Post-accident Analysis of Digital Sources for Traffic Accidents
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ABSTRACT
This paper describes sources of digital information which can be used for traffic analysis, and in particular post-accident analysis. We discuss how we can use this information to automatically find likely causes for traffic accidents and create a system which makes a simple report of an accident. With the Veins simulator we generate data of a head-tail collision and normal traffic situation in a vehicular ad-hoc network. This data is used as input to validate the system. It shows that the system can recognize when a collision between two vehicles occurs and provide a report about the behavior of the vehicles prior to the accident.

Keywords
VANET, EDR, CAM, post-accident analysis.

1. INTRODUCTION
Road transport is an essential activity in everyday life. To improve the traffic flow a lot of research is done in Intelligent Transportation Systems (ITS) in which vehicles are equipped with communication technology. This allows vehicles to communicate with each other and with static units placed next to roads to create a Vehicular Ad-hoc Network (VANET) [5]. In VANETs vehicles are represented as nodes in a network and can exchange messages with one another. These messages can contain information on their current status and their surroundings, i.e. information of a vehicle's speed, position, the announcement of a road hazard or traffic jam. This allows for applications which can increase the road safety and improve the driving comfort. The information in the messages can also be of use for the post-analysis of traffic accidents, i.e. knowing the speed and position of a vehicle and its surrounding vehicles moments before it crashes can provide a better understanding of the accident [1].

Post-accident analysis is nowadays mostly done by inspecting the crash-site and the data in the Event Data Recorder (EDR) of vehicles, an electronic data recorder device which stores data about the vehicle moments before, during and after the crash [4]. However, this does not always provide enough information to obtain a good picture of the accident and its cause. This happens for example with a large accident, which involves multiple vehicles; or in case of a hit-and-run, where only the EDR of the victim is available for analysis. Physical evidence on the crash-site can also get lost, for example skid marks can get lost over time and debris of the crash cannot always stay in place for a long period of time. The evidence on the crash-site is also often incomplete and misleading [6]. Therefore, the information of messages exchanged in a VANET can provide additional information about the accident and a more clear and reliable picture of the crash can be formed. This could then also potentially lead to new insights for traffic accident prevention and minimization of damage during an accident.

Current existing proposals for post-accident analysis only describe methods to gather additional information about the crash-site using VANETS and methods for maintaining the data integrity, authentication and non-repudiation in VANETS. This paper will analyze the different digital sources and their specific data available for post-accident analysis.

In this paper we will first describe digital sources which can potentially be used to give more insight in traffic accidents and we will discuss how we can make use of their information. Then systems and proposals which are related to post-accident analysis of digital information will be explored. Finally we create a system that uses the data in beacons transmitted between vehicles and the EDR installed in vehicles to perform post-accident analysis. We test this system by analyzing a simulation of a traffic accident. In this paper we will answer the following research questions:

1. Which sources of information can be used for post-accidents analysis in VANET?
2. What related systems are there currently for post-accident traffic analysis?
3. What are the capabilities/conclusions we can make based on this information?
4. How can we build a system for automatic post-accident analysis?

This paper is structured as following: first an overview is given of different digital data sources that can potentially be used for post-accident analysis. Next, existing proposals and systems that are relevant to post-accident analysis are described. Section 4 discusses how the data from digital sources can be used for post-accident analysis. In section 5 a system for post-accident analysis is created and results based on simulated accidents are described. Finally, in section 6 a short discussion on the privacy concerns of VANETs are handled.
2. SOURCES OF DIGITAL TRAFFIC INFORMATION

When determining the cause of a traffic accident a multitude of (digital) sources can be used. Here, we will describe some of the sources that can be used with a short discussion on how they can provide more insight in traffic accidents:

2.1 Nationale Databank Wegverkeer

Nationale Databank Wegverkeer (NDW) is a database that provides real-time data about the traffic network of the Netherlands. Each minute data is gathered at more than 24,000 locations in the Netherlands and an overview of the road situation is provided [15]. The data gathered includes:

- Traffic intensity: number of vehicles that pass a point during a period of time.
- Actual travel time: the average time all vehicles take to reach the end of the measured section during one minute.
- Estimated travel time: estimation of the average time all vehicles need to reach the end of their measured section during one minute.
- Pointspeed: the average speed of all vehicles that passed a specific point during a period of time.
- Vehicle category: classification of vehicles based on their length.

