DEVELOPMENT OF A ROAD COLLISION WARNING INFORMATION MODEL VIA TELEMATICS DEVICES ON SMART ROADS

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ABSTRACT

The primary purpose of this research is to develop a road collision warning information (RCWI) model using telematics devices on SMART roads. This paper focuses on the effect of real-time, environmental/incident-hazard information using telematics devices for in-vehicle unit advisory systems, and suggests a detection and estimation model using new IT technologies at signalized intersections for collision warning. Signalized intersections pose safety and operational challenges. For instance, dangerous situations may arise such as a failure to stop in time for, or blatantly running, a red light accelerating through a yellow light, or abruptly stopping in the middle of an intersection.

This paper presents the development of a road collision warning model for vehicles travelling in phase change using real-time vehicle speed and the time between multiple point detectors. For an evaluation of this model, VISSIM was used to create multiple detection situations in real-time, various inflow-volumes, changes in the remaining times for a green light period, and road design speeds. In our results, about 0.8 - 2.3% of the entire traffic flow was classified as collision warning vehicles, while 35.8% was classified as collision warning vehicles during a yellow signal. This research considers that new service applications for increasing safety at signalized intersections are possible. The road collision warning information model may directly contribute to providing such safety for overall vehicle users on SMART roads.

Keywords: Smart roads, ITS, Telematics, collision warning, real-time traffic detector

INTRODUCTION

In many countries, a variety of in-vehicle telematics systems are already available, while new systems are being currently designed. Telematics is defined as in-vehicle systems that offer positive safety and infotainment services as well as location and traffic information via wireless communications technologies such as CDMA (Code Division Multiple Access), GSM

(Global System for Mobile Communications), 2G, 3G, DSRC (Dedicated Short Range Communication) and WAVE (Wireless Access for Vehicular Environments). One of the killer applications of telematics systems is a service providing a safe means of avoiding traffic collisions. The range of these systems varies from those that provide drivers with real-time information, for example, traffic jam locations and dynamic routing, to more complex systems that may even take over driver tasks during hazardous situations. For advisory systems in telematics devices, the main issues determining a collision warning situation are very important.

In this paper, we are concerned with telematics/ITS services based on new IT technologies for SMART road systems, and we focus in particular on intersection collision avoidance issues. Through the use of ICT (Information and Communication Technology), particularly considering USN (Ubiquitous Sensor Network) traffic sensors, this paper proposes more advanced collision avoidance methods for Smart roads in order to more accurately predict dangerous vehicle situations. This paper presents a brief literature review, study methodology, study findings, and conclusions and recommendations. This paper also presents a new approach for enhancing real-time traffic safety levels by making predictions regarding traffic safety information on vehicle movement collected in real-time, e.g., with the help of USN traffic sensors. First, we introduce new ICT technology on Smart roads such as Smart Highway Projects, and USN technology at signalized intersections. USN networks and USN traffic sensors that have real-time detection and reliable road services are feasible. We then propose a definition of collision warning situations at a signalized intersection as a means to provide telematics information. Next, we develop a road collision warning information model via telematics devices for potential traffic conflicts at an intersection based on real-time traffic data collected on vehicles in the approaching lane. This research also addresses the concept of potential traffic conflicts at intersections. Finally, for an evaluation of this method, VISSIM was used to perform multiple detection situations in real-time. We also used various inflow-volumes and changes in remaining green light periods.

BACKGROUND AND LITERATURE REVIEWS

New ICT Technology on Smart Roads

Intelligent warning technology at signalized intersections

Over the past few years, a lot of attention has been given toward applying ICT (Information and communication technologies) on traffic safety, in that all real-time traffic detectors can dynamically and continuously create new information. For example, Cooperative Intersection Collision Avoidance Systems (CICASs), which are executed as a sub-project of the ‘Intelligent Vehicle Initiative’ funded by the US DOT, aim at intersection collision avoidance using cooperative communication between vehicular and roadside sensors and processors. INTERSAFE, which is executed as a sub-project of ‘Preventive Safety Applications (PReVENT)’ funded by the EC, seeks the development of algorithms for vehicle localization, the detection and classification of obstacles, the integration of traffic signal statuses, and the development of effective warning strategies. For solutions to these challenges, INTERSAFE uses vehicular video and laser scanner sensors. Besides these projects, there have been other various kinds of researches, for example, the ITS Architecture in Canada that has as its main points vehicle-based collision avoidance, infrastructure-based collision avoidance, sensor-based driving safety enhancement, and intersection safety cameras that allow photographs to be taken of the rear sections of vehicles that violate red lights, and so on.

