A Collision Pre-Warning Algorithm based on V2V Communication*

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***Abstract*—The WAVE (IEEE 1609) standard and vehicular technology creates a new opportunity for telematics service. Safety is one of the top issues of telematics service. In this paper, we focus on the safety application and WAVE communication to provide proactive safety which can alert drivers before the accident occurs. An algorithm named Collision Pre-Warning Algorithm (CPWA) was proposed to tackle the aforementioned issues. In CPWA, vehicles broadcast Relationship Information (RI) to neighboring vehicles periodically. Each vehicle calculates whether potential collision may happen or not upon the RI messages that were received. After calculation, the CPWA sends warning messages to drivers if the collision will occur before several seconds. The results show that CPWA has good performance and can always alert drivers suitably.**

Keywords: Telematics, DSRC, WAVE, Collision Warning

I. INTRODUCTION

Telematics combines with informatics and communication on vehicles to provide more applications and services. Telematics provides many kinds of services such as navigation, driving safety, communication, security, and information service sharing for different purposes. One of the most important applications on telematics is driving safety enhancement.

Driving safety is a very important issue in automobile industry. There are many researchers and engineers who aim at how to enhance driving safety. Generally speaking, driving safety can be classified into two parts: Passive Safety and Active Safety systems. A passive Safety System is used to reduce injury when an accident has occurred, which includes Occupant Protection Systems and Other Passive Safety Systems. On the other hand, an active Safety System is used to prevent accidents before they occur, which includes Vehicle Stability Systems, Driver Warning and Information Systems, and Collision Avoidance Systems, etc.

Base on driving safety reports, intersection is a dangerous place in which two cars may collide easily, especially for the intersection place which has no traffic light. Most reasons of accidents are caused by high velocity of cars, inattention of drivers, cars that are out line of sights, etc. Actually, traffic accidents can be avoided if the collision warning message can be provided to drivers before the accident occurs.

This paper proposes an algorithm called Collision Pre-Warning Algorithm (CPWA) to alert drivers. The basic idea of CPWA is to utilize the GPS system to obtain the location information and then broadcast it periodically. In CPWA, each vehicle calculates whether the collision will happen or not when Relationship Information (RI) that comes from other cars is received. CPWA utilizes location and vector information to find a Closest Point of Approach (CPA) between two moving nodes. To follow, we can get Time to CPA (TCPA) and Distance to CPA (DCPA) through equation (1). After calculation, CPWA can alert drivers on impending collision.

The rest of this paper is organized as follows: Section II presents related works and some issues about collisions at the intersection, and how to alert drivers. Section III describes the operation of CPWA in detail. The experimental results are given in section IV. Finally, conclusions are drawn in section V.

II. RELATED WORK

- *WAVE*

The DSRC standard was defined and developed by American Society for Testing and Materials (ASTM) and it uses the Time Division Multiple Access (TDMA) technique operation on 915MHz in 1992. ASTM redefines the DSRC standard as E2213-02 [3] based on IEEE 802.11a operating on 5.9GHz in 2002. A new version of DSRC was redefined as E2203-03 [4] in 2003. The DSRC standard is also called Wireless Access in the Vehicular Environment (WAVE) standard. It is based on 802.11a and operating on 5.9GHz. The WAVE protocol stack includes IEEE 1609.1[8], 1609.2[9], 1609.3[10], and 1609.4[11] protocols, which are depicted in Fig. 1.

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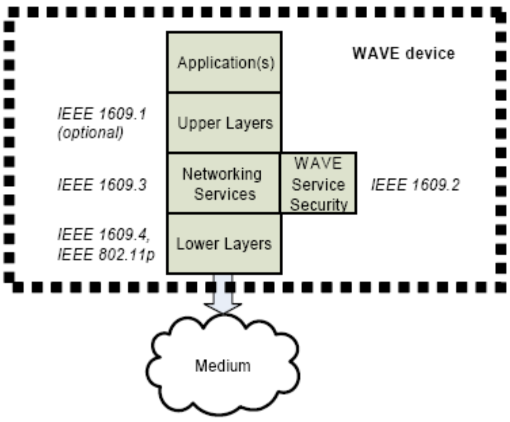


Figure 1 The WAVE protocol stack.