This information is used by road users and authorities. Road users can use applications for navigation and estimation for travel time. Authorities use the information for road management to create better road policies, monitor the national traffic situation and to coordinate road works.

However, the data cannot be reliably traced to a specific vehicle, i.e. it is not possible to get the speed of a specific vehicle. Therefore the data in NDW can only provide a global view of the traffic situation at a point of time. But this can still be valuable information to get insight into the accident, for example the data can provide insight in the road usage intensity and how fast vehicles were driving. Of course, when a sensor is nowhere near the accident, the NDW cannot be of use.

2.2 Event Data Recorder

Event Data Recorder (EDR) is a device installed in vehicles that collects crash data like its speed, heading, engine throttle etc. [8]. The main purpose of the device is to get a better understanding of a vehicle’s system performance in crash or near-crash situations, for example to see if the airbags have deployed properly in a car crash. A sudden change in speed or detection of faults triggers the device; this does not necessarily have to be a crash [16].

New models of vehicles are always installed with an EDR device [8]. A minimum set of information which needs to be recorded of the vehicle is given in Table 1. Furthermore, additional data also needs to be recorded by the EDR if the vehicle has the appropriate sensors, a specification of these elements can be found in [8], these include elements like engine rounds per minute, ABS activity, steering input etc.

The data stored in an EDR has also been proven to be useful for investigation of road accidents. Information about an accident like the velocity change of a vehicle is often difficult to estimate with traditional techniques, using an EDR has greatly enhanced the investigation of crashes and these data have also been used in court several times [4].

<table>
<thead>
<tr>
<th>Data element in EDR</th>
<th>Recording interval</th>
<th>Data Samples per Second</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta-V (longitudinal)</td>
<td>0 to 250 ms</td>
<td>100</td>
<td>+/- 5 %</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>-5.0 to 0 sec</td>
<td>2</td>
<td>+/- 1 km/h</td>
</tr>
<tr>
<td>Engine throttle %</td>
<td>-5.0 to 0 sec</td>
<td>2</td>
<td>+/- 5 %</td>
</tr>
<tr>
<td>Ignition cycle</td>
<td>-1.0</td>
<td>n.a.</td>
<td>+/- 1 cycle</td>
</tr>
<tr>
<td>Service brake (on/off)</td>
<td>-5.0 to 0 sec</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Safety belt status driver</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Frontal airbag warning (on/off)</td>
<td>-1.0</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Frontal airbag deployment driver</td>
<td>Event</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Frontal airbag deployment front passenger</td>
<td>Event</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Multi-event (one or two events)</td>
<td>Event</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Time from event one to two</td>
<td>As needed</td>
<td>n.a.</td>
<td>0.1 sec</td>
</tr>
</tbody>
</table>

As can be seen in Table 1, an EDR only needs to record data 5 seconds before the crash, however there exist EDR’s which collect data up to 6 minutes before the crash [4]. A traffic accident also often involves collisions with multiple vehicles/objects, called ‘events’. An EDR is only required to record two events [4]. So EDR data could potentially get ‘lost’ when three or more events occur.

2.3 IEEE 802.11p

IEEE 802.11p is a set of standards for Wireless Access in Vehicular Environment (WAVE). Wireless vehicular communication allows vehicles equipped with dedicated short range communication (DSRC) to broadcast messages to nearby nodes. These nodes can consist of other vehicles also equipped with DSRC or stationary stations at the side of the road. These messages provide information, such as safety warnings and traffic information, to aid the driver [1]. IEEE 802.11p defines two types of messages:

Cooperative Awareness Messages (CAM) is the first message specified in 802.11p. This is a message which is repeatedly broadcasted to all nearby nodes. These messages provide information of presence, position as well as basic status of communicating ITS stations [12]. Table 2 shows all data elements stored in a CAM.
An ITS stations broadcasts such messages with a frequency of 2 to 10 Hz, depending on their purpose [12]. A CAM is also generated when a large change compared to the last CAM is measured in one of the following elements:

- Heading: an absolute change between current heading and last CAM heading of more than 4º.
- Position: an absolute difference of more than 5m.
- Speed: an absolute difference of more than 1m/s.

Table 3 gives an indication of the accuracy of the data elements stored in a CAM. Outstanding is the very large error the position of the vehicle can have. The reader should note that this is the maximum error and the average error is likely much smaller. With additional positional technologies, such as SAFESPOT, it will be possible to determine the location of a vehicle with sub-meter accuracy [7].

