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AN EFFICIENT INTELLIGENT TRAFFIC LIGHT CONTROL AND DEVIATION SYSTEM FOR TRAFFIC CONGESTION AVOIDANCE USING MULTI-AGENT SYSTEM

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Abstract. An efficient and intelligent road traffic management system is the corner stone for every smart cities. Vehicular Ad-hoc NETworks (VANETs) applies the principles of mobile ad hoc networks in a wireless network for Vehicle-to-vehicle data exchange communication. VANETs supports in providing an efficient Intelligent Transportation System (ITS) for smart cities. Road traffic congestion is a most common problem faced by many of the metropolitan cities all over the world. Traffic on the road networks are widely increasing at a larger rate and the current traffic management systems is unable to tackle this impediment. In this paper, we propose an Efficient Intelligent Traffic Light Control and Deviation (EITLCD) system, which is based on multi-agent system. This proposed system overcomes the difficulties of the existing traffic management systems and avoids the traffic congestion problem compare to the prior scenario. The proposed system is composed of two systems: Traffic Light Controller (TLC) system and Traffic Light Deviation (TLD) system. The TLC system uses three agents to supervise and control the traffic parameters. TLD system deviate the vehicles before entering into congested road. Traffic and travel related information from several sensors are collected through a VANET environment to be processed by the proposed technique. The proposed structure comprises of TLC system and makes use of vehicle measurement, which is feed as input to the TLD system in a wireless network. For route pattern identification, any traditional city map can be converted to planar graph using Euler's path approach. The proposed system is validated using Nagel–Schreckenberg model and the performance of the proposed system is proved to be better than the existing systems in terms of its time, cost, expense, maintenance and performance.

Keywords: traffic control, traffic deviation, multi-agent, sensors, vehicle categorization, traffic light controller, intelligent transportation system.

Introduction

Intelligent Transportation Systems (ITS) is evolving at a high speed rate across various cities in the world. It enhances safety, efficiency and convenience of the road traffic system by means of advanced technologies; this minimizes the cost and provides a secured transport infrastructure. ITS is an interdisciplinary area, which is growing enormously and providing effective innovative techniques for traffic congestion avoidance and prediction. Intelligent based agents use neural networks, computational intelligence, cognitive science, cloud and big data to solve various complex problems. An intelligence structure in traffic management system is improving towards peak and various traffic solutions were addressed in many of the nations across the country. On the other hand, there is a gap between the advanced technologies and road infrastructure, as it is so huge that the rank of ITS function varies from world-class to a very low level in few countries.

The advancement and development of vehicular communication technologies, Vehicular Ad-hoc NETworks (VANETs) supports ITS in providing services in an efficient way. ITS will change the traditional systems into an automated system and helps to assist in emergency services. Vehicles can exchange real-time information about the traffic condition and further travel related information in VANETs. The network topology in VANETs varies with respect to vehicle velocity and lanes. There major characteristics of VANETs are secure and safe travel in road, convenient driving and commercial issued. Vehicle-to-

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Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication systems supports a wide range of applications in ITS based on VANETS. VANETs carry several applications from one hop propagation to multi-hop propagation. Most of the applications are concerned with Mobile Ad-hoc NETworks (MANETs) are relatively shown their interest in VANETs (Wang *et al.* 2015).