- *Intersection collision warning*

Driving safety is one of the most important issues in car industry. In [12], authors proposed a system that includes sensors, sink nodes, and base stations for avoiding collision on the curved road. However, the system needs to deploy some infrastructure, which may need some extra cost. Another problem of the system is that it is unsuitable to the intersection environment because a large number of information needs to be handled immediately.

On the other hand, authors in [5] indicated that the intersection scenario should not be one. There are many kinds of different scenarios that need to be considered. For example angle of two roads, multi roads on an intersection, et al. Furthermore, cars connect to the control center through infrastructure [7] [12] are unsuitable. The reason of that is a large number of information needs to be handled and delivered immediately.

According to news report [1] [2], an intersection avoidance system called Smart Intersection was successfully developed by Ford Company Ltd in July 2008. It reduces collision and congestion of vehicles on the intersection smartly. The major technique of Smart Intersection is to use Road-Side Unit (RSU) built on the roadside for delivering information to cars. Although the system achieves the goal of alerting drivers before a collision occurs, it still needs to build some infrastructure on the intersection.

In contrast to the aforementioned research and systems, people can consider how to have a low-cost and effective collision warning system that does not rely on infrastructure. In order to solve the aforementioned problems without using infrastructure, the proposed Collision Pre-Warning Algorithm (CPWA) has the following advantages: 1) non-infrastructure, 2) suitable to be applied on many kinds of intersections, and 3) low cost and high accuracy.

III. Collision Pre-Warning Algorithm

Two pieces of information that are used in the proposed Collision Pre-Warning Algorithm to calculate whether the collision will occur or not between host and target vehicles are (1) Location Information and (2) Vector Information, which are encapsulated into Relationship Information packet (RI). Hereafter, the host vehicle means a vehicle itself, and target vehicle is the other vehicle on the road. In our scenario, we assume that all vehicles are equipped with the GPS system and DSRC communication devices.

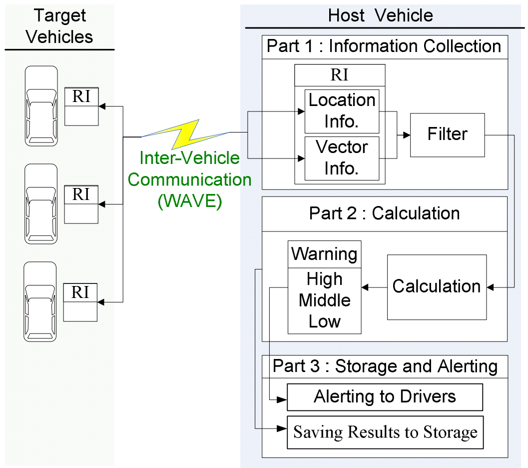


Figure 2 Architecture of the Collision Pre-Warning Algorithm.

In CPWA, each vehicle broadcasts RI packets periodically (once per second). The RI packet contains each vehicle's relative information, including location information, velocity, course, acceleration, vehicle identification, etc. All of the information in a RI packet comes from the GPS device. When a host vehicle receives RIs from other vehicles (target vehicles), it starts the CPWA operation. CPWA can be divided into 3 parts: (1) information collection, (2) calculation, and (3) storage and alerting.

