A Dynamic Traffic Lights Controlling Combined with Vehicle Routes Planning Solution for Alleviating Traffic Congestion

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***Abstract*—With the rapid development of the economy, the number of private cars is constantly increasing, and the limited road capacity combined with static time-controlled traffic lights leads to serious traffic congestion at intersections during peak hours. Traffic congestion has many adverse effects such as prolonged travel time, fuel waste, increased travel costs, air pollution and so on. In order to alleviate traffic congestion at intersections during peak hours, this paper proposes a solution that combines dynamic traffic light control with switching vehicle driving routes. Vehicle to Infrastructure (V2I) technology is used to allow the infrastructures to obtain real-time information about the traffic situation on the road. When the road is congested, the infrastructures send the congestion information to the behind vehicles , and allowing them to actively change their driving route, while controlling the traffic lights on non-congested roads, optimal the green light time and providing more passage time for congested roads. In this paper, the simulation is done on the SUMO traffic simulator. And the simulation results show that compared with Fuzzy Logic based traffic light control scheme, the proposed solution reduces the average travel time by about 15.7%, reduces the average waiting time by about 29.4% and reduces the average time loss by about 32.5%. Thus, the proposed solution can effectively alleviate the traffic congestion, reduce travel time and save fuel.**

Keywords—Intersection, Traffic congestion, V2I, Dynamic traffic light control, Vehicle route planning.

I. Introduction

With the rapid urbanization and economic development, the number of private cars is fast increased. This has led to a series of problems, such as increased traffic congestion, decreased air quality and increased vehicle management difficulties. In cities, traffic congestion is a very common problem, especially at intersections during peak hours in the morning and evening, causing drivers and passengers to wait on the road for long periods of time.

It is well known that the red-green traffic light control system for traffic management is widely used in many cities in the world, and this red-green traffic light control system is belong to vehicle-driven lights, so the time of the traffic lights are static [1]. This static traffic lights change the traffic light color according to the pre-set time interval, allowing vehicles and pedestrians to alternate passage according to the prescribed traffic light color. However, such traffic light controllers have many problems. Static traffic lights cannot be adjusted according to the actual traffic conditions, and when the traffic flow at the intersection is uneven, it is easy to cause traffic congestion and exacerbate it, resulting in increased fuel consumption by vehicles.

Traffic congestion issues continues to worsen in most urban areas, traffic management technology will play a crucial role in traffic control in the coming years[2]. In order to alleviate traffic congestion and improve driving safety, people are exploring Vehicle to Infrastructure (V2I) technology based on communication and interaction between vehicles and infrastructure. V2I technology connects vehicles and infrastructure, enabling them to communicate and coordinate in real-time and play a more important role in traffic scheduling and management. In the paper, a solution that combines dynamic traffic light control with switching vehicle driving routes is proposed based on V2I technology, dynamically controlling traffic lights and vehicle driving routes based on the length of traffic congestion at intersections. The SUMO open source traffic simulator is used for simulation, and the solution effectively alleviates congestion at intersections during peak hours.

II. Related work

Vehicle traffic management strategies designed to improve urban road traffic conditions can be divided into two categories[3]: vehicle rerouting algorithms using Vehicle Ad Hoc Networks(VANETs)[4]-[7]; dynamic traffic light control algorithms using wireless communication technology[8]-[11].

To alleviate traffic congestion during peak hours, Tseng and Ferng proposed an improved traffic rerouting strategy designed for VANETs[4]. A system composed of a fog computing and cloud computing hybrid architecture is used to collect traffic data for each time slot, monitor traffic conditions, and provide rerouting services to drivers. Nie et al. proposed an Automatic Route Guidance approach using VANETs(ARG-VANET) to guide vehicles to travel on smoother roads[5]. This method automatically creates clusters through inter-vehicle communication, and cluster heads collect vehicle speed and location information from their members to estimate traffic conditions and share them in VANETs. Nguyen et al. proposed a path planning and traffic clearing scheduling scheme[6] to actively control dynamic traffic, reserve lanes for emergency vehicles and reduce travel time for emergency vehicles in vehicular networks. Backfrieder et al. proposed an A*-based routing algorithm that provides a comprehensive framework for detecting, predicting and avoiding traffic congestion[7]. It assumes using V2X to transmit current vehicle data such as travel routes and destinations or current locations, as well as providing route recommendations to vehicles. In [8], Bani Younes and Boukerche introduced an ITL scheduling algorithm(ITLC) for isolated traffic light scenarios and an ATL control algorithm for open network scenarios. The