Reducing traffic congestion and providing a stuck free traffic network is a main objective of this paper. Fixed time controller (He *et al.* 2014), has been used to reduce the traffic congestion and several other mechanisms are supervisor agent system for urban traffic monitoring (Iscaro, Nakamiti 2013), intelligent cross road management system (Samadi *et al.* 2012), traffic monitoring in urban areas using supervisor agent (Iscaro, Nakamiti 2013) and classification using speed and length parameters (Cheung *et al.* 2005; Tao *et al.* 2014). Many of the solutions have employed a loop detector system with single loop. A single-loop detector system can be promoted to a system with double loop, then the scenario becomes complex due to heavy traffic flow operations, which fallouts at an expensive cost. Cheung *et al.* (2005) has addressed that wireless magnetic sensor can provide an enhanced solution for this problem. This is a general form of sensor intended for linear angle, speed and location measurements in industrial, automotive and various consumer based applications. To get the vehicle trajectory information, vehicle reidentification techniques can be used. Few related techniques are travel time estimation (Coifman 2002; Liu *et al.* 2007), monitoring highway (Chen *et al.* 2001) and incident detection (Yao *et al.* 2014; Oh *et al.* 2006; Jia *et al.* 2001). Few of the approaches have proposed to use Internet of Things (IoT) and Cloud computing technologies to provide better services for road transportation system (Aazam *et al.* 2014; Botta *et al.* 2016; Tao *et al.* 2014). A methodology is proposed for traffic management system using multiple-loop sensors (Ali *et al.* 2013). An intelligent system can be operated to monitor the road traffic conditions in an efficient way. Though various solutions are proposed for traffic management, most of the issues are yet to be solved. These sorts of problems are quite common happening in undisciplined traffic and also in most of the metropolitan cities.

To control the traffic and to avoid the congestion in urban undisciplined traffic, we propose an efficient framework in this paper. This will resolve the issues in any metropolitan city. Parameters used in vehicle measurement are vehicle count, vehicle categorization, vehicle speed and traffic arriving probability. The traffic deviation system is employed to diverge the route path of the vehicles intelligently, which consequences in avoiding traffic congestion. The main contributions of this paper are: (1) intelligent TLC System to control the heavy traffic flow in metropolitan cities, (2) intelligent TDS to deviate the traffic to avoid congestion, (3) valuable traffic parameters to control traffic management system.

1. Related works

National Electrical Manufactures Association (NEMA) had categorized the controllers are of two types: fixed controller and traffic response controller. Most of the proposed solutions, frameworks and several algorithmic schemas have used fixed cyclic time controller. In paper by Chiu, Chand (1993), they have proposed an approach by altering the fixed type controller approach. These have been programmed to function at pre-set timings for each series. This solution was used for various types of traffic scenarios and especially for undisciplined traffic. Several research algorithms had targeted to avoid the fixed cyclic controller system, but yet ITS needs an efficient approach to reduce traffic problems. Addressing a single issue may not be an efficient solution; several parameters have to be considered to avoid traffic congestion in advance. Vehicle speed and its length are considered as the two most important factors in traffic management system.

VANET is a technology that considers vehicles as a node in a network and creates a mobile network for data exchange and communication, where each vehicle will participate in exchanging information related to traffic condition. VANETs provide better techniques to collect real-time traffic related information in a cost effective manner and traffic information delivery (Hartenstein, Laberteaux 2010). V2V and Vehicle-to-Roadside (V2R) communications in VANETs helps to gather traffic updates from vehicles and roadside units. This gathered traffic data helps in providing a freeway traffic flow and can be used for path planning and vehicle localization (Hunter *et al.* 2009). A simple V2V and V2R communication exchange is shown in Figure 1. To collect real time traffic related information, most of the techniques rely on mobile and loop detectors. Since, cellular phones are not committed for traffic information exchange, these services are expensive and congestion results in high quantity of traffic data. The expenses toward implementing the loop detector systems are very high (Wang *et al.* 2014). The delay in communication and the degradation of safety results in an incompetent system. Timing and security issues in ITS with VANETs are addressed (Zheng *et al.* 2017).