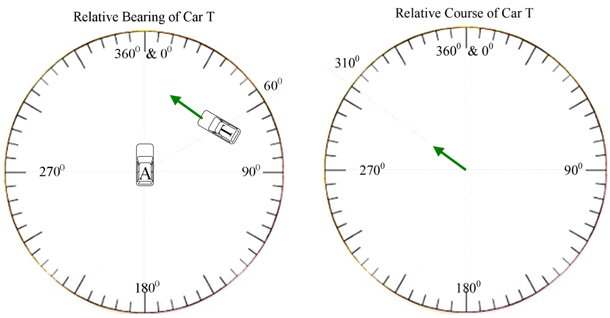
- *Part 1: Information Collection*

Vehicles transmit and receive RI packets through Inter-Vehicle Communication based on the WAVE protocol. CPWA was calculated at the host vehicle when RI packets are received from other vehicles. However, there are some situations that calculation is not needed in order to save computing resource. For example, it is not necessary to calculate if the target vehicle is far from the host vehicle and velocity of the target vehicle is low, or the target vehicle is leaving from the host vehicle. Therefore, we design a filter to avoid the problem. Before introducing the filter, we illustrate the Relative Bearing and Course as showed in Fig. 3 (a) and (b), respectively.

Relative Bearing is a bearing where a point located. From the view point of car A (see Fig. 3 (a)), the Relative Bearing of car T is 60^0. Relative Course is a direction where the target is coursing. From the view point of car A (see Fig. 3 (b)), the Relative Course of car T is 310^0. The filter that we designed was based on the Relative Bearing and Course.

The main idea of filtering in CPWA was shown in Fig. 4. Assume vehicle A is the host vehicle, and the other vehicles are target vehicles. There are 4 situations that must be considered in filter.

1. Relative Bearing of vehicle T at 0^0~90^0 and Relative Course of vehicle T is 180^0~360^0.
2. Relative Bearing of vehicle T at 270^0~360^0 and Relative Course of vehicle T is 0^0~180^0.
3. Relative Bearing of vehicle T at 180^0~270^0 and Relative Course of vehicle T is 0^0~90^0.
4. Relative Bearing of vehicle T at 90^0~180^0 and Relative Course of vehicle T is 270^0~360^0.



(a) (b)

Figure 3 Relative Bearing of a host vehicle.

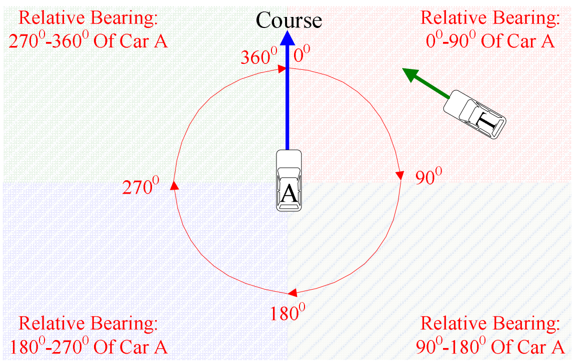


Figure 4 Relative Location of a host vehicle.

- *Part 2: Calculation*

After filtering, a RI packet is sent to calculation in order to judge whether two vehicles (host and target vehicle) may collide or not. The main idea of calculation is to utilize the Closest Point of Approach (CPA) scheme. Assume vehicle A is the host vehicle, and the target vehicle is vehicle B, which is depicted in Fig. 5. V_A denotes the vector of vehicle A, and some information in V_A can be obtained from the GPS device. Let V_B denote the vector of vehicle B. Relation Information (RI) that comes from vehicle B can be received at vehicle A through WAVE communication. Next, reversing vector V_A and then adding it to vector V_B can get a new point called NP. Extending the line from vehicle B to point NP until the link is near vehicle A. Then, finding another line which passes the vehicle A and perpendicular to the line that extended from vehicle B. After that, we can obtain a point called Closest Point of Approach (CPA) on the two lines intersection. Time to Closest Point of Approach (TCPA) is a time unit and can be obtained by equation (1).

