IWAY: Towards Highway Vehicle-2-Vehicle Communication and Driver Support

George Rigas, Penny Bougia, Dimitrios I. Fotiadis
Dept. of Computer Science,
University of Ioanninina,
Ioannina, Greece.

Christos D. Katsis, Anastasios Koutlas
Dept. of Medical Physics, Medical School,
University of Ioannina,
Ioannina,Greece.

***Abstract*—This paper describes the Alert Manager subsystem which merges information coming from: (i) an in-vehicle sensing system, (ii) the road infrastructure and (iii) neighbouring vehicles to generate high level and useful information for car drivers. The subsystem is a part of the I-WAY system, whose aim is to provide drivers with timely warnings and meaningful suggestions to avoid potential hazards in the driving environment. The Alert Manager can efficiently handle multiple information sources, fusion of complementary data and management of incoming events' priorities. Moreover, the Alert Manager controls the broadcasting of messages to keep Road Infrastructure and other vehicles updated about potential hazards. We focus on the determination of the dominant risk prevailing in the road environment.**

I. INTRODUCTION

During the last decades, the development of driver assistance systems is of growing importance as these systems are expected to improve road safety and traffic efficiency. The Advanced Driver Assistance System (ADAS) partly supports or take over the driver's tasks. ADAS can be defined as: it has a direct supporting interaction with the driver or the driver task. Their way of support may vary from informative to controlling [1], [2]. ADAS operates from inside the car, but may be connected to external sources. Several ADAS, such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW) and Intelligent Speed Assistance (ISA) are already popular among car manufacturers, or are under development. ADAS is part of a technology called Intelligent Transportation Systems (ITS). ITS incorporates intelligence in both roadways and vehicles in order to improve the traffic flow. Co-operative road-vehicle systems and vehicle-vehicle systems are also emerging worldwide. Intelligent vehicles and roads are the future standard and specialised research addresses the identification of their impact as well as their adaptation to the real user needs for safer and efficient transportation services. Currently, ADAS are designed to support drivers in maintaining safety thresholds or ensuring compliance with formal driving rules, such as maintaining safe time headways in car-following situation or adhering to speed limits [3], [4].

I-WAY is a cooperative driving platform which enhances significantly drivers' perception on road environment by producing high-level and useful information for the driver through the analysis and fusion of real-time data obtained from: (i) an in-vehicle sensing system, (ii) the road infrastructure and (iii) neighboring cars. The core of this system is I-WAY DSS, a Decision Support System that encapsulates all the intelligence required by an ADAS. The key features of I-WAY DSS are: (i) the proactive risk assessment, which previews an event/situation and provides notification messages to the driver about potential risks and (ii) the scouting function, which detects events in the local environment and sends updated information to the road infrastructure and other cars. I-WAY DSS receives information on the surroundings of the vehicle through continuous monitoring of the road scenery with on-board sensors, the driver status from a dedicated driver monitoring module, the vehicle position, speed and heading via GPS, the weather and traffic conditions or other incidents on the highway like road constructions, blocks etc. via Road Infrastructure, local environment and behavior of other vehicles. The information is fused to perform enhanced situation assessment is performed and an optimal warning strategy for road hazards is adopted. As optimal warning strategy is considered the delivery of tailored messages to the driver in terms of message content (information about the most critical event), message type (notification, warning, alert), message format (text, vocal) and delivery time (considering also repeating messages when necessary). To efficiently handle the incoming data and determine the appropriate message content for driver notification, a part of the I-WAY-DSS, called Alert Manager was developed. In this work we focus on the functionality of the Alert Manager which is able to merge different incoming information provided by different sources with the scope to i) efficiently handle message broadcasting, ii) evaluate the dominant risk prevailing in the road environment that the driver should be aware of and iii) produce integrated, high level information from the available data.

II. MATERIALS AND METHODS

In Fig. 1 is shown the architecture of the Alert Manager subsystem. The subsystem is based on six modules which include:

- *Communication*,
- *Ego-Vehicle Event detector*,
- *Event Handler*,
- *Event Manager*,
- *Decision Maker*,
- *Alert Generator*.