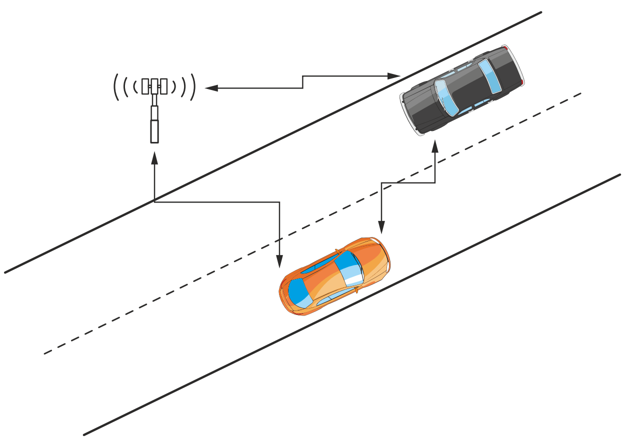

Figure 1. V2V and V2R Communication

Floating car data is used to provide a feasible automated incident detection system (Houbraken *et al.* 2017). The automated systems depends on the on the traffic monitoring sensors that are fixed in the roads. Few approaches are proposed to track the vehicles based on the real time data and video processing units (Cai *et al.* 2010; Coifman *et al.* 1998). Feature based vehicle flow detection and measurement parameters are addressed to identify the vehicle flow (Huang *et al.* 2012; Pan *et al.* 2010). A novel multiple inductive loop sensor system was proposed to detect vehicles in a mixed and lane-less traffic (Ali *et al.* 2012). The proposed loop sensor detects the vehicles based on its size and occupancy. This system separates the vehicle types and provides the quantity of vehicles in a mixed traffic stream. A method to classify the vehicle based on Fourier transform (Lamas-Seco *et al.* 2015) with a single -loop is proposed to improve traffic management system. Categorization (Ki, Baik 2006; Lu *et al.* 2012; Meta, Cinsdikici 2010) and evaluation (De Lima *et al.* 2010; Jia *et al.* 2001) based on single-loop system are used widely. Wang *et al.* (2018) proposed a prediction model based on non-parametric regression approach.

Achieving accuracy using only one loop is yet to be resolved. The transportation infrastructure can be integrated with various advanced sensor technologies to achieve a feasible smart and ITS. The benefits of employing multiple sensors on different elements in a traffic management system are discussed (Guerrero-Ibáñez *et al.* 2010, 2018; Kaewkamnerd *et al.* 2010). Few protocols are addressed to work with wireless sensor networks (Tong, Tang 2010). In paper by Taghvaeeyan and Rajamani (2014), a classification approach is proposed which is based on magnetic length. The vehicles are categorized into 4 groups and this overcomes the disadvantage of the existing techniques. The length of the vehicle can also be measured using the magnetic length. Group I and Group II vehicles are compared within the same group by means of the Group III and Group IV vehicles, since there is dissimilarity in the length. The overall traffic weight was calculated based on the precedence in research by Samadi *et al.* (2012) and sum of the sensors are computed. Thus, we propose to compute the overall traffic weight depending on its comparative weight, speed and length to enhance the effectiveness of the system.

2. Proposed system

In this section, we describe the efficient TLC and TLD systems, which also consists of vehicle detection and count, vehicle categorization, speed and length of the vehicle. Several traffic issues can be resolved efficiently. An intelligent agent system (Iscaro, Nakamiti 2013) was proposed using a supervisor agent system. This approach is not efficient since it requires double agents to observe the entire process. Controller and supervisor are the two agents used.

In our multi-agent system approach, for activities such as colleting and processing data an agent is assigned and a supervisor agent. Vehicle count and categorization has to be done by the data collector agent. The assessment of length of the vehicle, speed and possibility of comparative weight of the vehicle has to be done by data processor agent. At last the light control method was employed which depends on the data processed. This will help to reduce the traffic congestion but this may not avoid traffic congestion problems completely, so we have introduced deviation approach to make the system function better. The proposed system architecture is depicted in Figure 2.

2.1. Elements of the proposed framework

The constituent elements of the proposed model and functions are explained below.

2.1.1. Sensors

Wireless magnetic sensor is chosen as traffic sensor since it is flexible, lower installation, less in cost and reliable inductive loop detector system. Four sensors are used – SN0, SN1, SN2 and SN3. All the sensors are disseminated suitably prior to the traffic. One sensor was intended for traffic lights. The traffic administration decides the distance between the sensors and sensors location. To make the deviation signal system to receive the signal, another one sensor is used.

