Final Report

A LTP-based Future Urban Transport System under Fully Autonomous Vehicle Assumption

Zhang Xieyuan（张解元）

Feng Jiexun（冯捷迅）

Ding Jialiang（丁家梁）

Muhammad Rehan（里恩）

Dec 30, 2017

Content

Background

Nowadays, traffic congestion at intersections has become a severe problem in urban transportation system. It not only causes large-scale delay in road network but also increases accident frequency. As an alternative solution, overpass system has been introduced. However, this system obviously has very high complexity, as is shown in Figure 1, resulting in a long construction period and high cost.

Figure 1 Urban overpass system

Being aware of the current problem, we started to look into the cause of it. It is mentioned in previous literature that left turns have negative impact on transportation systems: left turn vehicles have potential to crash with oncoming vehicles, and usually wait for longer time, and thus left turn prohibition (LTP) has been adopted as a possible solution in order to overcome the mentioned issues. Another analysis perspective is from the change of conflict points, as is shown in Figure 2, when all left-turn directions are forbidden, the number of conflict points can be reduced from 16 to 4 compared with no LTP measure.

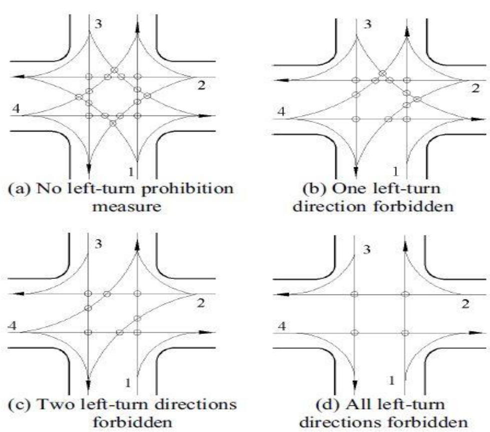


Figure 2 Conflict characteristics of left-turn traffic at un-signalized intersections

Project Framework

Our framework is shown in Figure 3. First, in order to analysis the effect of LTP, we built VISSIM models of conventional intersections and LTP intersections based on the real-world data (geographical features of road network and daily traffic volume). However, our simulation shows that there remains congestion problem even if LTP has been implemented which indicates the true nature of congestion at intersection is existence of conflict points. In order to eliminate conflict points at intersection, we proposed two approaches: LTP-Bridge Intersection and LTP-CAV Intersection. As for LTP-Bridge Intersection, we designed our structure and rule for different types of intersections and used the most typical cross-intersection to build our VISSIM model and real model.

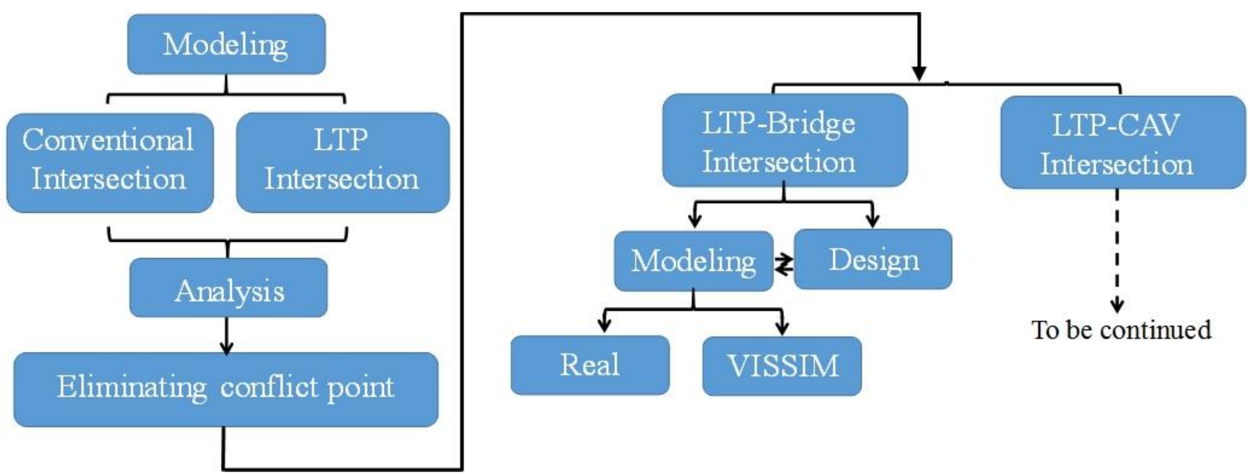


Figure 3 Framework of our project

Work Distribution

Group work

- Literature review on LTP;
- Proposal of framework;
- Analysis and comparison of the two intersection models;

Zhang Xieyuan

- Modeling and simulation of conventional intersection, LTP intersection and LTP-Bridge intersection using VISSIM;

Feng Jiexun

- Design of LTP-Bridge intersection rules and structure aiming at different types of intersections;

Ding Jialiang

- Real Model of LTP-Bridge intersection;

Muhammad Rehan

- Preliminary scheme of LTP-CAV intersection;
- Literature review on V2X, wireless technology and FCFS method.

Analysis of Conventional and LTP Intersection

Modeling

We decided to build our model based on the real-world data of Hell's Kitchen, Manhattan. There are two concerns for our choice: first, the road network of Manhattan is more regular and unified compared with that of Beijing; second, the traffic flow data of Manhattan is easier to access.

The road network model is shown in Figure 4, the area we selected contains a five by five rectangular network of 25 intersections, and the length of roads and size of intersections are measured via Google Map.

