algorithm with Gaussian and Trapezoidal membership functions and a modified Karnik-Mendel algorithm; it was showed that a Modified T2-FS in the Karnik-Mendel algorithm can indeed obtain better runtime performance than the standard one. The algorithms should thus improve traffic light timing and reduce redundancy when low traffic is experienced while in turn speed-up processing times.

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APPENDIX

FIELD DATA FOR SIMULATIONS RUMUOKORO TRAFFIC CIRCLE

A. North-South Readings from Owerri before Rumuokoro Traffic circle

S/N	CAR	BUS	TRUCK	OCCUPANCY TIME(s)	LABEL
1	1	0	0	90	No traffic
2	0	1	0	100	Traffic
3	1	0	0	90	No traffic
4	0	1	0	90	No traffic
5	1	0	0	120	Traffic
6	1	0	0	36	No traffic
7	1	0	0	53	No traffic
8	1	0	0	44	No traffic
9	1	0	0	118	Traffic
10	1	0	0	63	No traffic
11	1	0	0	39	No traffic
12	1	0	0	30	No traffic
13	1	0	0	35	No traffic

B. East-west readings from choba end before Rumuokoro Traffic circle

S/N	CAR	BUS	TRUCK	OCCUPANCY TIME(s)	LABEL
1	1	0	0	485	Traffic
2	1	0	0	0	No traffic
3	1	0	0	185	Traffic
4	1	0	0	100	Traffic
5	0	1	0	100	Traffic
6	1	0	0	0	No traffic
7	1	0	0	39	Traffic
8	1	0	0	0	No traffic
9	0	0	1	76	Traffic
10	1	0	0	0	No traffic
11	0	0	1	0	No traffic
12	0	1	0	66	Traffic
13	1	0	0	0	No traffic

Fuzzy Parameters:

Parameter	Type
And method	Prod (product)
Or method	Probor
Implication	Min
Aggregation	Max
Type reduction and defuzzification	KM