



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: III Month of publication: March 2019

DOI: <http://doi.org/10.22214/ijraset.2019.3312>

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A Survey on Automated Traffic Management Systems

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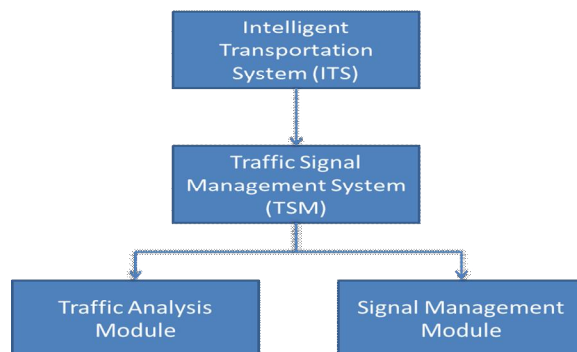
Abstract: The goal of the survey is to analyze and evaluate the proposed and existing models for the automated traffic management. The evaluation of the proposed frameworks will be based on their effectiveness of their solution, adaptability, scalability, the level of automation and processing time. The provided parameters will be used to determine the differences between the proposed frameworks.

Keywords: Traffic signals, adaptive control, connected vehicles, traffic analysis, Signal Management.

I. INTRODUCTION

Highway Ever since the invention of vehicles, roads were not capable of handling the traffic especially in the intersections. Thus leading to the concept of traffic signals, whose primary purpose was to regulate the traffic with minimal delay. Over the past few decades several traffic signal management systems were developed, but none of them were capable of rivaling the traditional Signal management system (manual Systems). The Traffic Signal Management (TSM) is a sub-system of the Intelligent Transportation System (ITS) which is an automated transport management system responsible for all the transport related activities. This includes Traffic management, Public transports, Railway crossings and traffic signals. The Transport Signal Management system is responsible for managing the traffic signals and the level crossings. These traditional systems are semi-automated which rely on human intelligence for decision making and can perform basic operations automatically. Due to recent advancements in the field of computation technology lead to the concept complex system designs capable of mimicking human intelligence. Several automated systems were developed to manage signals with minimal human interaction as possible. The Traffic Signal Management System consists of two primary modules, The Analysis module and the Signal management module. The Analysis Module is responsible for mining the traffic data and to analyze the acquired data and to generate a distribution function or a prediction model. This module is responsible for converting the raw data into machine understandable data format and to generate an analysis from the given data the mining is based on the input feed format, it may be a video or a set images or even sensor data relating to traffic flow or a value denoting a vehicle density function. The analysis module must be capable of parsing the input data into machine understandable format, this format can either be a value or a distribution function. The Signal Control Module is responsible for managing the traffic flow by controlling the traffic signal in an efficient manner. This is the primary module of a TSM, which is responsible for controlling the traffic signal and thus dictating the traffic flow. Its functioning depends upon the data forwarded by the analysis module, since it is a real-time system there is a periodic updates on the traffic data. The signal module must be capable of handling the traffic based on the recently updated traffic data instead of predefined rules and instructions. This module acquires the data (i.e. the traffic distribution function) and manages the traffic flow based on the updated data. Several methods have been undertaken by researchers to effectively handle and deploy a fully automated traffic management system (TSM). The following are some effective methods of TSM design, these are categorized based on their purpose and working principle.

II. MAJOR CLASSIFICATION IN TRAFFIC SIGNAL MANAGEMENT



A. *Traffic Analysis Module*

This section incorporates various existing techniques introduced to estimate traffic flow in arterials, trajectories and intersections in major cities.

