Evaluation of Safety and Efficiency Simulation of Cooperative Automated Driving through Intersection

Kenta Kimura
Computer and Information Science
Graduate School of
Science and Engineering
Doshisha University
Kyoto, Japan
Email:kenta.kimura@nislab.doshisha.ac.jp

Shuntaro Azuma
Computer and Information Science
Graduate School of
Science and Engineering
Doshisha University
Kyoto, Japan
email:syuntaro.azuma@nislab.doshisha.ac.jp

Kenya Sato
Computer and Information Science
Graduate School of
Science and Engineering
Doshisha University
Kyoto, Japan
email:ksato@mail.doshisha.ac.jp

***Abstract*—The research and development of automated driving are recently thriving, and a mechanism continues to progress through which the car itself assumes the role of the driver. However, when automated driving only uses information that is collected by onboard sensors, no information on vehicles in the intersecting lanes can be obtained from intersections where the visibility is often bad and suffers from large potential blind spots. This situation increases the risk of collisions. Since no information can be obtained on blind spots until entering the intersection, the vehicle must temporarily slow down to confirm the safety of the situation. To improve safety and efficiency, information must be obtained for each vehicle and communicated with the surrounding vehicles. In this research, we examine safety and efficiency by comparing cases of automated vehicles with and without communication when entering an intersection with poor visibility. We evaluated with a simulator and identified safety and efficiency effects when an automated vehicle uses communication at an intersection that features poor visibility.**

Keywords–cooperative automated driving; V2V communication; traffic flow.

I. INTRODUCTION

The research and development of automated driving have increased in recent years. A camera, laser radar, and milliwave radar are mounted on an autonomous automated vehicle for collecting peripheral information. Then the vehicle's operation is controlled using the surrounding environment information. However, such in-vehicle sensors have drawbacks because detection is impossible outside the range of the viewing angles, and so avoiding collisions is difficult at intersections that suffer from poor visibility.

With Vehicle-to-Vehicle (V2V) communication, blind spot information can be acquired that the vehicle cannot see directly. To operate safely using this information, research on cooperative automated driving is being conducted. The recognition rate near 300 m increases by sharing the host vehicle's information and the sensor information using V2V communication instead of automated driving that relies solely on sensor information [1].

The level of automated driving techniques has already been defined by Society of Automotive Engineers (SAE) international. Level 2 vehicles, in which the automated vehicle partially controls the vehicle's operation, are beginning to appear on the market. For example, when a vehicle predicts an accident, it automatically brakes. This is not completely automated driving; it just illustrates the scope of driving support. In this research, we evaluate automated vehicles that can operate such vehicles whose popularity is expected to increase in the future. In this research, we determine the safety criterion for passing through intersections when using communication and compare cases with and without sharing the surrounding information of a vehicle. Based on our results, we evaluate the influence of shared communication on traffic efficiency and safety when passing through an intersection that suffers from poor visibility.

The remainder of this paper is structured as follows. Section II details of problems at intersections with blind spots. Section III details of the calculation method when vehicles pass through the intersection. Section IV details the evaluation of the proposal. Section V details the consideration obtained from the evaluation results. Section VI details the conclusion.

II. PROBLEMS AT INTERSECTIONS WITH BLIND SPOTS

Accidents at intersections with poor visibility are a problem. According to official police statistics of traffic accident occurrences, urban intersections are the most common place for such accidents [2]. The number of accidents occurring at Japanese urban intersections in 2016 is 208,404. Since the number of accidents occurring at non-urban intersections is 46,952, there are many accidents at urban intersections. As shown in Figure 1, at intersections with poor visibility, the blind spots are large. At such intersections, since the probability of crossing collisions is high, drivers must pause before entering intersections and pass through them only after confirming that they are safe. This action is necessary regardless of the presence or absence of a vehicle in the intersecting lane. If there is no vehicle in the intersecting lane, the time required to confirm safety becomes wasted as the vehicle passes through the intersection. These situations and decisions are identical for automated vehicles.