SMART Highway R&D Project as Smart roads

Driven by a government body, the SMART highway R&D Project of South Korea was launched in September of 2008 and is expected to be completed by 2017. This four-phase project will develop the technology to allow roadways to communicate with automobiles. Road and car radios will be able to exchange real-time information on traffic conditions and detours to avoid traffic stalls. The SMART highway system basically requires such data as vehicular information, traffic flows, traffic control, safety information, road conditions and weather information. The important key issue is providing each vehicle with ICT technology safely and efficiently. The SMART highway is a future high-speed road for reducing accident rates and supporting an intelligent and convenient environment to drivers by providing road, vehicle, environmental, and human information so that the users can concentrate solely on their driving. Many countries in the world are aggressively investing in ITS research areas.

USN technology at signalized intersections

Resent trends in other IT technologies are USN sensors for intersection traffic detection. Sensors in the form of sensor nodes are randomly deployed around a target area where approaching lanes cross at an intersection. A distinguishing feature of a sensor network compared with general communication networks is its automatic collection of distantly scattered information such as vehicular data. In other words, traffic sensor nodes can acquire surrounding data and transmit their sensing data toward a base station through their neighbors based on a predetermined automatic mechanism, and the user can then access the database to create a new service.

USN traffic sensors consist of traffic USN sensor nodes, sink nodes, and a local RSE (Road Side Equipment) server. An RSE server located at the center of a crossroad gathers vehicular information from sensor nodes and transmits the gathered information to approaching vehicles. Sensor nodes installed on the road surface acquire vehicular information from all cars adjacent to the nodes and transmit the information to the RSE server. Each vehicle that approaches the crossroad can then predict and avoid possible traffic accidents.

Variable Collision Warning Model on the Road

Dilemma zone problems at signalized intersections

The most fatal accidents at signalized intersections are caused by dilemma zone problems. The portion of the roadway in advance of an intersection, where a driver may be indecisive as to whether they should stop or proceed into and through the intersection at the onset of a yellow light, is called the dilemma zone (Federal Highway Administration, 2006).

To solve potential problems in the dilemma zone, researchers have suggested various methods for advanced warning signals (such as"Prepare to Stop When Flashing" warning signs), and detection-signal control methods (such as call-extension techniques). Pant and Xie (1995) showed that advanced warning signs affect the speed of vehicles approaching signalized intersections on rural roads. In some cases, these signs resulted in reduced speeds, but in others the "Prepare to Stop When Flashing" (PTSWF) messages resulted in vehicles speeding up to make a green light. Some advanced warning treatments are actually very basic in nature. Radwan et al. (2006) used a driving simulator to show the potential benefit in providing advanced warning at intersections in the form of "signal ahead" pavement markings. Some treatments such as the Intersection Collision Warning System (ICWS) described by the Federal Highway Administration are sophisticated combinations of vehicle detection and advanced warning. For example, the ICWS considers the approaching speeds on a main road and determines the likelihood of a signal violation based on vehicle speeds at a specified distance (i.e., detector location) from the stop line. Control-based treatments detect vehicles on high-speed intersection approaches and alter the traffic signal timing (e.g., green) to accommodate safe passage through an intersection. Zeeger and Deen (1978) reported on the use of a green extension to provide dilemma zone protection and mitigate right-angle and rear-end crashes at high-speed intersections. The literature also presented examples of several other treatments aimed specifically at improving intersection safety.

Time-To-Collision vs Time-to-Accident indicator Model on Highways

There are indicators such as Time-To-Collision (TTC) and Time to Accident (TA) for collisions between vehicles on a highway. First, TTC is a safety indicator measure based on an objective measure of speed and distance for conflicting road-users in relation to a common point of conflict. The TTC measure is recorded continually throughout a conflict event and is independent of evasive actions by conflicting road-users. Next, a TA indicator is also a safety measure determined in accordance with the Traffic Conflict Technique based on a subjective estimation of speed and distance by trained observers for conflicting road-users in relation to a common point of conflict. A Time-to-Accident measure is recorded only once, at the time when an evasive action is first taken by a conflicting road-user. TA values are used in conjunction with speed to determine whether or not a conflict is a serious or non-serious event in accordance with a threshold function.