- 1) *Traffic Clustering Analysis*: A real-time traffic prediction model based on spatio-Temporal clustering analysis and Deformable Convolution Neural Networks (TCA-DCNN). The Traffic Clustering Analysis [4] (TCA) is done using Differential Evolution and Hierarchical clustering to differentiate traffic patterns over time. The Deformable Convolution neural networks are trained with the data from the TCA and the prediction is based on the result of the DCNN generated from the trained data. The DCNN consists of four layers: Deformable, Convolution layer, pooling layer, input and output layers. The convolution layer parses the spatio-temporal matrix by making use of the Deformable Convolution Kernels generating a feature map of the traffic data. The input layer is used to design a spatio-temporal matrix from the acquired traffic data like speed, time and vectors. The pooling layer is responsible to reduce the feature map from the convolution layer using the down-sampling transformation. The output layer is essentially traditional ANN used to generate a final prediction result from the reduced feature map. The Temporal Clustering Algorithm makes use of the Differential Evolution (DE) and Hierarchical Clustering (HC) to partition historical data with the relevant traffic environment in order to train the DCNN as the training set and the prediction is selected based on the estimation reward of each prediction. When in comparison with Convolution Neural Network (CNN) and Long Term Short-Memory (LSTM) the TSA-DCNN performs well in terms of correlation of data, prediction errors, Adaptability and can effectively extract the traffic speed data effectively.
- 2) *Set Packing Framework (SPF)*: A real-time traffic prediction model based on Joint Head Light Pairing and Weighted Set Packing for vehicle tracking using night time surveillance videos. The applications of this concept include multi-vehicle tracking, traffic flow analysis and vehicle parking detection. This proposed method is effective for vehicle identification and tracking during dusk and night time. The effectiveness of this system is based on the headlight pairing mechanism which is used to identify and detect vehicles. The Set Packing [12] (SP) model is suitable for this concept due to its ability to handle inter-frame-non-sharing-headlight constraint for the headlight pairing and the ability to make use of the high order motion information by making use of track based hypothesis for vehicle tracking. The Set Packing (SP) is used to perform data Association Operations based on the observations two consecutive frame sequences. The AdaBoost-Haar detector is used for identifying the vehicle head lights and pair them based on the training set to effectively determine positive result (The headlight itself) and to ignore negative result (light reflected from other objects like roads and other surfaces). Based on the Multi-Target Tracking a track hypothesis is generated for each vehicle trajectory, only a limited hypothesis is managed by the system so as to effectively reduce conflicts from post hypothesis. The vehicles are identified based on their headlight pairing for a certain number of frames, if a single headlight is detected without any frames for twenty frames it is identified as a motorbike. This proposed model has been effective in handling and managing the traffic data from night time traffic surveillance systems and to generate an analysis of the vehicle trajectory and traffic data.

B. *Road Traffic Anomaly Detection Based On Fuzzy Theory*

A Real-time traffic anomaly detection model based on Fuzzy theory for traffic system. This model makes use of traffic surveillance data to detect anomaly in the traffic flow patterns and traffic density using vehicle detection and tracking.

The traffic anomaly is detected based on the traffic speed, density, and trajectory and vehicle moment to generate a [14] fuzzy traffic density.

An anomaly is detected if there is a sudden deviation in the specified parameters a grid based approach is employed to detect any anomalies in the vehicle trajectories.

The proposed mechanism only considers four states of interest in traffic conditions namely retrograde, slight congestion and heavy congestion denoting the state of the traffic based on the vehicular distribution in the region.

C. *A Functional Data Analysis Approach to Traffic Volume Forecasting*

A Prediction method based on the historical-data analysis of the region. This method emphasizes the use of pre-recorded historical data to determine the traffic flow in the region or the lane, thus providing the average vehicular distribution [6] based on time. This method makes use of a pre-recorded time stamped data samples taken at different time intervals. These samples are further refined by reducing the data samples until it is suitable to construct a generating function. The data sampling is reduced by increasing the time interval between the two consecutive data sets. Thus, further refining the information from the data sets and generate a function capable of defining the traffic flow in the area considering the factors influencing the traffic flow.

D. Dynamic Platoon Dispersion Models

A Dynamic traffic flow analysis and prediction model based on cross-sectional vehicle detection using Radio Frequency Identification and Detection (RFID). The traffic analysis of the traffic is done by considering the factors such as the timestamp of the vehicle detection, distance between successive detection to predict the speed of the traffic flow in a specific region. The Dynamic Speed-Truncated Normal Distribution Model (DNDM) [10] can calculate the speed of an independent vehicle in the region and generate a probability distribution function based on the recorded data. The other algorithm proposed in this model emphasizes the use of time based traffic distribution by time stamping and employing time window to observe various traffic characteristics. Other algorithms include Dynamic Average Speed model (DAM) and the Constant Speed Model both of them are employed to analyze and predict the vehicle's moment independently. And the Static Robertson Model (SRM). The algorithm is decided based on their respective performance Evaluation Index in certain environments. The environment factors include the road conditions, width of the road and the geography. The computation performance for each algorithm is evaluated to determine the suitable algorithm for the environment.