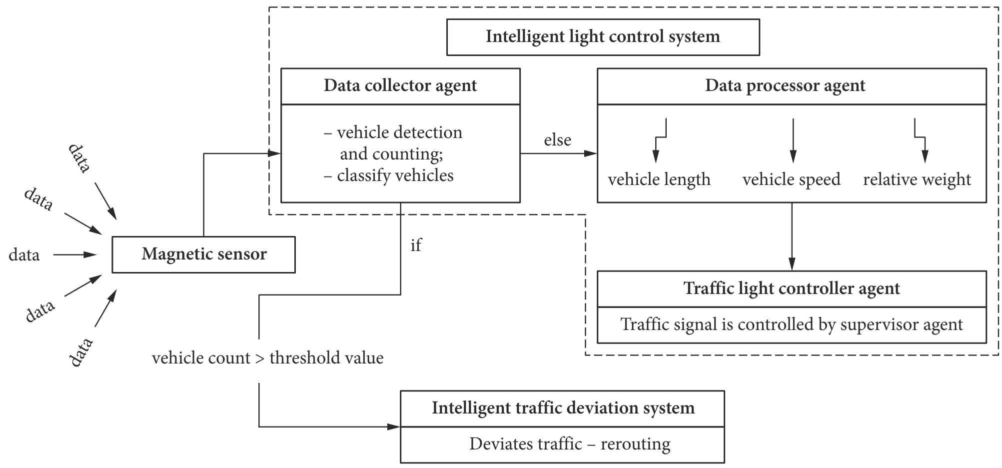

Figure 2. Architecture of the proposed system

2.1.2. Data collector agent

This agent task is to examine the data composed through the sensors; they are vehicle count and vehicle categorization. In the proposed approach, data collector is a component and it is a part. This acts as first representative in the multi-agent system approach.

2.1.3. Data processor agent

This agent behaves as a next agent in the traffic system. Its role is to operate the vehicle length, velocity and relative quantity of traffic. In the proposed system, data processor agent acts a part of the system. The traffic data will be manipulated by the data processor and the input will be give to intelligent Traffic Light Controller (TLC) system. Both the agents are independent.

2.1.4. Intelligent TLC

To control the traffic and various traffic security issues such as to overcome the traffic hijack problem, rerouting, traffic jam, these issues will be handled by secret supervisor agent. This will decrease the traffic system issues but may not be completely. Hence, a traffic congestion prediction system is needed for an ITS. This system has a threshold value depending on the traffic area and if the value exists then an alert signal will be sent to deviation system.

2.1.5. Intelligent traffic deviation system

If a congestion state is predicted, the deviation system provides a signal to deviate the vehicles arriving in the congested path. Whenever it is required, this system will play the role actively. Another sensor was placed to diverge the route of the traveling vehicle; this will be performed by the deviation system. Once an alert is made by the intelligent deviation system, the vehicles are not permitted to use the same route.

2.2. Vehicle detection and counting

Magnetic sensors are used to detect the vehicles counting and also for communication between the sensor plates. Since this sensor has improved measurement capability. To count the vehicles, which are inward on the arrival route is a random process. To locate the number of vehicles inward at in a time period of T (t_1, t_2, ...), Poisson distribution can be used. Poisson distributed can be applied to get the vehicles arrival information in a random system. In finding the number of vehicles arrival and modelling the random process at a given time period, Poisson distribution is used conventionally. To calculate the probability of a definite amount of vehicles arriving during a certain length of time then "t" would be the length of time and "n" would be the number of vehicles. The flow rate would be given as "λ". λ and t should be computed using the same time units.

Probability of v vehicles in a period of time can be represented in equation as:

$$P\left(v\right)=e^{-\lambda}\cdot\left(\frac{\lambda^{k}}{k!}\right), \quad (1)$$

where: v – represents the vehicles; $P(v)$ – probability for the event v; λ – average number of vehicles; e – Euler's number (e = 2.71828); k – values varies from 0, 1, 2, …:

$$k!=k\cdot\left(k-1\right)\cdot\left(k-2\right)\cdot\ldots\cdot 2\cdot 1.$$ is the factorial of k.

This computation will be made for each and every time period T. The probability of vehicles arrivals is computed using Poisson distribution (Table 1). This is obtained using $P(v = N)$. In this v indicates the vehicles. Flow rate is computed as λ = 300 veh/h = 300/60 = 5 veh/min. Using this we can compete $F(v)$ with the support of probability density function.

