Pre-Crash Scenario Framework for Crash Avoidance Systems Based on Vehicle-to-Vehicle Communications

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ABSTRACT

This paper prioritizes and statistically describes pre-crash scenarios as a basis for the identification of crash avoidance functions enhanced or enabled by vehicle-to-vehicle (V2V) communication technology. Pre-crash scenarios depict vehicle movements and dynamics as well as the critical event immediately prior to the crash. The prioritization of pre-crash scenarios is based on the societal harm from persons who were injured in pre-crash scenarios involving at least two vehicles. The crash must also involve at least one light vehicle (e.g., passenger car, van, minivan, sport utility vehicle, or pickup truck) with a gross vehicle weight rating less than 4,536 kg. This paper also introduces a framework that serves to connect pre-crash scenarios to crash avoidance functions and provides information that will enable the identification of appropriate functional requirements, performance specifications, objective test procedures, and initial system effectiveness benchmarks. The framework incorporates crash statistics about the driving environment, contributing and causal factors, and kinematic information. In addition, time-to-collision equations for each pre-crash scenario are derived to identify key variables that must be measured to recognize and assess the crash threat of driving conflicts. Crash statistics are obtained from national crash databases including the 2004-2008 General Estimates System, the National Motor Vehicle Crash Causation Survey, and the Event Data Recorder database. A set of ten pre-crash scenarios are identified as a priority for the development of V2V-based safety applications. These priority scenarios are arranged into five crash avoidance packages that consist of rear-end, lane change, opposite direction, junction crossing, and left turn across path/opposite direction crash countermeasures. This paper delineates the priority pre-crash scenarios and maps them to V2V-based safety applications under development.

INTRODUCTION

This paper describes a pre-crash scenario framework that facilitates the development and evaluation of crash avoidance systems based on vehicle-to-vehicle (V2V) communications using dedicated short-range communications at 5.9 GHz. This framework is constructed in support of the V2V safety application program as part of the United States Department of Transportation's Intelligent Transportation System program [1]. Safety applications will be designed to increase situational awareness and reduce or eliminate crashes through V2V data transmission that supports driver advisories, driver warnings, and vehicle controls. It is envisioned that each motor vehicle on the roadway will be able to communicate with other vehicles, and that this rich set of data and communications will support a new generation of active safety applications and systems.

The pre-crash scenario framework is established to further define the crash problem and identify new crash avoidance capabilities. It serves to connect pre-crash scenarios to crash avoidance safety applications and provide information that will enable the identification of their functions that address the most pressing aspects of the crash problem, performance guidelines, and initial effectiveness benchmarks. This framework also contributes to the classification and grouping of crash avoidance technology so deployed crash avoidance systems can be ranked for their ability to reduce the likelihood and severity of crashes. This framework will be used to determine requirements for safety applications and set priorities for investment.

The following five steps were performed to develop the pre-crash scenario framework for V2V-based crash avoidance systems:

1. Identify target pre-crash scenarios for V2V-based safety applications
2. Describe target pre-crash scenarios based on national crash statistics
3. Prioritize and rank target pre-crash scenarios by frequency and severity
4. Depict priority pre-crash scenarios and determine crash avoidance needs and countermeasure profiles
5. Highlight V2V-based countermeasures for priority pre-crash scenarios

The pre-crash scenario framework was developed separately for light vehicles and heavy trucks. Light vehicles encompass passenger cars, vans, minivans, sport utility vehicles, and light pickup trucks with gross vehicle weight ratings of less than or equal to 4,536 kg. This paper summarizes the results of the five steps listed above for light vehicles only.

TARGET PRE-CRASH SCENARIOS

V2V-based safety applications predominantly apply to crashes that involve multi-vehicle pre-crash scenarios. This criterion recognizes that, in general, V2V-based systems require two equipped vehicles in communication to be effective. The exception is the broadcast of control loss message in the single-vehicle control loss pre-crash scenarios. This analysis adopted the control loss warning function under investigation by the Crash Avoidance Metrics Partnership (CAMP) in the Vehicle Safety Communications – Applications (VSC-A) project [2]. Consequently, a total of 22 pre-crash scenarios were deemed applicable to V2V-based safety functions. These target scenarios form a subset of the 37 pre-crash scenarios that were developed by the National Highway Traffic Safety Administration to establish a common crash avoidance research foundation for prioritization of traffic safety issues and development of concomitant crash avoidance systems [3]. The 37 pre-crash scenarios depict vehicle movements and dynamics as well as the critical events occurring immediately prior to most police-reported crashes.