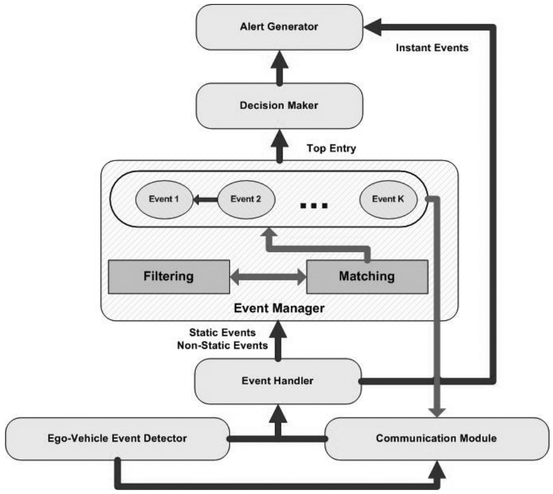

Fig. 1. The Alert Manager architecture.

A. Communication

This is the module where the communication between vehicles (V2V) and infrastructure and vehicles (I2V and V2I) is performed. Each vehicle produces a number of messages related to potential hazards either detected by the Ego-Vehicle Event detector or received as messages by other I-WAY vehicles or the Road Infrastructure. In this work we do not focus on communication details and only the average delay (as a function of distance and relative speed) is considered.

B. Ego-Vehicle Event detector

The Ego-Vehicle Event detector is the in-vehicle embedded system which is responsible to recognize events and conditions in the local environment of the I-WAY vehicle using on board sensors. It consists of: i) a radar and two cameras which continuously monitor the road scenery. The perception of the road geometry (curvature, number and width of lanes) and potential obstacles (vehicles ahead, fixed front/lateral objects) is accomplished through real time object detection and road modelling [5], [6]. (ii) Vehicle CAN-bus and GPS receiver used to collect specific vehicle parameters such as position, speed, acceleration, braking and temperature. Using this information a number of events nearby the vehicle can be detected: traffic, road narrowing, road condition, lane invasion, static or slow moving obstacles and sudden brake of foregoing vehicle [7]. The recognized events are fed to the Communication Module to be broadcasted to other vehicles and the Road Infrastructure (scouting function) and also pass to the Event Handler for further processing.

C. Event Handler

Incoming messages arriving from Communication Module and Ego Vehicle Event Detector feed the Event Handler (the classification of events, as well as the source of information, are shown in Table I). Three types of events exists:

- Static events: Those are events reported from infrastructure or other vehicles located in a fixed position on the highway. These events are not removed from the Event list until the vehicle reaches their location.
- Non-static events (such as slow moving vehicles, slowing down traffic etc.): Those are events reported from other vehicles or Road Infrastructure, but their presence is not guaranteed by the time that the ego-vehicle reaches their reported location.
- Instant Events: Those are events either detected from Ego-Vehicle Detector (i.e. lane invasion) or received from other vehicles (i.e. sudden braking) occurring in short distance from the I-WAY vehicle.

TABLE I
EVENT CLASSIFICATION

Event	Event Category	Source
Road works	Static	I2V
Accident	Static	I2V
Road Narrow	Static	V2V/I2V
Road condition	Static	V2V/I2V
Traffic	Non-Static	V2V/I2V
Fixed or Slow Moving Vehicle	Non-static/Instant	V2V/I2V/ Ego-vehicle detector
Sudden brake of foregoing Vehicle	Instant	V2V
Lane invasion	Instant	Ego-vehicle detector

The first two categories refer to events on the highway which are potential obstacles for the ego-vehicle. That is, if the vehicle approaches the event with a speed over a safe limit, this event becomes threat for the driver. Let the obstacle speed (or the safe speed limit) be u_0 and the ego-vehicle speed u_e. The risk measure is considered as the braking effort required in order to reach obstacle's speed, multiplied by a constant, defined as:

$$r = c\frac{u_r^2}{2d}, \tag{1}$$

where r is the risk, $u_r = u_0 - u_e$ the relative speed between ego-vehicle and the obstacle, d the distance between ego-vehicle and the obstacle and c is a constant depending on the vehicle and the weather conditions. This constant is common for all events.

The last category of events requires an instant warning; thus they are directly forwarded to the *Alert generator* without processing by the *Event Manager*.

D. Event Manager

The Event Manager is responsible to keep a list of incoming events and sort them according to their risk. Each node of the list corresponds to a particular event which in turn consists of the variables: distance (*d*) which is the distance between the event and the ego-vehicle, relative speed (u_r) which is the relative speed between ego-vehicle and an obstacle, category (*c*) and iiv) type (*t*). An example of category is Static/Non-Static and for type is road works, road narrowing etc.