We can use the above two safety indicators for road collision warning via telematics devices. For example, drivers can be provided dangerous collision information (using telematics devices as in-vehicle unit advisory systems) through a collision warning model that maintains the mean and variance of driver speeds and safety indicators. In this study, however, a solution regarding highway collision warnings is not covered.

ROAD COLLISION WARNING INFORMATION MODEL

RCWI model at signalized intersections

Concepts

In this study, we suggest a new technology that gives warning information to drivers upon entering an intersection. When a collision warning vehicle enters an intersection, the driver violates the traffic signal as a necessary result. As the system provides a USN detection method and warning information before the vehicle enters the intersection, it is possible to provide the vehicle with driver safety. That is, using the warning information, the vehicle can safely cross the intersection during a yellow light or stop at the stop line.

Figure 1 illustrates an example of the collision warning information model at a signalized intersection of a SMART road with a USN wireless network and USN sensors installed. Point detecting sensor nodes are installed in each lane. The point detecting sensor nodes transmit sensed data to a local RSE sever, which provides information to drivers, and a traffic signal controller after analyzing the gathered data. The RSE server then performs collision warning algorithms using real-time traffic signal times and the point detecting sensor information.

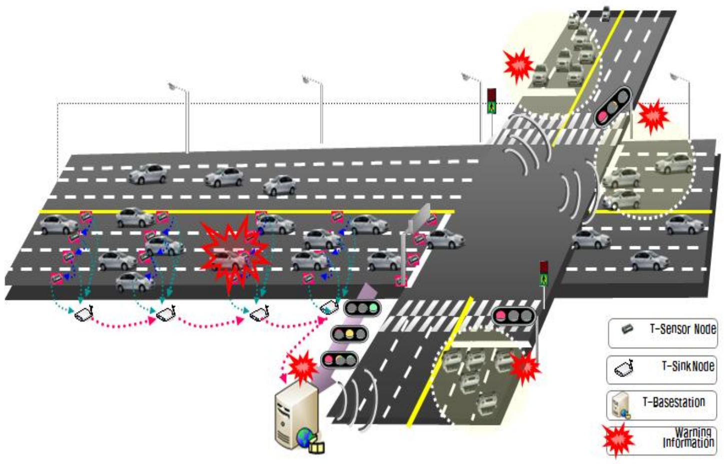

Figure 1. Wireless warning service for intersection collision avoidance

Algorithms

In this study, we developed a road collision warning information model for potential traffic conflicts at intersections based on real-time traffic data collected on vehicles in the approaching lane. This research also addresses the concept of potential traffic conflicts at an intersection. As an RCWI model for signalized intersections, this research includes a dilemma situation forecasting model for intersections that considers the signal phase and remaining signal time when vehicle location, speed, and time data are collected using multiple traffic sensors on the approaching lane. A flowchart for the algorithm used in the model is shown in Figure 2. There are 3 alternative cases, WT1, WT2 and WT3, given in step 4.