 ISBN: 978-1-61208-643-9

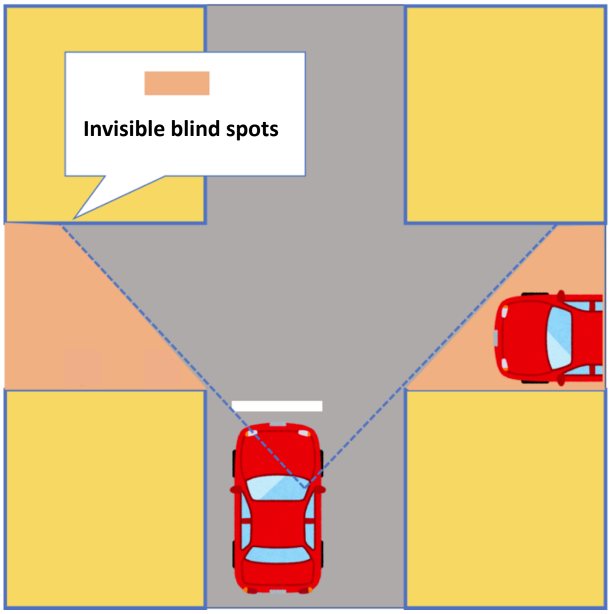

Figure 1. Intersection blind spot

III. PROPOSAL

A. Outline

Whether vehicles passing through intersections will collide with vehicles traveling from intersecting lanes must be verified. When no communication is used and the vehicle enters an intersection without traffic lights, it pauses before entering it and checks whether it might collide with a vehicle in the intersecting lane. If no collision is imminent, it passes through the intersection. At an intersection with traffic lights, vehicles run based on the signals. In this research, we evaluate passing through intersections based on the premise that accurate position information and speed information can be acquired using V2V communication.

B. Precondition

We set the following preconditions:

1) Automated vehicles can communicate with each other.
2) Communication loss is ignored.
3) Position information error is ignored.
4) Communication is shared every 0.1 seconds.
5) The crossing lanes are blind spots and invisible.

C. TTC

As a criterion for passing through an intersection, we use Time-To-Collision (TTC) [3]. As shown in Figure 2, the position and speed of the following and preceding vehicles are defined as x_f, v_f, x_p, and v_p. If TTC is defined as t_c, it can be expressed by (1):