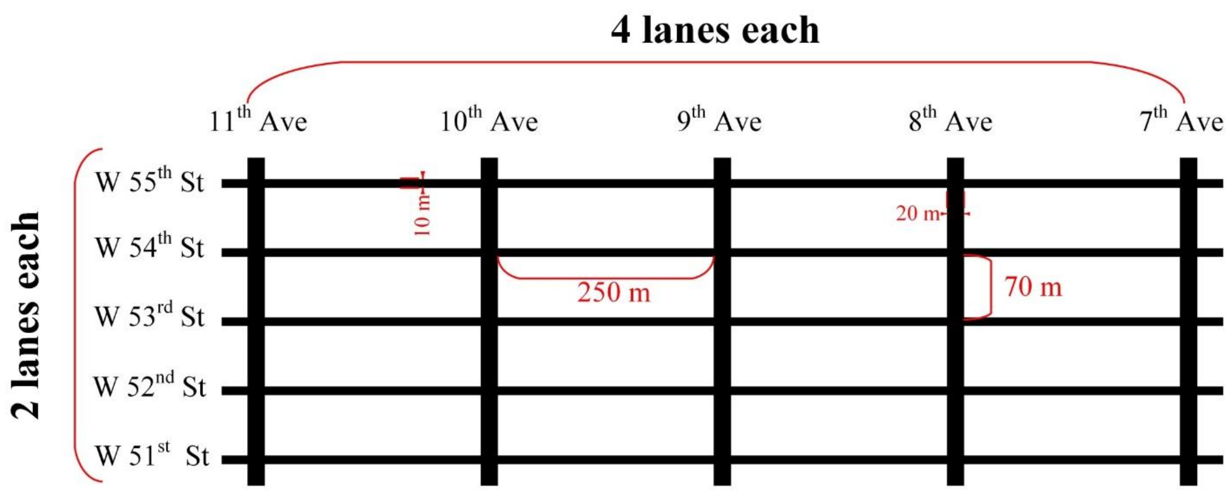


Figure 4 Road network

Concerning traffic volume modeling, we collected daily traffic volume data of this area from New York City Government website and used the average number of nine days. It need to be mentioned that all the northbound and southbound traffic volume data is the data of 8th Ave while all the eastbound and westbound traffic volume data is the data of W 55th Street due to the missing data of other roads. But considering the similarity of the road structures as well as their connectivity, we assume that this data can reflect the average volume of this area.

The processed traffic volume is shown in Figure 5:

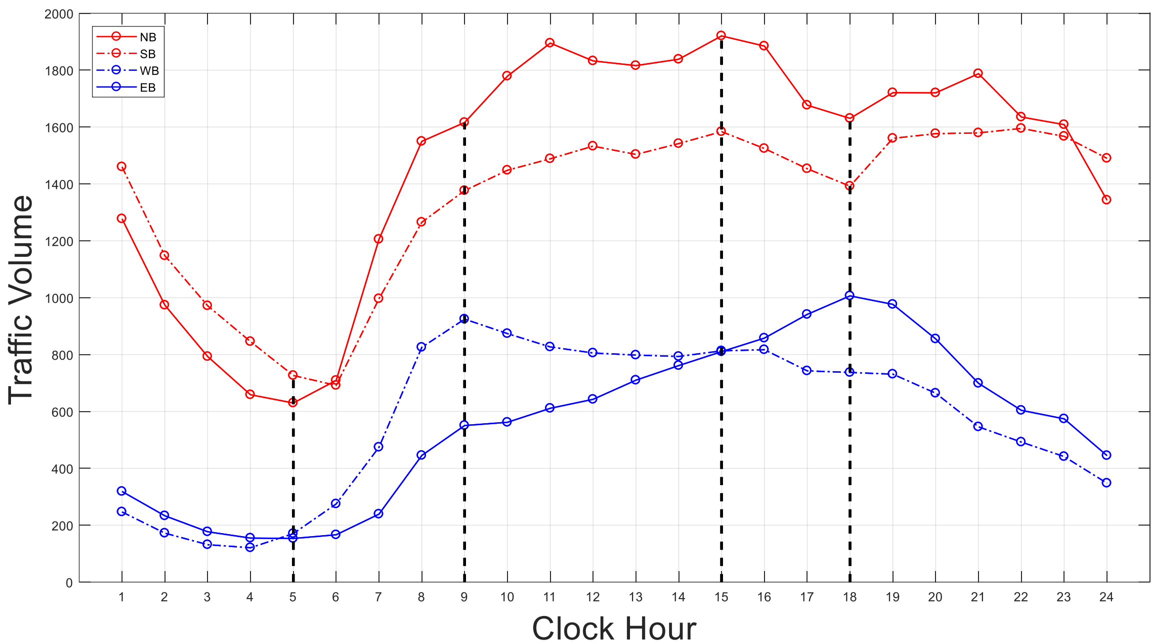


Figure 5 Traffic Volume

We can obtain several conclusions from this figure:

(1) Northbound and southbound traffic volume are larger than eastbound and westbound traffic volume at any time in a day;

(2) Northbound and southbound traffic volume share a similar changing pattern, both of their peaks appear at 2-3 p.m. and their valleys at 4-5 a.m.;

(3) Eastbound and westbound traffic volume appear to be symmetrical, eastbound peak is at 5-6 p.m. (evening peak) while westbound peak is at 8-9 a.m. (morning peak). Majority of drivers travel across this area from east to west to go to work in the morning which creates the morning peak and returns oppositely in the evening.

In our following modeling and simulation of intersections, we used the data of 2-3 p.m. to represent a relatively heavy traffic, the data is shown in Table 1. Further simulations can be based on light traffic, morning peak and evening peak.

Table 1 Selected traffic volume data

Northbound	Southbound	Westbound	Eastbound
1920	1584	813	810

Necessary conditions adopted in VISSIM modeling of conventional intersection and LTP intersection are shown in Figure 6 and Figure 7. Traffic rules, traffic flow distribution at intersection and priority rules at conflict points are my three major concerns.