Table 1. Probability of vehicles arrival rate

N	$P(v)$	$p(k \le v)$	$F(v)$
0	0.0190	0.0190	1.9086
1	0.0832	0.1022	4.8934
2	0.1546	0.2568	8.9816
3	0.1973	0.4541	11.736
4	0.1973	0.6514	11.736
5	0.1564	0.8078	9.387
6	0.1039	0.9117	6.912
7	0.0596	0.9713	3.547
8	0.0301	1.0014	1.873
9	0.0141	1.0155	0.785
10	0.0053	1.0208	0.318

Notes:
N – represents the count of vehicles arriving in an interval;
$P(v)$ – represents the probability that certain count of vehicles arriving in an interval;
$F(v)$ – number of intervals in a hour where there is no vehicle arriving.

2.3. Vehicle categorization

In categorizing the traffic management applications vehicle categorization is more important. Road intend, maintenance and organization, model design and development, traffic signal control system design, etc., these are the various categories taken into the traffic management system classification. Size of vehicle on each side can be estimated using vehicle categorization. While categorizing individual vehicle exact measurement is needed. In our proposed approach, vehicles are divided into nine groups based on the highway classification.

2.4. Compute vehicle length depending on speed rate

In traffic flow conditions, vehicle length is the most important parameter. With this, the congestion problems can also be predicted. It is the deepest important research issue in ITS. The vehicle length was measured only for the duration of the red series and green series in the similar period in paper by Cheung *et al.* (2005). This approach was not efficient in calculating the length of the vehicle. Therefore, in our paper we propose to compute the length of the vehicle along with the velocity rate. Since the arrival rates of vehicles are random, the velocity cannot be determined randomly since it rises the cost. This paper proposes to compute the vehicle length, which depends on the vehicle speed rate by using magnetic sensor. Few sensors that are suitable for road traffic system are discussed. Piezo sensors are used to collect count and classify, pneumatic road sensors are applied to record vehicles, to detect the vehicle movements microwave detectors are used, proximity sensors are applied in detecting the vehicle getting close to an object and road tube counters are used in collecting vehicle volumes.

Here, time period can be determined by:

$$t = \Delta T_{end} - \Delta T_{begin}, \quad (2)$$

velocity can be determined by:

$$v_{avg} = \frac{\Delta D_{end} - \Delta D_{begin}}{t},$$

where: v_{avg} – average velocity; ΔD_{end} – final destination; ΔD_{begin} – begin destination; ΔT_{end} – time to reach the end; ΔT_{begin} – begin time from the initial stage; t – time period.

The vehicle length can be computed by:

$$L = T \cdot v, \quad (3)$$

where: L – vehicle length; T –interval time period; v – velocity.

Once the vehicle length is computed, then it is easy to determine the speed rate of the vehicle. The speed can be computed by:

$$S = \frac{N}{L},$$

where: S – speed; N – count of vehicles; L – vehicle length.

2.5. Light control system and measurement of vehicle

The whole weight is computed by means of summing the values of all sensors located in three sides of road and the relative mass of the vehicles. If the vehicles are moving with same speed and length, this approach (Salama *et al.* 2010) is good. Since traffic flow is a random process, this may occur randomly. Therefore, to compute we use a few traffic parameters.

Traffic information Collector Agent collects the traffic information and the data will be stored. The light controller agent controls the traffic indication using the traffic information, which was transferred to the undisclosed supervisor agent. Then the data processor will process the data and provide the input to TLC controller agent. At the end, the effective smart Light Control system can be achieved by computing whole average weight, vehicle length, speed through summing up of the sensor values and the relative mass of the vehicles probability on each road as:

$$T_{AW}\left(RT_k\right)_{k=1\to 4} = \sum_{j=0}^{3} SN_j + P_k + S_k + L_k, \quad (4)$$

where: $T_{AW}\left(RT_k\right)$ – total average weight; SN_j – sensors placed in road side; P_k – relative weight probability; S_k – speed of vehicle; L_k – vehicle length.