$$t_c = -\frac{x_f - x_p}{v_f - x_p} \tag{1}$$

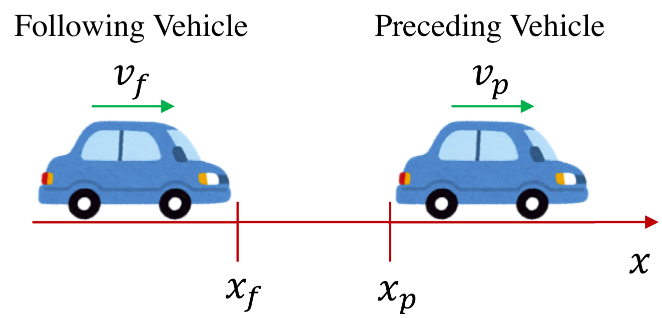

Figure 2. TTC Value

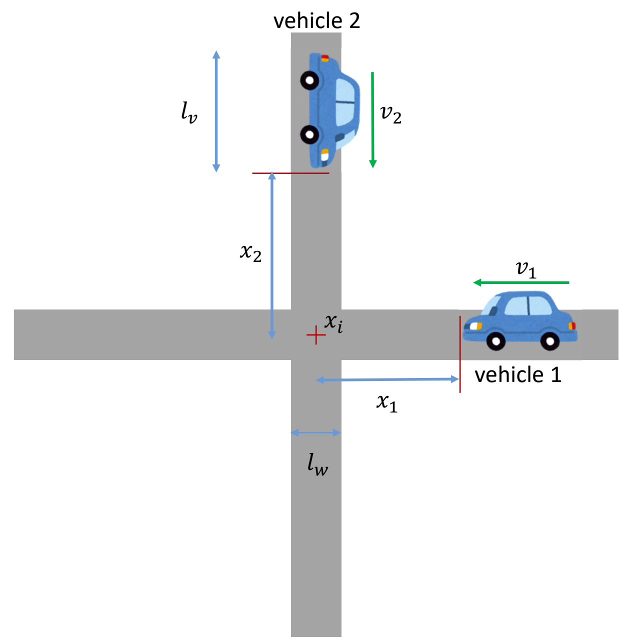

Figure 3. Value at intersection

D. TTC in This Research

However, since TTC is an index for vehicles in the same lane, the formula must be converted into a calculation between vehicles on crossing lanes. Each value at the intersection is shown in Figure 3. Here, a vehicle on a non-priority road is defined as vehicle 1, and a vehicle on a priority road is defined as vehicle 2. We also define the distance to the center of the intersection as x_1 and x_2, the speed as v_1 and v_2, the length of the vehicle as l_v, and the length within the intersection as l_w.

First, we calculate the time until vehicle 1 reaches the intersection's entrances. If this time is assumed to be t1, it can be obtained by (2). The distance to the intersection's entrance can be obtained by subtracting half of the intersection's width from its center distance:

$$t_1 = \frac{x_1 - \frac{l_w}{2}}{v_1} \tag{2}$$

Next, we calculated the time it takes for vehicle 1 to completely pass through the intersection. If this time is defined as t_2, it can be obtained by (3), and t_2 is the time obtained by adding t_1 to the time required for vehicle 1 to travel the

 ISBN: 978-1-61208-643-9

total distance of the width of the roadway and the length of the vehicle:

$$t_2 = t_1 + \frac{l_w - l_v}{v_1} \tag{3}$$

Next, we calculate the position of vehicle 2 of time t_1 and t_2. Here the position during each time lapse is defined as $x_{2,1}, x_{2,2}$, obtained by (4) and (5):

$$x_{2,1} = x_2 + v_2 t_1 \tag{4}$$

$$x_{2,2} = x_2 + v_2 t_2 \tag{5}$$

The TTC value that is allowed when crossing an intersection is defined as t_{ttc}, which determines whether the position of vehicle 2 is dangerous when vehicle 1 passes through the intersection. x_i is the center position of the intersection. When either (6) or (7) is satisfied, it is dangerous for vehicle 1 to pass through the intersection, and passage is denied:

$$x_i - \frac{l_w}{2} - v_2 t_{ttc} \leq x_{2,1} \leq x_i + \frac{l_w}{2} + v_2 t_{ttc} + l_v \tag{6}$$

$$x_i - \frac{l_w}{2} - v_2 t_{ttc} \leq x_{2,2} \leq x_i + \frac{l_w}{2} + v_2 t_{ttc} + l_v \tag{7}$$

Vehicles that are not allowed to cross the intersection will be stopped before they enter it.

IV. EVALUATION

A. Simulator

Our evaluation uses Vissim [4], a microscopic multi-modal traffic flow simulation software package developed by Planung Transport Verkehr (PTV) AG in Karlsruhe, Germany, that can extract such problems as congestion and the influence of road construction. It can also visually confirm a set simulation with 3D graphics.

Vissim also supports the Component Object Model (COM) interface through which it can communicate with external applications and scripts. Using this function, we can set input data to Vissim and obtain output data from it. In this research, we collected vehicle information from Vissim using Python 2 and calculated TTC.

B. When Only a Straight Traveling Vehicle is being Operated

In this section, we evaluate the case where the vehicle does not make a left or a right turn and only moves forward toward an intersection.

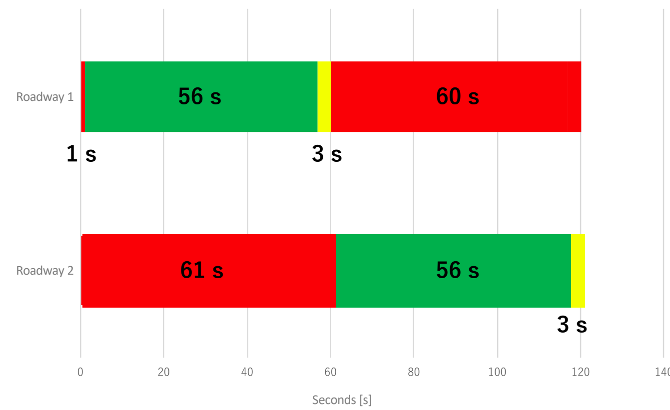

Figure 4. Traffic light setting

1) Evaluation method: According to technical government guidelines [5], the criterion for braking in automated braking systems is a TTC of 1.4 seconds or less for passenger cars. Therefore, we set the TTC value of this intersection's passing criterion to 1.4 seconds and calculated the intersection passing determination from the timing when the vehicle enters within around 100 m of the intersection.