Based on statistics from the 2005-2008 National Automotive Sampling System (NASS) General Estimates System (GES) crash databases, V2V-based safety applications would potentially address about 4,336,000 police-reported light-vehicle crashes annually, with the 95 percent confidence interval between 3,691,000 and 4,981,000 [4]. Considering the 22 target pre-crash scenarios, V2V systems have the potential to deal with 76% of all crashes involving at least one light vehicle.

The 22 target pre-crash scenarios were down-selected to 17 pre-crash scenarios for further analysis [5]. Control loss (with or without prior vehicle action), backing, parking, and "other" pre-crash scenarios were excluded because they may be more efficiently addressed by autonomous vehicle-based systems or because additional V2V data about a vehicle losing control serve as an input to advisory systems rather than crash imminent warning systems. The remaining 17 target pre-crash scenarios are listed below:

1. Rear-end crash/lead vehicle stopped (LVS)
2. Rear-end crash/lead vehicle moving at slower constant speed (LVM)
3. Rear-end crash/lead vehicle decelerating (LVD)
4. Rear-end crash/lead vehicle accelerating (LVA)
5. Rear-end crash/following vehicle making a maneuver
6. Opposite direction/no vehicle maneuver
7. Opposite direction/vehicle making a maneuver
8. Left turn across path from opposite directions (LTAP/OD) at signalized junctions
9. LTAP/OD at non-signalized junctions
10. Straight crossing paths (SCP) at non-signalized junctions
11. Turning at non-signalized junctions
12. Turning right at signalized junctions
13. Running red light
14. Running stop sign
15. Changing lanes/both vehicles traveling in same direction
16. Drifting/both vehicles traveling in same direction
17. Turning/both vehicles traveling in same direction

Vehicle maneuver in the list above refers to a vehicle passing, parking, turning, backing up, changing lanes, merging, or making a successful corrective action to a previous critical event.

PRE-CRASH SCENARIO STATISTICS

The 17 target pre-crash scenarios were statistically described in terms of their driving environment, driver characteristics, contributing and causal factors, and kinematic information. Data sources included the 2004-2008 GES, National Motor Vehicle Crash Causation Survey (NMVCCS), and Event Data Recorder (EDR) crash databases. The EDR database contains a subset of cases from the 2000-2007 NASS Crashworthiness Data System (CDS) crash databases.

GES Statistics

The GES crash database estimates the national crash population each year based on a weighted sample of about 55,000 police-reported crash cases that include all vehicle types and injury levels [6]. This paper presents results based on an average annual estimate from yearly crashes over a five-year period including 2004-2008 datasets. These crash estimates do not account for non-reported crashes. The GES was selected for this study because it is updated annually, is nationally representative, and includes attributes for crash type, pre-crash detail, driving environment conditions, driver and vehicle contributing factors, and injury levels of persons involved. Table 1 lists the GES variables that were queried for this analysis.

Table 1. Queried GES Variables

Category	GES Variable
Driving Environment	Roadway Alignment
	Roadway Surface Conditions
	Atmospheric Conditions
	Relation to Junction
	Traffic Control Device
	Lighting Condition
	Speed Limit
Driver Characteristics	Age
	Gender
Driver Contributing Factors	Police-Reported Alcohol Involvement
	Police-Reported Drug Involvement
	Person's Physical Impairment
	Violations Charged
	Speed Related
	Driver's Vision Obscured By
	Driver Distracted By
Vehicle Factors	Vehicle Contributing Factors
Driver Action	Corrective Action Attempted

Key observations about the driving environment from the analysis of all 17 pre-crash scenarios are [5]:

- Most crashes occur on a straight road and dry surface in clear weather.
- Many rear-end pre-crash scenarios are reported at intersections controlled by 3-color signals, particularly LVS and LVA scenarios.
- Most crashes occur in daylight. Opposite direction pre-crash scenarios happen more in dark conditions than any other scenario.
- A large portion of crashes associated with changing lanes/same direction, drifting/same direction, rear-end LVM, and rear-end LVM pre-crash scenarios occur at speed limits greater than or equal to 55 mph (88 km/h).
- A very large portion of crashes tied to running stop sign, turning/same direction, and LTAP/OD, SCP, and turning at non-controlled junction pre-crash scenarios are reported at speed limits less than or equal to 35 mph (56 km/h).