Comparing the accuracy of data from CAMs with data from EDR device shows that the EDR has a greater accuracy. The EDR only stores data moments before, during and after the crash while CAMs can provide information of periods long before and after the accident, as long as all received CAMs are all stored by the vehicle.

Table 2: Data elements in a CAM [12]

<table>
<thead>
<tr>
<th>Data element in CAM</th>
<th>Station ID</th>
<th>Geographical position</th>
<th>Vehicle type (e.g. bus, taxi, tram)</th>
<th>Vehicle speed</th>
<th>Vehicle speed confidence</th>
<th>Heading</th>
<th>Station length</th>
<th>Station width</th>
<th>Curvature</th>
<th>Curvature confidence</th>
<th>long/Acceleration</th>
<th>posConfidenceEllipse</th>
<th>Exterior lights</th>
<th>Acceleration control</th>
</tr>
</thead>
</table>

Table 4: Vehicle travel distance between two consecutive CAMs with frequency of CAM and speed of vehicle

<table>
<thead>
<tr>
<th>Broadcast Speed of vehicle (km/h)</th>
<th>30</th>
<th>60</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.17m</td>
<td>8.33m</td>
<td>16.67m</td>
</tr>
<tr>
<td>5</td>
<td>1.67m</td>
<td>3.33m</td>
<td>6.67m</td>
</tr>
</tbody>
</table>

The frequency at which CAMs are being broadcasted influences the reliability a vehicle knows about the presence of neighboring vehicles. Table 4 shows the distance a vehicle can travel between the broadcasting of two consecutive CAMs. The table varies in broadcasting frequencies and vehicle movement speed. At large speeds the distance travelled can get quite large. However, keep in mind that when large differences in position, speed or heading are measured, a CAM is also broadcasted. Therefore, a maximum travel distance between two consecutive CAMs is 5 meters, with the assumption that there is no package loss.

**Decentralized Environmental Notification Message (DENM)** is the second message specified by 802.11p. This is a message which is broadcasted to other ITS stations when a certain event occurs to warn other vehicles. Examples of such events are wrong-way driving, accident, road-work, etc. Table 5 provides an overview of all the use cases for DENMs and when a DENM is sent. When an ITS station detects such an event, it immediately start broadcasting a DENM to other ITS stations in the area which are concerned by the event, this can be a specific geographical location. This is repeated as long as the event is present. The broadcasting ends either after a predefined period of time when the event is no longer detected, or when a special DENM is generated to inform that the event has disappeared [13].

Table 5: Triggering conditions of DENM sending [13]

<table>
<thead>
<tr>
<th>Use case</th>
<th>Triggering condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency electronic brake light</td>
<td>Hard breaking of a vehicle</td>
</tr>
<tr>
<td>Wrong way driving warning</td>
<td>Detection of a wrong way driving by the vehicle being in wrong driving direction</td>
</tr>
<tr>
<td>Stationary vehicle -- accident</td>
<td>e-Call triggering</td>
</tr>
<tr>
<td>Stationary vehicle - vehicle problem</td>
<td>Detection of a vehicle breakdown or stationary vehicle with activated warnings</td>
</tr>
<tr>
<td>Traffic condition warning</td>
<td>Traffic jam detection</td>
</tr>
<tr>
<td>Signal violation warning</td>
<td>Detection of a vehicle being violating a signal</td>
</tr>
<tr>
<td>Road-work warning</td>
<td>Signaled by a fix or moving roadside ITS station</td>
</tr>
<tr>
<td>Collision risk warning</td>
<td>Detection of a turning collision risk by a roadside ITS station</td>
</tr>
<tr>
<td>Detection of a turning collision risk by a roadside ITS station</td>
<td></td>
</tr>
<tr>
<td>Detection of a merging collision risk by a roadside ITS station</td>
<td></td>
</tr>
<tr>
<td>Hazardous location</td>
<td>Detection of a hazardous location</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Detection of heavy rain or snow by a vehicle (activation of the windscreen wrappers)</td>
</tr>
<tr>
<td>Road adhesion</td>
<td>Detection of a slippery road condition (ESP activation)</td>
</tr>
<tr>
<td>Visibility</td>
<td>Detection of a low visibility condition (activation of some lights or antifog)</td>
</tr>
<tr>
<td>Wind</td>
<td>Detection of a strong wind condition (stability control of the vehicle)</td>
</tr>
</tbody>
</table>
3. RELATED SYSTEMS
In this section an overview of related systems for accident analysis will be given.