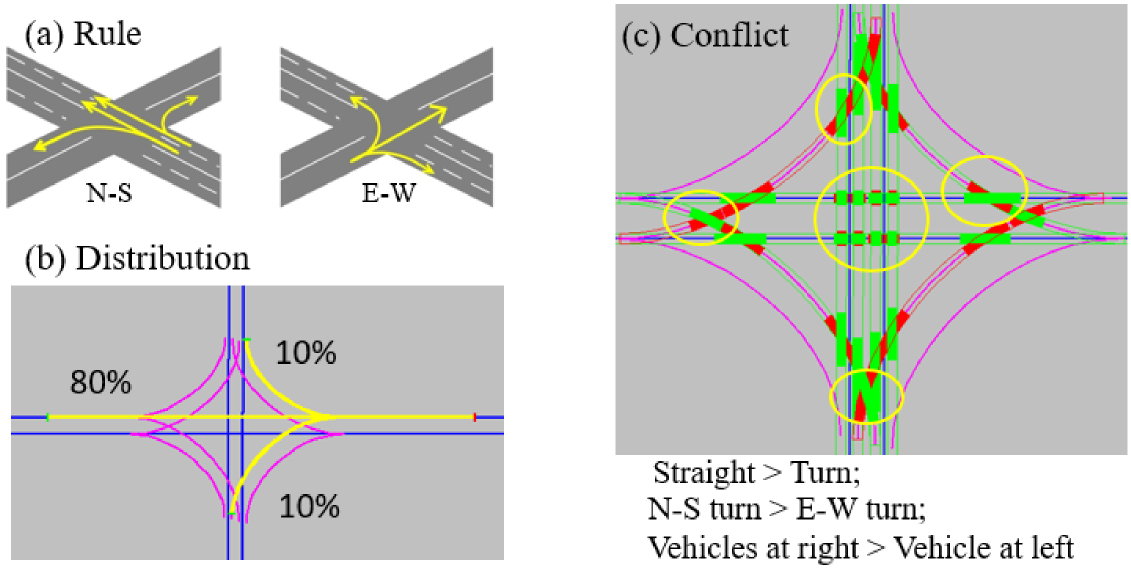


Figure 6 Conventional intersection

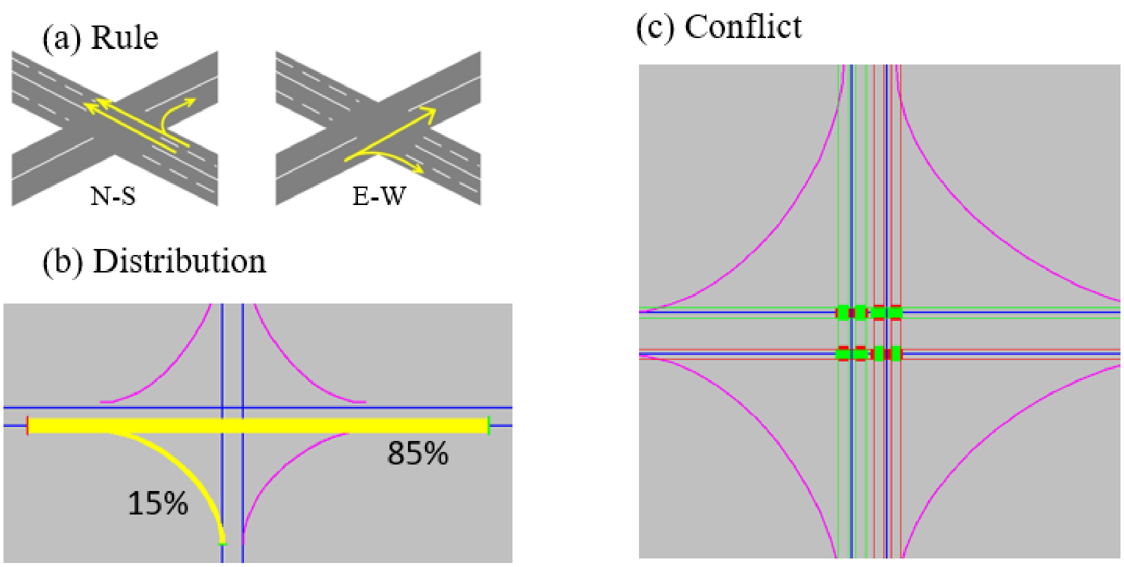


Figure 7 LTP intersection

Results and comparison

Simulation results of these two intersections are shown in Figure 8 and Figure 9. In order to obtain more comparable results, evaluation on the following two parameters: total number of vehicle possessed by the network and maximum delay (referring to delay on the most congested road section) is given in Table 2 and Table 3.