2.6. Traffic deviation system

On successful processing of intelligent TLC mechanism, several traffic issues can be reduced, however it may not be completely. Most of the traffic issues may not be solved, although this can be barred by means of using intelligent TLD system. This system diverge the traffic into various other alternative routes to avoid the traffic blockage problems before it occurs. In avoiding the traffic issues, this system will have an important role in avoiding traffic congestion. This can be applied on various positions of the geographical areas. Hence, this model will be efficient on outer parts of the city or high traffic issue areas to avoid traffic blocking prior to the vehicles addicted to traffic. With this approach traffic congestion can be prevented in advance. The workflow of the proposed work is shown in Figure 3.

3. Results and discussion

Intelligent TLC and TLD Systems will prevent the congestion problems and assist the system in route deviation. This proposed scheme will be appropriate for few geographical areas. Therefore, this model can be used mostly on the outside of the city or an area with high traffic issues to stay away from the traffic congestion in prior the vehicles enters into the traffic area.

In the Figure 4, the outer border region of Chennai (India) has considered as sample model and the notations used are explained in Table 2. In the Figure 4, the route towards to reach Chennai is represented in *violet* colour and the deviation route is represented in *red* colour. The above model is a simple case for vehicle deviation. Therefore, the proposed intelligent traffic congestion avoidance and deviation system can be used in particular areas, which comprise deviating route ability. Instead of constructing new roads to reduce traffic congestion, vehicles can be deviated to avoid congestion and this also promotes several benefits to travellers like fuel consumption, save cost and time and in maintaining a green environment.

If any vehicle is traveling from A to B (Figure 5), it requires a time t_1 (x is the distance from A to B). If suppose there is any traffic congestion in the traveling route, then the traveling time of the vehicle will be increased, say $t_1 + \mu$ is the time taken to reach the destination B (μ will represent the delayed time). When the vehicles are deviated, then the vehicle takes t_2 time to reach A to B (deviating signal is used deviate the vehicles). This deviated alternate route path may be faintly longer than the regular route, with this the speed of the vehicle can be raised and the vehicle will be free from traffic congestion. This will help in reaching the destination quickly and also results in a relax travel.