Statistical observations of driver characteristics, crash contributing factors, and causes were obtained from the vehicle/driver of interest. Drivers of interest refer to light-vehicle drivers who were charged with traffic control device violation, attempted a maneuver, or were in the following vehicles in rear-end pre-crash scenarios. Demographics of drivers of interest are:

- 31.6% younger drivers (≤ 24 years old), 59.7% middle-age drivers (25-64 years old), and 8.7% older drivers (≥ 65 years old).
- 56% male drivers and 44% female drivers.

Crash contributing and causal factors are [5]:

- About 3% of all drivers were cited with alcohol. Higher involvement rates are coded in running stop sign, drifting/same direction, opposite direction, lead vehicle moving, and turning right at signalized junction pre-crash scenarios.
- Drugs are implicated in only 4% of all drivers.
- Violations are cited to about 42% of all drivers.
- Speeding is attributed to 13% of all vehicles. Striking vehicles in rear-end pre-crash scenarios account for 89% of all speeding vehicles.
- Inattention is noted by 27% of all drivers. Higher inattention rates emerge in running red light, running stop sign, rear-end, and turning in LTAP/OD at non signalized junction pre-crash scenarios as compared to other scenarios.
- Vehicle contributing factors account for 0.6%.

NMVCCS Statistics

The NMVCCS data provide detailed information about different aspects of the crash including pre-crash movement, critical pre-crash event, critical reason, and associated factors [7]. On-scene information was collected on the events and associated factors leading up to 6,949 crashes that involved light vehicles during a three-year period from January 2005 to December 2007. Of these, 5,470 crashes comprised a nationally representative sample. Table 2 lists the NMVCCS variables that were investigated in the analysis.

Table 2. Investigated NMVCCS Variables

Category	NMVCCS Variable
Critical Reason	Critical Reason for the Critical Precrash Event
Driver Condition	Fatigue
Driver Recognition Error	Inattention
	Driver Conversing
	Inadequate Surveillance
	Other Driver Recognition Factor
Driver Decision Error	Misjudgement of Distance/Speed of Other Vehicle
	False Assumption of Other Road User's Action
	Following Too Closely
	Other Driver Decision Factor
Driver Action	Inadequate/Incorrect Evasive Action

The analysis of NMVCCS causal factors revealed the following key observations [5]:

- Fatigue is a factor in about 10% of all drivers. Higher fatigue rates are noted in opposite direction (27%), changing lanes/turning/drifting – same direction (15%), rear-end LVD (13%), and rear-end LVS (13%) pre-crash scenarios.
- Inattention is cited in 15% of all drivers. Higher inattention rates are observed rear-end LVS (23%), running red light (23%), and rear-end LVD (18%) pre-crash scenarios.
- Inadequate surveillance is implicated in 55% of all drivers. Rates over 65% show up in running red light/stop sign, LTAP/OD, and SCP/turning at non-signalized junction pre-crash scenarios.
- False assumption of other road user's action is mentioned by 13% of all drivers. This rate amounts to 26% in LTAP/OD at signalized junction by left turning and other vehicles, 30% in turn right at signalized junction, and 25% in rear-end LVS pre-crash scenarios.
- Inadequate evasive action by all vehicles is 5%. This rate is highest in opposite direction pre-crash scenarios at 24%, followed by rear-end LVS pre-crash scenario at 13%.

EDR Kinematic Data

EDR records were analyzed to quantify driver speed and braking response to an imminent crash from 5 seconds before the crash [8]. A sample of General Motors EDR vehicle cases from the 2000-2007 CDS databases were used in the analysis. Pre-crash data such as brake switch status and vehicle speed are recorded and stored at 1-second increments for 5 seconds from the start of a triggering event (i.e., crash). This analysis assumed that the start of this triggering event coincides with the exact instant of the collision; i.e., time-to-collision equals to zero. Figure 1 illustrates the proportion of vehicles that braked in response to a lead vehicle stopped from 5 seconds before the crash [5]; 3 seconds before the crash, only 23% of the vehicles initiated a brake response. The intensity of braking exerted by the vehicles was also computed by taking the difference in speeds over one second between five and four, four and three, three and two, and two and one second before the crash when brakes were applied. Similarly, the effective deceleration was calculated from the change in velocity over the five one-second intervals immediately before the crash.

