Intelligent Intersection Management: A Survey

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Abstract-*In today's transportation system, intersection management is one of the most difficult challenges to solve. Traffic lights are unable to cope with the system's increased mobility due to its growth. Co-operative junction management is new intersection management that has emerged as technology and communication mediums have advanced. All elements, such as road users, infrastructure, and traffic signal controllers, may efficiently communicate and coordinate traffic flow in collaborative junction management. We'll talk about how to improve road crossings using new adaptive communication approaches, as well as the obstacles that come with it.*

Keywords: Non-signalized intersection, signalized intersection, WAVE, VTL, Intelligent intersection management, Intelligent traffic control system.

1. Introduction

Keeping traffic flowing smoothly and safely is a huge difficulty in cross-section or junction management. Road traffic crashes and risk categories in India [1] presented a case study on Andhra Pradesh vehicle crashes (AP). In 2001, AP accounted for 7% of the country's population but 9.4% of deaths. In 2008-2009, the proportion of urban to rural RTCs was 45 percent to 65 percent, with fatal collisions occurring near schools, bus stops, gas stations, and pedestrian crossings accounting for 5%, 8%, 4%, and 7%, respectively. Large vehicles were involved in 24 percent of fatal collisions in 2009-2010, whereas two-wheeler deaths nearly quadrupled between 2000 and 2009. Vehicles under the age of four were engaged in 43 percent of fatal injuries, with 'overturning' and 'head-on' collisions accounting for 11 percent to 15% of fatal crashes; more than 74 percent of crashes were caused by driver error. At 'undisciplined' junctions, 40% of RTCs occurred, whereas, at police-regulated places, the collision probability was 42 percent but at traffic signals. Road cross-sections hamper traffic movement. By estimating traffic, specific algorithms such as SCOOT [2], Sydney Coordinated Adaptive Traffic (SCAT) [3], and RHODES [4] have been tested to improve the efficiency of adaptive traffic light signaling.

New intelligent transportation (ITS) solutions for junction management are being propagated due to recent advancements in information and communication technology (ICT). Nowadays, cars are equipped with various sensors that allow for a more accurate view of the surroundings. Such data will be sent from vehicle to vehicle (V2V) or vehicle to infrastructure (V2I) via the Vehicular Unplanned Network (VANET) [5]. Cooperative Intelligent Transportation (C-ITS) is defined as sharing real-time information by enabling the connectivity and collaboration between road users, transport operators, and traffic signal equipment. Vehicles and infrastructure equipped with C-ITS, for example, can send each other a warning, after which drivers are informed about the impending traffic condition in time to take the necessary precautions to avoid potential injury. Reduced congestion and increased driver comfort are two other possible advantages of using C-ITS. The paper Wireless access of auto environment (WAVE) using IEEE1609 standards [6] was published by the Institute of Electrical and Electronics Engineers (IEEE) to support this.

Signalized intersections and Non-Signalized intersections are the two most common types of intersections. On one side, traffic lights are employed to help people decide whether or not to cross a signalized junction, whereas, on the other side, there are no traffic lights at all. IIM allows automobiles to advertise with the infrastructure at a signalized intersection, allowing the infrastructure to sense the traffic clearly. However, in non-signalized junctions, IIM allows autonomous cars to communicate with one another and determine whether or not to cross the intersection without human intervention.

The complex difficulties of intersection management inspired me to write this study. A brief review of signalized junction management was offered in Section II. In part III, a detailed study of non-signalized junctions will be offered. The fourth section of the report provides an overview of traffic sensor technologies. Section V discusses several traffic control projects in cities. Section VI details the work previously been done to improve the intersection's intelligence through intelligent traffic control management.

2. Signalized Intersection Management

The intersection is a shared area that is utilized by many approaches at the same time. A signalized intersection is a space where a set of techniques are used to create a predefined time interval for the shared space. Delay and queuing processis the critical problem of any convergence, and through these problems, we can analyze and design the intersection for a greater extent of services. The primary research area of improving the traffic light and traffic flow at the intersection are such as fuzzy logic [7-9], mathematical model [10-14], rolling horizon approach [16], neural network-based control [17], Petri Net based control [18-20], Markovian based control [21], queue theory [22] and some agent-based learning methods [23-26]. Some authors [27] proposed V2X communication where some vehicles negotiate with the intersection controller for the green light. Using V2V communication, a vehicle calculates the traffic queue length based on its intended travel route. The group leader is selected based on the group's size and direction. All the different groups from different sides can communicate with the intersection controller and send their queue length for negotiating the green light. Different types of delay models [28] we can analyze such as (Figure 1).