ITLC algorithm uses VANETs technology to collect real-time traffic characteristics of all traffic flows at intersections, allowing the traffic flow with the maximum density to pass through the intersection first. In the ATL algorithm, the phase sequence is set at each traffic light based on the ratio between the traffic density of each traffic flow and the saturation density, ensuring the smoothness of backbone lines in open network scenarios. Kapusta et al. proposed a new traffic light preemption control algorithm[9]. Dynamic signal light control is used based on the position of emergency vehicles and the length of the intersection queue data, prioritizing emergency vehicles to reduce travel time. To reduce fuel consumption and carbon dioxide emissions, Suthaputchakun and Sun proposed an adaptive traffic signal scheduling scheme based on two-way communication between traffic lights and vehicles (TLVC)[10]. Using two-way communication between vehicles, real-time exchange of vehicle traffic information is used to determine the optimal red-light and green-light scheduling, and higher priority is assigned to heavy-duty vehicles passing through the intersection. Moel et al. proposed a traffic light management system for intersections that combines machine learning technology with traditional traffic light management systems[11]. To address traffic congestion and waiting time issues, Q-learning algorithms make decisions at intersections to reduce waiting time.

In recent years, the traffic congestion problem in many large cities has become increasingly serious, especially during peak hours. Due to the lack of reasonable coordination and control, vehicle queues, overflow and even intersection "lock-up" phenomena occur frequently[12].To alleviate traffic congestion, most studies only use dynamic traffic light control algorithms or vehicle rerouting algorithms, neither considering the combination of both algorithms to alleviate traffic congestion problems. During peak traffic hours, in the literature [5], only using vehicle rerouting methods to select smoother routes can actually increase the travel distance for vehicles, resulting in significantly longer travel times compared to dynamic traffic light control. In the literature [7], only using path planning methods and implementing traffic restrictions over a large area, including reserving lanes for electric vehicles, can lead to long queues and waiting times for vehicles. In the literature [10], only using dynamic traffic light control algorithms allows the traffic light controller to determine the appropriate traffic light scheduling for the next cycle based on the algorithm, but it is not real-time traffic light control. This approach only provides a limited level of congestion relief.Therefore, this paper based on V2I technology researches an algorithm that combines dynamic traffic light control with vehicle rerouting to alleviate traffic congestion.

III. Research process

A. Road Network Construction

In this paper, we used the SUMO platform to construct a dual carriageway intersection with 8 lanes, and used this road network to simulate a congested intersection during peak hours.The simulated road network is shown in Figure 1.

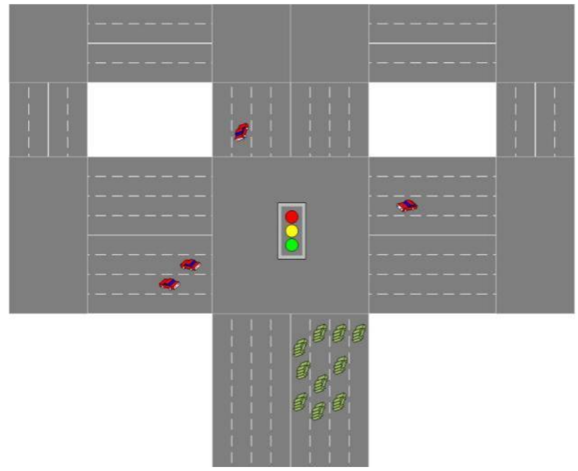

Fig. 1. Road network.

The traffic signal cycle of this intersection is 250 seconds with 4 phases. The first phase is for north-south through traffic, the second phase is for north-south left turns, the third phase is for east-west through traffic and the fourth phase is for east-west left turns, with a yellow light for caution following each phase. The green light for east-west and north-south through traffic is 83 seconds, and the green light for east-west and north-south left turns is 36 seconds, with a 3 seconds yellow light for caution. Right turns are not controlled by the traffic signals. The signal phases for the intersection are shown in Figure 2.