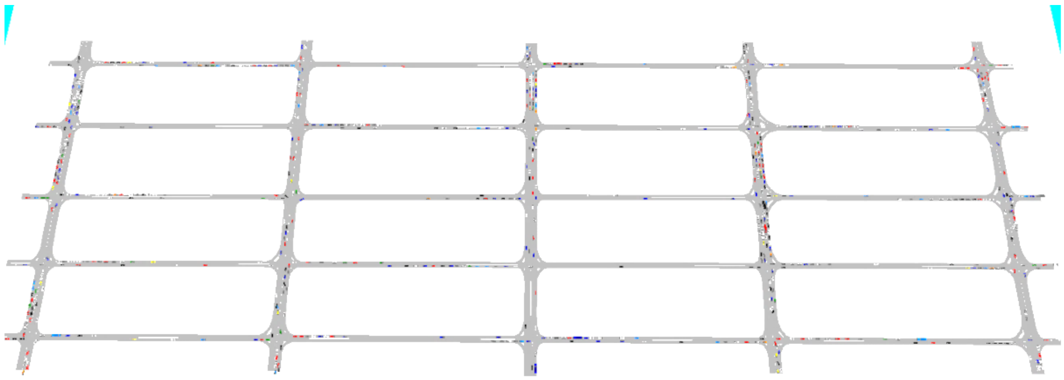


Figure 8 Conventional intersection

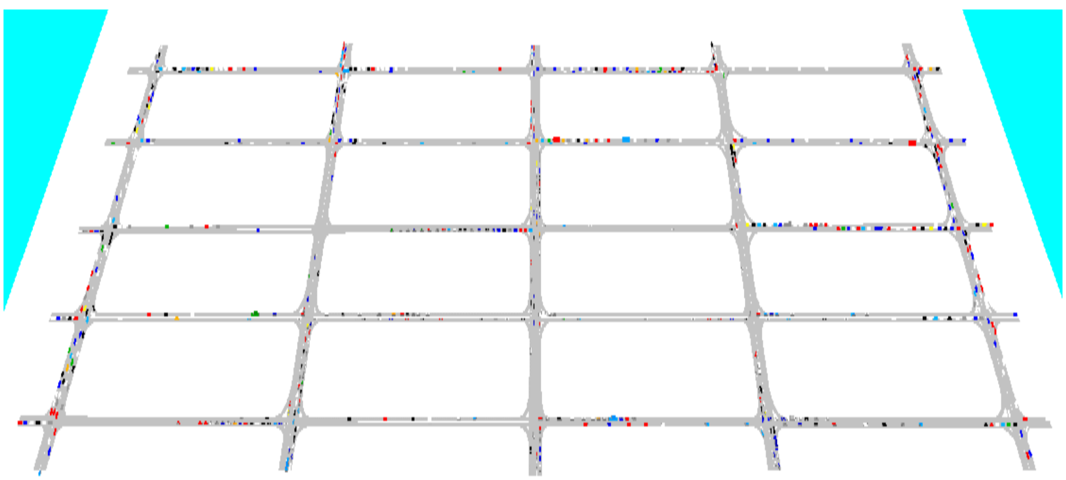


Figure 9 LTP intersection

Table 2 Total number of vehicle possessed by the network

Conventional	714
LTP	747
Improvement	4.6%

Table 3 Maximum delay

	Delay(s)	Standstill (s)	Stop
Conventional	36.0	14	2.78
LTP	29.8	10.9	2.42
Improvement	17.20%	22.10%	12.90%

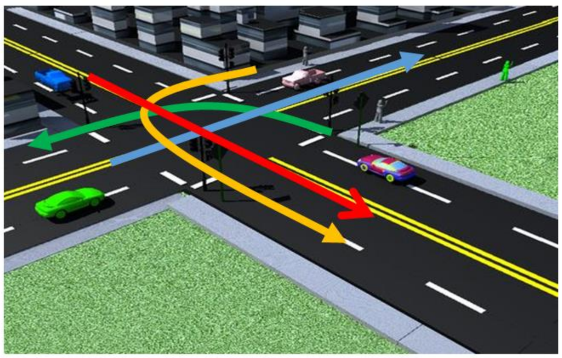
After comparison, we found that LTP intersection can improve the system performance and relieve congestion to some extent, but its effect is limited. As a result, we further analyzed our simulation by replaying the simulation demo and noticed a frequently occurred scenario: at one intersection, when one vehicles traveling N-S is about to meet another vehicle traveling E-W, one vehicle stops to follow the priority rule defined at this conflict point. As vehicles going straight always make up the vast majority of traffic flow at intersections, this delay turns out to be the main reason of congestion. In other words, the true nature of congestion is existence of conflict point instead of left turns.

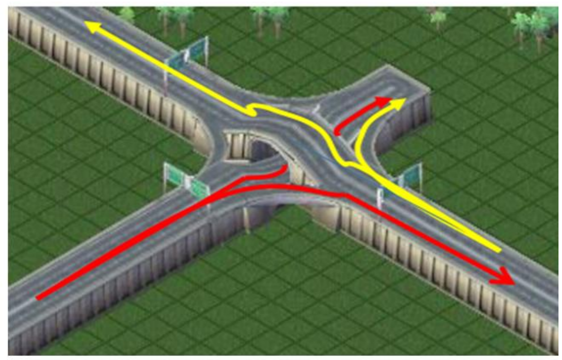
After our discussion, we proposed two solutions to eliminate conflict points at intersection: on the one hand, as is raised previously, we can use LTP to reduce conflict points from 16 to 4, meanwhile, we can build bridge at intersection to eliminate the remaining 4 conflict points caused by vehicles going straight from upright directions; on the other hand, we can combine LTP with CAV to solve this problem as well.

LTP-Bridge Intersection

We proposed different solutions for various types of intersections, including the most typical cross intersection, T intersection and five-way intersection, our design is shown in Figure 10-12.

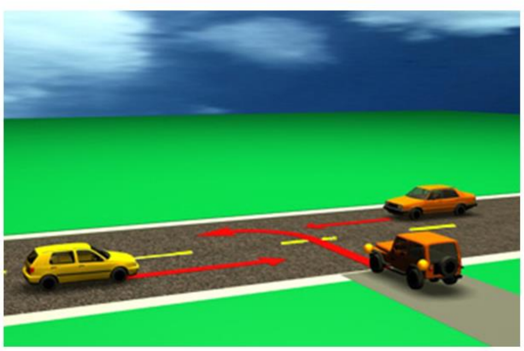
In a cross intersection and a five-way intersection, a simple bridge need to be constructed and vehicles shall follow LTP rule to pass such intersections. As for a T intersection, LTP alone can avoid all conflict points.