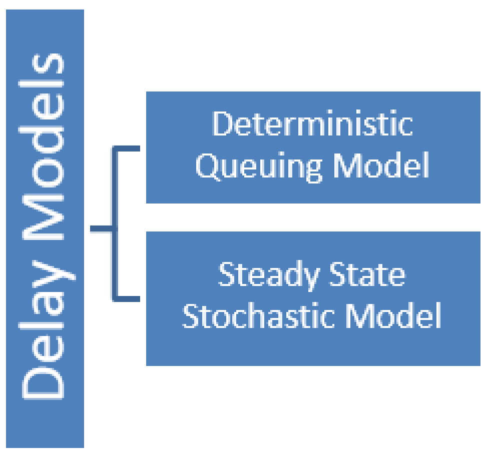

Figure 1: Different types of delay models

Deterministic Queuing Model:

Pre-assumptions-

i) Single lane which is controlled by traffic signal

ii) Arrival and departure process are deterministic

This model is for predicting the average delay by vehicle within the signal cycle. There are basically two types of flow conditions of vehicle i.e. saturated flow conditions and unsaturated flow conditions. First we will go through with an unsaturated flow condition where all the arrived vehicles in the given cycle are cleared before the next cycle. Few more assumptions we have to take for this model that are-

i) All the vehicles will arrive at constant and uniform flow rate.
ii) Acceleration and deceleration of the vehicles are instantaneous. Thus, it will convert into stop delay; therefore, we can estimate the total delay incurred by vehicles attempting to cross the intersection. And the last assumption is

iii) Vehicle queue should be vertical to the stop line of intersection.

$$tu = \frac{C(1-\lambda)2}{2(1-X\lambda)}$$

Where, tu is average delay because of unsaturated flow, λ is fraction of effective green (EG) to cycle length(C) i.e. $\lambda=\frac{EG}{C}$, X is approach volume (v) to capacity (C) ratio or saturation ratio.

Here approach volume $X \leq 1$.

In oversaturated condition, number of vehicles approaching to intersection number of vehicles can be served by the traffic light signal (Here X1). The total delay is divided into two components: the unsaturated component and the over-saturated component. This procedure works by dividing the total delay into two components.

$$to = C - \frac{EG}{2} + \frac{T}{2} * (X-1)$$

Where to average delay due to over-saturated flow is, T is the over-saturated flow time.

Steady State Stochastic Model:

In this model, we are taking randomness of arrivals. When the demand is approached to the saturation level (X>=1), that time estimated delay would be tending to infinity.

Assumptions:

- Here a number of arrivals follow a well-known distribution called a poison distribution and does not change over time.
- Departures from the stop line follow a known distribution with constant mean.
- When vehicles' unexpected arrival increases the system's saturation, we assume that the unsaturated system will remain steady over the analysis period.
- All these models still consider that vehicles accelerate and decelerate right away.

3. Non-Signalized Intersection Management

In non -signalized intersection management has no traffic lights and no other controlling systems. Traditionally through eye contact, drivers could interact with each other for safe overtaking. By communicating with each other, V2V communications improve the efficiency and accuracy of driver interactions. One example of this is collision detection warning [29], which uses the information gathered from various sources to improve the decisions.. This proposed method identified some critical factors like driver response time, vehicle speed, location accuracy, communication range, etc. The platooning concept was used in [30] for cooperative intersection management. This concept says when vehicles have approached an intersection. A concept presented in this section is a virtual platoon, where each member of the group is responsible for the intersection. Another example is a map-free collision warning [31] system called Forwards. In this system DSRC was used to communicate between the vehicles, and the Kalman filter used for collision avoidance. The above-mentioned work was just for quick revision into the applications of Intelligent Intersection Management (IIM). In the next following parts, we will be discussing one of the effective methods for non-signalized intersections, including virtual traffic light (VTL), in detail.

