Collision Prediction at Intersections in Sensor Network Environment

Oje Kwon, Sang-Hyun Lee, Jun-Seok Kim, Min-Soo Kim, and Ki-Joune Li

Abstract— **This paper presents several algorithms to predict collisions between vehicles at intersection and access road, where the information about the movement of vehicles within interesting region is exchanged via sensor network and local broadcasting. Experiments show that these algorithms give very accurate results with about 0.5 average false warnings at access road on highway. In comparison with access road, they give relatively more false warning reports at intersections.**

I. Introduction

Recent development of wireless communication and sensor technologies allows the inter-vehicle communication for exchanging vehicular status. An important application type of these technologies is related with safety control. For example, intersection collision warning systems are one type of these applications that can prevent collisions or at least decrease their severity. By exchanging necessary information via wireless inter-vehicle communication, such as position, velocity, and acceleration, onboard systems can compute the possibility of a collision and warn drivers at intersections or access roads.

In order to warn drivers and prevent collisions, the collision prediction is a fundamental functional requirement for such types of applications. The accuracy of collision prediction is determined by two terms. The first term is the ratio of the number of predicted collisions over the the total number of collisions. This is called *prediction ratio* and critical to the safety of drivers. The second term is *false warning ratio*, which is the ratio of expected number of collisions but never coming true. Although the first term is directly related with the safety and the second term is less critical than the first term, and it is preferable to reduce false warning ratio. A number of researches have been done to reduce false warning ratio keeping prediction ratio 100% by using several sensing methods and communication techniques [1] [2] [3] [4] [5] [6] [7]. In particular, some collision warning methods have been proposed based on hybrid sensor network and P2P [4] [5].

In real world, traffic accidents are frequently reported from the intersection. Most of these collision warning methods are focused on accidents at intersections. For example, a network simulator with collision prediction module was developed to prevent collisions at intersections [1]. But by these methods predict collisions just before entering an intersection. In this case, drivers are not capable of avoiding a collision even though they realize the probability of collision. In this paper, we propose several algorithms to predict collisions sufficiently before drivers enter an intersection. We also present the feasibility of our collision prediction methods, where they are applied for an environment of sensor network and local broadcasting. And we also propose a collision prediction algorithm at access roads to highways, since many accidents are also taken place at the access road on the highway.

This paper is organized as follows; in section 2, we introduce the sensor deployment and wireless communication environment and a collision scenario that we assume in this paper. And then we propose several collision prediction algorithms in section 3. In section 4, we study the feasibility of these method by simulation. Finally, we conclude our research and propose future works in section 5.

II. Sensor Deployment and Scenario

In this paper, we assume that sensors are uniformly installed on roads as shown by figure 1. They detect and send the status of vehicles such as location and speed to the base station located at the center of intersection. The base station collects the status information of vehicles approaching to the intersection and spread it other vehicles within its local broadcasting area as figure 1. Each vehicle is equipped with a GPS and an onboard system and can compute the possibility of collision with the data from the base station. The location and speed data acquired from GPS are sent to sensors on roads.

Under this sensor deployment and communication environment, we consider the following scenario shown by figure 2.

- step 1. Sensor detects the position and speed of the vehicle passing over it.
- step 2. Sensor transmits the detected information to the base station via sensor network.
- step 3. Base station collects the information of vehicles around the intersection and periodically broadcasts the information to the vehicles within the broadcasting coverage area.
- step 4. Each vehicle performs collision prediction algorithm with the information received from the base station via local broadcasting.

And the values of parameters are given as follows to define the environment and scenario more precisely.

These values will be also used as input to analyze the feasibility of collision prediction in section 4. Our collision prediction algorithms are also based on these values.