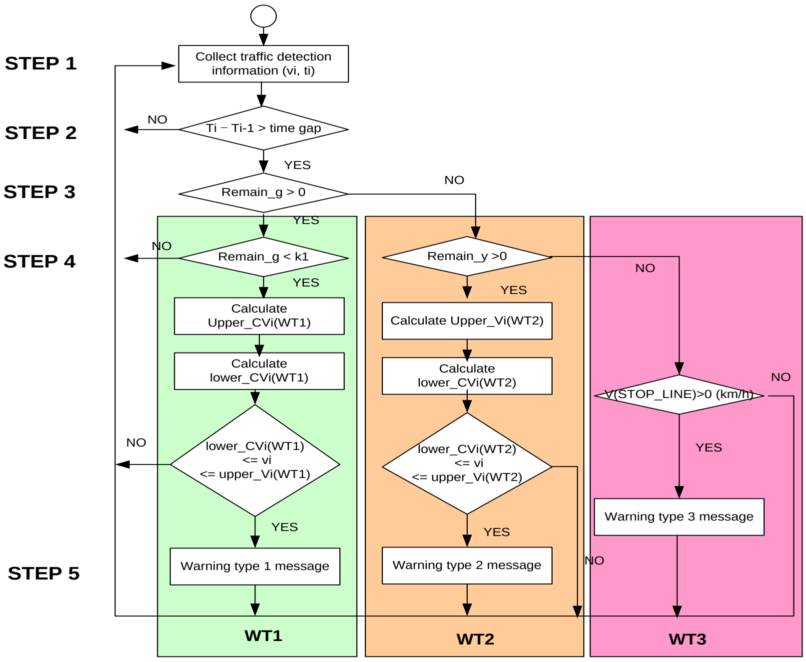

Figure 2. Flowchart for the collision warning technique

Step 1: Collect real-time vehicle speed and location data at an intersection using multiple tiny USN sensors through USN networks.

Step 2: Calculate whether the time gap between continuous vehicles is bigger than a critical length. If the time gap between continuous vehicles is bigger, then go to step 3.

Step 3: Calculate whether the remaining time for a green light is more than 0.
If so, go to the WT1 process in step 4.
Otherwise, go to the WT2 process in step 4.

Step 4: In a WT1 case, if the remaining time for a green light is less than k1, calculate the road collision warning information as in equations (1) and (2):

$$lower\_CV_i^{WT1} = \frac{-t_{PRT} + \sqrt{t_{PRT}^{\ 2} + \dfrac{2 \cdot X_i}{d + G \cdot g}}}{1/(d + G \cdot g)} \quad \text{eq (1)}$$

$$upper\_CV_i^{WT1} = \frac{Xi + (W + L) - \dfrac{1}{2} a(remain\_g + extend\_y - t_{PRT})^2}{remain\_g + extend\_y} \quad \text{eq(2)}$$

In this case, if $lower\_CV_i^{WT1} \le v_i \le upper\_CV_i^{WT1}$, a collision warning situation is determined.

The WT2 case calculates whether the remaining time for a yellow light is more than 0. If so, the following equation of a dangerous vehicle collision is calculated. Otherwise, proceed to the WT3 stage.

$$lower\_CV_i^{WT2} = \frac{-(t_{PRT} + remain\_y - Y) + \sqrt{(t_{PRT} + remain\_y - Y)^2 + \frac{2 \cdot X_i}{d + G \cdot g}}}{1/(d + G \cdot g)} \quad \text{eq (3)}$$

$$upper\_CV_i^{WT2} = \frac{X_i + (W + L) - \frac{1}{2}a(remain\_y - t_{PRT})^2}{remain\_y} \quad \text{eq (4)}$$

In this case, if $lower\_CV_i^{WT2} \le v_i \le upper\_CV_i^{WT2}$, a collision warning situation Is determined.

Finally, in WT3 case, if the speed indicated at the point detecting sensor nodes on a stop-line is more than 0 km/h during a red light, a collision warning situation is determined.

Our proposed collision warning information algorithms for Smart roads include the following variables and parameters:

- ✓ V_i : the vehicle speed indicated by a point detecting sensor node at location i
- ✓ t_{PRT} : driver perception and response time (sec)
- ✓ a : acceleration rate ($m/\sec^2$)
- ✓ W : intersection width (m)
- ✓ L : vehicle length (m)
- ✓ d: stationary deceleration rate (gravity rate * friction factor) ($m/\sec^2$)
- ✓ g: gravity rate ($9.8m/\sec^2$)
- ✓ G: grade (m/m, %)
- ✓ Extend_y : extended time (sec)
- ✓ Remain_g : remaining green time (sec)
- ✓ Remain_y: remaining yellow time (sec)
- ✓ X_i : distance between location i to stop line (m)
- ✓ $upper\_CV_i^{WT1}$: critical speed in which a vehicle cannot stop in a WT1 case (km/h, m/s)
- ✓ $upper\_CV_i^{WT2}$: critical speed in which a vehicle cannot stop in a WT2 case (km/h, m/s)
- ✓ $lower\_CV_i^{WT1}$: critical speed in which a vehicle can stop in a WT1 case (km/h, m/s)
- ✓ $lower\_CV_i^{WT2}$: critical speed in which a vehicle can stop in a WT2 case (km/h, m/s)

Step 5: If the discrimination results of collision warning information indicate a collision warning situation, the warning information is provided to the vehicle's telematics devices using wireless communication networks such as DSRC, WAVE, WLAN, USN, and so on.