3.1 EVIGEN
In particular situations, it can be useful for a vehicle to prove its recent behavior. Examples of such situations are to prove one’s innocence when a faulty speeding fine is given or when an accident occurs. In the work of de Fuentes, González-Tablas, and Ribagorda [3] a protocol named EVIGEN (EVIDence GENeration) is described to provide such proof. EVIGEN makes use of the perception of neighboring vehicles about itself to create evidence. Vehicles can sense each other with their sensors (these sensors can range from ultrasound sensors up to video cameras) and via a VANET they can communicate their perception about each other. Thus, neighboring vehicles act as witnesses and provide a testimony which can be used as evidence.

By creating evidence based on the perception of neighboring vehicles rather than using the sensors of its own vehicle, it creates an extra level of reliability because the sensors of its own vehicle could have been tampered with. There also exists an incentive to tamper with the sensors of the vehicle, for example to evade a speeding ticket.

The creation of the evidence happens in two steps: first the requesting vehicle makes a request for information and then the testimonies are gathered. When the testimonies are gathered, all neighboring vehicles send an estimation about the requested data. To use this data in court, a consensus must be made. Because the high mobility of the nodes in VANETs and the short time nodes can communicate with each other, the requester is allowed to create such a consensus on its own. It does so by using the values set agreed on by most neighbors.

Along with the data about how neighbors perceive the requester, the neighbors also send a special endorsement token. This endorsement token contains the conditions under which the requester is allowed to use the testimony for evidence. This prevents illegal use of the testimonies not allowed by the witness.

3.2 Cooperative Collision Warning Reconstruction
In the work of Young, Chung-Ping, et al [10] a system is described for road-accidents reconstruction. The system makes use of the Cooperative Collision Warning (CCW) system, which is an active safety mechanism to provide early warning signals to road users in order to prevent accidents. Messages with static and dynamic information about a vehicle are broadcasted to neighboring vehicles via a VANET, and with this information the vehicles can compute the relative safety distance between each other and warn the driver if needed. These messages are also stored on the vehicle and based on these messages it is easy to reconstruct the trajectory and interaction between the host and neighboring vehicles. With the Highway Traffic Simulator images of the accident can be created along with information like velocity change and vehicle speed can be shown. These images can give a view how the accident occurred, as long as all vehicles involved in the accident are equipped with DSRC.

3.3 Accurate Accident Reconstruction in VANET
In the work of Yuliya Kopylova, Csilla Farkas, and Wenyuan Xu [6] a forensic VANET application is proposed which looks like a composition of the two systems mentioned above. The paper describes a mechanism to gather two types of evidence:

- **Primary evidence**: this consists of all sensor data of the host vehicle and all beacons received by the host vehicle. This data can be used to create a reconstruction of all vehicles trajectories involved in the accident.
- **Corroborative evidence**: this consists of witness data obtained from nearby vehicles. It contains data needed to verify the primary evidence. This data is used to counter falsification of data, similar as in EVIGEN.

When an accident occurs, vehicles nearby and involved in the accident sent their corroborative evidence to road-side units. There the data is stored so that the primary evidence, found in the vehicle involved in the crash, can later be verified.

3.4 Crash Data Retrieval Tool
The Crash Data Retrieval (CDR) tool is a commercial tool to gather and image crash data stored in EDR. Unlike the other systems mentioned above, this tool only uses the data stored in the EDR of a vehicle and does not make use of any data transmitted in a VANET. The tool creates a detailed report about the host vehicle moments before, during and after the crash. This tool already exists for many years and is being used by accident reconstructionist/investigators. It has also been used numerous times in court [16].

4. DISCUSSION CAPABILITIES PROTOTYPE
A tool that reports details on an accident based on EDR data already exists. However, there does not yet exist a tool that uses data available from CAMs and DENMs. The CCW in section 3.2 does show that it is possible to reconstruct an accident based on CAMs. This section discusses the potential to analyze the behavior of drivers prior to the accident and derive causes for the accident.

Traffic accidents can be categorized in two types, namely a traffic accident which involves only one vehicle equipped with DSRC or an accident which involves two or more vehicles equipped with DSRC.

In the first case analysis on CAMs and DENMs will not provide more insight, since only the CAMs and DENMs of one vehicle are available and from this vehicle we can also study the EDR. Analyzing the EDR makes more sense since this device provides more details and is more accurate.

