Modern Electronic Technology
http://www.advmodoncolres.sg/index.php/amor/index

A Review of Traffic Conflict Avoidance Methods at Intersection Using Vehicle-Infrastructure Cooperation System

Danping Wang*

School of Automobile and Transportation, Tianjin University of Technology and Education, Tianjin, 300222, China

ARTICLE INFO

Article history
Received: 20 September 2021
Revised: 27 September 2021
Accepted: 18 October 2021
Published Online: 25 October 2021

Keywords:
Traffic conflict avoidance algorithm
Intersection
Vehicle-Infrastructure Cooperation System (VICS)

ABSTRACT

Road intersections are important nodes for the convergence, turning, and diversion of traffic flows in the urban road network, but at the same time, due to the large traffic volume and conflict points at the intersection, it has become a traffic congestion and accident-prone area, which seriously affects road traffic safety and vehicle traffic efficiency. Therefore, it is of great significance to study the collaborative control strategy of urban intersections. This paper analyzes and summarizes the methods of intersection cooperative control based on intelligent connected vehicles in recent years, and looks forward to the future development trend and prospects of the combination of intersection cooperative control and Vehicle-Infrastructure Cooperation System.

1. Introduction

Intersection is an important road traffic node in the city, which is a link between roads in different directions. According to statistical data, about 36% of traffic accidents in the United States are related to intersections, and about 35% of traffic accidents resulting in injuries or deaths are related to intersections [1,2]; Traffic fatalities and injuries at intersections account for more than 20% of total accidents in Europe [3]; Japan has 42% of traffic accidents at intersections [4]. In the more densely populated urban roads, 80% of the traffic delays are related to road intersections. The efficiency of vehicle movement at road intersections is only 50% of the efficiency of movement on other road sections [5]. The determination of intersection access priority, between vehicles these are the main reasons for the frequency of traffic accidents at intersections. With the application of computer technology, control technology, electronic sensing technology and other research and development integration in the intelligent transportation, how to control the intersection operation with the consideration of traffic delay, energy consumption, has also become one of the hot spots of many scholars research. By effectively linking information on vehicle operations, drivers, and the road network environment through communication networks, establish a close coupling of cooperative control to achieve an information and intelligent traffic control system, Reduces vehicle delays and traffic accidents by resolving conflicts over intersection space-time resources.

**Corresponding Author:*
Danping Wang,
School of Automobile and Transportation, Tianjin University of Technology and Education, Tianjin, 300222, China;
Email: 1933835537@qq.com

 https://doi.org/10.26549/met.v5i2.8491

2. Collaborative Traffic Control System at Intersections Using VICS

Traditional intersection control methods are mainly divided into signalized and unsignalized control. Intersection control with signals generally calculates the estimated time of green light for an intersection based on the car travel delay equation, and cannot adjust the signal timing according to the current traffic flow, weather conditions and road information, which has certain limitations. Traffic control methods with signalization include. (1) Single-point timing multi-phase signal coordination control, i.e., calling a preset scheme by clock to reduce traffic conflicts, in conjunction with early break and late start when necessary. (2) Vehicle sensing real-time adaptive coordination control, i.e., by adjusting the period, green letter ratio, and increasing the effective green light time, etc., in accordance with the arrival of traffic flow. (3) User priority cable-free arterial coordination control, which refers to “green wave control” used on arterials to prioritize traffic flow on arterials by coordinating cycle and phase differences and taking care of pedestrians, buses, special vehicles, etc. (4) Real-time adaptive area control refers to the optimization of efficiency indicators, traffic flow simulation and other advanced means to ultimately achieve the purpose of balanced regional traffic flow. Han Yilei et al [6] conducted statistics on traffic volume and signal timing at intersections in the morning and evening peak hours. Optimize the design of the intersection capacity in terms of lane function division and signal timing, etc. based on VISSIM, the solution design was verified to reduce the average delay of intersection vehicles by 55.77%. The intersection traffic flow dynamic control method was studied by Liang Zijun et al [7]. Viewing traffic flows as independent control units and proposing a variety of cooperative control logics. It is also verified that the method can reduce the phenomenon of vehicle congestion at intersections.