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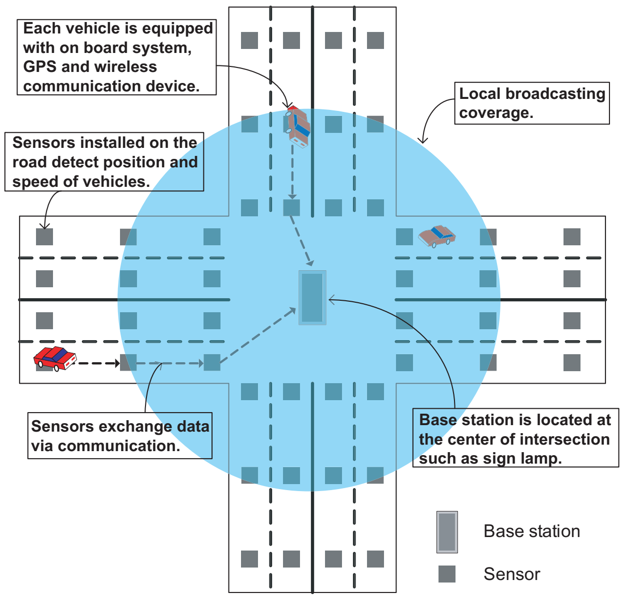


Fig. 1. Sensor Deployment and Wireless Communication at Intersection

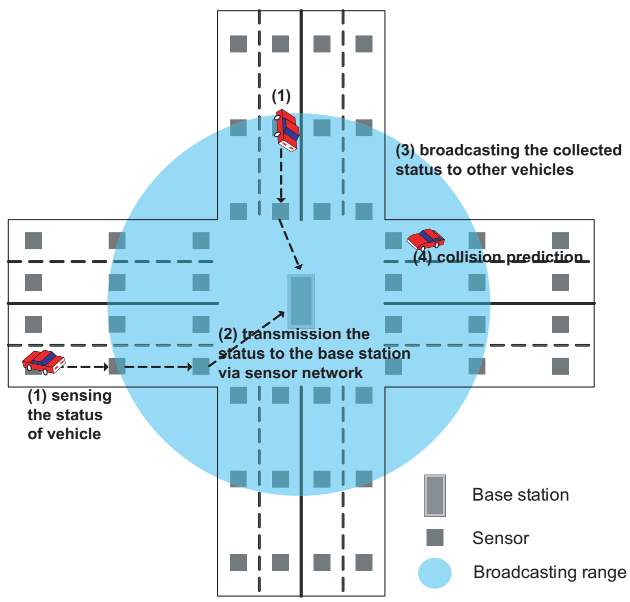


Fig. 2. Scenario

TABLE I

IMPORTANT PARAMETERS AND VALUES

Parameter	Value
accuracy of distance	less than 3 meters
accuracy of speed	less than 5 Km/h
temporal accuracy	less than 0.1 sec.
transmission time between sensor and base station	less than 1 second

Each vehicle has to perform collision prediction in real time, as it receives the information of neighbor vehicles from the base station. The performance requirements of collision prediction algorithms are given as follows;

- The collision prediction time is less than 1 sec. Otherwise, the total processing time including the transmission time would be greater than 2 seconds, which implies that the prediction becomes meaningless.
- At the intersection, drivers have to predict collisions before she/he enters the intersection. The prediction should be reported to drivers before at least 2 seconds to give enough time to react.
- At access roads on highway, drivers have to be reported collision warning before she/he access the highway.

III. COLLISION PREDICTION

Under the conditions described in the previous section, we present four algorithms to predict collision at intersection and an prediction algorithm for access road to highway.

A. *Collision prediction at the intersection*

In this paper, we assume an intersection with four streets as figure 3. Sensors are installed on each lane to 400 m from the intersection. The turning at the intersection is illustrated by figure 3, where u-tern is not allowed. Left turn is allowed only on the first lane, while right turn is allowed on the second lane. Note that there is no traffic sign at the intersection.