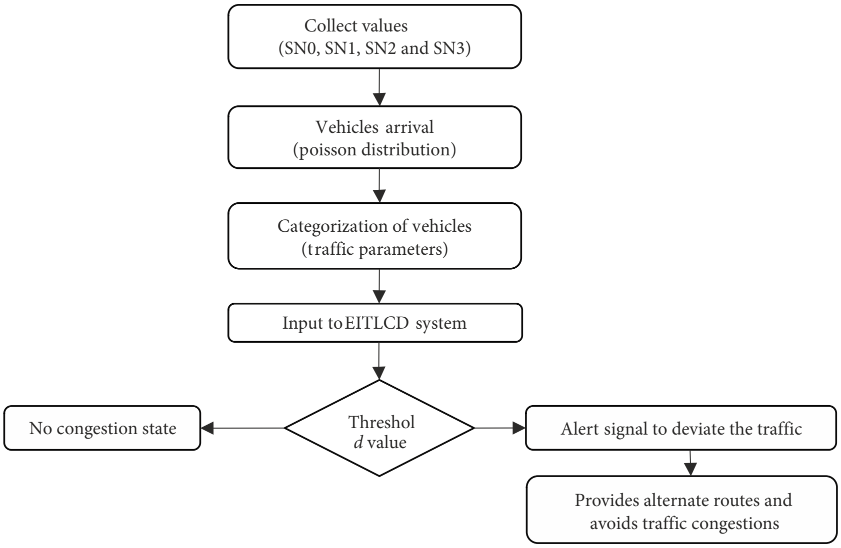

Figure 3. Work flow of proposed framework

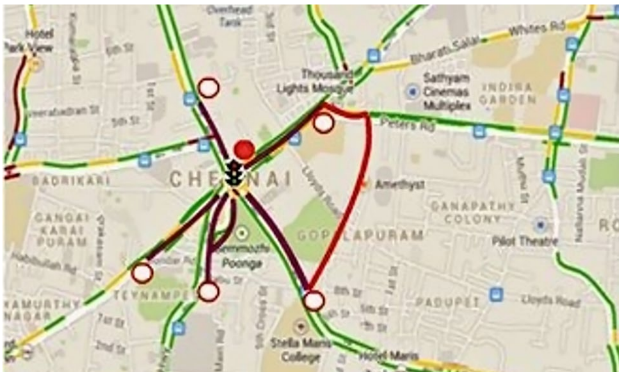

Figure 4. Sample model route map

Table 2. Notations

No	Symbol	Meaning
1.		traffic symbol
2.		border route to Chennai
3.		deviation route
4.		source route
5.		destination route

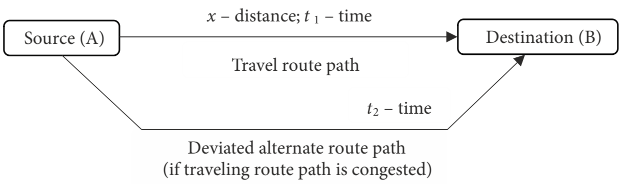

Figure 5. Traffic system assumption

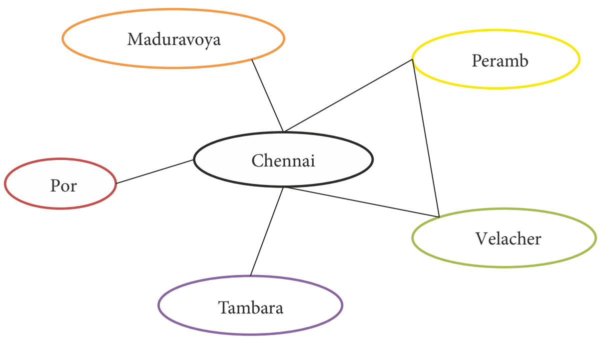

Figure 6. Graph from map

3.1. Conversion of map to graph

We now use a fascinating discovery of Euler, which will make our graph using Six colour theorem possible. Initially, convert the considered graphs into number of vertices and edges by mathematical jaunt.

In research by Iscaro and Nakamiti (2013), "Euler has proved in a different manner, where number of vertices minus the number of edges plus the number of faces of a polyhedron is always equal to two", "any planar graph has Euler characteristic equal to 2".

$$X = V - E + F,$$

where: V is the vertex of the map; E is the edges of the map; F is the faces of the map.

If a graph has a single vertex, then the value of X equal to 2 ($V - E + F = 1 - 0 + 1$). So, join additional vertices to each edge for each vertex, and then it always remains 2.

The Figure 6 represents the Chennai map converted to graph using the help of six colour theorem. Six colour nodes are fixed as six places; each node is related with the root node as Chennai. The diagram provides the various route paths entering towards Chennai city. In prior to the beginning of city boundary, the vehicle population is considered and followed by the vehicles are deviated to various different route ways to enter into the city.

3.2. Validation

The proposed system was assessed with a range of issues such as the quantity of time spent by a vehicle in the traffic queue, fuel and time expenditure. Using the proposed deviation system time spent in the traffic queue can be reduced. Fuel and time wastage can be avoided. Figure 7 elucidates the assessment of performance with the available related systems. The methodology is compared in terms of performance and cost, the approach by Zhu and Jin (2011) makes use of single loop detector and this method uses 15-th percentile vehicle passage time over the detector. Cheung *et al.* (2005) make use of a single magnetic sensor (Chiu, Chand 1993), reduce the traffic cost and as a result have 63%. Taghvaeeyan and Rajamani (2014) makes use of sensing system and achieved 95% and Coifman (2001) computes the individual vehicle lengths and achieved 85%. Based on the previous works, only sole parameter was addressed by everyone but this framework incorporates all the parameters and offer solutions for various traffic problems. NetLogo (*https://ccl.northwestern.edu/netlogo/download.shtml*) was used to test the proposed system by considering the real Chennai traffic flow dataset (Salama *et al.* 2010). A multi-agent monitoring model is proposed (Hamidi, Kamankesh 2018), this model monitors the traffic conditions and guides the driver in case of an emergency. The proposed approach is an agent based approach. The proposed system comprises two solutions for the traffic system; they are TLC system and TLD system. Therefore, if there any traffic congestion is predicted, traffic issues can be resolved using the traffic deviation system. According to Liu *et al.* (2007), the test statistic used by the proposition is given by Z-test calculation.