$$TCPA_{A,B} = \text{Distance}_{CPA,B} \,/\, \text{Distance}_{NP,B} \qquad (1)$$

$$\text{where} \begin{cases} \text{TCPA}_{A,B} = \text{Time to CPA of Vehicle A and B} \\ \text{Distance}_{CPA,B} = \text{Distance between point CPA and Vehicle B} \\ \text{Distance}_{NP,B} = \text{Distance between point NP and Vehicle B} \end{cases}$$

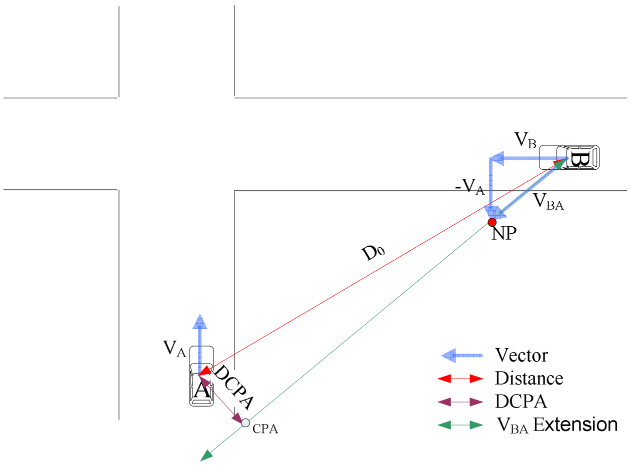


Figure 5 Collision calculation.

The distance between point CPA and vehicle A is called DCPA. After calculation, we can say that vehicle A and vehicle B will collide after TCPA time units if DCPA is equal to zero. After TCPA time units, the minimum distance between vehicle A and vehicle B is DCPA if DCPA is not equal to zero.

Based on the calculation, we can know whether collision between two vehicles may occur or not, and when it will happen.

- *Part 3: Storage and Alerting*

Sending packets for calculation does not mean the collision between two vehicles will occur. Even if the collision will occur, it may happen in the next several seconds or more. Some alerts may be too early to be sent to driver if collision is oncoming, and some of them are not. For example, the alert should not be sent to drivers before 30 seconds. In our designing, we believe that it should have some different setting, which was determined by drivers. The warning level is considered in order to solve the problem. To tackle the aforementioned concern, default warning levels can be chosen by drivers in our design. They are high, middle, and low warning levels. The low warning level, which sets TCPA to be less than 3 seconds, could minimize the number of warning messages alerting to the driver. The middle warning level sets TCPA to be less than 6 seconds, and the high warning level sets 9 seconds.

On the other hand, after the calculation, we store the information, including RI packets of two vehicles, calculation results, warning level, etc., in order to provide some information for accident identification if collision really occurs.

Table I depicts the definition of symbols and Table II depicts the algorithm in the pseudo code format.

TABLE I. SYMBOLS DEFINITION

$D_{A,B}$	Distance between vehicle A and B
V_A	Vector of Vehicle A
$TCPA_{A,B}$	Time to Closest Point of Approach between vehicle A and B
$DCPA_{A,B}$	Distance to Closest Point of Approach between vehicle A and B
t	Time
RI	Relationship Information
RBV_B	Relative Bearing of target vehicle B
RCV_B	Relative Course of target vehicle B
$RVV_{A,B}$	Relative Velocity of vehicle A and B
ST	Setting Time of warning level //Low: 3s Mid:6s High:9s

TABLE II. PSEUDO CODE OF CPWA ALGORITHM

Broadcast:
Broadcasting RI every 1 second (Each vehicle)