Virtual traffic light

A way to improve the safety and efficiency of the transportation system can be achieved through the combined efforts of transportation system experts and computational scientists [32]. Intersection safety is a very crucial research challenge within inter-vehicle communication (IVC) society. There are different solutions presented by researchers, such as intersection collision warning, collision avoidance scheme, and some more intelligent assistant systems [33], [34], [35], [36]. In India or most countries, more than 60% of intersections are regulated through traffic lights. And more than 50% of them are in need of repair. In the U.S., more than 2lac traffic lights are regulating the intersections [37]. Out of them, more than 50% need repairing [38], and the other 40% need reconfiguration [37] for the optimality of traffic delays. Repairing and reconfiguring the traffic lights are costlier. A very new approach that is the complement of a physical traffic light has been investigated, known as virtual traffic light (VTL) [39] [40] [41]. In this approach, vehicles that are approaching intersections act like a virtual traffic light. This can be possible via exchanging the message between the vehicles wirelessly. Through this message passing, dynamic traffic light program is created for the intersection. This information is then visible to the driver in their vehicle inbuilt display device. It means the whole traffic light infrastructure is replaced by the in-vehicle display.

There are several benefits of using VTL:

- Eliminates infrastructure cost for deploying traffic lights on every street's intersection.
- VTL gives quick response in microscopic traffic conditions rather than the normal traffic light. VTL concept is firstly introduced by M. Ferreira et.al. [39]. they introduce in-vehicle displays for controlling the intersection. The application of VTL is based on following assumptions:
  - Vehicles as a whole should be armed with DSRC devices.
  - Entirely vehicles should share the same road map.
  - Entirely vehicles should be equipped with GPS so that they can sync their positional information to each other correctly.

The overview of a simple VTL algorithm is given in figure 2. It simply describes the election of a unique leader and then computes and transmits the VTL program to other vehicles. One of the wireless technologies that VTL can be created is IEEE 802.11p standard [42]. Based on this technology IEEE standardized DSRC/WAVE and ETSI ITS G5 for vehicular networking. The US Dot makes this technology mandatory for new cars [43]. One of the authors [44] proposed a new system design, leader selection algorithm for selecting 1-out-of-n approached vehicles.

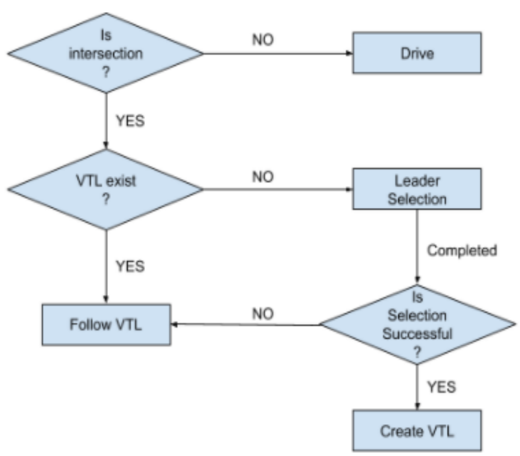

Figure 2. Shows the normal VTL flow. It shows the steps has to be taken by a car at intersection.

This paper is addressing the following problems:

- They are using Veins frame work with OMNeT++ with vehicular simulator SUMO.
- They established a leader selection algorithm for VTL.

- And they analyze the network performance of VTL through the simulator.

They are mainly focused on leader selection problem and if the leader is selected then the process will be successfully executed or not. For this they are taking few assumptions that are:

- Every car should be equipped with wireless networking devices so that they can communicate to each other. This can be possible through the IEEE 802.11p standard [42].
- Every car should have a GPS device so that they can obtain the accurate position information.
- Every car should maintain the car information table that contains vehicle IDs and positions.

Following tasks, they have shown in their algorithm. First, broadcast the VTL program periodically and again broadcast to tell other vehicles that it is the current leader. When the last car crosses the intersection, then again estimate the traffic light program. And finally, when the leader is green therefore crosses the intersection then the current leader assigns the leading role to the vehicle that is very near to the intersection. One of the authors [44] proposed one of the primary critical issues of VTL, that is, leader selection problem i-out-of-n solved via round-based algorithm. Round-based algorithms involve round-based communication among the vehicles for one leader selection out of n approached vehicles towards interaction. Failure in communication may lead to extensive message losses, and due to this, some vehicles are unable to participate in the leader selection process. This is also assigned to as disagreement of the leader selection. The author's work is to calculate the possibilities of disagreements. Disagreement relies on some parameters like a number of vehicles, chances of communication failure, and a number of communication rounds. Two types of communication failures were studied, i.e., symmetric and asymmetric failure. In symmetric failure, all the approached vehicles failed to receive a message, while in asymmetric failure, a subset of the approached vehicles was unable to receive a message

