Intelligent Intersection Management: a Survey

Shishir Chauhan and Dilip Kumar

October 18, 2021

Intelligent Intersection Management:A Survey

Shishir Singh Chauhan
Computer Science and Engineering
NIT Jamshedpur
Jamshedpur, India
Email: shishirsingh913@gmail.com

Dr. Dilip Kumar
Computer Science and Engineering
NIT Jamshedpur
Jamshedpur, India
Email: dilip.cse@nitjsr.ac.in

***Abstract*— Intersection management is one of the biggest challenging problems in the current scenario of the transportation system. Due to the expansion in the mobility of the system, traffic lights cannot deal with it. Nowadays, advancement in the technology and communication medium has developed one different type of intersection management: cooperative intersection management. In collaborative intersection management, all the entities like road users, infrastructure, and traffic light controllers can efficiently communicate and coordinate traffic flow. We will discuss practical techniques for improving the road's intersections through new adaptive communication techniques and the challenges of doing such things.**

Keywords Non-signalized intersection signalized intersection WAVE VTL

I. INTRODUCTION

Cross-section management or intersection management is a great challenge to keep the traffic flow smooth and safe. Road traffic crashes and risk groups in India [1] gave one case study of road traffic crashes in Andhra Pradesh (AP). In 2001, AP had 7% of the nation's population but 9..4% fatalities. In 2008-2009, the share of urban: rural RTCs was 45%:65%, while 5%, 8%, 4%, and 7% of fatal crashes appeared near schools, bus stops, gas stations, and pedestrians- crossings, respectively. In 2009-2010, 24% of fatal crashes were recognized to heavy vehicles, while two-wheeler fatalities quite tripled during the 2000–2009 period. Vehicles under four years old were involved in 43% of the fatal crashes while 11% to 15% of the fatal crashes were recognize to ‘overturning’ and ‘head-on’ collisions; more than 74% of crashes were due to driver fault. 40% of RTCs occurred at ‘undisciplined’ intersections, while the crash risk at police-regulated locations was 42% but at traffic signals. Road cross sections are the hindrance of traffic flow. Some algorithms like SCOOT [2], Sydney Coordinated Adaptive Traffic (SCAT) [3], and RHODES [4] are tried to enhance the efficiency of adaptive traffic light signaling by estimating the traffic.

Recent advancement in information and communication technology (ICT) propagates the new methods of intelligent transportation (ITS) for intersection management. Nowadays vehicles are equipped with different-different sensors through which they will enable the richer perception of the environment . Such sort of information they will transmit vehicle to vehicle (V2V) called V2V communication or vehicle to infrastructure (V2I) called V2I communication through Vehicular unplanned Network (VANET)[5]. Real time information is often exchanged by enabling the connection and cooperation between
Road_users, traffic controllers and traffic signal infrastructure which is understood as Cooperative Intelligent transportation (C-ITS).
Vehicles and infrastructure equipped with C-ITS can, as an example, communicate a warning to every other, after which the drivers are briefed about the forthcoming traffic situation in time for them to require the required actions to avoid potential harm. Other potential benefits of the utilization of C-ITS include reduced congestion and improved driver comfort. To support this, the Institute of Electrical and Electronics Engineers (IEEE) released the article Wireless access of auto environment (WAVE) through IEEE1609 standards [6].

There are typically two categories of intersection i.e., Signalized intersection and Non-Signalized intersection. Traffic lights are used for the decision making for crossing the intersection in signalized while in the other side there is no traffic lights at all. In the signalized intersection, IIM allows vehicles to advertise with the infrastructure to perceive the traffic clearly. But in non-signalized intersections, IIM facilitate autonomous vehicles to interact with each other and decide for crossing the intersection without any human interference.