When a new event is received the Event Manager, undertakes the following tasks:İnitially the Event filtering procedure removes irrelevant to ego-vehicle events, while the relevant ones (*Filter Pass*) are directed to the matching procedure. During this procedure the incoming events are compared with

Algorithm 1 Handling new Event Procedures

$IS-MERGED = FALSE$
if $FilterPass(E) == FALSE$ **then**
  for each $E' \in A$ **do**
    if $Merge(E, E') == FALSE$ **then**
      $IS-MERGED = TRUE$
    end if
  end for
  if $!IS-MERGED$ **then**
    AddInList(E)
  end if
end if

Algorithm 2 Update list

for each $E' \in A$ **do**
  if *Expired*(E') **then**
    Delete(E')
  else
    Update Position and Risk of E'
  end if
end for
Re-sort List(E')

existing events (nodes in the list) and are merged with nodes referring to the same event (*Merge*). If no merge occurs, the incoming event is added as a new node in the list. The overall procedure is outlined in Algorithm 1. The *Filter Pass* and *Merge* procedures are described below:

1) Filter Pass: This is the function within Event filtering which determines whether the incoming event is worth reported in terms of relevance with the ego-vehicle. This function reduces computational cost by avoiding irrelevant information.

The criteria to consider an event as non worth reported are:

1) The events whose reported position is either backward or in opposite highway direction from the ego-vehicle. Hence, such events are not considered forthcoming hazards.
2) For the non-static events we consider the possibility of not-being valid when ego-vehicle approaches their reported location. To handle this case, an expire horizon is assigned to non-static events, according to the relative speed and distance.

$$t_{expire} = \frac{u_r}{s} + T_0, \quad (2)$$

where T_0 is a constant indicating a time margin used to assure the event expiration. When *time-to-live* of the message in the Event list becomes equal to t_{expire}, then the message is discarded.

2) Merge: Merge is a function of the matching procedure which removes multiple nodes in the event list referring to the same event. For instance, suppose a vehicle detecting a narrow road in some distance ahead. If the same event is already a node in the even list (provided by another source through the communication module) we can merge or ignore the message coming from the Ego-Vehicle Event Detector.

Another important feature of the Merge function is its ability to provide high level information from individual messages. Consider for example the scenario of a queue of K vehicles in some distance ahead from the ego-vehicle detector. Each I-WAY vehicle in the queue recognizes a slow moving vehicle in front and broadcasts a message. Therefore, a number of messages with overlapping information is received. This scenario reveals the necessity of an aggregation mechanism which combines single incoming messages about slow moving objects and generates high level information such as heavy traffic.

The usual information coming from other I-WAY vehicles is about obstacles (slow moving vehicles or fixed objects). Moreover the Ego-vehicle detector is able to detect other vehicles in the vicinity (near lanes) and monitor their relative speed. Using the above information the Merge function can infer Traffic situation using different approaches such as rules or probabilistic inference. In this work a simple rule-based approach is considered, based on: all highway lanes are occupied by detected vehicles, the relative speed between ego-vehicle and other vehicles approaches zero and the ego-vehicle speed is below a threshold (typical 15 m/s).

If all the above conditions are satisfied then a traffic jam event is inferred.

Another level of merging information is the reasoning about specific non-static events. For example merging traffic jam (non-static event) with Road works (static event) in near location, traffic jam is due to Road Works is concluded. Thus, the driver is provided with a single message containing high-level information instead of two separate messages.

3) Prioritization: The Prioritization function is responsible for storing the new event in the list (*Add Node*) keeping the priority order. This involves the re-estimation of all events' risk according to equation (1). The Event list is then re-sorted in descending order. The highest risk event (top entry) is then forwarded to the Decision Maker, which decides whether and in which way to notify the driver.

4) Update list: A periodic update of the Event list is performed to ensure that contained events are still relevant according to the ego-vehicle current position (outlined in Algorithm 2). The *Expired* routine determines when the nodes of the Event list are no longer valid and the *Delete* routine removes them. The events are considered non-valid when the criteria described in section II-D1 are met. Those are summarized below:

1) If the event type is *static* and the distance is smaller than zero, $E_d < 0$.
2) If the obstacle type is *non static* and $t_w > t_{expire}$ where t_w is the *time-to-live* of the message in the Event list.

If the event is not deleted, we update the distance of the event $E_d = E_d - E_{u_r}$ and the risk is calculated again. After all events' risks are updated the list is re-sorted.