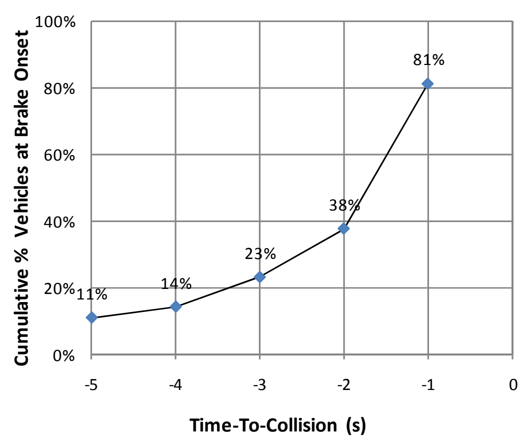

Figure 1. Illustration of Brake Response by Striking Vehicles in Rear-End LVS Scenario

Quantitative crash data on speed, driver braking response, and brake intensity support the development of performance guidelines and objective test procedures for crash countermeasure systems, and enable system developers, for instance, to set minimum operating speeds and determine alert timing for crash warning algorithms. Moreover, travel speed information helps to project the potential safety benefits of safety applications based on V2V communications.

PRIORITY PRE-CRASH SCENARIOS

Ten scenarios with the greatest societal harm were prioritized from the 17 target pre-crash scenarios for further examination so as to gain the most benefit by reducing the occurrence of these crashes. The cost of pre-crash scenarios was estimated from the 2004-2008 GES as a function of two harm measures: comprehensive economic cost and functional years lost. These harm measures were derived from the maximum injury severity of all injured persons in a crash according to the Abbreviated Injury Scale – a classification system for assessing impact injury severity developed by the Association for the Advancement of Automotive Medicine.

Table 3 lists the 17 target pre-crash scenarios in a descending order in terms of their comprehensive cost based on 2007 economic values. It should be noted that these cost estimates reflect the injury levels of persons involved in police-reported crashes only. This analysis excluded the cost of crashes that were not reported to the police. The total cost of the 17 pre-crash scenarios account for 73% of all cost derived from the original 22 V2V target scenarios. The excluded control loss scenario contributed to about 24% of the comprehensive cost [5].

The 17 target V2V pre-crash scenarios were organized into six target pre-crash scenario groups as seen in Table 4. These groups were logically organized by their crash characteristics including movement and relative positioning between vehicles prior to impact. The traffic control device (TCD) violation group is different from the other five groups as it requires a specific driver violation at junctions controlled by 3-color signals or stop signs. This particular group was excluded from further analysis since its pre-crash scenarios are best addressed with safety applications based on vehicle-to-infrastructure communications such as the cooperative intersection collision avoidance system for violations developed by CAMP [9].

Table 3. Societal Harm of Target Scenarios

Pre-Crash Scenario	Annual Crashes	Comprehensive Cost	
		Total	Portion
SCP @ non signal	647,000	$ 41,095,000,000	14.95%
Rear-end/LVS	942,000	$ 29,716,000,000	10.81%
Opposite direction/no maneuver	118,000	$ 29,558,000,000	10.75%
Running red light	237,000	$ 18,274,000,000	6.65%
LTAP/OD @ non signal	184,000	$ 15,481,000,000	5.63%
LTAP/OD @ signal	204,000	$ 14,777,000,000	5.37%
Rear-end/LVD	398,000	$ 12,215,000,000	4.44%
Rear-end/LVM	202,000	$ 10,342,000,000	3.76%
Changing lanes/same direction	336,000	$ 8,414,000,000	3.06%
Turning/same direction	202,000	$ 6,176,000,000	2.25%
Opposite direction/maneuver	11,000	$ 3,500,000,000	1.27%
Drifting/same direction	105,000	$ 3,483,000,000	1.27%
Running stop sign	41,000	$ 3,075,000,000	1.12%
Rear-end/striking maneuver	83,000	$ 2,381,000,000	0.87%
Turn @ non signal	45,000	$ 930,000,000	0.34%
Turn right @ signal	31,000	$ 908,000,000	0.33%
Rear-end/LVA	21,000	$ 667,000,000	0.24%