The motivation of writing this paper is the challenging issues of an intersection management. Section II presented a short discussion about signalized intersection management. Detailed discussion about non-signalized intersections would be presented in section III. Section IV gives the overview of traffic sensing technology. Section V about some urban traffic management projects. Section VI covers the maximum possible work that has already been completed to make the intersection more intelligent with the intelligent traffic control management.

II. 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 process

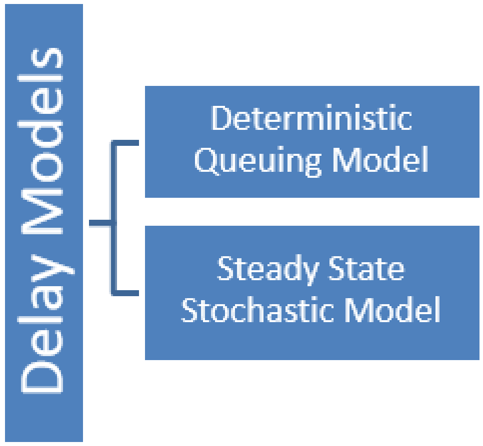

Figure 1: Different types of delay models

is 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 (In figure.1)

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 ($X \geq 1$), that time estimated delay would be tends to infinity.

Assumptions:

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

III. 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

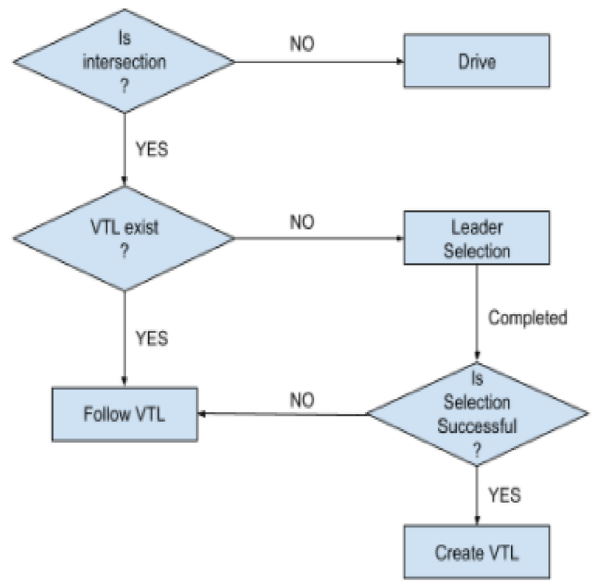

Figure 2. Shows the normal VTL flow. It shows the steps has to be taken by a car at intersection.

new cars [43]. One of the authors [44] proposed a new system design, leader selection algorithm for selecting 1-out-of-n approached vehicles. 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

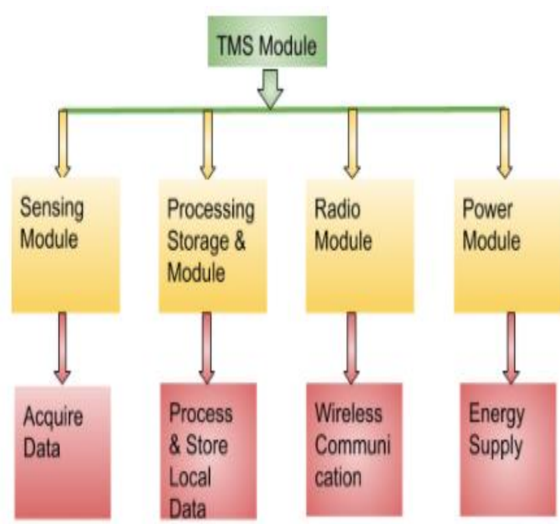

Figure 3 shows the working of different traffic monitoring sensor (TMS) modules

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.

IV. 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 thousand 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 uses radio waves for	-High Speed	-Interference

RFID	transmitting or receiving the data between the reader and the tag that is attached with the vehicles.	-High Accuracy -Multiple Reading	-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 piezoelectric material and this activates the controller.	-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
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.