Table I details the setting. The intersection has one lane on each side. One of the lanes in it is the priority road, and the vehicle on the non-priority road determines the passing through the intersection based on the TTC. The speed limit is 50 km/h.

We simulated two other models to measure the effect of passing through the intersection using V2V communication.

The first model does not communicate. The vehicle on the non-priority road side pauses for 0.5 seconds to confirm the intersection's safety before entering it. If it is safe, then it passes through the intersection. The safety criterion is judged by whether the vehicle from the priority road side is approaching within 100 m from the intersection.

In the second model, the vehicle does not communicate and advances based on the intersection's traffic light. The traffic light's cycle is shown in Figure 4. One cycle is set to 120 seconds: 2 minutes for the signal's total time, 1 seconds for red, 56 seconds for green, and 3 seconds for yellow.

The third model measures a vehicle's travel time on a 1000-m non-priority road that includes an intersection. Travel time refers to the time spent driving on a specified section.

2) Evaluation results: We conducted three different types of evaluations and measured the travel times of the three models in the above intersection.

In the first evaluation, when the number of vehicles in each lane was set to 500 vehicles/hour, we measured the travel

TABLE I. SIMULATION PARAMETERS

Simulator	Vissim 9.00-09
Number of vehicles in one lane per hour	100～700 vehicles per hour
Measurement time	10 minutes
Measurement section	1000 m
Road width	7 m
Center position of intersection	500 m position
Speed limit	50 km/h

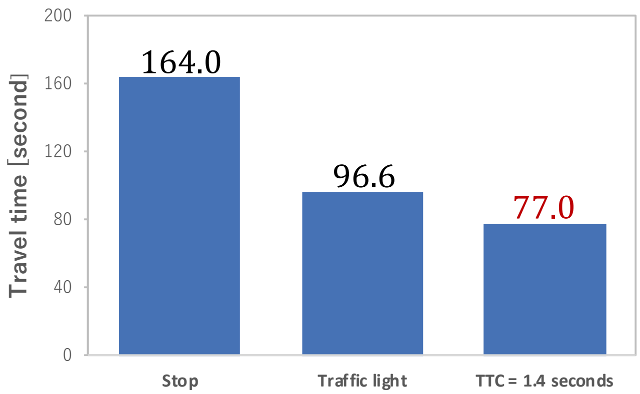

Figure 5. Travel time by model

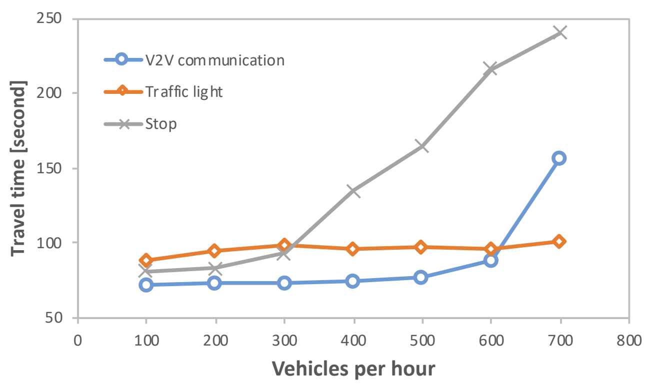

Figure 6. Travel time by number of vehicles

time required for a vehicle to travel 1000 meters on the non-priority road side. As described above, 1.4 seconds is the safety criterion used by TTC for calculating safe passage through the intersection using communication (Figure 5). The traveling time was short in the following order: the model using the proposed method using communication, the model using the traffic light, and the model based on the determination of safety by pausing.