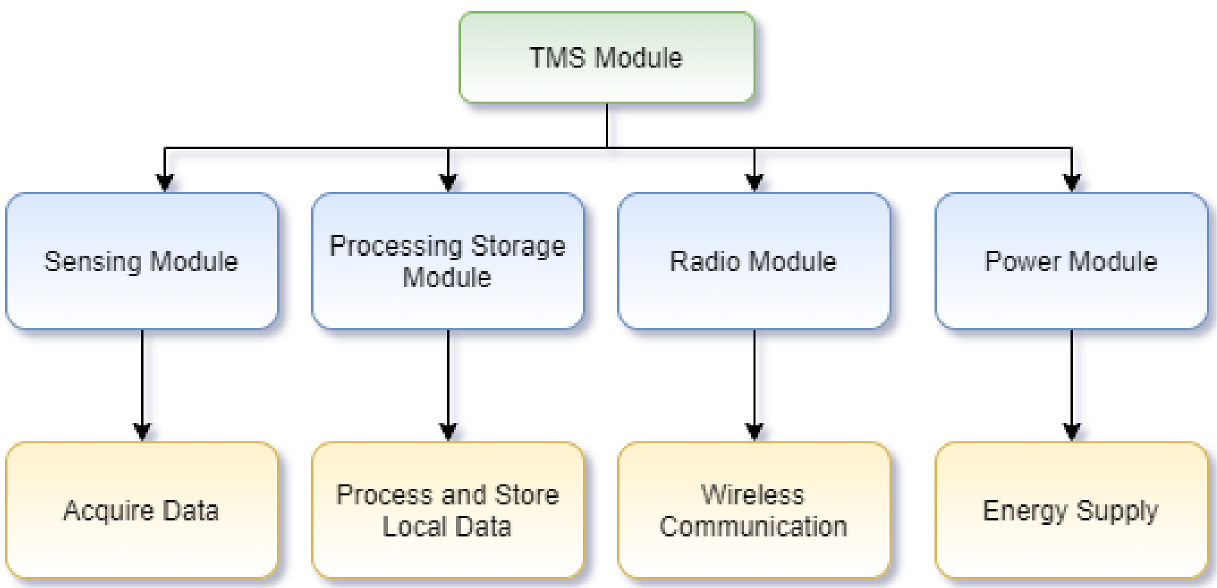

Figure 3: Working of different traffic monitoring sensors(TMS) modules

4. Overview of Traffic Sensing Technology

In the past decade, various industries started adopting these technologies (i.e., traffic management system, travel assistance etc.) for various reasons. There is a requirement for advanced technology for controlling the traffic flow at intersections. One of the approaches that are used for traffic control flow is the use of sensor technology. In table1, we have tried to come out with a list of few sensing technologies, including their principle, advantages of those technologies, and disadvantages. All the sensor devices are transducers that can convert light, temperature, pressure velocity, or any other physical nature parameters into the form of electronic signals. Traffic monitoring sensors (TMS) are typically divided into four modules, as given in Figure 3. In general, a radio module is used by the sensor for wireless data communication. The distance that can be reached between two points is often defined by the communication technology used from few meters (Wi-Fi, ZigBee etc.) to thousands of kilometers (GSM, Wi-Max etc.).

Table 1: Overview of traffic sensing technologies

Technology	Principles	Advantages	Disadvantages
Inductive loop	When the vehicle passes over the loops or rests on the loops then the inductance is reduced. This cause detection and signalled into the control box	-Flexible design -Well defined zone of detection -Accurate count data	-Very sensitive to the installation -Install in good pavement -Massive loops are required for location covering
Video Image Processors	Operators select different vehicle detection zones within the camera's field of view (FOV). Image processing algorithms are applied to selected zones in real time and to extract information like vehicle speed and occupancy.	-They are mounted above the road. - Operator select the vehicle detection zone. -We can programme the shape of detection zone.	-Detection artifacts caused by shadow, weather, and reflections from the roadway surface
RFID	RFID uses radio waves for transmitting or receiving the data between the reader and the tag that is attached with the vehicles.	-High Speed -High Accuracy -Multiple Reading	-Interference -Overhead reading (fail to read)
Infrared Detector	They are two types, i.e., Active and passive. Active infrared detectors are transmitting energy by a light-emitting diode or laser diode. Laser or Led diode illuminates the target, and the target reflects the energy again to the detector in the form of pixel or array of pixels. Then measured data is processed by different signal processing algorithms and to extract the required information from them.	-They can operate any time either day or night. - They can accurately measure the vehicle speed, class, position etc. by transmitting the beam to the target.	-Very sensitive detector, it can be affected by the bad weather.
Piezoelectric Sensor	It collects the data by the transformation of mechanical energy into electrical energy. It consists of a long strip made of piezoelectric material. It generates the voltage when the vehicle compresses the	-indicating exactly when and where the vehicle is passed. -It can measure the vehicle speed.	-Permanent installation -It must be installed over the pavement of the road so every time when the road is repaved, the sensor would need to be replaced