Receive (RI)   / * Filter * /
{
  While($D_{A,B} \geq 400\text{m}$ & $V_B \geq 90\text{km/h}$ ||
    $D_{A,B} \geq 300\text{m}$ & $V_B \geq 60\text{km/h}$ ||
    $D_{A,B} \geq 200\text{m}$ & $V_B \geq 40\text{km/h}$ ||
    $D_{A,B} \leq 100\text{m}$&){
    While($0^0 \leq \text{RBV}_B \leq 90^0$ & $180^0 \leq \text{RCV}_B \leq 360^0$ ||
      $270^0 \leq \text{RBV}_B \leq 360^0$ & $0^0 \leq \text{RCV}_B \leq 180^0$ ||
      $180^0 \leq \text{RBV}_B \leq 270^0$ & $0^0 \leq \text{RCV}_B \leq 90^0$ ||
        $90^0 \leq \text{RBV}_B \leq 180^0$ & $270^0 \leq \text{RCV}_B \leq 360^0$) {
        Calculation(RI)
    }
  }
  If $DCPA_{A,B} \leq 3\text{m}$ & $TCPA_{A,B} \leq ST$
    Alerting
  End If
  Storet, RI, $TCPA_{A,B}$, $DCPA_{A,B}$
}

Calculation (RI)   / * Calculate the CPA * /
{

$$\Delta = -V_A + V_B$$

$$\alpha = \frac{\arccos(\Delta^2 + D_{A,B}{}^2 - D_{A,B}{}^2 \cdot \Delta)}{2 \cdot \Delta \cdot D_{A,B}}$$

$$\rho_{CPA} = D_{A,B} \cdot \sin(\alpha)$$

$$DCPA_{A,B} = D_{A,B} \cdot \cos(\alpha)$$

$$TCPA_{A,B} = DCPA_{A,B} / RVV_{A,B}$$

Return $DCPA_{A,B}, TCPA_{A,B}$
}

IV. SIMULATION

We utilize the network simulation tool NS-2 to simulate the communication and motion of vehicles. In addition, all communications in the simulation employ WSM packets based on the WAVE protocol. In our simulation, we assume that the velocity of each vehicle is constant in order to evaluate the accuracy of CPWA. First, we simply simulate two vehicles in different scenarios in order to evaluate the alerting hit rate. Alerting hit rate is an accurate rate of alerting messages. Referring to Fig. 6 (a), the values of included angle α are 10, 30, 45, 60, and 90 degree. The other parameters are vehicle's velocities which are 10, 15, 20, 25, 30, and 35 meter/second. In this environment, we can get 100% alerting hit rate in the simulation.

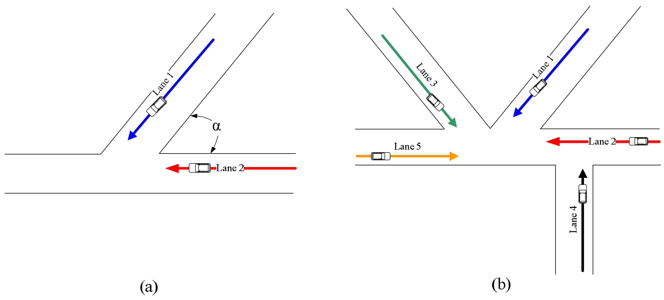


Figure 6 Intersection of α included angle.

The second environment is depicted in Fig. 6 (b). There are several vehicles on different lanes driving to the same multi-intersection. We employ the same parameters as the first simulation and also get 100% alerting hit rate in the multi-intersection environment.

For more vehicles simulation, we defined the performance evaluation as follows:

- Transmission Delay: time difference between sender and receiver (Target and host vehicles).
- Delivery Rate: the rate of sending and receiving RI packets.
- Hit Rate: accurate rate of alerting messages.

- Miss Rate: missing rate of alerting messages.
- Error warning message: the number of alerting messages that should not be sent.