Unsignalized intersections are prone to traffic accidents due to the control method of non-right-of-way assignment and signal-guided management. General through the unsignalized intersection is the vehicle approaching the intersection area to observe the intersection conditions in advance, to determine whether the vehicle through or slow down and stop. At present, the control mode of signal-less intersection is mainly divided into vehicle-vehicle cooperative control mode and central control station control mode. Vehicle-vehicle cooperative control is to be informed of the location, speed and road conditions of the surrounding vehicles through sensors. Regulating the speed and trajectory of self-vehicles can solve the problem of conflicting spatial and temporal resources that exist when vehicles pass through intersections. The method can be effectively implemented in road conditions with fewer vehicles, but when the intersection traffic volume is high and the road conditions are complex, it is impossible to macro-regulate the intersection vehicles. When the central control station control mode is used, the vehicle communicates mainly with the roadside intelligent devices. A large amount of information interaction between different vehicles is avoided, thus reducing the system requirements for wireless communication networks to some extent.

2.1 Framework of VICS

VICS-based intersection control is a real-time data collection of raw sensory data such as images and video point clouds in the current coverage area through sensory devices such as cameras and millimeter wave radar. Send the collected real-time data to the road test calculation control unit for real-time processing. Obtaining participant status information, road condition information, traffic flow information, weather information, etc. of the road traffic environment. send the processed information to the vehicle subsystem or other road subsystem via the road test unit in real time; When a centralized control of the vehicle is required, Intelligent roadside computing control unit for autonomous driving, which can specify control strategies based on the prevailing traffic conditions and the individual conditions of the vehicle. The decision planning strategy and control data are sent down to the vehicle subsystem, and the vehicle-side computing control unit processes the raw sensing data from the on-board sensing devices in real time. Obtain information on the status of traffic participants in the road traffic environment, etc. The processed information will be notified in real time to the vehicle subsystem or road subsystem via the on-board unit. Generate the vehicle’s driving strategy in real time and send the driving strategy to the autonomous vehicle’s in-line control system The in-line control system controls the vehicle via the vehicle bus, in-vehicle Ethernet and other links. including control of the vehicle’s braking system, steering system, transmission system, body control, etc. It is also able to control vehicle acceleration, deceleration, steering, lights, double flashing, etc. The roadside traffic control facility regulates traffic conditions through traffic signals, dynamic speed limits and other strategies based on data processed in real time from current data. Resolve congestion caused by traffic conflicts at intersections. The VICS-based intersection control system is shown in Figure 1:

https://doi.org/10.26549/met.v5i2.8491

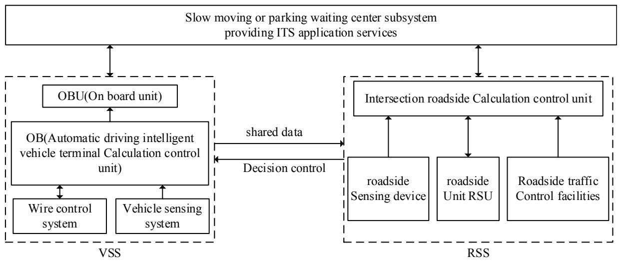

Figure 1. The intersection control system based on vehicle-road cooperation

2.2 Traffic Applications Using CIVS

Comparison of traffic conflict avoidance models S. Jin et al. [8] based on cooperative control system, for intersection without signal control proposed the use of improved hybrid frog-hopping algorithm to develop an optimal strategy to avoid collisions, wireless communication technology can obtain information between vehicles and vehicles and between vehicles and control center, which improves the stopping delay time, travel time, and vehicle traffic efficiency. Wenjuan E [9] proposed a vehicle conflict monitoring and elimination strategy based on vehicle-road cooperative technology to obtain vehicle perimeter information, set the priority level of passage for vehicles approaching at the intersection, and establish an intersection passage rule base for the problem of vehicle conflicts at unsignalized intersections. Zhou Jianshan et al. [10] studied the optimization of signal control at single-point signal intersections and used neural computation principles and fuzzy decision-making techniques in signal optimization control strategies to establish optimal signal timing schemes considering the diversity of traffic flow patterns, in order to online traffic flow OD estimation, a traffic OD matrix estimation model based on the principle of great entropy, a SOM neural network model, and a Takagi-Sugeno-Kang fuzzy decision system for effective identification and optimal control of traffic flow patterns at single-point signal intersections. According to the local development plan (such as industrial areas, residential areas, scenic spots, etc.) the time of day or each week or quarter population flow presents certain regular characteristics, and the signal timing scheme is designed according to the law of data mastered by the survey, but this law needs to consume long time and large labor cost, and with the economic development population flow will also change, not with real-time, and less adaptable range [11-13]. Dresner K et al. [14] established a multi-agent intersection coordination control center based on a vehicle-road cooperative system, which sends the operational status to the control center when the vehicle reaches the control range and the control center coordinates to guide the vehicle speed based on the current traffic flow information of the road.