When two or more vehicles equipped with DSRC are involved in an accident studying the CAMs and DENMs communicated with each other becomes more interesting. Using the data provided by the CAMs communicated with one another, a vehicle will know the position, speed and heading of neighboring vehicles. This data along with any received DENMs can then provide clues about the behavior of vehicles that led to the accident. Table 6 lists potential causes for traffic accident, along with indications of how the cause can be recognized. For example, when the driver is under influence of alcohol/medicine it is likely that the vehicle was swaying a lot before the crash. This can be detected by...
comparing the heading and position of consecutive CAMs in a period before the crash. Some causes of traffic accidents however, do not have any indicators available with the data from CAMs/DENMs.

**Table 6: enumeration of causes for traffic accidents and indication which elements of EDR/CAM/DENM can indicate the cause**

<table>
<thead>
<tr>
<th>Cause of traffic accident</th>
<th>Indication of the cause based on CAM/DENM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speeding</td>
<td>Speed of vehicle</td>
</tr>
<tr>
<td>Tailgating</td>
<td>Speed, distance between vehicles</td>
</tr>
<tr>
<td>Driving under influence of alcohol/drugs/medicine</td>
<td>Heavy swaying, fluctuating speed</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Swaying, fluctuating speed</td>
</tr>
<tr>
<td>Wrong way driving</td>
<td>Heading and position</td>
</tr>
<tr>
<td>Road rage</td>
<td>Speed, position, heading</td>
</tr>
<tr>
<td>Ignoring traffic light (in case that traffic light is an ITS)</td>
<td>Status traffic light, position vehicle and time, wrong way driving warning (DENM use case)</td>
</tr>
<tr>
<td>Bad weather conditions</td>
<td>Precipitation (DENM use case), visibility (DENM use case)</td>
</tr>
<tr>
<td>Aquaplaning</td>
<td>Precipitation (DENM use case), road adhesion (DENM use case)</td>
</tr>
<tr>
<td>Ignoring traffic sign</td>
<td>-</td>
</tr>
<tr>
<td>Distracting activities</td>
<td>-</td>
</tr>
<tr>
<td>Deficient road structure</td>
<td>-</td>
</tr>
<tr>
<td>Deficient driving experience</td>
<td>-</td>
</tr>
<tr>
<td>Technical defect of vehicle</td>
<td>-</td>
</tr>
<tr>
<td>Incorrect use of directional indicators</td>
<td>-</td>
</tr>
<tr>
<td>Wild animals crossing</td>
<td>-</td>
</tr>
</tbody>
</table>

A system can be developed that automatically tries to find the causes of a traffic accident. Based on the indications in the second column of Table 6, the following checks need to be performed in order for the system to potentially recognize the listed causes of accidents:

- Check the speed of the vehicles and the maximum allowed speed. Is a vehicle speeding? Are there big differences in the speed of the vehicles?
- Check the distance between the vehicles, taking into account their speed.
- Check the heading of the vehicles. Are they driving the same way? Is a vehicle driving in reverse? Is a vehicle swaying a lot?
- Check the positions of the vehicles. Is a vehicle on the wrong side of the road?
- Check if any DENMs have been send.

These are simple checks the system can perform. Then the observed behavior and the likelihood of what caused the accident can be reported. Note that an accident can have multiple causes, for example a vehicle who’s speeding and tailgating. More complex analysis on the available data may also reveal other possible causes of an accident. For example when a traffic light is an ITS station, checks can be performed whether vehicles are ignoring red signs or not. However, identifying all causes of traffic accidents and their corresponding indicators goes beyond the scope of the paper.

Interesting cases to study with such prototype are hit-and-runs. Because a vehicle drives away after the accident, we do not have any EDR data available from the fleeing vehicle. However, if the vehicle was equipped with DSRC other vehicles nearby the accident will still have received the beacons send by the fleeing vehicle. Note that the vehicle of the victim does not necessarily need to be equipped with DSRC. As long as there is a vehicle or road-side unit equipped with DSRC nearby during the incident and we are able to track this vehicle/RSU, we will have access to the beacons send by the fleeing vehicle.

A problem for the prototype is that not all vehicles will be equipped with DSRC. Using information of CAMs and DENMs to gain insight of road accidents can create misleading information when vehicles without DSRC are also involved. This can leave behavior of the other vehicles unexplained.