5) Broadcasting handler: For efficient scouting functionality, a continuous broadcasting of the forthcoming events (nodes in the Event list) is necessary due to communication range limitations. If detected events are broadcasted only once, the currently out of range vehicles will not be updated for potential hazards. Hence, all nodes in the Event List have to pass to the communication module for broadcasting. Using no reduction strategy the total number of messages is $(N-1)^2$. To confront with bandwidth limitations, we apply a simple reduction strategy: If the position information of an incoming event (message from Communication module) is close to ego-position with respect to communication range, we consider that other vehicles within the range of the ego-vehicle are already aware of the event and thus, this particular message is not broadcasted.

E. Decision Maker

The main I-WAY aim is to provide the driver with tailored messages about critical forthcoming events. The types of messages vary according to a number of parameters like the severity of a given event (which is interpreted by the braking effort required by the driver until he reaches the safety limit), the driver state (stress and fatigue levels), the local weather and traffic conditions, etc. A sophisticated decision making is necessary to ensure that the driver is aware of forthcoming events well in advance so he has enough time to react while at the same time the alerting system is as less distractive or irritating as possible. The possible actions of the Decision Maker are: no notification, text Message with information, light vocal message and intense vocal message

The Decision Maker is based on the Influence diagrams [8] and it is described in detail in [9].

F. Alert Generator

This module composes and forwards the appropriate messages to the driver through a specially designed user interface.

III. Simulation Environment

A simulation environment [10], [11], has been developed in $C\#$ to be used in our experiments. A brief description of the environment follows:

A. Vehicle Model

To model the vehicle behavior in a highway environment we used the Intelligent Driving Model (IDM) [12]. The following equations describe the model:

$$\frac{dv}{dt} = a[1-(\frac{v}{v_0})^{\delta}-(\frac{s^*}{s})^2] \tag{3}$$

$$s^* = s_0+(vT+\frac{v\Delta v}{2\sqrt{ab}}), \tag{4}$$

where, v_0 is the desired speed of the vehicle, s^* is the desired dynamical distance between tho vehicles, s the actual gap, T is the safety time headway when following other vehicles, a is the acceleration in everyday traffic, b is the ”comfortable” braking deceleration everyday traffic, s_0 is the minimum bumper-to-bumper distance to the front vehicle, δ is the acceleration exponent and Δu is the relative speed.

To produce a more realistic model we have expanded the IDM to allow:

1) Lane Change: Vehicles are allowed to change lanes if they are following a vehicle with speed lower than the desired. In a lane highway each lane has a low and an upper speed limit. Each vehicle aims to reach the appropriate lane according to desired speed u_0.

2) Obstacle detection: In each time instance, vehicles detect obstacles ahead in a range R. If an obstacle is detected at distance d, the actual gap s in equation (3) is set to d. Otherwise s is set to a maximum value indicating that no obstacle exists.

3) Potential hazard detection: Vehicles detect obstacles in their current and adjacent (± 1) lanes. We characterize an obstacle as potential hazard if the speed of the obstacle is lower than a predefined threshold. If all adjacent lanes are occupied by slow moving obstacles then we assume that a traffic. Furthermore, if ego-vehicle is slow moving, it's status is directly forwarded to the communication module described below.

B. Communications Simulation

The communication characteristics considered in the simulation, are the following:

- The communication ranges of V2V, V2I and I2V.
- The latency as a function of distance and type of communication (V2V, V2I and I2V).

Vehicles produce three types of messages: i) Obstacle detected by ego-vehicle (Slow Moving vehicles or fixed obstacles) ii) Traffic detected by ego-vehicle when many slow moving vehicles are present in adjacent lanes, iii) events reported by other vehicles. These messages are broadcasted to Road Infrastructure and neighboring vehicles. Whenever vehicles come into the range of an I-WAY vehicle or a Road Infrastructure base station a new session is initialized and messages are received within dT (latency time). The message delivery fails if the source and target distance exceeds the communication range.

IV. Results

We used the simulation environment to evaluate the Alert Manager. Those results are used to provide measures on communication characteristics (range, latency) and the involved risk (braking effort gain) and demonstrate the way that information received from different sources (nearby I-WAY vehicles or road infrastructure) is merged. The latency of the communication is constant, i.e. if the broadcasting duration set to T, the communication delay is dT, the actual broadcasting duration is $T+dT$.