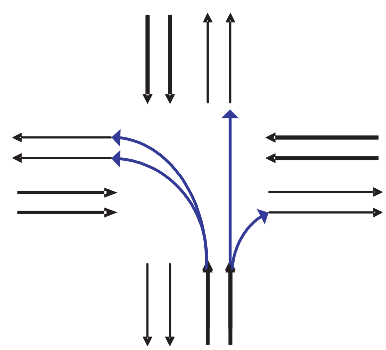
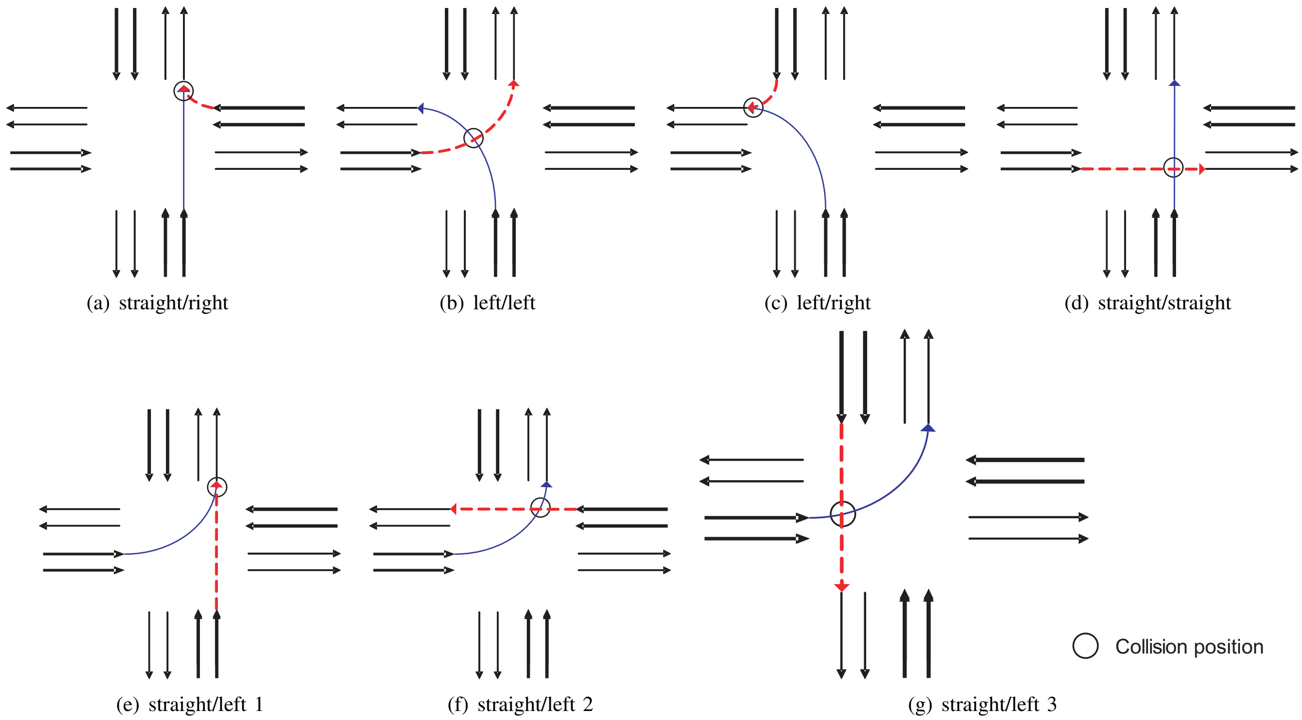


Fig. 3. Turning at Intersection

At the intersection defined as figure 3, collisions are classified into seven types as depicted by figure 4. We consider these collision types to design our collision prediction algorithms. The location of collision is depicted as a circle in figure 4.

The collision location and the arrival time to this location are the most essential factors in predicting collision. The collision location can be easily calculated by analyzing the possible trajectories of vehicles. The arrival time is however very difficult to estimate and depends on the speed of vehicle to the collision location. Since we cannot estimate the exact speed and consequently the exact arrival time to the collision location, we define the arrival time interval, which we simply call *collision time interval*, instead of the collision time.



(a) straight/right (b) left/left (c) left/right (d) straight/straight

(e) straight/left 1 (f) straight/left 2 (g) straight/left 3

Fig. 4. Seven collision cases

TABLE II
NOTATIONS

notation	description
p_v	position where prediction algorithm is performed
t^A_{cen}	Collision time of vehicle A by current speed.
t^A_{min}	Collision time of vehicle A by maximum speed.
t^A_{max}	Collision time of vehicle A by minimum speed.
$I^A_{collision}$	$[t^A_{min}, t^A_{max}]$

Depending on the ways of interpretation of collision time interval, we propose four algorithms to predict collisions at intersection. Table II shows some important notations we need to explain collision prediction algorithms, and they are explained in figure 5.