V. 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 CO_2 emission as well.

Intelligent Traffic Management Projects:

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 [50]	Management of road weather	Research and Innovative Technology Administration, US	2013

VI. 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).

VII. 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.

REFERENCES

[1] Road traffic crashes and risk groups in India: Analysis, interpretations, and prevention strategies

[2] P. Hunt and D. Robertson, "The SCOOT on-line traffic signal optimi- sation technique," Traffic Eng. Control, vol. 23, no. 4, pp. 190–192, 1982.

[3] A. Sims and K. Dobinson, "The Sydney Coordinated Adaptive Traffic (SCAT) system philosophy and benefits," IEEE Trans. Veh. Technol., vol. 29, no. 2, pp. 130–137, May 1980.

[4] P. Mirchandani and L. Head, "A real-time traffic signal control system: Architecture, algorithms, and analysis," Transp. Res. Part C: Emerging Technol., vol. 9, no. 6, pp. 415–432, Dec. 2001

[5] Vehicular ad-Hoc networks (VANETs)—An overview and challenges.

[6] IEEE Guide for Wireless Access in Vehicular Environments (WAVE)— Architecture, IEEE Std 1609.0-2013, Mar. 2014.

[7] J. Niittymäki and M. Pursula, "Signal control using fuzzy logic," Fuzzy Sets Syst., vol. 116, no. 1, pp. 11–22, Nov. 2000.

[8] D. Teodorovic, P. Lucic, J. Popovic, S. Kikuchi, and B. Stanic, "Intel- ligent isolated intersection," in Proc. 10th IEEE Int. Conf. Fuzzy Syst., 2001, vol. 1, pp. 276–279.

[9] S. M. Rahman and N. T. Ratrout, "Review of the fuzzy logic based approach in traffic signal control: Prospects in Saudi Arabia," J. Transp. Syst. Eng. Inf. Technol., vol. 9, no. 5, pp. 58–70, Oct. 2009.

[10] P. Marcotte, "Network optimization with continuous control parame- ters," Transp. Sci., vol. 17, no. 2, pp. 181–197, May 1983.

[11] H. K. Lo, "A novel traffic signal control formulation," Transp. Res. Part A, Policy Pract., vol. 33, no. 6, pp. 433–448, Aug. 1999

[12] W. H. Lin and C.Wang, "An enhanced 0-1 mixed-integer LP formulation for traffic signal control," IEEE Trans. Intell. Transp. Syst., vol. 5, no. 4, pp. 238–245, Dec. 2004.

[13] C. Beard and A. Ziliaskopoulos, "System optimal signal optimization formulation," Transp. Res. Rec., vol. 1978, pp. 102–112, 2006.

[14] F. Fang and L. Elefteriadou, "Development of an optimization method- ology for adaptive traffic signal control at diamond interchanges," J. Transp. Eng., vol. 132, no. 8, pp. 629–637, Aug. 2006

[15] H. M. A. Aziz and S. V. Ukkusuri, "Unified framework for dynamic traffic assignment and signal control with cell transmission model," Transp. Res. Rec.: J. Transp. Res. Board, vol. 2311, pp. 73–84, 2012.

[16] G. Newell, "The rolling horizon scheme of traffic signal control," Transp. Res. Part A, Policy Pract., vol. 32, no. 1, pp. 39–44, Jan. 1998.

[17] J. Spall and D. Chin, "Traffic-responsive signal timing for system- wide traffic control," in Proc. 1997 Amer. Control Conf., 1997, vol. 4, pp. 2462–2463.

[18] C. Petri, "Kommunikation mit Automaten," Ph.D. dissertation, University of Hamburg, Hamburg, Germany, 1962.

[19] G. F. List and M. Cetin, "Modeling traffic signal control using Petri nets," IEEETrans. Intell. Transp. Syst., vol. 5, no. 3, pp. 177–187, Sep. 2004.