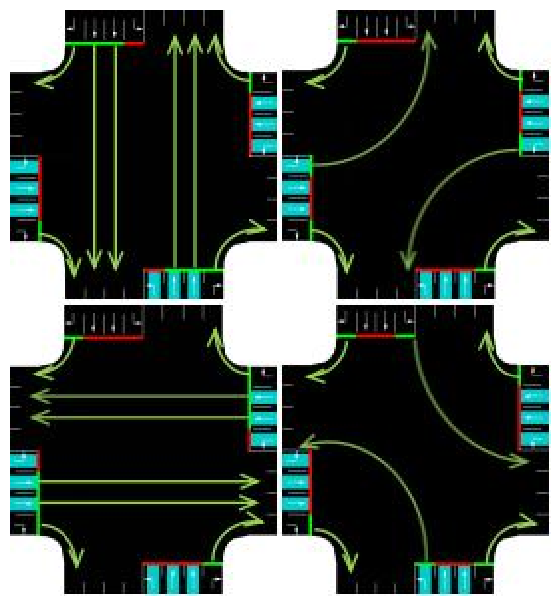

Fig. 2. Signal phases.

B. Dynamic Traffic Lights Control and Vehicle Control

Urban intersections often experience vehicle congestion during peak hours, and because of the concentration of workplaces, vehicles tend to be concentrated on certain roads, leading to severe traffic congestion on those roads.To relieve traffic congestion at urban intersections during peak hours, this paper propose a combined scheme of controlling the traffic lights and vehicle routes dynamically according to the vehicle congestion length using based on the V2I technology. The proposed combined control steps are as follows:

Step 1: Using the V2I technology, the infrastructure obtains real-time traffic information, such as the the length of congestion on each lane.

Step 2: Comparing the lengths of congestion on each road, if the current lane has a higher congestion level than other lanes, then reduce the green light duration for the other lanes.

Step 3: If the length of congestion of the current lane is greater than L meters(L is a threshold to judge the road congestion or not. In the following simulation, we set L = 150 meters), the infrastructure sends congestion information to vehicles behind the road, prompting them to change their driving route and escape the current congestion road.

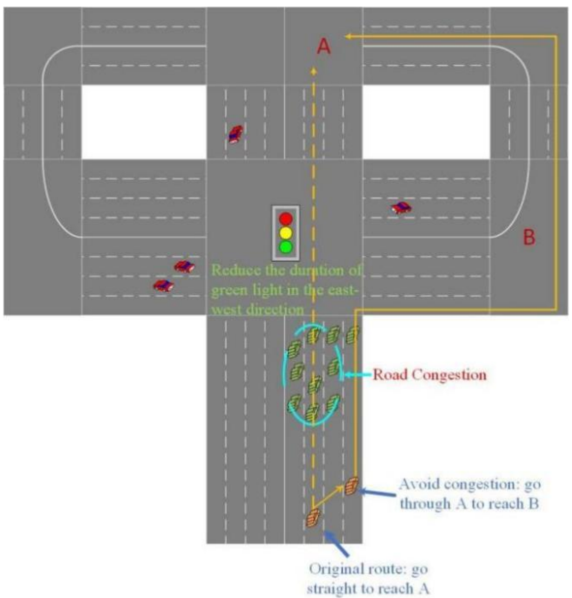

Fig. 3. Traffic lights and vehicle control.

Take the scenario shown in Figure 3 as example, the congestion on the north-south straight and left-turn lanes is greater than that on the east-west straight and left-turn lanes, so the green light duration for phases 3 and 4 is reduced. If the congestion length on the north-south straight and left-turn lanes is greater than L meters, the infrastructure sends congestion information to the vehicles located behind the intersection. At this time, the orange vehicle wants to pass through the traffic light and arrive at point A. If the vehicle proceeds straight, it will exacerbate the intersection congestion. Therefore, the orange vehicle is directed to change its travel route and go through point B to reach point A, thus relieving the road congestion.

The core of the proposed solution is to compare the congestion levels of the current green light phase with the congestion levels of the other three red light phases. If the congestion level of any of the other red light phases is greater than that of the current phase, the duration of the current phase will be reduced. If the vehicle congestion length on any lane is greater than L meters, the infrastructure will send congestion information to the vehicles located behind the intersection, and the vehicles will be prompted to change their travel route. The process of traffic light and vehicle route control is shown in Figure 4.