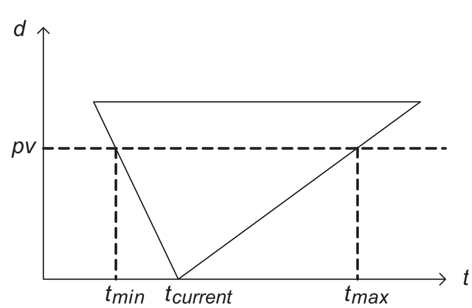


Fig. 5. Notations

The first algorithm is based on the overlapping ratio between two collision time intervals $I^A_{collision}$ and $I^B_{collision}$ of vehicle A and B. If the ratio exceeds a given threshold, they are supposed to collide at the collision position. This algorithm is explained in *Algorithm 1* and by figure 6.

Algorithm 1: *Algorithm Overlapping Interval*

---

input : Vehicle A;

begin

  for *each vehicle* B *in the set of collision candidates* **do**

    if *Length(Intersection(*$Interval^A$*,* $Interval^B$*))* $> \gamma_{interval}$ **then**

      return Result(A, B);

  end

end

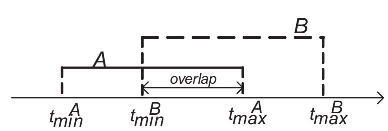


Fig. 6. Algorithm 1: Overlapping interval

The second algorithm is based on the current speed. If the difference between the arrival times of two vehicles in the current speed is less than a given threshold, then we consider that the collision will take place. This algorithm is shown by figure 7 and explained in *Algorithm 2*.

The third algorithm is a modification of algorithm 1. Instead of computing the overlapping ratio of two collision time intervals, we compute two difference $|t^A_{min} - t^B_{min}|$ and $|t^A_{max} - t^B_{max}|$, where A and B are two vehicles. If one of the

Algorithm 2: *Difference in current speed*

input : Vehicle A;
begin
  for *each vehicle B in the set of collision candidates* **do**
    if *Length(Difference(t^A_{cen}, t^B_{cen}))* $< \gamma_{center}$ **then**
      return Result(A, B);
  end
end

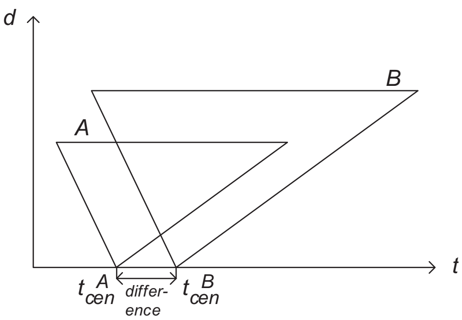


Fig. 7. Algorithm 2: Difference of arriving time in current speed

differences is less than a given threshold, we conclude that the collision will happen. Note that two different thresholds can be given to distinguish $|t^A_{min} - t^B_{min}|$ and $|t^A_{max} - t^B_{max}|$. The algorithm is given in *Algorithm 3* and explained by figure 8

Algorithm 3: *Difference in Min and Max speed*

input : Vehicle A;
begin
  for *each vehicle B in the set of collision candidates* **do**
    if *Length(Difference(t^A_{max}, t^B_{max}))* $< \gamma_{min}$ && *Length(Difference(t^A_{min}, t^B_{min}))* $< \gamma_{max}$ **then**
      return Result(A, B);
  end
end

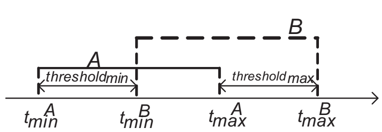


Fig. 8. Algorithm 3: Difference of arriving time in Min and Max speed

The last algorithm is a hybrid one of Algorithm 2 and Algorithm 3 to complement the problem of Algorithm 3 by Algorithm 2.

The threshold values used in the above algorithms are important to determine the accuracy of algorithms. Collision prediction ratio and false warning ratio are determined by these thresholds and the relationships will be discussed in section 4.

Algorithm 4: *Hybrid*

input : Vehicle A;
begin
  for *each vehicle B in the set of collision candidates* **do**
    if *Length(Difference(t^A_{cen}, t^B_{cen}))* $< \gamma_{center}$ **then**
      if *Length(Difference(t^A_{max}, t^B_{max}))* $< \gamma_{min}$ && *Length(Difference(t^A_{min}, t^B_{min}))* $< \gamma_{max}$ **then**
        return Result(A, B);
  end
end

B. Collision prediction at the access road on highway

Another type of collision prediction can be performed at access roads on highway, which is simpler and gives more accurate results than at intersection. The configuration of access road on highway is illustrated in figure 9. There are two collision cases at access roads on highway;

- case 1) vehicle A collides at the left side with vehicle B on the highway when A enters the highway.
- case 2) vehicle A is collided backward with vehicle B on the highway after A enters the highway.