Traditional signalized intersections can avoid vehicle conflicts to a certain extent, but they are prone to traffic congestion because they cannot be adjusted according to traffic flow and road conditions. The unsignalized intersection control method can be effectively executed for the road conditions with low traffic flow, but it is less effective for the complex road conditions with high traffic flow and cannot play a macro control role. With the continuous development of smart networked vehicle technology, the centralized processing of vehicle information can also meet the requirement of real-time. Makes it possible to control the behavior of vehicles at unsignalized intersections using Smart Grid technology. For cooperative vehicle-road control systems the efficiency of the control algorithm generation directly affects the safety and efficiency of road traffic. Therefore, effective conflict avoidance and traffic efficiency improvement are of great importance to the research of vehicle-road cooperative control.

3. Comparison of Traffic Conflict Avoidance Models

Currently, there have been many studies on vehicle conflict coordination control algorithms at intersections. With the development of vehicle-road cooperative intelligent networked vehicles, intersection passage no longer relies solely on signal control, and the fundamental problem of conflict elimination is still how to coordinate control between vehicles. At present, there are mainly acceptable gap model, control model based on dynamic game theory, conflict collision avoidance decision model based on dominance and conflict table algorithm based on resource lock.

3.1 Acceptable Gap Model

In 1968, Drew [15] proposed an acceptable gap model for the interpolation gap of vehicle operation at unsignalized intersections after analysis of the system. Vehicles that need to merge into the target lane at the intersection should slow down in advance to observe the traffic conditions and whether there are conditions (interpolable gap), and when the actual gap is greater than the acceptable critical gap in the driver's mind, they can wait for the opportunity to adjust the speed through the intersection, otherwise slow down or stop and wait for the right time.

 https://doi.org/10.26549/met.v5i2.8491

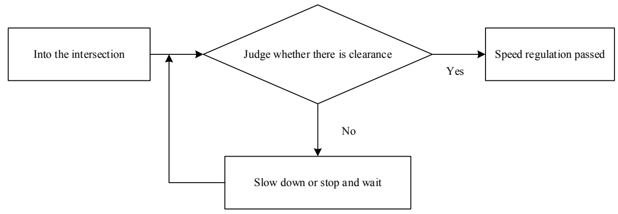

Figure 2. Driving mode through intersection based on acceptable gap model

A critical gap calculation method based on roundabouts considering driver behavior, vehicle travel characteristics and roundabout entrance geometry characteristics was proposed by Jia Hongfei et al. [16] The capacity simulation error of 4.2% was calculated by investigating the weekday evening peak data, which is a significant reduction compared with the capacity simulation error of 7.7% by the Raff method, 15% by the great likelihood method, and 18.6% by the Ashworth method, but the influence of pedestrians and non-motorized vehicles was ignored in the data investigation, which still has a certain error compared with the real data. However, the effect of pedestrians and non-motorized vehicles is ignored in the data investigation, and there is still some error with the real data. Hailong Gao et al. [17] established a mathematical model for analyzing and calculating critical clearance considering driver and vehicle characteristics to verify its feasibility. Different drivers generate different pressures through different intersections, and the intersection road conditions are complex, and the critical clearance can vary.