TABLE III. SIMULATION PARAMETERS

Environment	6000m * 6000m
Number of lanes	Lane 1 ~ 4
Lane length	3000m
Number of vehicles	40 ~120
Velocity	10m/s ~ 35m/s
Lane width	4m
Warning level	Low (before 3s)
Included angle (α)	90

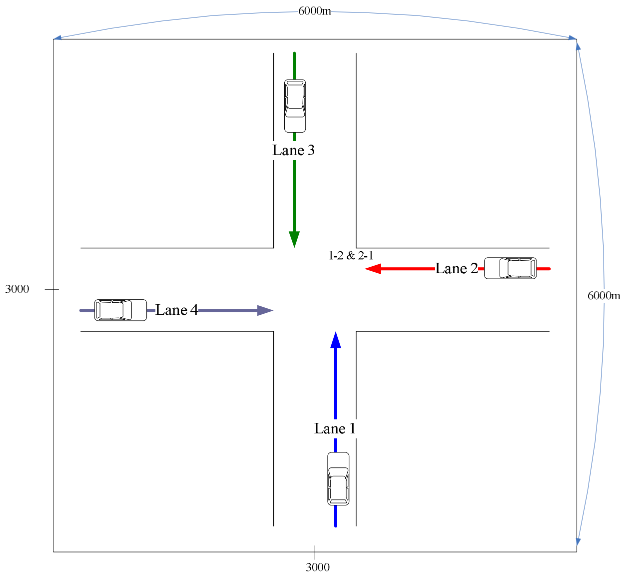
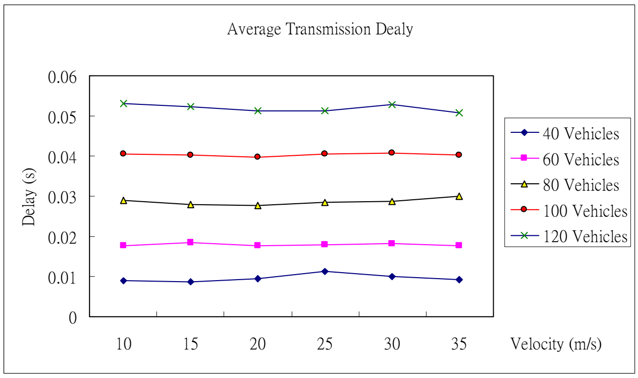
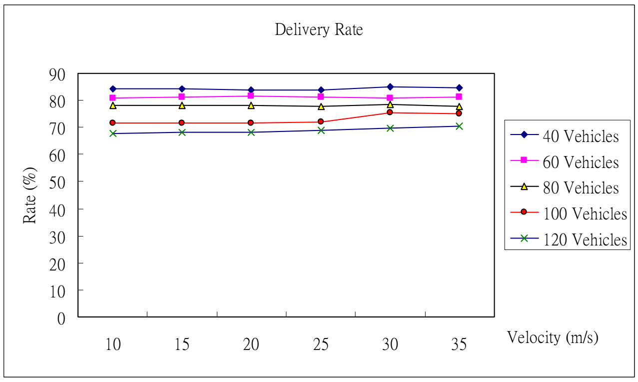


Figure 7 Simulation environment.

Table III contains the parameters of the simulation, and the simulation environment was illustrated in Fig 7. Fig. 8 is results of average transmission delay and delivery rate respectively. Referring to Fig. 8(a), the velocity is not a main factor that affects transmission delay, but the number of vehicle is. According to Fig. 8(b), delivery rate decreased only if the number of vehicles were increased. The main reason is packets colliding around an intersection, which results in increasing transmission delay and decreasing delivery rate when the number of vehicles is increased.



(a)



(b)

Figure 8 (a) Average transmission delay, (b) delivery rate.

Another important metrics of collision warning performance is the alerting hit rate of alerting messages. The hit rate in our simulation is shown in Fig. 9 (a). In the simulation, CPWA has 100% hit rate when the number of vehicles is less than 60, which is the total number of vehicles on 4 lanes. Hit rate is decreased only when the velocity increases to 35 m/s and the number of vehicles is 80. The reason is that some packets are not successfully transmitted at the intersection. In Fig. 9 (a), when the number of vehicles reaches to 100 and 120, the alerting hit rate is decreasing due to too many vehicles are around the intersection, which could result in packet collision. If the packet collision is very serious, it may result in that none of the vehicles can receive the RI message to calculate whether the collision between two vehicles will occur or not. However, the curved line of the hit rate increases when the velocity of vehicle is more than 20 m/s. It is because when vehicles pass the intersection faster, they also result in the packet collision decreasing at an intersection. Therefore, the curved line of the hit rate on the number of vehicles 100 and 120 decreased first and then increased. In Fig. 9 (b), the miss rate is opposite to the hit rate.