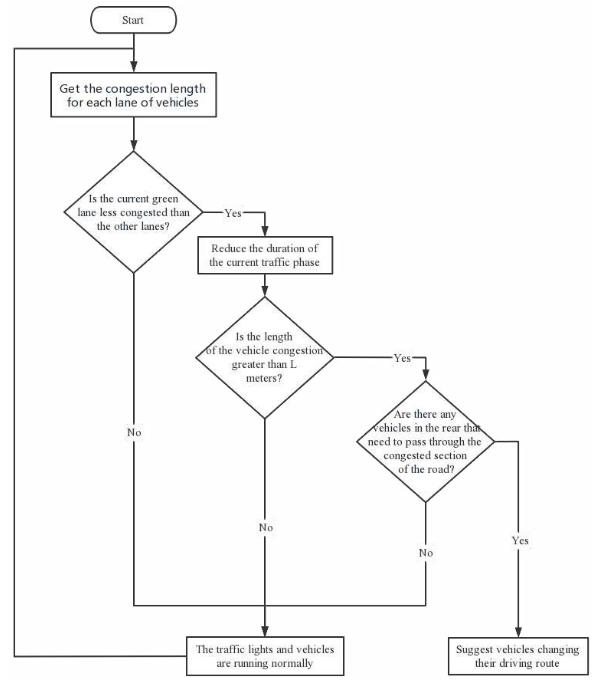

Fig. 4. The control process for traffic lights and vehicles.

IV. SIMULATION RESULTS

In the paper, the SUMO traffic simulator is used to simulate the congestion of intersections during the traffic peak period. Its Traci interface is used to implement intelligent control of traffic lights and vehicles route, and is compared with the Fuzzy Traffic Lights Control (FTLC) algorithm[13]. The simulation related parameters are set as shown in Table I. In the simulation, the north-south road is the main road with heavy traffic and is prone to congestion with a high probability of congestion. The east-west road is a secondary road with less traffic and is less prone to congestion.

TABLE I. SIMULATION PARAMETERS

Parameters	**Values**
Number of lanes	4
Maximum speed	50km/h
Acceleration	1.6km/s^2
Deceleration	2.5km/s^2
Minimum safe distance	2.5m
Car-following model	Krauss model
Traffic congestion threshold L	150m

In the simulation, we evaluated the system from three aspects: Travel Time, Waiting Time and Time Loss. Travel Time refers to the time it takes for a vehicle to travel from the starting point to the destination. Waiting Time refers to the time a vehicle waits due to traffic congestion or signal waiting during the journey. Time Loss refers to the difference between the actual time spent by the vehicle during travel and the time it should take for the vehicle to travel the same distance at the same speed under ideal conditions. Under different traffic flow rates, we take the average of each evaluation indicator, namely Average Travel Time, Average Waiting Time and Average Time Loss, as shown in the following formula.

$$\overline{TT} = \frac{\sum_i^N TT_i}{N_v} \tag{1}$$

$$\overline{WT} = \frac{\sum_i^N WT_i}{N_v} \tag{2}$$

$$\overline{TL} = \frac{\sum_i^N TL_i}{N} \tag{3}$$

Where $\overline{TT}$ is the average travel time, TT_i is the travel time of vehicle i, $\overline{WT}$ is the average waiting time, WT_i is the waiting time of vehicle i, $\overline{TL}$ is the average time loss, TL_i is the time loss of vehicle i, N is the total number of vehicles.

Firstly, we evaluated the vehicles that changed their travel routes from three aspects and compared the proposed Our Control (OC) scheme performance with the other control schemes, such as the No Control(NC) and Fuzzy Traffic Lights Control (FTLC) algorithms, as shown in Table II. The current traffic flow is set as follows: North-South through traffic is 2118 vehicles/h, North-South left turns are 582 vehicles/h, North-South right turns are 960 vehicles/h; East-West through traffic is 720 vehicles/h, East-West left turns are 180 vehicles/h, East-West right turns are 300 vehicles/h.

TABLE II. EVALUATION RESULTS UNDER DIFFERENT CONTROLS

Evaluation Indicator	NC	FTLC	OC
Average Travel Time	262.6	235.9	172.1
Average Waiting Time	171.1	101.4	3.0
Average Time Loss	202.0	175.6	50.3

According the results shown in the Table II, it is clear to see that the FTLC algorithm has much better performances than NC scheme, the average travel time, average waiting time, and average time loss of the vehicles have all slightly decreased. Our proposed control algorithm has the best performances. Compared with NC, the average travel time of the vehicles has been reduced by 63.8s, and compared with FTLC, the average travel time has been reduced by 90.5s. Since vehicles turning right are not controlled by traffic lights, there is almost no waiting time during the process of changing travel routes, and the time loss is greatly reduced.