## 5. TRAFFIC ANALYSER

Here we will describe the prototype created for analysis of post-accident traffic analysis. The prototype is created to evaluate whether it is possible to automatically perform checks described in section 4 on traffic accidents, based on CAMs communicated between vehicles. Creation of an advanced system which tries to identify all possible causes goes beyond the scope of this paper. The system is therefore not able to detect all causes listed in Table 6.

The prototype makes use of CAMs communicated between vehicles. Since we do not have a set of data available for analysis, this data will be generated by a simulator. The Veins simulator has been used for this purpose. Veins is an open source framework for running vehicular network situations. Veins consists of SUMO, a road traffic simulator, and OMNeT++, an event based network simulator [17].

The Veins simulator has built-in functionality for vehicles to broadcast messages to each other. These messages have been updated to contain the data elements of a CAM, see table 2. The messages are being broadcasted with a frequency of 10 Hz and power level of -89dBm, which is typical for 802.11 networks. Furthermore, the vehicles in the simulator have been updated to store all send and received CAMs in two separate files.

Two traffic situations have been simulated: a head-tail collision and a normal traffic situation where no collisions occur. All vehicles in the simulation are equipped with DSRC. All broadcasted and received CAMs for all vehicles are stored in two separate files as following:

```
<Timestamp, owner, Address, Position, Speed, Direction>
```

Timestamp indicates the moment when the CAM is broadcasted. Owner is the vehicle who received the CAM and address is the sender of the CAM. Then these files are used as input for analysis:
Input: for all vehicles in the accident from which data could be obtained: a file with all send and received CAMs and DENMs
Output: report of the accident.
Algorithm:
1: Sort all input files in two maps:
   CAMsReceived = Map<Vehicle_ID, Map<timestamp, CAM>>
   CAMsSend = Map<Vehicle_ID, Map<timestamp, CAM>>
2: For each vehicle:
   3:     For each CAM received:
   4:         If received CAM-position is in collision with this vehicle-position:
   5:             Add CAM to list of events
6: For each event:
   7:         report vehicleSpeed()
   8:         report interVehicleDistance()
   9:         report vehicleHeading()
  10:     #report vehicleSwaying()
  11:     #report vehicleGhostRiding()
  12:     #report receivedDENM()

The stored received and send CAMs are then used as input for the analyzer. The analyzer creates an overview of all send and received CAMs per vehicle (line 1). For each vehicle the CAMs are sorted by timestamp. With this construction it is easy to only look at the data available from a select number of vehicles and at a certain period in time.

In order to automatically show the relevant data, the analyzer first tries to find a moment of collision and the vehicles involved in the collision (lines 2 to 5). Once this is found, the behavior of these vehicles before the collision is reported. These are basic checks on the vehicle’s speed, position and heading (line 7-12), as described in section 4. Accident investigators can use these reports to get more insight in the accident.

The simulator did have some limitations. It was not designed to realistically simulate crashes. Crashes have been simulated by simply letting vehicles collide over each other, thus they do not experience any consequences of the impact, i.e. a sudden change in velocity and/or direction. Therefore, this paper only focusses on the behavior of the vehicles till the moment of impact. It is also not possible to vehicles sway on the road, drive off the road or drive on the wrong side of the road. Furthermore, the simulator has not implemented to make use DENM. This makes the checks performed on line 10, 11 and 12 of the algorithm useless, thus their implementations have been omitted.

In the case of the normal traffic situation, the prototype did not find any collisions between vehicles and no report about an accident was created. This is as expected.

In the head-tail collision, the prototype was able to find the moment of collision and generate a report about the behavior of the two vehicles involved. Figure 1 and 2 show some of the results from the report. Both graphs have the time in seconds depicted on the x-axis, where t=0 depicts the moment the vehicles collide. In this example they show the behavior 30 seconds before the collision occurs. This timeframe is variable and can become larger or smaller if needed. Figure 1 has the speed of the vehicles in meters per second on the y-axis. It shows both vehicles accelerating until they suddenly have to make an emergency break causing vehicle1 to collide with vehicle0 with a speed of approximately 6 m/s. The maximum allowed speed limit on the road is also depicted as the red line; both vehicles do not exceed this limit. Figure 2 shows the distance between both vehicles over time. At t=0 the distance between the vehicles is 0 and the vehicles have collided.

The report is solely generated with the information available of its behavior prior to the accident. The report is solely generated with the information available of its behavior prior to the accident.