Initially we provide results, concerning the range and broadcasting frequency of communication and their impact on risk reduction. We consider 10 I-WAY vehicles moving on the highway and a slow moving vehicle being in some distance ahead. Moreover, we suppose that all vehicles are moving in the same lane and lane changes are not allowed. The distance between I-WAY vehicles is initially set to 1.5 km. For comparison purposes, we introduce for each I-WAY vehicle a corresponding Zombie vehicle (conventional vehicle

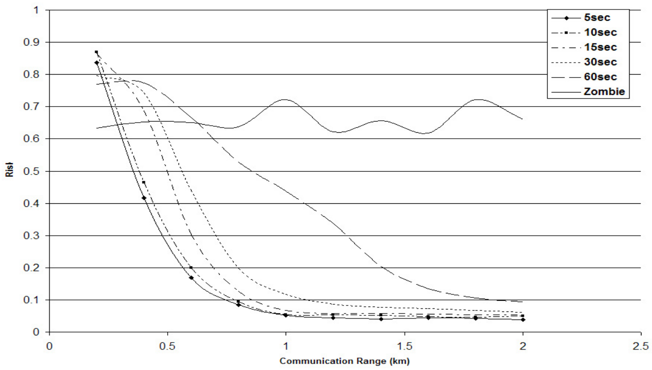

Fig. 2. The risk according to the range of communication for different update intervals (Slow moving vehicle speed = $20m/s$).

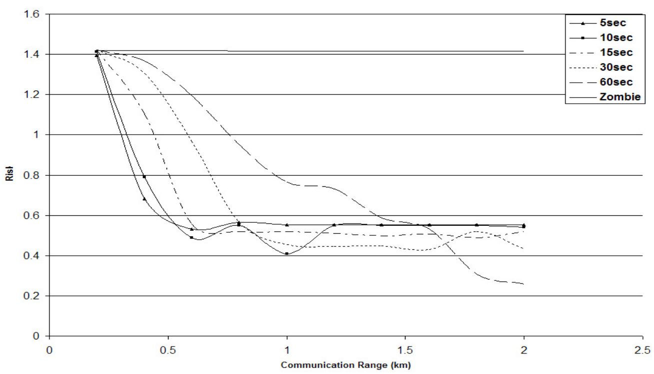

Fig. 3. The risk according to the range of communication for different update intervals (Slow moving vehicle speed = $10m/s$).

without communication ability). Each Zombie vehicle has the same initial position, speed and IDM parameters (as described in Eq. (3)) with its corresponding I-WAY vehicle. To illustrate the performance (in terms of mean breaking effort) we consider two cases; In the first case, the speed of the slow moving vehicle is set to 10 m/s and in the second 20 m/s. In both cases, all other vehicles have an initial speed of 35 m/s. Visibility (the maximum distance where an obstacle or a foregoing vehicle is detected) is set to 200 m.

In Figs. 2,3 we provide the mean braking effort of the Zombie vehicles and I-WAY vehicles with broadcasting duration 5, 15, 30 and 60 secs for both cases of slow moving vehicle speed. We observe that the braking effort in the first case is very high (a safe value for normal conditions is 0.2 [13]) while in the second case the safety requirement is achieved with a communication range of 600 m and broadcasting duration smaller than 15 sec. From the above scenario we conclude that for the second case is almost impossible to ensure safety with only V2V communication. Then we examine the case of I2V and V2I communication. The great benefit is that the communication range for this case is almost unlimited, because when a infrastructure station receives a message from a vehicle it can broadcast it to all other stations using a LAN. In Fig. 4, we provide the braking effort of the I-WAY vehicles with and

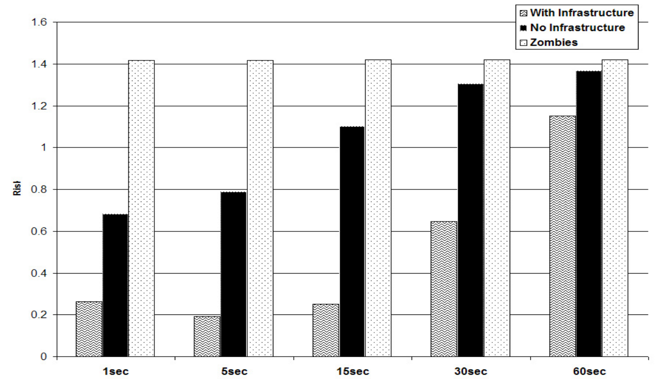

Fig. 4. The risk of Zombie and I-WAY vehicles with and without Road Infrastructure communication. Communication range is set to $400m$ and visibility to $200m$.