[20] J.-L. Gallego, J.-L. Farges, and J.-J. Henry, "Design by Petri nets of an intersection signal controller," Transp. Res. Part C, Emerging Technol., vol. 4, no. 4, pp. 231–248, Aug. 1996.

[21] A. Stubberud, "Markovian decision control for traffic signal sys- tems," in Proc. 36th IEEE Conf. Decision Control, Dec. 1997, vol. 5, pp. 4782–4787.

[22] P. B. Mirchandani and N. Zou, "Queuing models for analysis of traffic adaptive signal control," IEEE Trans. Intell. Transp. Syst., vol. 8, no. 1, pp. 50–59, Mar. 2007.

[23] B. Abdulhai, R. Pringle, and G. J. Karakoulas, "Adaptive traffic signal control," J. Transp. Eng., vol. 129, no. 3, pp. 278–285, 2003.

[24] A. L. Bazzan, D. de Oliveira, and B. C. da Silva, “Learning in groups of traffic signals,” Eng. Appl. Artif. Intell., vol. 23, no. 4, pp. 560–568, Jun. 2010.

[25] S. El-Tantawy and B. Abdulhai, “Towards Multi-Agent Reinforce- ment Learning for Integrated Network of Optimal Traffic Controllers (MARLIN-OTC),” Transp. Lett., Int. J. Transp. Res., vol. 2, no. 2, pp. 89–110, 2010.

[26] F. Zhu, H. M. A. Aziz, X. Qian, and S. V. Ukkusuri, “A junction-tree based learning algorithm to optimize network wide traffic control: A coordinated multi-agent framework,” Transportation Research Part C: Emerging Technologies, to be published.

[27] H.-J. Chang and G.-T. Park, “A study on traffic signal control at signal- ized intersections in vehicular ad hoc networks,” Ad Hoc Netw., vol. 11, no. 7, pp. 2115–2124, Sep. 2013.

[28] https://www.civil.iitb.ac.in/tvm/nptel/572_Delay_A/web/web.html.

[29] R. Miller, “An adaptive peer-to-peer collision warning system,” in Proc. IEEE VTC Spring, 2002, vol. 1, pp. 317–321.

[30] N. Neuendorf, T. Bruns, and J. Luckel, “The vehicle platoon controller in the decentralised, autonomous intersection management of vehicles,” in Proc IEEE ICM, 2004, pp. 375–380.

[31] L. Tu and C. Huang, “Forwards: A map-free intersection collision- warning system for all road patterns,” IEEE Trans. Veh. Technol., vol. 59, no. 7, pp. 3233–3248, Sep. 2010.

[32] S. Winter, M. Sester, O. Wolfson, and G. Geers, “Towards a compu- tational transportation science,” Journal of Spatial Information Science, vol. 2, no. 1, pp. 119–126, 2011.

[33] S.-H. Chang, C.-Y. Lin, C.-C. Hsu, C.-P. Fung, and J.-R. Hwang, “The effect of a collision warning system on the driving performance of young drivers at intersections,” Transportation Research Part F: Traffic Psychology and Behaviour, vol. 12, no. 5, pp. 371–380, 2009.

[34] H. Berndt, S. Wender, and K. Dietmayer, “Driver Braking Behavior during Intersection Approaches and Implications for Warning Strategies for Driver Assistant Systems,” in IEEE Intelligent Vehicles Symposium (IV’07). Istanbul, Turkey: IEEE, Jun. 2007, pp. 245–251.

[35] S. Joerer, M. Segata, B. Bloessl, R. Lo Cigno, C. Sommer, and F. Dressler, “To Crash or Not to Crash: Estimating its Likelihood and Potentials of Beacon-based IVC Systems,” in 4th IEEE Vehicular Networking Conference (VNC 2012). Seoul, Korea: IEEE, Nov. 2012, pp. 25–32.