The performance evaluation of the proposed system with the various related systems are shown in Figure 7. Pro-activeness, adaptability, performance, time and cost are the various key factors considered for the comparison with various approaches. The magnetic wireless sensor has a few constraints in a signal processing like facing noisy situation (Chen *et al.* 2001). To determine the vehicle count in a given time of interval, Poisson distribution can be used and Nagel–Schreckenberg model can be used to validate, it is a theoretical model for the freeway traffic. This model is suitable only to the traffic congestion rising without any external influences. Most of the research has provided various algorithms for a particular aspect like vehicle length, vehicle classification, vehicle speed, etc., which are not sufficient for the traffic system. This paper integrates various factors like length of the vehicle, vehicle speed and vehicle classification to make the traffic system control more effectively and efficiently. A new traffic deviation approach is introduced to avoid the traffic congestion completely. Figure 8 illustrates the traffic density of the system previous to deviation and after deviation. Consequently, the values of average velocity of the vehicles are assumptions taken under the normal computation of the traffic flow.

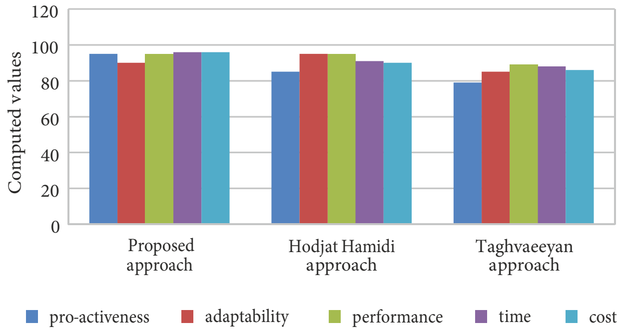

Figure 7. Comparison of approaches

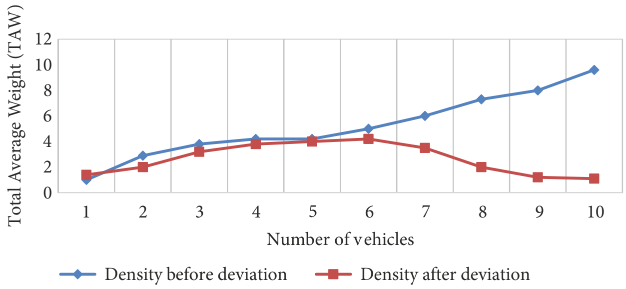

Figure 8. Traffic density before and after deviation

The values are computed same as with the above assumptions. This graph depicts that traffic density of the vehicles are reduced after deviating the vehicles. These graphs are drawn based on the analysis of the traffic system. Both the figures represents the traffic density, Figure 8 shows the density before adapting the traffic deviation method and the density after adapting traffic deviation method. The curve in the figure proves the efficiency of the proposed system by showing that the traffic condition is optimal.

Conclusions

An Efficient Intelligent Traffic Light Control and Deviation (EITLCD) system is proposed in this paper to reduce the traffic congestion problem before it happens. This system will decrease the traffic queue size and provides an alternative route for the vehicles to avoid traffic and to achieve free flow of vehicles.

An intelligent traffic light control system is deployed to prevent the traffic congestion before it occurs and based on an alert signal traffic route will be deviated. This can help the travellers to have free flow traffic.

Traffic jam can be avoided and the condition of the traffic flows in many of the metropolitan cities can be improved.

The Euler's approach used to convert map to graph was tested on a metropolitan city graph and the results are found to be satisfactory.

Finally, the overall framework is statistically proven to be better than the related traffic congestion models.

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