In the second evaluation, the number of vehicles per hour in each lane was increased in increments of 100. The result is shown in Figure 6. The travel time when controlled by signals did not significantly affect the travel time in the number of vehicles in the measured range. However, in the models that did not use both communication and traffic signals, the traveling time increased as the number of vehicles increased. When using communication, the travel time did not change greatly from 100 vehicles per hour to 600 vehicles per hour. But if the number of vehicles per hour increased to 700, the travel time increased significantly.

For the third evaluation, we measured the travel time every 0.2 seconds from 1.4 to 2.0 seconds for the TTC seconds used for judging passage through the intersection using V2V communication. For passenger vehicles and larger vehicles, the distance from braking to actually stopping is different. In the case of larger vehicles, operating the automated brake system is desirable when the TTC is 1.6 seconds or less [6]. Therefore, we measured the travel time by changing the TTC value (Figure 7). The higher the TTC value is, the higher is

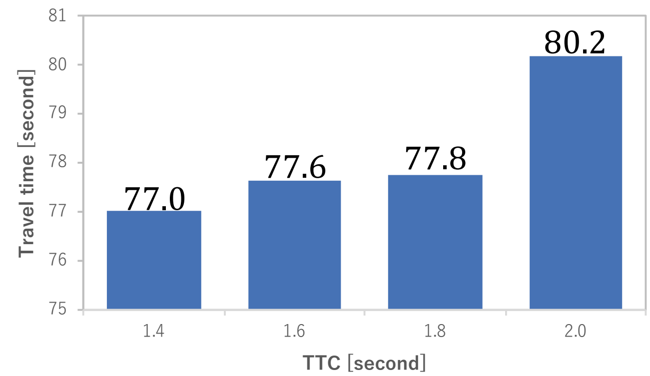

Figure 7. Travel time by TTC

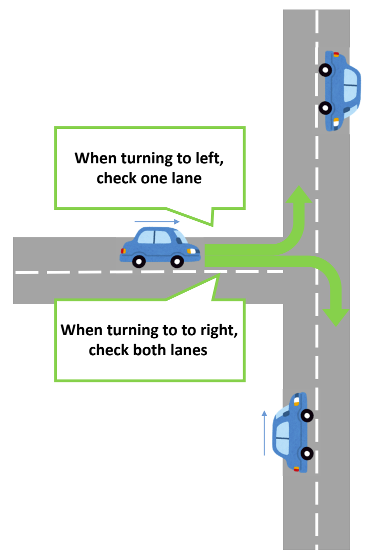

Figure 8. Shape of T-junction

the travel time value.

C. At a T-junction

In this subsection, we evaluated when a vehicle on a non-priority road makes a left or a right turn at a T-junction. As a precondition, the vehicles on the priority road side must go straight ahead. Vehicles are driven on the left－hand side of the road.

1) Evaluation method: The T-junction’s shape is shown in Figure 8. We can judge whether a left turn is possible by checking the safety of one lane when turning left. However, when turning right, the safety of both lanes must be checked, and the conditions for passing through the intersection become stricter than when turning left.

For the evaluation, we compared the proposed method’s model, a model that paused at the intersection, and a model that obeyed the traffic light. Pause and signal period settings were evaluated with settings that resemble those in the previous section. The simulation settings are shown in Table II. We established an intersection 500 m from the point of the vehicle and measured the travel time when the vehicle on the non-priority road that makes a left or a right turn travels 1000 m. Here the vehicle traveling on the non-priority road chooses left