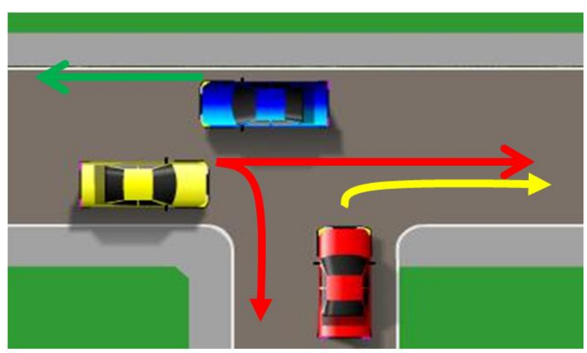




Previous New

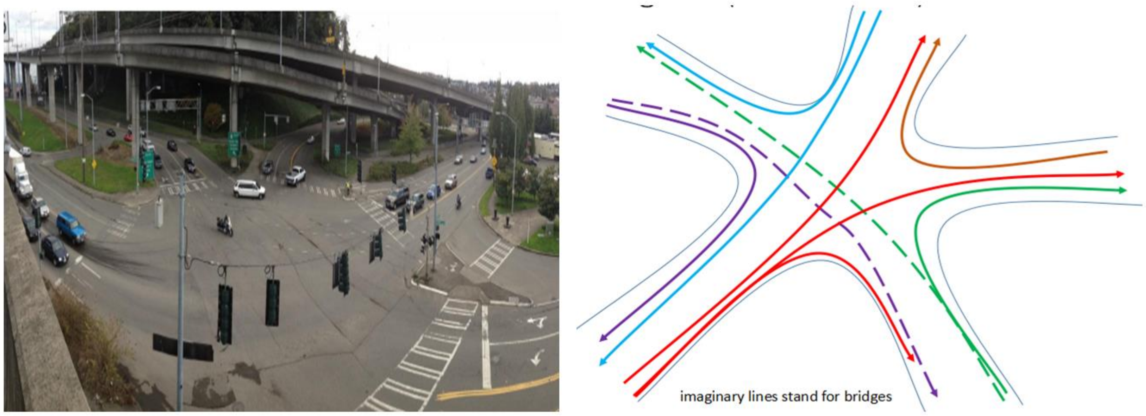
Figure 10 Cross intersection





Previous New

Figure 11 T intersection



Previous New

Figure 12 Five-way intersections

Meanwhile, we also planted this idea in our model, for the VISSIM model, I only built such bridge intersection on 9th Ave, reasons for this are listed as follow: (1) 9th Ave has heavy traffic volume and is located in the middle of whole network; (2) It seems to have serious congestion in both conventional and LTP cases; (3) In this way it's easy to evaluate the effect of bridge intersection compared with other normal intersections.

The new road network is shown in Figure 13 and 14.

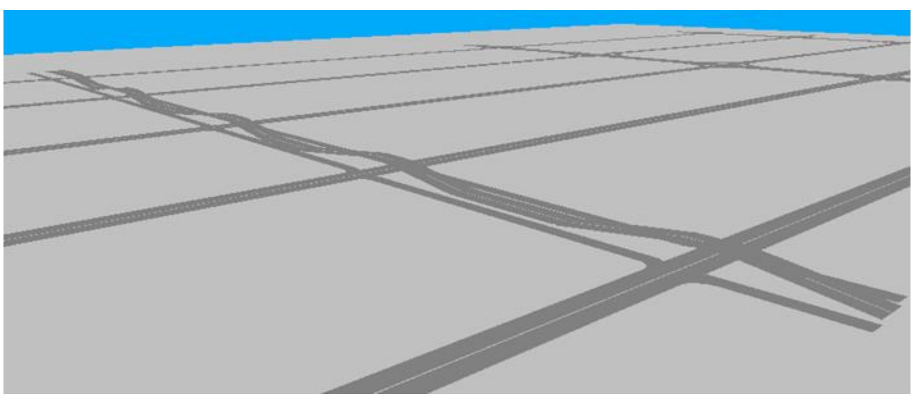


Figure 13 General view of LTP-bridge intersection

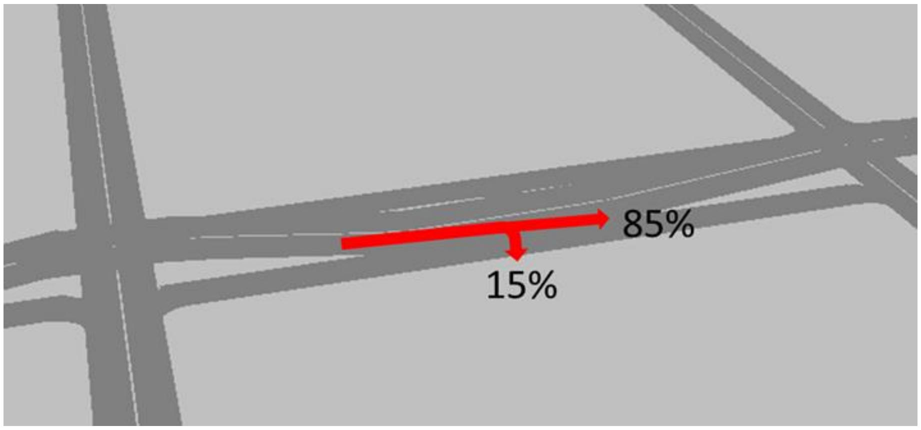


Figure 14 Detail view of LTP-bridge intersection

Using this model we did another simulation and it proved LTP-bridge intersection could bring significant positive effect to the whole network. However, there are still more evaluations to conduct similar to what we've done when comparing the conventional intersection and LTP intersection. Please find the simulation demo in the attached video file.

We also constructed a real model which is shown in Figure 15.