EVALUATION OF RCWI MODEL

Evaluation of RCWI model at signalized intersection

Experiment Design

The evaluation of in- and out-of-vehicle traveler information systems is well suited to laboratory techniques, which have an advantage over roadway studies, because they allow the examination of parameters of interest in difficult and critical driving situations without subjecting drivers to unnecessary risks. The first step for a simulation experiment is to design a simulated intersection system that can replicate real-world traffic conditions and IT technology. To ensure the reliability and quality of the simulated results, this study has calibrated the simulation program. Table 1 summarizes the simulated conditions such as traffic and road situations, signal control factors, and detecting points. After simulating using VISSIM scenarios, we analyzed the *.mer file of each point detector. Using algorithm-equipped automated software, we then performed the warning collision model with real-time synchronized signal times using software implemented in Java.

Table 1. Simulation input data

Categories	Detailed Description	
Traffic condition	Input volume	100 veh/h, 200 veh/h, 300 veh/h, 400 veh/h, 500 veh/h, 600 veh/h, 700 veh/h, 800 veh/h, 900 veh/h, 1000 veh/h, 1100 veh/h, 1200 veh/h, 1300 veh/h, 1400 veh/h, 1500 veh/h (Total is 15 cases)
	Turning rates	Left turn- through – Right turn:15%-70%-15%
	Classification	Passenger car: 90%, other vehicles: 10%
Road condition	Number of lanes	4 lanes * 4 lanes
	Width of lanes	3.5m
	Operation of lanes	Lane 1: left turn only, lanes 2-3: through only, lane 4: right turn only
Signal control	Cycle: 120 seconds G-Y-R: 27 seconds-3 seconds-90 seconds Phase: Left + Through	
Detecting point	A total of 50 point detectors at lanes 2 and 3. First location is the stop line, with 5 m intervals for further detectors	

The scenarios for the simulation testing of the collision warning information model are as follows. There were a total of 120 scenarios based on road design speed parameters, input volume parameters, and driver perception response time parameters.

- Road design parameters: 50km/h, 60km/h, 70km/h, 80km/h (4 cases)
- Input volume parameters: 100 veh/h - 1500 veh/h (15 cases)

- Perception response time (PRT): 1.5 sec, 2 sec (2 cases)

Simulation Evaluation Results

Collision warning discrimination rate by input volume variation

In this research, we validate and evaluate the prediction model using micro-simulation tools (VISSIM). For the evaluation of this RCWI model, VISSIM was used to perform multiple detection situations in real-time, various inflow-volume changes (from 100 veh/h to 1500 veh/h), changes in remaining time for green light periods (5 secs, 3 secs, 2 secs and 1 secs) and design speeds. In the results, about 0.8-2.3% of the entire traffic flow was classified as collision warning vehicles, and 35.8% were classified as collision warning vehicles during a yellow signal. The risk ratio of collision warning vehicles by traffic flow changes is shown in Figure 3. Figure 4 illustrates the risk ratio of WT, WT2, WT3 cases in lane 2.