Fig 10 and 11 show two collision cases at an access road on highway.

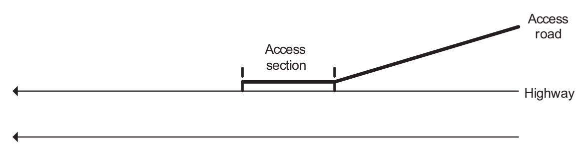


Fig. 9. Highway and access road model

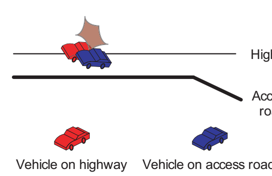


Fig. 10. Collision type 1 on access road

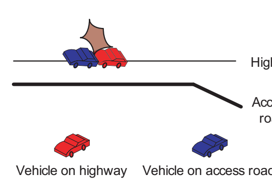


Fig. 11. Collision type 2 on access road

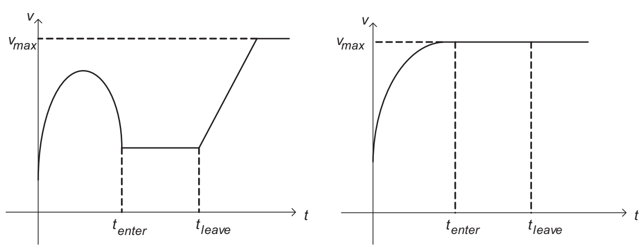
Collision prediction algorithm at access roads is simple. First, the collision of case 1 takes place when vehicle A enters on the highway and there is another vehicle at the same position on the highway. For the second type of collision, suppose that the current speeds of vehicles on the highway and access road are $v^B_{highway}$ and v^A_{access} respectively. While $v^B_{highway}$ is nearly constant, v^A_{access} increases to $v^B_{highway}$. We can compute the time $t_{A=B}$ that $v^A_{access} = v^B_{highway}$ based on a realistic speed model. If there is an overlapping between two trajectories of vehicle A and B in time interval $[t_{current}, t_{A=B}]$, then the collision of type 2 will occur on the highway.

IV. Simulation

In order to study the accuracy and the feasibility of our prediction algorithms, we performed experiments by simulation with synthetic data.

A. Data generation

For the simulation, we generated several synthetic data sets of vehicles at an intersection. Two speed models are used to reflect the real behavior of vehicles at intersections. By the first speed model, each vehicle approaching the intersection reduces its speed as shown by figure 12-a. According to the second speed model, the speed becomes constant once it reaches to the maximum speed as figure 12-b. t_{enter} and t_{leave} indicate the time when vehicle enters and leave the intersection. We defined v_{max} as 30 km and 70 km. We mixed two speed models and two v_{max} values and generated four data sets.



(a) Speed pattern 1 (b) Speed pattern 2

Fig. 12. Speed patterns at intersection

We also generated a synthetic data set at the access road such that the speed of vehicles at the highway is 100 Km/h, and the speed of vehicles on the access road at t_{enter} is 80 Km/h. Vehicles on the access road randomly enter the highway then accelerate the speed to 100 Km/h.

B. Simulation results

We performed experiments to analyze the accuracy of collision prediction algorithms. The accuracy measure is classified into two values as follows.

- h_T(collision prediction ratio): This is the ratio that algorithm predicts true collisions. Since this measure is extremely important for the safety of driver, we have tuned the threshold values of the algorithms to get $h_T = 1$ for the simulation. For this reason, we will not compare h_T in the graphs, since it is always 1.
- h_F(False warning ratio): This is the ratio that algorithm predict collisions, which do not happen in real world. Under the condition that $h_T = 1$, this measure is to be used to compare our algorithms.

Fig 13 shows the simulation results about four different algorithms. Thresholds are defined so that $h_T = 1$ from five seconds before vehicle enters the intersection. X-axis indicates the time interval that the prediction is performed. Y-axis indicates the number of false warning.

In Fig 13, the average and maximum number of false warnings using *Algorithm 1* are less than the other algorithms. It implies that this algorithm is better than the others. Even though it is not explained in this paper, we observed that this algorithm is more stable than others in tuning threshold values. The average and maximum number of warning messages using *Algorithm 2* are worse than the others. This is because it uses only the current speed of vehicle, which is variable in real world.