Figure 15 Real model of LTP-bridge intersection

LTP-CAV Intersection

The alternative solution for signal free intersection is provided by control network and Autonomous vehicles. The connected and automated vehicles come with a number of potential benefits. But in order to control them we need a strong control network. We used a decentralized controller here to control the traffic. We were needed a distributive controller in order to reduce congestion, collision avoidance, reduce detour and to detect the infinite loop if there is any.

Decentralized or Distributed Controller

This controller is installed directly on to the vehicles. It works dynamically as the vehicle move. It gets data from all the sensors including, LIDAR, RADAR, GPS and cameras and then process and give orders to vehicle. It uses a multi-hop network to talk to other vehicles.

Multi-hop routing is a type of communication in radio networks in which network coverage area is larger than radio range of single nodes. Therefore, to reach some destination a node can use other nodes as relays. Since the transceiver is the major source of power consumption in a radio node and long distance transmission requires high power, in some cases multi-hop routing can be more energy efficient than single-hop routing.

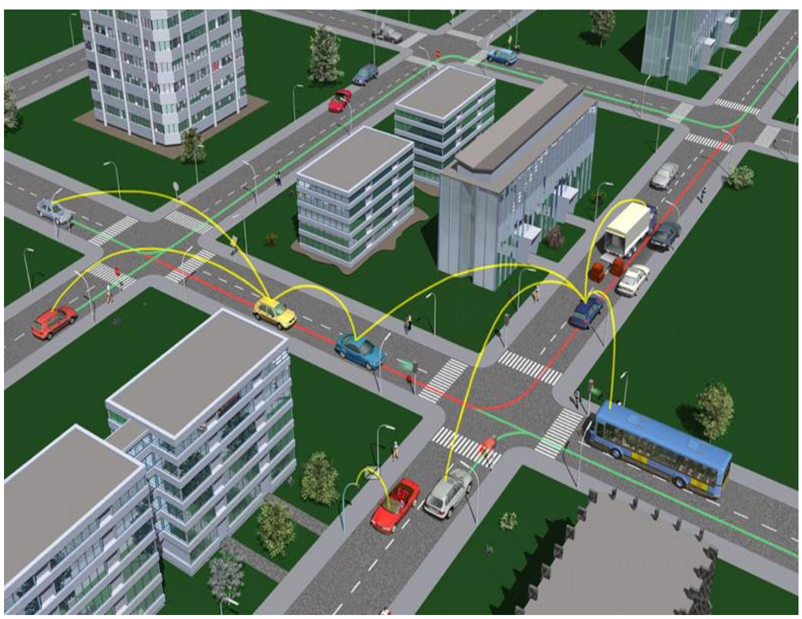


Figure 16 Distributed controller and multi-hop routing

Wireless Technology

Following were the requirements for a control network in order to decide which technology to be used.

Table 4 Requirements for a control network

Average vehicle distance	10 m (jammed), 30 m (smooth)
Message generation interval	50–500 ms
Transmission range	10-1000 m
Average velocity	70 km/h-120 km/h
Packet payload size, P	100-300 bytes

DSRC

The 5.9 GHz DSRC is a wireless interface to support high speed, short-range wireless interface between vehicles, and surface transportation infrastructure, as well as to enable the rapid communication of vehicle data and other content. It can accommodate all necessary vehicle-to-vehicle and vehicle-to-infrastructure communications in modules that are already commercially available. A DSRC radio has limited range, so, even if it could be hacked, it would only be able to communicate to a limited number of vehicles.

We did comparison between DSRC and 4G-LTE and the following results.