	piezoelectric material and this activates the controller.		
Magnetic sensor	It works on the principle of a large metal object disturbing the earth's magnetic field. It detects the change of magnetic field when the vehicle is passed over it	-Insensitive towards bad weather. - It can be use perfectly where small are of detection is required	-Multiple detectors are required just for detecting the smaller vehicle. -Not capable of detecting stationary vehicles.
Ultrasonic sensor	This sensor propagates ultrasonic waves and collects echoid waves from an object. It extracts the location of a vehicle by using the time-space between transmitted and reflected sonic waves.	-It can monitor more than one lane. - It can detect over height vehicles easily.	-Very sensitive with respect to environmental conditions.

5. State of The Art Review

This section gives you the complete review of intelligent traffic management projects. Table 2 shows the all- dedicated work for making traffic management more intelligent and their realistic implementation is also done worldwide. Some advanced methods like digital maps, positioning systems, and sensors have been used for making intersections intelligent so that we can take the intersection safety guarantee and reduce CO2 emission as well.

Table 2: Intelligent Traffic Management Projects

Project Name	Objective	Project sponsor	Completion year
Advanced Traveler Information System (ATIS) for Indian Cities [45]	To provide different types of information like alternate route, alert for road accidents	Deity, India	2014
Agent Based method for traffic management and reinforcement learning for intersection during congestion [46]	Minimize travel time	Research and Innovative Technology Administration, US	2010 onwards
Intersection decision support [47] [48]	The project main aim was to develop the application for infrastructure-based traffic system for improving the intersection safety	Department of Transportation (DOT) of Minnesota, California and Virginia and the Federal High- way Administration (FHWA), US	2002-2005
Connected Vehicle Reference Implementation Architecture (CVRIA)	The objective of this project is to find out the key interfaces across the connected vehicle environment	USDOT through the ITS Joint Program Office (JPO)	2011-2014
KO-PER [49]	This project was aimed to design a cooperative perception system at intersections based on multiple sensor networks. The main objective was to provide the improved view of the intersection for better decision making.	German Federal Department of Commerce and Technology	2009-2013
Advanced Weather Responsive Traffic Management Strategies	Management of road weather	Research and Innovative Technology Administration, US	2013

[50]			

6. Discussion and Research Trends

Intelligent Intersection Management (IIM) methods share many fundamental aspects. IEEE forecasts that traffic lights may become history after 15 to 20 years. VTL has the power to replace the traditional traffic light in the future with autonomous vehicles. In this regard, we have discussed intersection management based on signalized and non-signalized intersections. In signalized intersections, delay models are discussed by taking some pre-assumptions. On the other hand, non-signalized intersection VTL is the main critical issue for the discussion. Here, VTL can significantly shift the research trend from infrastructure traffic controlling system to an infrastructure-less traffic controlling system with autonomous vehicles' help. One of the authors' primary keys is how to select one vehicle out of 'n' arrived at an intersection for the execution of the VTL algorithm. Many discussions are going around the one problem that is the election of 1-out-of-n vehicles. Communication is one of the significant issues for IIM that faces challenges in reality. The current communication is based on ITS-G5. The capacity of communication is limited due to the spectrum allocation. Uncertainties should be considered as an essential part of Intelligent Intersection Management (IIM).

7. Conclusion

Traffic management is one of the most tedious tasks in the transportation system, especially at intersections. Advancement in technology, primarily when the vehicles can communicate with each other, plays a significant role in improving intersection performance to a greater extent. It is expected that as the automation of the vehicle will be increased, intelligent intersection management is promised to provide the best and efficient method for coordinating intersection traffic. This paper is about developing Intelligent Intersection Management (IIM) methods that are enabled by V2X communications. This paper also talks about the optimization of traffic lights at intersections by using advanced wireless communication technologies. This paper also discusses some traffic sensing technologies with their principles and the advantages and disadvantages of those traffic sensing technologies.

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BIOGRAPHIES

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