Fig 14 shows the simulation results at access roads. The maximum numbers of false warning for three data sets are less than two and the average numbers are less than 0.5. This implies that our prediction algorithm at access roads is very accurate and can be used in real applications.

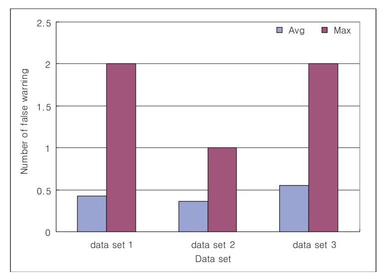


Fig. 14. Simulation result at access road on highway

V. Conclusion and Future Work

This paper presents several algorithms to predict collisions between vehicles at intersection and access road, where the information about the movement of vehicles within interesting region is exchanged via sensor network and local broadcasting.

The contributions of these methods are as follows; first they report collision warning to drivers at least two seconds before entering intersection, while the previous prediction algorithms report just before the entering. The second contribution is that our methods are developed for the case where sensor network and wireless communication devices are installed on roads and intersection. With the rapid progress of sensor network, this environment will be popular and inexpensive.

To validate our algorithms, we need to implement them with the data acquired from real vehicles at intersections and access roads. And we can extend our algorithms to several environments, such as intersections with signal lamp and more lanes.

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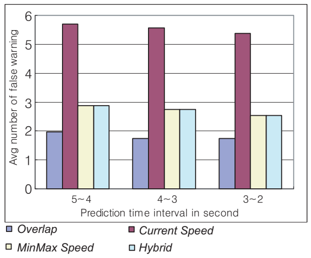
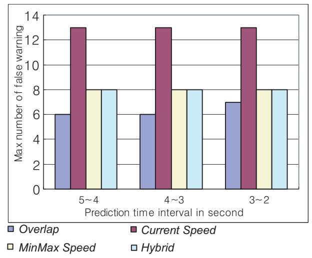
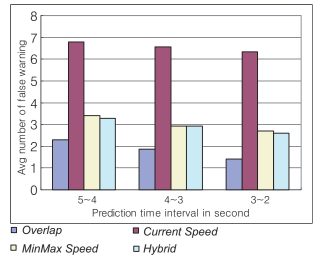


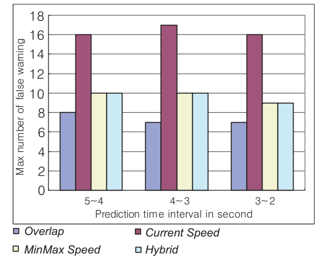
(a) Average number of warning messages(data set 1)



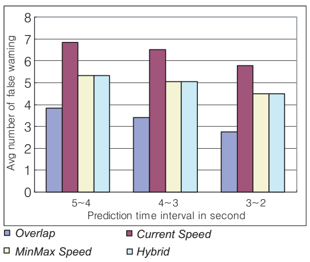
(b) Max number of warning messages(data set 1)



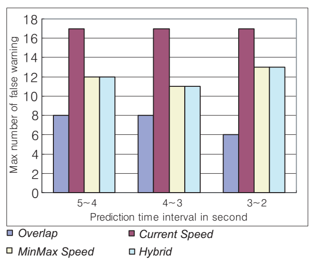
(c) Average number of warning messages(data set 2)



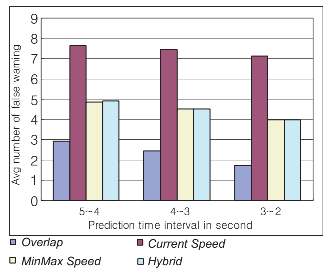
(d) Max number of warning messages(data set 2)



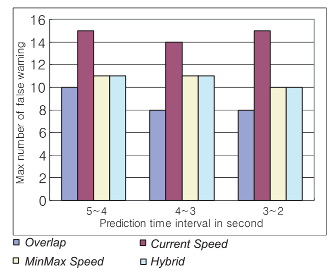
(e) Average number of warning messages(data set 3)



(f) Max number of warning messages(data set 3)



(g) Average number of warning messages(data set 4)



(h) Max number of warning messages(data set 4)

Fig. 13. Simulation results at intersection

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