E. Double Window Vehicle Detection Algorithm

A dynamic vehicle detection concept based on the magnetic signature of the vehicle using data analysis. The magnetic sensors have always been in use to detect vehicles as a primary system but as the variety and the characteristics of the vehicle changed, the mechanism became less reliable and more obsolete. The proposed system is capable of providing accurate results even during various traffic patterns. This was possible due to the unique vehicle detection mechanism which utilizes significant characteristics of both the magnetic sensors and the data analytics approach to effectively detect vehicles in different scenarios. The concept makes use of the [5] Double window based vehicle detection algorithm (DWVDA) system which will detect the moment of the vehicle in a two stage system and the vehicles are identified based on their unique magnetic patterns using a magnetic sensor. This method is suitable for detecting the vehicle moment over a particular area but is heavily dependent of the magnetic properties of the vehicle, which may depend on the physical and magnetic properties of the vehicle. This is a robust and most likely the suitable method for detecting the vehicle flow through an area in an efficient manner.

F. Pseudo-Wavelet Filter

An innovative and effective vehicle detection mechanism which makes use of a strip downed version of an image processing based system. This framework emphasizes the use of the [1] Pseudo-Wavelet Filter (PWF) and the Circulatory Factor (CF) to accurately identify the wheels of a vehicle; by detecting the location of the wheels we can easily find the class and the count of the vehicle in a region. This framework also makes use of the Weight-In-motion (WIM) based mechanisms to detect the type of vehicles in a region. The proposed system can only function in a grey scale environment (i.e. Black and White format). The maximum observable angle of the camera providing the data can be of 165° in coverage. It can be utilized as a light weight vehicle detection mechanism which can count and detect the vehicle passing through a lane.

G. Support Vector Machine

A Congestion prediction model which focuses on the use of sensory data and big data to provide predictions on the occurrence of traffic congestion in a region. The framework primarily makes use of the [2] Support Vector Machine (SVM) and the Traffic Theory (TT) to analyze the traffic flow in the region. The SVM is primarily used to classify the data with respect to its impact on the traffic situation. The proposed mechanism has two modes of data which is processed to extract the traffic information 1) Spouts which refer to the previously analyzed data function based on which the predictions are made. 2) Bolts refer to the real time data collected in the region. The bolt data include weather reports, weather condition, social media data, vehicle density data and other important factors influencing the road traffic. The Fuzzy Model makes use of the weather data and the traffic data to primarily assess the risk factors of the roads in the region.

H. EGO-OBJ Model

The proposed system is a novel framework specializing in the vehicle moment prediction in the region according to the road factors, obstacles and goals. The system also specializes in vehicle tracking on an individual scale in order to gather the information needed for the moment prediction. The system only considers two factors in an instance namely the EGO-moment and the OBJ-position, referring to the major factors affecting the vehicle's moment. The vehicle actual moment is categorized into two maneuvers CUTIN and CUTOOUT based on the position of the OBJ and EGO. The moment tracking is based on the data from the vehicular sensors and an Object oriented Bayesian Network (OBN) [3] with the use of virtual boundaries. The vehicular moment which is also known as Lane Change (LC) maneuver is trained using the OBN but is recognized with the use of Dynamic Bayesian Network (DBN) to

effectively recognize the maneuvers. This framework can also be used to determine the distribution of the vehicles in a traffic signal based on the position and analyzed data.

I. Distributed Agent Model

The proposed system is a novel framework for dynamically simulating the traffic in a region. The framework is based on the assumption that the vehicles communicate via an inter-vehicle communication and also can share information like heading, speed, traffic factors. And the agents are also assumed to have awareness of other agents in the area which is the major factor for simulating the traffic condition in a real-time mechanism. The simulation is categorized into two based on the scope and the reference object, Micro and Macro simulation [11]. The micro simulation is specialized for a small scale simulation based on a single reference object or an agent. The Macro simulation is a large scale simulation where a region is referenced with all the agents involved with the region. The Diffusive Load Balancing mechanism is used in environmental simulation to effectively distribute the load or agents during a simulation.