3.2 A Conflict Avoidance Decision Model Based on Preemptive Level

Based on the dominant model refers to the vehicle in the conflict point of the dominant position and the psychological factors of the driver to determine the priority of the vehicle in the conflict point of passage. The driver observes in advance whether there is a conflict point between his own vehicle and the surrounding vehicles in the future running trajectory, if there is no conflict point can pass normally, if there is a conflict point according to the actual situation of the corresponding conflict avoidance decision. Amundsen et al. [18] in 1977 studied intersections to give a suitable definition of traffic conflict: a traffic conflict is a conflict of resources in time and space for operating vehicles, and a collision occurs if this resource conflict problem cannot be coordinated in advance. Xiao Yongjian et al. [19] considered the influence of driver psychological factors and established a subject-object virtual trajectory field where the vehicle has passed the body length of the conflict point to calculate the dominance assessment in the conflict, introducing a critical dominance characterizing the driver's decision threshold, and the field collection parameters were calibrated to verify that the method obeys a normal distribution $N(0,0.2^2)$.

3.3 Control Model Based on Game Theory

The game can be divided into a static game and a dynamic game according to the state, and the participants of the static game only take action once at the same time. In many conflict resolution models, the study of the driver's decision to perform the conflict belongs to one decision, ignoring the analysis of the mutual influence between different drivers' behavioral decisions in the process of intersection. Repeated game is a special kind of discrete dynamic game, assuming that the set of participants at the intersection conflict point is A= {A1, A2,A3}, as shown in Figure 3 below:

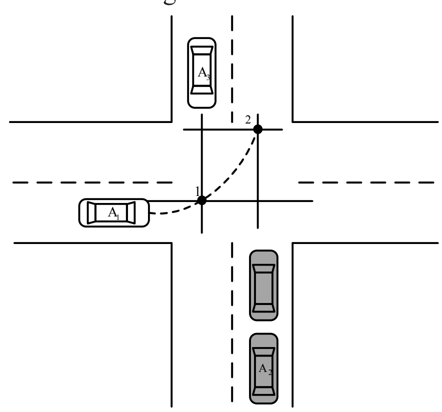

Figure 3. Schematic diagram of vehicle insertion at unsignalized intersection

The multiple times game in the process of car insertion uses game tree to represent the acceleration and deceleration and decision time characteristics, in which different driver behaviors have a great impact on the outcome of the game. Liu et al. [20] analyzed the driver behavioral decision at a smaller spatial scale, established a model of driver intersection intersection behavior without light control based on dynamic repeated games, classified drivers into cautious and risky free combination types, analyzed the Nash equilibrium and driver behavioral decision in the intersection game process, and proved the reasonableness of the model. The Nash equilibrium and drivers' behavioral decisions in the intersection game are analyzed, and the rationality of the model is proved. However, multiple gaming can sometimes have an impact on vehicle travel, and the effectiveness of this algorithm has yet to be verified in the case of more vehicles at intersections. Jingxian Li [21] analyzed the interfering nature of pedestrians on straight ahead and left-turning

  https://doi.org/10.26549/met.v5i2.8491

vehicles, according to the optimal control strategy and rule making taken when vehicles travel in different directions on the road with pedestrians crossing the road for gaming, from the practical point of view non-motorized vehicles are also one of the very important interfering factors. Liu Na [22] established a dynamic game model of straight and left turn when considering the influence of driver personality factors on straight and left turn conflicts, whether this method is applicable to other conflict point elimination at intersections remains to be studied in depth.

4. Conclusions and Discussions

The intersection cooperative control method has been studied and summarized, and it is found that the intersection cooperative control only relies on the traffic signal and the information interaction between vehicles to solve the intersection conflict problem, which has certain limitations. If these methods are combined with the vehicle-road cooperative technology, the information obtained by advanced road measurement equipment and vehicle-mounted units can be used to provide a reference basis for intersection conflict resolution, and if each intersection is also controlled in cooperation with each other, the capacity of vehicles on the road will be greatly improved.

Funding

Tinajin Research Tnnovation Project for Postgraduate Students: Research on multi-sensor fusion vehicle detection algorithm in complex weather conditions(2020YJSS086).

References

[1] E.Commission. Traffic Safety Basic Facts on Seasonality[R]. Technical Report, 2016.

[2] S.Huang, A.W.Sadek and Y.Zhao. Assessing the mobility and environmental benefits of reservation-based intelligent intersections using an integrated simulator[J]. IEEE Transactions on Intelligent Transportation Systems,2012, 13(3):1201-1214.