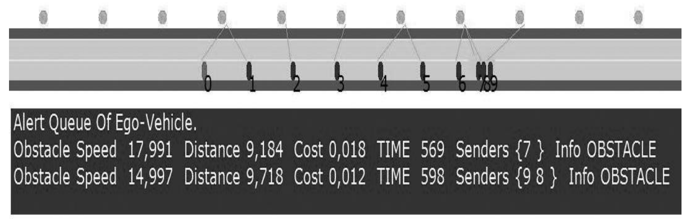

Fig. 5. Ego-vehicle receives through the Road Infrastructure messages reported by I-WAY vehicles with id numbers 7, 8 and 9.

without infrastructure communication and for Zombie vehicles for comparison. We observe a significant reduction in braking effort. Moreover, in this case we can achieve the safety margin of 0.2 braking effort even in the extreme case of an obstacle with speed of 10m/s.

Next we provide qualitative results for the function of the *Event manager*, using screenshots from the simulation of the Slow Moving Vehicle scenario. In this simulation V2I communication is allowed and information fusion is performed and broadcasted. The simulation illustrates a mini-map of the highway, where the vehicles are shown as ellipses with an id number assigned, while Road Infrastructure base stations are indicated as ellipses above the highway. In the bottom of the screenshot we provide a log display where the Event list of the ego-vehicle (id 0) is indicated. Early in the simulation when no queue is formed yet, two obstacle messages are reported to the Road Infrastructure. The first comes from I-WAY vehicle with id 8 which also merged the message from the slow moving vehicle (id 9) and the other from the I-WAY vehicles with id number 7 (Figure 5). The Road Infrastructure broadcasts this information, which in turn is received by the ego-vehicle. Later when the queue has been formed (from vehicles 7,8,9), the broadcasted messages from individual vehicles are merged (into vehicle 7) inferring a queue situation (Figure 6) forwarded through infrastructure to ego-vehicle.

Furthermore, we developed a second, more complicated scenario, in order to demonstrate the Alert queue when many events are present. We assume road works taking place in

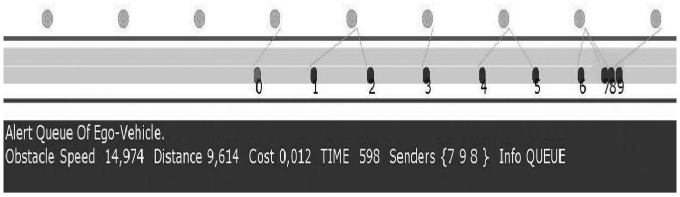

Fig. 6. When three vehicles are very close they are considered as a queue. Ego-vehicle receives Road Infrastructure messages reporting an obstacle and a queue of vehicles.

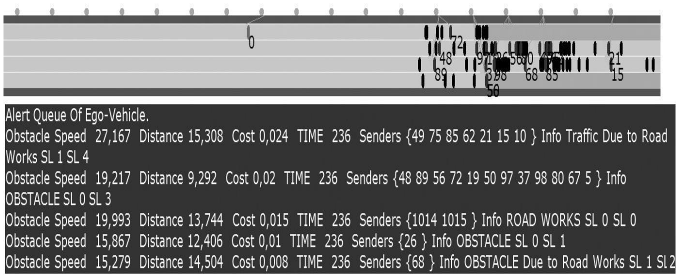

Fig. 7. A more complicated scenario. The alert queue of ego-vehicle contains a number of messages sorted by their risk.

two out of the four lanes of the highway. Furthermore, near the Road Works event we deploy a large number of vehicles with different speed in order to create a traffic congestion. In this case, the ego-vehicle receives a large number of messages about slow moving vehicles along with a message from Road Infrastructure reporting Road Works in the same area. The Event Manager of the ego-vehicle merges the aforementioned messages producing a high level message, e.q. *"Traffic due to Road Works"*. A screenshot of this complex scenario simulation is illustrated in Fig. 7. Also, the log display demonstrating the Event list of the Ego-Vehicle sorted by the estimated events' risk is provided.