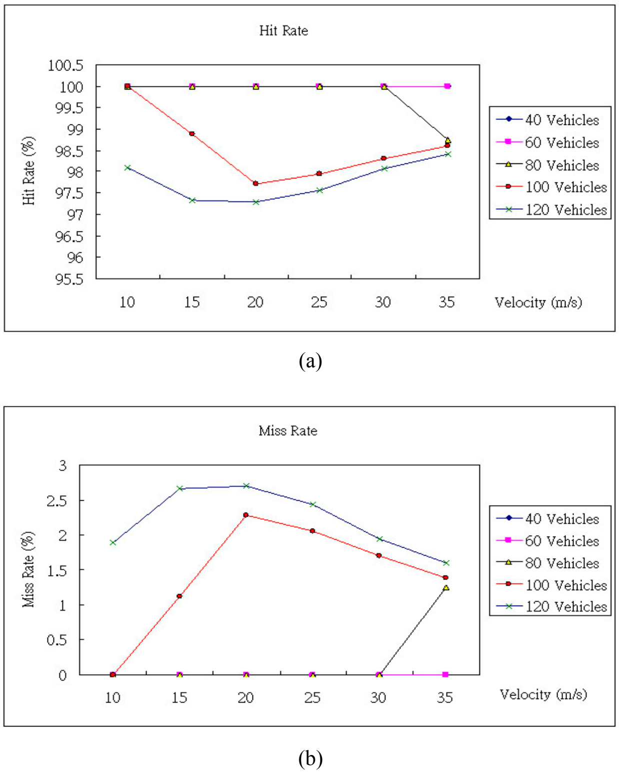


Figure 9 (a) hit rate, (b) miss rate.

Finally, a simulation result of erroneous warning messages is depicted in Fig. 10. The results of erroneous warning messages increased when the number of vehicles increased. One of the reasons is that the density of vehicles on the road is higher and higher. Another reason is about vehicle's position and timer. These reasons lead to erroneous warning messages increased when the number of vehicles increased.

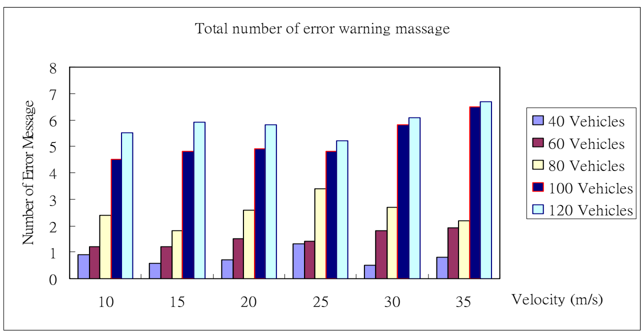


Figure 10 Erroneous warning message.

V. Conclusion

Driving safety is one of the most important issues in car industry. There are some researches trying to provide collision warning systems to achieve the goal of more safety. However, some of them need to build infrastructure to reach their purposes. It may be expensive. In this paper, we have proposed a Collision Pre-Warning Algorithm (CPWA) based on V2V WAVE communication which is low cost and more easily implemented. CPWA utilizes RI packets that transmitted and received through the WAVE communication protocol. After the RI packet was received, CPWA utilizes location and vector information to calculate whether the collision will happen or not. In our simulation, CPWA has high accurately rates at most scenarios, and some miss rates occur when the number of vehicles is increased.

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