[3] European Road Safety Observatory. Traffic Safety Basic Facts 2006 Junctions[EB/OL]. Safety Net, Project co-financed by the European Commission, 2007, 4.

[4] Xie Boyuan. Vehicle Cooperative Control Basd on Information Exchange and Motion Coupling [D]. Beijing: Tsinghua University,2014.

[5] SUN Liyun. Research on Urban Road Intersections-accident Prediction Model and Algorithm [D]. Beijing Jiaotong University,2011.

[6] HAN Yilei, HAN Yin, HU Rong. Optimization Design of Intersection Traffic Organization Based on VISSIM Simulation [J]. Logistics Sci-Tech,2021,44(09):83-86.

[7] LIANG Zijun,ZHANG Weihua,YANG Wei, et al. Research on dynamic control method of traffic streams at intersection based on time space resouree optimization [J]. Journal of Hefei University of Technology (NATURAL SCIENCE),2020,43(09):1240-1249.

[8] JIN Li-sheng,ZHENG Yi,GAO Lin-lin, et al. Cooperative vehicle intersection control algorithm for intelligent vehicles [J]. Journal of Chang'an University (Natural Science Edition),2015,35(S1):7-11.

[9] E Wenjuan. Reasearch on Vehicle Conflict Detection and Resolution Algorithm at Unsignalized Intersection [D].JilinUniversity,2012.

[10] Jianshan Zhou,Daxin Tian,Xu Han et al. A Self-adaptive Optimal Control Approach for Urban Isolated Signalized Intersection Based on VII [A]. China Intelligent Transportation Association. The 7th China Intelligent Transportation Conference Excellent Paper Collection - Intelligent Transportation Technology [C]. China Intelligent Transportation Association: China Intelligent Transportation Association,2012:12.

[11] CHEN Yudong, ZHANG Yi, HU Jianming et al. Pattern Discovering of Regional Traffic Status with Self-Organizing Maps[J]. In Proceedings of the IEEE ITSC, 2006, MC7.5: 647-652.

[12] Wong Y.K, Woon W.L. Improving traffic signal control system using demining[J]. In Proceedings of the MMU international symposium of information and communication technologies, 2006.

[13] Wong Y.K, Woon W.L. An iterative approach to enhance traffic signal optimization[J]. Expert Systems with Application, 2008, 34(4):2885-2890.

[14] Dresner K, Stone P.A multiagent approach to autonomous intersection management[J]. Joournal of Artificisl Intelligent Research 2008,31(1),591-656.

[15] Qu Zhaowei,Jin Yong,Chen Yongheng,et al.Planning methods and effect analysis of advance right-turn[J]. Journal of Traffic and Transportation Engineering,2008,8(2):106-109,115.

[16] JIA Hongfei,LI Bolin.Calculation of Traffic Capacity at Signalized Roundabouts Based on Gap Acceptance Theory[J].Journal of Transport Information and Safety,2018,36(03):64-71.

[17] GAO Hailong,WANG Wei,CHANG Yulin, et al. A mathematical model for critical gap of unsignalized intersections[J]. China Journal of Highway and Transport,2001(02):80-82.

[18] CHIN H C,QUEK S T． Measurement of traffic conflicts[J].Safety Science,1997,26(3):169-185．

[19] XIAO Yongjian,YANG Jianguo,WANG Zhaoan.

Driver's conflict avoidance decision model based on preemptive level[J]. Journal of Traffic and Transportation Engineering,2009,9(05):116-120.

[20] LIU Xiao-ming, WANG Xiu-ying Vehicle-cross Action Model in Intersection Without Traffic Light Based on Reduplicate Game [J]. China Journal of Highway and Transport,2011,24(04):94-100.

[21] Li Jingxian Traffic Signal Optimization Based on game models of the Interference of Turning Traffic in the Intersection [D]. Chang'an University,2018.

[22] Liu Na. Research on Conflict Model of Straight and Left Turning Vehicles Based on Game [D]. Xi'an University of Architecture and Technology,2019.

  https://doi.org/10.26549/met.v5i2.8491