 ISBN: 978-1-61208-643-9

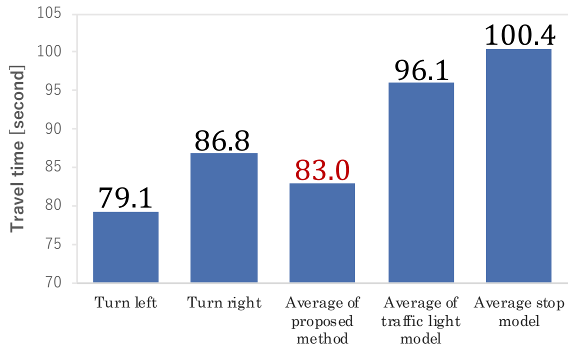

Figure 9. Travel time of T-junction

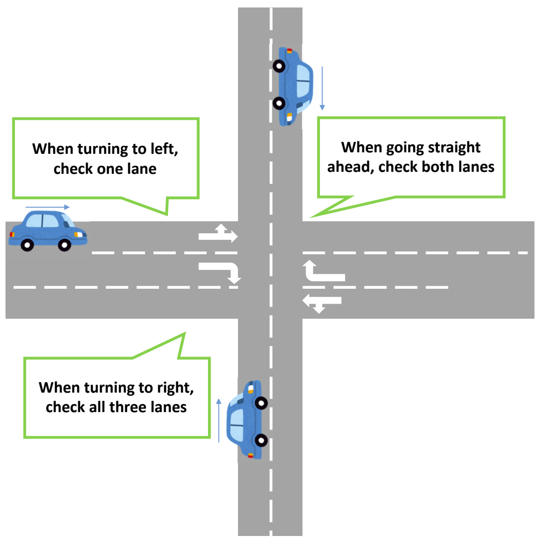

Figure 10. Shape of crossroad

or right turns with a 50 % probability. Then we measured the travel time by the traveling direction.

2) Evaluation result: The evaluation result is shown in Figure 9. The time to travel 1000 m for left turns is 79.1 seconds and the travel time for right turns is 86.8 seconds. This result suggests that the safety criterion is more severe and the travel time is longer when turning right than left.

D. At a Crossroad

Next, we evaluate when the vehicle on the non-priority road side makes a left or a right turn or continues straight ahead and travels on the crossroad. As a precondition, the vehicles on the priority road side should go straight ahead. Vehicles are again driven on the left - hand side of the road.

TABLE II. SIMULATION PARAMETERS FOR T-JUNCTION AND CROSSROAD

Number of vehicles in one lane per hour	300 vehicles per hour
Measurement time	10 minutes
Measurement section	1000 m
Road width	7 m
Center position of intersection	500 m position
Speed limit	50 km/h
TTC value of intersection passing criterion	1.4 seconds

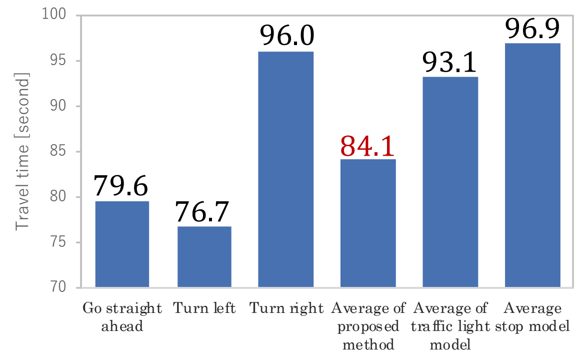

Figure 11. Travel time of crossroad

1) Evaluation method: The shape of the crossroads is shown in Figure 10. It is necessary to check the safety of one lane when turning left, two lanes when going straight, and three lanes when turning right. Thus, the safety criterion depends on the traveling direction, and the criteria become stricter in the order of left turn, straight run, and right turn. When turning right, the traveling direction of the oncoming vehicle must be confirmed. However, when right-turn vehicles face each other, no collision occurs in the intersection. Therefore, in addition to the vehicle ' s speed and position information, information of the traveling direction must be shared. Unlike the other evaluations, the condition is set to share information of traveling directions.

For our evaluation, we compared the following models: our proposed method, one that paused before entering the intersection, and one with traffic lights. The pause settings and the signal period settings are evaluated with settings that resemble those used in the previous section. We established an intersection 500 m from the vehicle and measured the travel time at 1000 m. We assume that a vehicle on the non-priority road side is selected with a probability of 70 % for straight ahead, 20 % for a left turn, 10 % for a right turn, and measured the travel time for each traveling direction.

2) Evaluation result: The evaluation result is shown in Figure 11. The traveling time increased as the number of lanes whose safety must be confirmed also increased in the crossroad.