[36] S. Joerer, M. Segata, B. Bloessl, R. Lo Cigno, C. Sommer, and F. Dressler, “A Vehicular Networking Perspective on Estimating Vehicle Collision Probability at Intersections,” IEEE Transactions on Vehicular Technology, 2014, to appear.

[37] “National Traffic Signal Report Card,” National Transportation Opera- tions Coalition (NTOC), Report 2012, 2012.

[38] P. Koonce, W. Kittelson, L. Rodegerdts, K. Lee, C. Swartz, J. Bonneson, P. Tarnoff, B. DeRoche, D. Bullock, and W. Tighe, “Traffic Signal Tim- ing Manual,” U.S. Department of Transportation, Publication FHWA- HOP-08-024, Jun. 2008.

[39] M. Ferreira, R. Fernandes, H. Conceição, W. Viriyasitavat, and O. K. Tonguz, “Self-organized traffic control,” in 7th ACM International Workshop on Vehicular Internetworking (VANET 2010). Chicago, IL: ACM, Sep. 2010, pp. 85–90.

[40] V. Gradinescu, C. Gorgorin, R. Diaconescu, V. Cristea, and L. Iftode,“Adaptive Traffic Lights Using Car-to-Car Communication,” in 65th IEEE Vehicular Technology Conference (VTC2007-Spring), Apr. 2007, pp. 21–25.

[41] K. Dresner and P. Stone, “Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism,” in 3rd Interna- tional Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2004). New York, NY: IEEE, Jul. 2004, pp. 530–537.

[42] “Wireless Access for Vehicular Environments,” IEEE, Draft Standard P802.11p/D4.0, Mar. 2008.

[43] US DOT. The Connected Vehicle - Next Generation ITS. [Online]. Available: http://www.itsa.org/industryforums/connectedvehicle.

[44] N. Fathollahnejad, E. Villani, R. Pathan, R. Barbosa, and J. Karlsson, “On reliability analysis of leader election protocols for virtual traf- fic lights,” in Proc. 43rd Annu. IEEE/IFIP Conf. DSN-W, 2013, pp. 1–12.

[45] Sivanandam, R.; Lelitha Devi, V.; Ravi, V.; Krishna Kumar, S. Advanced Traveller Information System (ATIS) for Indian Cities. Available online: https://coeut.iitm.ac.in/umcsp/pdfweb/v2iitm _ATIS%20For%20indian%20cities_v2.pdf (accessed on 14 April 2015)

[46] Benekohal, R.F. Agent-Based Traffic Management and Reinforcement Learning in Congested Intersections. Available online: http://ntlsearch.bts.gov/researchhub/search.do?managed=&stgrpid=&range=&so=asc&q=traffic+monitoring&p=107&sb=ti_sort&manageableMode=&psize=50&pid=&mode=&size=1 (accessed on 14 April 2015).

[47] V. Neale and C. McGhee, “Intersection Decision Support: Evaluation of a Violation Warning System to Mitigate Straight Crossing Path Colli- sions,” Virginia Tech Transp. Inst., Blacksburg, VA, USA, Tech. Rep. VTRC 06-CR10, 2006.

[48] B. Bougler, D. Cody, and C. Nowakowski, “California Intersection Decision Support: A Driver-Centered Approach to Left-Turn Collision Avoidance System Design,” Univ. California, Berkeley, CA, USA, Tech. Rep. UCB-ITS-PRR-2008-1, Jan. 2008

[49] M. Goldhammer et al., “Cooperative multi sensor network for traffic safety applications at intersections,” in Proc. 15th Int. IEEE Conf. Intell. Transp. Syst., 2012, pp. 1178–1183.

[50] Alfelor, R. Advanced Weather Responsive Traffic Management Strategies. Available online:http://ntlsearch.bts.gov/researchhub/search.do?managed=&stgrpid=&range=&so=asc&q=traffic+management+projects&p=158&sb=ti_sort&manageableMode=&psize=50&pid=&mode=&size=1 (accessed on 14 April 2015).