We optimize signal lights and routes planning simultaneously. When vehicles encounter congestion, we reduce the green light duration on non-congested roads to allow vehicles on congested roads to pass quickly, greatly reducing waiting time. Additionally, we also suggest vehicles to change lanes to non-congested sections and utilize those sections to travel to their destination, further reducing travel and waiting times. Thus, through the combination of these two optimization methods, our indicators are far superior to those of FTLC and NC.

Then, we analyzed the Average Travel Time, Average Waiting Time and Average Time Loss of congested road vehicles under different traffic volume, the simulation results are shown in Figure5, Figure 6 and Figure 7. As shown in Figure 5-7, as the traffic volume increases, the Average Travel Time and Average Time Loss of the vehicles also gradually increase.

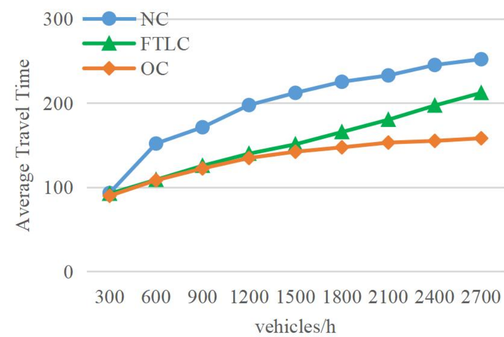

Fig. 5. Average Travel Time of congested road vehicles under different traffic volumes

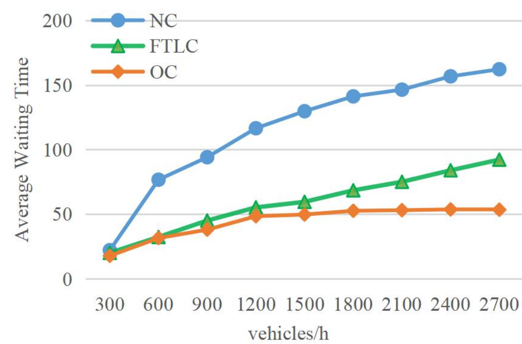

Fig. 6. Average Waiting Time of congested road vehicles under different traffic volumes

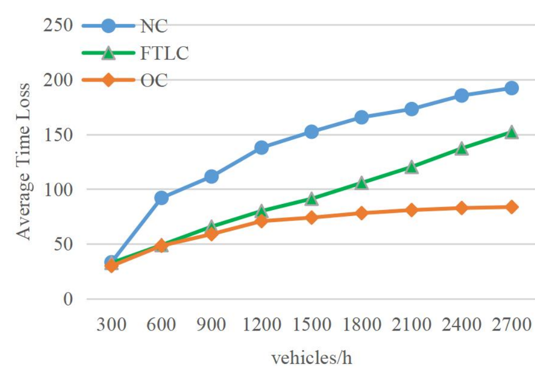

Fig. 7. Average Time Loss of congested road vehicles under different traffic volumes

After optimization through our proposed control algorithm, compared with NC, the vehicle's travel time has been reduced by about 35.2%, the average waiting time in congested sections has been reduced by about 64.1% and the average time loss in congested sections has been reduced by about 53.8%. Compared with FTLC, the vehicle's travel time has been reduced by about 15.7%, the average waiting time in congested sections has been reduced by about 29.4%, and the average time loss in congested sections has been reduced by about 32.5%.

The fuzzy traffic light control algorithm described in [13] calculates the corresponding green light duration based on the traffic volume on different roads, but it is unable to control the traffic lights in real-time. In our proposed solution, we combine traffic signal control with vehicle route planning. This approach not only allows real-time control of traffic lights by reducing the green light duration on non-congested roads, enabling faster passage for vehicles on congested roads, but it also suggests that vehicles on congested roads change lanes to non-congested roads. By utilizing the non-congested roads to travel to their destinations, this solution greatly alleviates traffic congestion, reduces travel time, waiting time, and overall time loss for vehicles.

V. CONCLUSION

In the paper, we proposed a scheme based on V2I technology to simultaneously control traffic lights and vehicle routes. Real-time control of traffic lights and vehicle routes is carried out according to the length of congestion at intersections in order to alleviate traffic congestion during peak hours at intersections. We use SUMO for simulation and evaluate it from three aspects: Average Travel Time, Average Waiting Time and Average Time Loss. Compared with the Fuzzy Traffic Lights Control solution, the proposed solution reduces vehicle travel time by about 15.7%, reduces the average waiting time in congested sections by about 29.4%, and reduces the average time loss in congested sections by about 32.5%. Therefore, this proposed solution can effectively alleviate traffic congestion, reduce driving costs and improve travel efficiency.

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