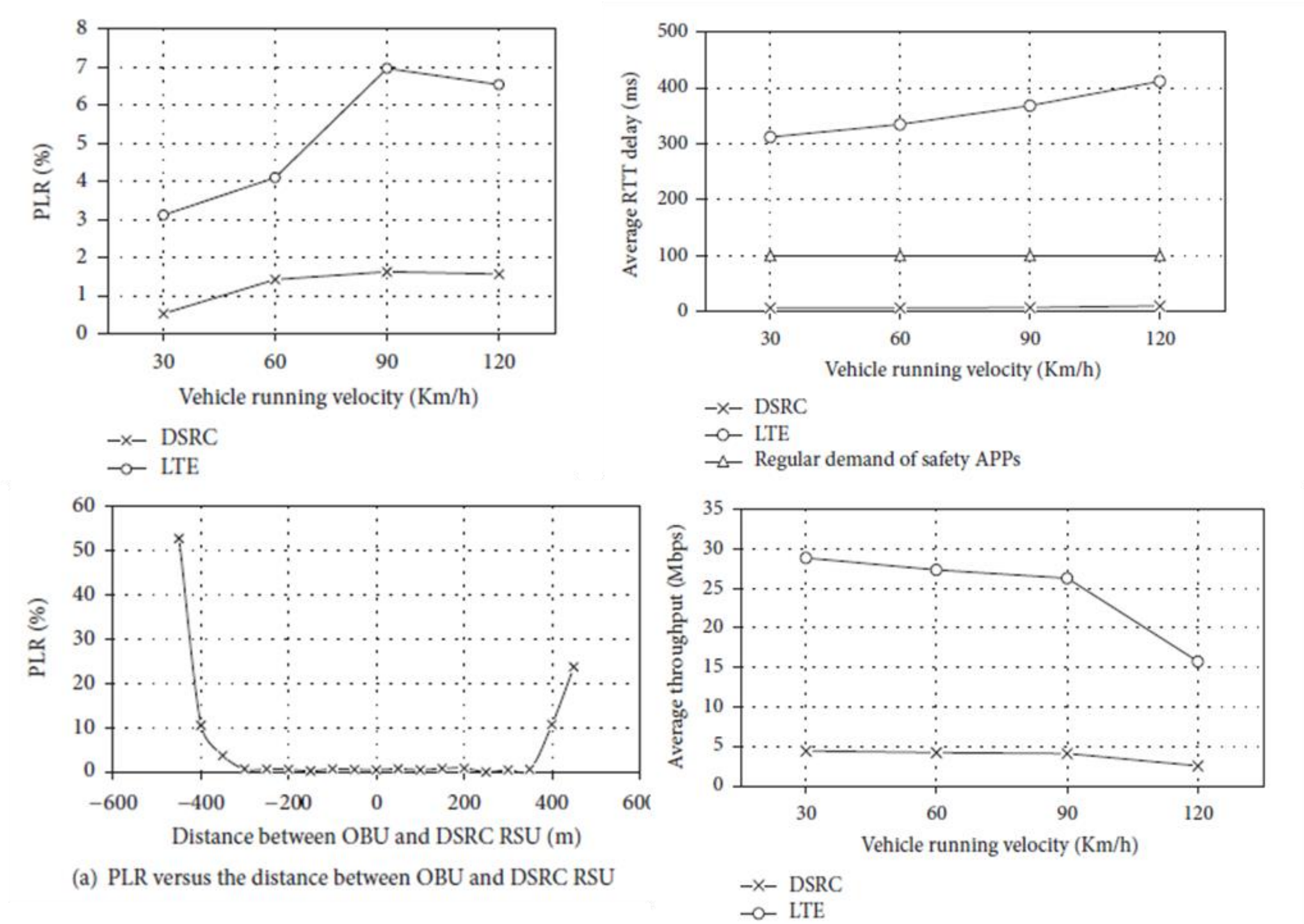


Figure 18 Comparisons between DSRC and 4G-LTE

It proved that for collision avoidance DSRC it better than 4G but for non-safety measures 4G was better.

5G

5G operating in the millimeter wave bands (28, 38, and 60 GHz), holds promise of improved performance in terms of reduced latency, increased reliability and higher throughput under higher mobility and connectivity density, which is expected to meet the V2X requirements from autonomous driving. 5G promises are as below.

Table 5 Technical Parameters of 5G

Latency	1 ms (1-5 ms)
Density	100 devices/m2
Throughput	Up to 10 GB/s
Vehicle velocity	Up to 160 Km/h (280 Km/h relative)
Coverage area	3X

First come first served (FCFS)

FCFS is a fairness-based method for accepting reservations that has been used in most previous studies. When a vehicle requests a reservation, the intersection manager accepts it if it does not conflict with previously accepted reservations. Otherwise, it is rejected. Well, rejection here doesn't mean that it would not enter a circle, it will but with reduced velocity.

For this our controller draws an imaginary circle around intersection. And whatever car comes first is served first and it reserves its place. Its path is then calculated for future decisions.

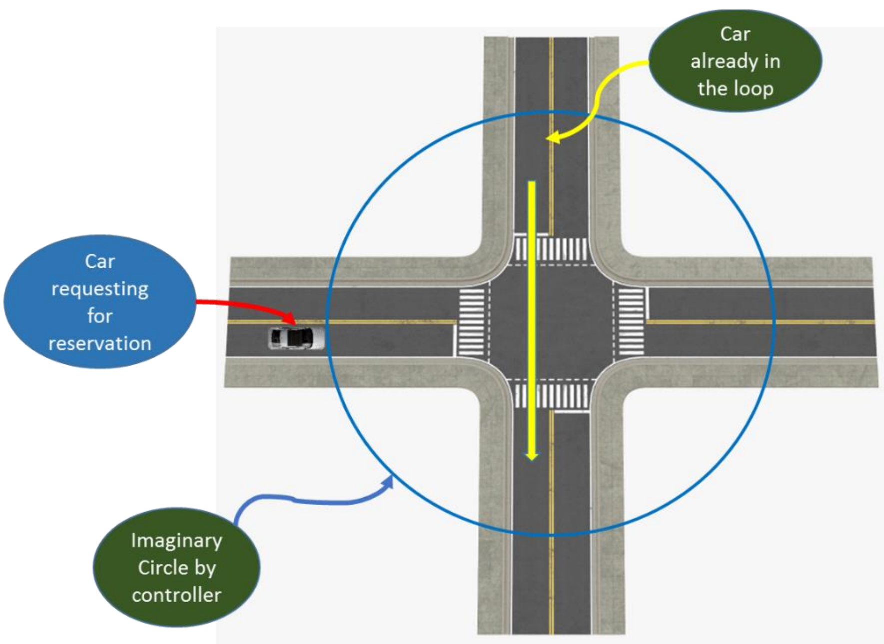


Figure 19 First come first served

Conflict Detection

Now if another vehicle tries to make a reservation and controller detects that its requested path coinciding with a vehicle already in the loop it is rejected.

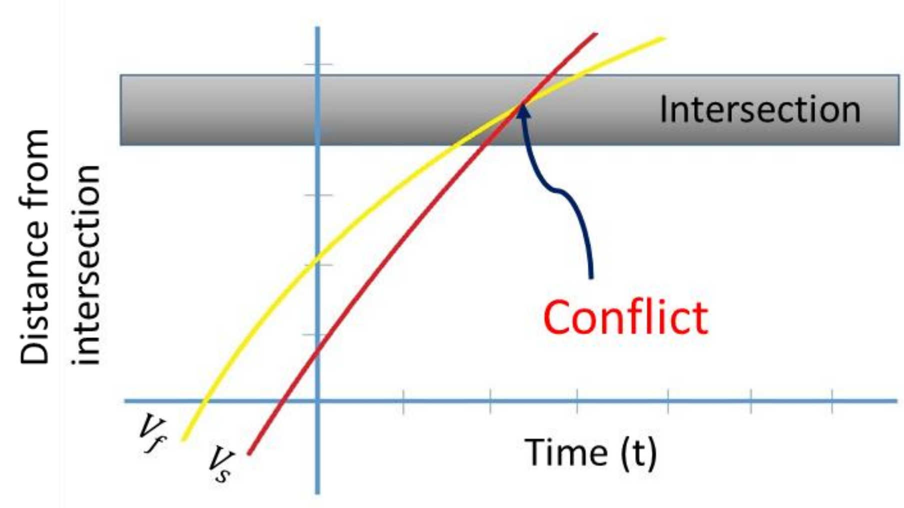


Figure 20 Conflict detection

For detection of possible conflict controller divides the whole intersection into small tiles and every vehicle occupy a certain amount of tiles now it checks whether the requesting vehicle is overlapping the tiles of previous vehicle or not.