V. Conclusions

We have presented the Alert Manager, which is a part of I-WAY DSS. Its purpose is to support drivers mainly through provision of a preliminary prediction of road situations they are about to confront and to provide suggestions for hazard avoidance and accidents' prevention. It introduces drivers to an effective coupling of knowledge with decisions. The Alert Manager is capable of: merging different information sources, fusing heterogeneous data,evaluating individual risks, prioritizing events according to their involved risk and producing high level information and reasoning about forthcoming hazards. The aforementioned functionalities lead to an enhanced situation assessment concerning the highway environment. The enhanced assessment is further used by the I-WAY Decision Support system [9] in order to provide the driver with an optimal warning strategy about forthcoming hazards. Apart from Driver notification purposes, the Alert Manager serves as an advanced controller for the broadcasting mechanism of the Communication module, since it determines the number of outgoing messages as well as the broadcasting frequency. A simulation environment, based on an enhanced IDM, was used in order to model vehicles' behaviour in a highway. We tested the Alert Manager in a simulation environment and a significant reduction in the braking effort (risk) was observed for I-WAY vehicles in relation to vehicles without communication capabilities. As future work, more complicated scenarios are going to be tested, also taking into account false/miss-detected events, in an improved simulation model, to better represent the real driving environment.

Acknowledgments

This work is part funded by the European Commission, Information Society Technologies (IST) as part of the project "I-WAY (IST-2004-027195) - Intelligent co-operative system in vehicles for road safety" and by the Greek Secretariat for Research and Technology (PENED: project 03ED139, Title: "Intelligent system for monitoring driver's emotional and physical state in real conditions").

References

[1] W. H. Janssen, H. Alm, J. A. Michon, and A. Smiley, "Driver support," pp. 53–66, 1993.

[2] T. Kosilo, J. Kolakowski, and Z. Walczak, "Project safespot (smart vehicles on smart roads)," *Microwaves, Radar and Wireless Communications, 2006. MIKON 2006. International Conference on*, pp. 215–215, 22-24 May 2006.

[3] T. Kim and D. Lovell, "Observation of real driving behavior in car-following: preliminary results," *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, vol. 5, pp. 2939–2943 Vol. 5, 30 May-1 June 2005.

[4] J. Piao and M. McDonald, "Low speed car following behaviour from floating vehicle data," *Intelligent Vehicles Symposium, 2003. Proceedings. IEEE*, pp. 462–467, 9-11 June 2003.

[5] D. Alonso, L. Salgado, and M. Nieto, "Robust vehicle detection through multidimensional classification for on board video based systems," in *IEEE International Conference on Image Processing*, San Antonio (USA), September 2007, pp. 321–324.

[6] M. Nieto, L. Salgado, F. Jaureguizar, and J. Cabrera, "Stabilization of inverse perspective mapping images based on robust vanishing point estimation," in *IEEE Intelligent Vehicles Symposium*, Istambul (Turkey), June 2007, pp. 315–320.

[7] F. Dittmann, K. Geramani, G. Rigas, C. Katsis, and D. Fotiadis, "Towards advanced information fusion for driver assistant systems of modern vehicles," in *2nd IEEE International Symposium on Wireless Vehicular Communications*, 2008.

[8] F. V. Jensen, *Bayesian Networks and Decision Graphs*. Secaucus, NJ, USA: Springer-Verlag New York, Inc., 2001.

[9] G. Rigas, C. D. Katsis, P. Bougia, and D. I. Fotiadis, "An intelligent decision support system for driver assistance based on vehicle, driver and road environment monitoring," in *7th European Congress and Exhibition on Intelligent Transport Systems and Services*, 2008, accepted.

[10] S. Eichler, B. Ostermaier, C. Schroth, and T. Kosch, "Simulation of car-to-car messaging: analyzing the impact on road traffic," *Modeling, Analysis, and Simulation of Computer and Telecommunication Systems, 2005. 13th IEEE International Symposium on*, pp. 507–510, 27-29 Sept. 2005.

[11] B. S. Kerner, S. L. Klenov, and A. Brakemeier, "Testbed for wireless vehicle communication: a simulation approach based on three-phase traffic theory," 2007. [Online]. Available: http://www.citebase.org/abstract?id=oai:arXiv.org:0712.2711

[12] M. Treiber, A. Hennecke, and D. Helbing, "Congested traffic states in empirical observations and microscopic simulations," *Physical Review E*, vol. 62, p. 1805, 2000. [Online]. Available: http://www.citebase.org/abstract?id=oai:arXiv.org:cond-mat/0002177

[13] http://www.safespeed.org.uk/, "Last visited 10-3-2008."