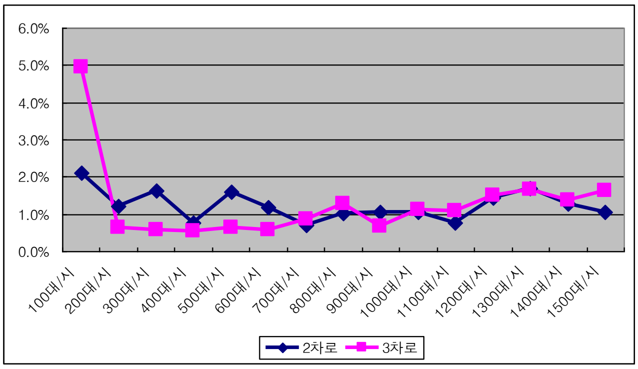

Figure 3. The ratio of collision warning vehicles by traffic flow changes

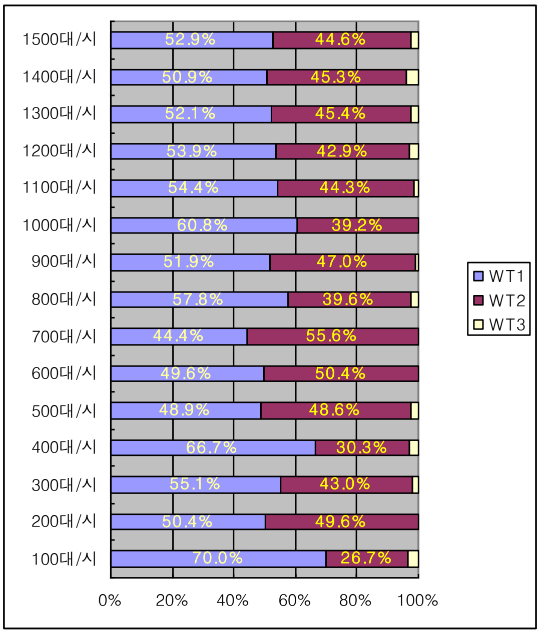

Figure 4. The ratio of WT, WT2, WT3 cases in lane 2

Collision Warning Discrimination Rate by Road Design Speed Variations

The evaluation results of the simulation show that the correlation of input volume and collision warning rate has a plus (+) relationships, which is significant. The road design speed and collision warning rate are also correlated in a + relationship. Figure 5 shows the collision ratio of inflow-volume variation (100veh/h-1500veh/h) and design speed changes (50km/h, 60km/h, 70km/h, 80km/h). If the design speed is higher, so is the collision ratio. Also, a high ratio value of collision probability is a design speed of 80 km/h and input volume between 400 and 600 veh/h.

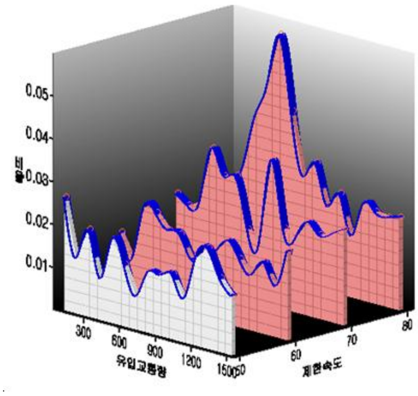

Figure 5. The collision ratio of inflow-volume and design speed change

Verification of the model results

There are two main methodologies of verification for the developed model. The first method compares the results of the RCWI model with the field value of a vehicular data's collision ratio in the real world. The other method compares the results of simulation with the value of the simulation's collision ratio under simulation environments. We use the second method in which we locate the verification detectors at a collision location in an intersection and analyze whether they are the same collision vehicles. In other words, we compare the predictive collision warning vehicle ID of the RCWI model with the simulated vehicle ID in a travelling collision situation. Table 2 shows the verification results of the RCWI model based on VISSIM tools. For verification, we use a remaining yellow light period of 1 sec and a beginning red light period of 5 sec. The results are the average values of the scenarios. In these results, the number of collision warning vehicles of the RCWI model is 30 and the number of non-collision warning vehicles is 524. In this case, the number of real travelling vehicles is about 25 based on the vehicle ID verification. Thus, the percentage of RCWI prediction is 88.5%. And the correct classification rate is 98.5% (4.6% + 93.9%). Here, correct classification means whether collision vehicles are properly classified or not. Thus, this current model is considered to have a very significant level

Table 2. Verification of the model results

Classification		Real running vehicle state(veh)(%)		Total (veh)(%)
		Collision warning vehicle	Non-collision vehicle	
Results of prediction (veh)(%)	Collision warning vehicle	25.3 (4.6%)	5.1(0.9%)	30.4(5.5%)
	Non-collision vehicle	3.3 (0.6%)	521.1(93.9%)	524.4(94.5%)
Total (veh)(%)		28.6 (5.1%)	526.3(94.9%)	554.9(100%)

CONCLUSION

This paper presents the development of a driver warning information model as an intersection collision avoidance system that can be deployed around a signalized intersection. The system allows a driver to reduce his speed by notifying the driver whether the car is expected to be in a collision. With the information, the driver can safely stop at the stop line. Moreover, in cases in which a car is predicted to not stop at a stop line, the system provides information to the traffic signal controller, which creates a red traffic signal for all lanes. This research considers the possibility that the application of a new service is possible for the safety of signalized intersections. The road collision warning information model may be directly provided to all vehicle users on SMART roads.

The general results of this study are consistent with our previous findings, which show that the RCWI model can be effective in helping with driver safety at signalized intersections on SMART roads. In the future, we suggest a further examination of situations in which the operators perform complex tasks with critical warning systems under distracting conditions.

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