J. Short-Term Traffic Forecasting

A traffic forecasting framework which focuses on short term forecasting and frequent updating mechanism which can accurately forecast real-time traffic situations for a short time interval suitable using Adaptive Neighborhood selection Based On Selection Strategy (ANSES). The proposed method is proven to be efficient than the k-means algorithm in terms of Principal Component Analysis (PCA) to reduce the linear dimension. The data inference from the ANSES is provided to a K-nearest neighbor (KNN) to identify the nearest cluster. The performance was evaluated based on two indicators Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) each providing the error margins based on the percentage and vehicle count respectively.

1) *Weight in Motion*: The proposed methodology is to effectively monitor and determine the traffic distribution in an area. The proposed system makes use of visual detection of the vehicle moments observed from designated “Weight-in-Motion stations” (WIM) [13] monitoring the traffic in the surrounding region. The information is acquired as vehicle characteristics like axle-load, approximate weight, spacing and count passing through the region. This information is utilized to accurately calculate the Annual Average Daily Traffic (AADT). The AADT is derived from the data of the WIM stations and Hierarchical Bayesian network to process the data into relevant information deriving the Poisson Distribution (PD) of the traffic in the region. This traffic distribution is simulated as a 2-dimensional map representation depicting the traffic distribution in each region based on the vehicle count per unit area.

III. TRAFFIC SIGNAL MANAGEMENT MODULE

This section specializes in handling the traffic flow based on the traffic situation in the region. These include several novel algorithms and frameworks specifically designed to enhance the traffic flow through the region.

A. DTSTOS

The proposed framework is a traffic signal optimization mechanism which evaluates the lane priority based on the fuel consumption of the vehicles on the lane. It is a geo-friendly approach for handling the pollution rates due to traffic. The proposed mechanism calculates the fuel consumption rate of the vehicles in lane and determines the highest consumption rated lane is given higher priority. This system heavily relies on the Vehicular Ad-hoc network (VANET) to obtain the fuel consumption data from the vehicles using the Connected Vehicles (CV), Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) to establish and maintain the network. The Dynamic Traffic Signal Timing Optimization Strategy (DTSTOS) [9] is a highly eco-friendly signal optimization strategy for handling the traffic.

B. Dynamic O-D Estimation (DODE)

The goal of the proposed system is to dynamically handle the traffic flow in the region based on the factors affecting the traffic conditions. The factors include the vehicle density, Vehicle flow, road condition, topography etc. These provided factors enable the system to perfectly analyze the characteristics of the road. The secondary goal of the system is to effectively re-route the traffic based on the traffic flow in the region. This evaluation is done by the Dynamic O-D estimation (DODE) [8] which evaluates the road using its performance index factoring the road's Total Time Spent (TTS) and Total Waiting Time (TWT).

C. Mainline Ramp Cooperation

A novel framework for detecting and handling Bottlenecks in a lane using long-queue strategy. The framework specializes on the identification and handling of the bottlenecks otherwise “snag”, which are sections of the road in which the vehicles tend to bunch up causing congestion. The framework first emphasizes the importance of identifying the snags on the road section, the road sections are

identified into snags and on-ramp sections. The secondary objective of this framework is to find the distribution and analyze the bottlenecks in order to derive a solution for the snags. Initially the lanes are evaluated based on the Ramp Metering (RM) mechanism which makes use of several factors influencing the traffic flow in the section and directly relating the acquired data to handle the bottleneck sections. The Mainline Ramp Cooperation (MRC) [7] is developed making use of the provided mechanisms to detect and handle the bottlenecks or snags based on the Queue Discharge Flow (QDF) of the Lane.

IV. CONCLUSION

A comparative literature review emphasizing the difference between the existing frameworks depicts the significance of each framework. This comparative analysis will be used to understand and employ the above frameworks with full potential to exploit the weaknesses in the existing systems.

A. Future Research

The recent technological developments provide a huge scope of development but a single framework will not be able to address all the problems with the existing system. The future of this domain relies on effective integration of the recent technologies to improve the Intelligent Transportation System (ITS). Some imminent concepts include [5] Magnetic Sensor based vehicle detection using a data analytic approach, this framework has an immediate effect on the vehicle detection concept. The primary reason for this mechanism is due to its high rate of accuracy and the ability to track vehicle individually (i.e. the concept is similar to SONAR mechanism which can identify the vessel based on its radar cross-section). The other improvement to the ITS will be the concept of AI powered management systems based on prediction and analysis models. The goal of these systems is to impart human level intelligence in Traffic Management System (TMS) which can handle traffic on its own without human interference and can provide insight over the flow of traffic in the region.

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