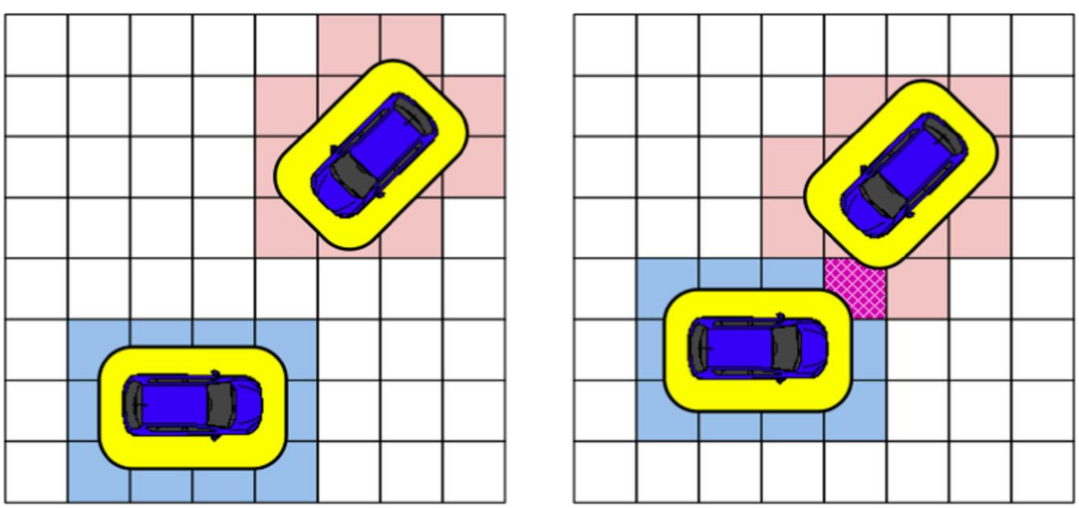


Figure 21 Conflict detection

Conclusion

In this project, we are motivated to relieve intersection congestion problem which is serious in urban transport systems. After our modeling and simulation of conventional intersection and LTP intersection, we realized that the true nature of congestion is existence of conflict point instead of left turns.

As a result, we proposed two possible solutions to eliminate conflict points at intersection: the LTP-Bridge Intersection and LTP-CAV Intersection. Although we've given a primary demonstration on the feasibility of LTP-Bridge Intersection, a comprehensive and accurate proof need to be provided in order to defend our claim that the new system could have significant benefits on both drivers and the urban transport network. As for LTP-CAV Intersection, we need to demonstrate how LTP could bring benefit on the control of such intersection. What's more, we need to take into consideration the more general road network instead of simply focusing on the special case of Manhattan.

References

1. VISSIM 4.30 User Manual.
2. Feng, S., Zhang, F., & Ci, Y. (2010). Left-turn prohibition measures warrants at unsignalized intersections.
3. Hajbabaie, A., Medina, J. C., & Benekohal, R. F. (2010, September). Effects of ITS-based left turn policies on network performance. In Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on (pp. 80-84). IEEE.
4. Tang, Q. (2016, November). Lane-based optimization of signal timing including left turn prohibition in communication scenarios. In Intelligent Transportation Systems (ITSC), 2016 IEEE 19th International Conference on (pp. 2071-2076). IEEE.
5. Ma, X., Chen, X., & Refai, H. H. (2009). Performance and reliability of DSRC vehicular safety communication: a formal analysis. EURASIP Journal on Wireless Communications and Networking, 2009(1), 969164.
6. Ma, H. S., Zhang, E., Li, S., Lv, Z., & Hu, J. (2016). A V2X Design for 5G Network Based on Requirements of Autonomous Driving (No. 2016-01-1887). SAE Technical Paper.
7. Xu, Z., Li, X., Zhao, X., Zhang, M. H., & Wang, Z. (2017). DSRC versus 4G-LTE for connected vehicle applications: a study on field experiments of vehicular communication performance. Journal of Advanced Transportation, 2017.
8. Hou, T. C., & Li, V. (1986). Transmission range control in multihop packet radio networks. IEEE Transactions on Communications, 34(1), 38-44.
9. Zhang, M., Mezzavilla, M., Ford, R., Rangan, S., Panwar, S., Mellios, E., ... & Zorzi, M. (2016, April). Transport layer performance in 5G mmWave cellular. In Computer Communications Workshops (INFOCOM WKSHPS), 2016 IEEE Conference on (pp. 730-735). IEEE.
10. Levin, M. W., Boyles, S. D., & Patel, R. (2016). Paradoxes of reservation-based intersection controls in traffic networks. Transportation Research Part A: Policy and Practice, 90, 14-25.
11. Chang, Y., & Edara, P. (2017). Evaluation of a reservation-based intersection control algorithm for hurricane evacuation with autonomous vehicles. International Journal of Disaster Risk Reduction.
12. Zhang, Y., Su, R., Sun, C., & Zhang, Y. (2017, August). Modelling and traffic signal control of a heterogeneous traffic network with signalized and non-signalized intersections. In Control Technology and Applications (CCTA), 2017 IEEE Conference on (pp. 1581-1586). IEEE.