V. CONSIDERATION

A. When Only a Straight Traveling Vehicle is being Operated

From Figure 5, using V2V communication at an intersection where only straight-ahead vehicles run reduces the travel time. Traffic efficiency is defined as the time to reach a destination. With V2V communication, travel time was reduced and efficiency was improved. TTC calculation verified the collision delay time with the vehicle in the lane that intersects when passing through the intersection and improved safety more than without communication.

From Figure 6, the travel time of the models using V2V communication is the shortest when the number of vehicles per hour ranged from 100 to 600. However, the travel time is longer than in the model with traffic signals if the number of generated vehicles increased to 700. A vehicle on a non-priority road cannot cross the intersection because it runs on the priority road without interruption. If a certain traffic volume is exceeded, negotiation is required at the intersection. For example, one method is to yield at an intersection to a vehicle that has stopped for a certain period before entering an intersection.

According to the result in Figure 7, the travel time also increases as the TTC value is increased. Although the risk of collisions is reduced by widening the distance (that remains safe) between vehicles, the travel time's efficiency is degraded. Therefore, safety and efficiency have a trade-off relationship. The TTC needs to set a value that maximizes the efficiency by ensuring a minimum level of safety.

B. For a T-junction

Considering the left or right turn of a vehicle on a non-priority road, the travel time at a T-junction is shown in Figure 9. The traveling time for a right turn is about seven seconds longer than for a left turn. The average travel time of left or right turns is 83.0 seconds. The vehicle ' s average speed in the 1000-m section is about 43.4 km/h, which is relatively fast since the speed limit is 50 km/h. Our proposed method is effective for traffic efficiency at T-junctions.

C. In Case of Crossroad

Figure 11 shows that the traveling times increase as the number of lanes whose safety must be confirmed increases. The average travel time of the proposed method is 84.1 seconds, meaning that the average speed of a vehicle in the 1000-m section is about 42.8 km/h. Since the speed limit is 50 km/h, this level is fast. In addition, the model ' s travel time using traffic signals is 93.1 seconds, and model ' s travel time that pauses is 96.9 seconds. Since the travel time of the proposed method is the shortest, it is effective for the traffic efficiency of crossroads.

VI. CONCLUSION

In recent years, research on automated driving has been increasing. The information that can be obtained by an automated vehicle as a single unit is limited, and it is impossible to collect information on blind spots when viewed from the vehicle. We must supplement the missing information by sharing information with various objects. We verified the safety and efficiency when using cooperative automated vehicles at an intersection where the outlook is bad and blind spots are large. With communication, the speed and position information of vehicles around the intersection are acquired to judge whether safe passage is possible.

Evaluation results showed that efficiency and safety were improved more than the case of confirming the safety of passing through the intersection without communication when it confirms safe passage.

ACKNOWLEDGMENT

This work was supported in part by JSPS KAKENHI Grant Number 16H02814.

REFERENCES

[1] H. Gunther, R. Riebl, L. Wolf, and C. Facchi, ”Collective Perception and Decentralized Congestion Control in Vehicular Ad-hoc Networks”, Vehicular Networking Conference(VNC), 2016.

[2] National Police Agency, ”Occurrence of traffic accident accident in 2017”, URL: https://www.npa.go.jp/toukei/koutuu48/toukei.htm[accessed : 2018-04].

[3] T. Hiraoka and S. Tanaka, ”Collision Risk Evaluation Based on Deceleration for Collision Avoidance”, The Society of Instrument abd Control Engineers, Vol.47, No.11, 2011, pp.534-540.

[4] ”PTV Vissim”, URL: http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/[accessed : 2018-04].

[5] Ministry of Land, Infrastructure, Transport and Tourism, ”Reference material - Ministry of Land, Infrastructure, Transport and Tourism”, URL: www.mlit.go.jp/common/000162826.pdf[accessed : 2017-8].

[6] T. Sawada, T. Hirose, N. Kasuga, and M. Zeniya, ”Study on Evaluation of Collision Mitigation Brake System”, International Association of Traffic and Safety Sciences, Vol.33, No.4, 2008, pp.311-338.