Figure 1: Screenshot of speed report, at 0 seconds the collision has occurred

Figure 2: Screenshot of relative distance report, at 0 seconds the collision has occurred

The report is solely generated with the information available of only 1 vehicle, the leading vehicle in this case. Generating a report with the information solely on the other vehicle (the ‘tail-vehicle’) generates similar results. This shows some of the strengths using VANET technologies in traffic accident analysis. Would one vehicle flee the scene, then there is still information available of its behavior prior to the accident.

6. PRIVACY

Privacy in VANETs is of critical importance for technologies to be accepted and used by public. Being able to trace vehicles to places they have been, employers tracing the exact arriving and departure time of their employees, insurance companies gathering statistics about a vehicles behavior are some examples of unwanted privacy infringements made possible by storing information about vehicles.
Protecting the information stored in an EDR device is easy since attackers need to get physical access to the vehicle. The data can be further protected by storing it in Hardware Security Modules; this also provides protection against modification of the stored data [8].

Protecting against privacy infringements in the vehicular networks faces more difficult challenges. Eavesdroppers can easily store all received messages for long periods of time and abuse this information. Making vehicles anonymous solves this problem. However, this is in conflict of security measurements since in order to hold nodes in the network accountable for their actions and take proper action against abusers, they need to be linked to a node in the network. Besides that, application protocols often require a unique identifier, for example as source or destination address [2]. For example, the prototype created in this paper needs to be able to identify vehicles in order to know which CAMs are relevant. So completely hiding the identity of a vehicle is not a feasible option.

In order to hide privacy, one could also blur information, for example by broadcast CAMs at a lower frequency. However this renders most safety applications in VANETs inoperable since exact information about the vehicle’s position is required [9]. The prototype in this paper for example, would not be able to detect the collisions anymore.

Current proposed solutions for privacy usually make use of pseudonyms. Vehicles continuously switch between a large pool of pseudonyms to sign their messages. This way two messages using two different pseudonyms cannot be readily be matched to the same vehicle [5].

However, in the work of Wiedersheim et al. [9] it has been shown that an attacker is strong enough, i.e. has the ability to receive all messages send by a vehicle, it can still trace vehicles even when they’re making use of pseudonyms. This is due to the predictable and orderly movements of vehicles.

Research in privacy and security is still a hot-topic in VANETs and receives a lot of attention by the academia, governments and industry. For vehicular communication to become possible, and thus allowing applications like the post-traffic analyzer described in this paper, privacy concerns need to be addressed.

7. CONCLUSIONS

In this paper we searched for methods to provide additional information about, and gain more insight in traffic accidents. A prototype has been developed which makes use of CAMs being communicated between vehicles. With this data the prototype can detect when a collision has occurred and creates a report about the behavior of the involved vehicles prior to the accident. This can help investigation officers of accidents gain more insight in the accident and safe time.

There exist a multiple of digital sources which can be used to provide more insight in traffic accidents. The most promising sources for post-accident analysis are the EDR device installed in vehicles, and CAM and DENM messages communicated between vehicles equipped with DSRC. Furthermore, the NDW (and similar databases in other countries) can provide estimations in the traffic situation during the accident, i.e. how busy the roads were and how fast vehicles were driving.

The commercially available CDR tool already makes use of the EDR data to provide information about an accident. The CCW system shows that it is possible to create a reconstruction of the accident based on CAMs.

By using the CAMs and DENMs send in VANETs, it is possible to analyze the behavior of vehicles prior to the accident. This can give indications of the cause of the accident. A prototype has been created to perform some basic checks on CAMs communicated between vehicles. It tries to find likely causes for the accidents based on the behavior of the drivers prior to the accident and gives a report of its findings.

A normal traffic situation and a head-tail collision, generated by the Veins simulator, have been used as input for the analyzer. They show that the prototype works. Especially in hit-and-runs, a system like this can provide valuable information.

Future work can be done in research for enhancing the prototype. A complete overview of traffic accidents and indications of their causes should be made by traffic accident experts. With this information the system could implement automatic detection of the traffic accident. Research in the reliability of such a system should also be conducted.

Additionally, the system could implement a verification system, similar to EVIGEN, which uses sensors of vehicles to verify CAMs of neighboring vehicles. This will make the system more reliable and can also provide methods to gather information of vehicles which are not equipped with DSRC technology.

8. REFERENCES