Table 4. Target Pre-Crash Scenario Groups

Pre-Crash Scenario	
Group	**Scenario**
Rear End	Rear-end/LVS
	Rear-end/LVD
	Rear-end/LVM
	Rear-end/striking maneuver
	Rear-end/LVA
Lane Change	Changing lanes/same direction
	Turning/same direction
	Drifting/same direction
Opposite Direction	Opposite direction/no maneuver
	Opposite direction/maneuver
LTAP/OD	LTAP/OD @ non signal
	LTAP/OD @ signal
Junction Crossing	SCP @ non signal
	Turn @ non signal
	Turn right @ signal
TCD Violation	Running red light
	Running stop sign

The 15 remaining target pre-crash scenarios were selected down to a total of 10 priority pre-crash scenarios for V2V-based safety applications [10]. This reduced selection excludes target pre-crash scenarios that contributed to less than 1% of the annual societal harm listed in Table 3. In addition, the two LTAP/OD pre-crash scenarios were combined as one since they have similar kinematics.

The 10 priority pre-crash scenarios are arranged below by their respective group in a descending order of societal harm:

1. Rear-end: cost = $52,273,000,000 and frequency = 1,542,000
    a. LVS
    b. LVD
    c. LVM
2. Junction crossing – SCP at non-signalized junctions: cost = $41,095,000,000 and frequency = 647,000
3. Opposite direction: cost = $33,058,000,000 and frequency = 129,000
    a. No vehicle maneuver
    b. Vehicle making a maneuver
4. LTAP/OD: cost = $30,258,000,000 and frequency = 388,000
5. Lane change: cost = $18,073,000,000 and frequency = 643,000
    a. Changing lanes/both vehicles traveling in same direction
    b. Turning/both vehicles traveling in same direction
    c. Drifting/both vehicles traveling in same direction

The rear-end pre-crash scenario group is comprised of multiple-vehicle crashes that occur longitudinally while traveling in the same lane in the same direction. The junction crossing SCP group incorporates the scenario in which the two vehicles approach each other from perpendicular directions at non-signalized junctions. The opposite direction pre-crash scenarios involve two vehicles approaching each other from opposite directions, either in the same lane or adjacent lanes prior to the critical event, typically away from road junctions. The LTAP/OD pre-crash scenarios consist of two vehicles approaching each other from opposite directions, initially in adjacent lanes, with one vehicle initiating a left turn maneuver across the path of the other. Lane change crashes are characterized by predominantly laterally-oriented two vehicles traveling in the same direction in adjacent lanes.

PRE-CRASH SCENARIO DEPICTIONS

The 10 priority pre-crash scenarios were depicted to convey information that will be helpful in the development of functional requirements, performance specifications, objective test procedures, and estimation of safety benefits for V2V-based safety applications [10]. The depiction of pre-crash scenarios consists of the following four key elements:

- General crash characteristics
- Relative location and motion of involved vehicles
- Supporting demographic data
- Kinematic crash representations

General Crash Characteristics

Each pre-crash scenario group was depicted in a typical configuration to illustrate the common kinematic and time-dependent elements. Generic illustrations were created to show the simplest roadway geometry and define the critical quantitative physical parameters. Each pre-crash scenario group was also linked to a primary critical event that made the crash imminent:

1. Lane departure leading to encroachment onto the travel lane of another vehicle. The two vehicles may be traveling in the same or opposite directions.
2. Approaching a vehicle in the same lane. The two vehicles may be traveling in the same or opposite directions.
3. Encroaching onto the travel lane of another vehicle at junctions including turning across the path or straight crossing paths. In turning across the path, the two vehicles may be initially traveling from the same or opposite directions.

Relative Location and Motion of Vehicles

The location and trajectory of the subject vehicle and other relevant vehicles are the essence of the mathematical description for the time-to-collision (ttc) variable. The initial state of the vehicles must be understood and the potential influence of other driving factors must be estimated in order to predict possible intersection of their paths. In addition to the subject vehicle, other vehicles of interest include target vehicles located ahead, behind, and to either side of the subject vehicle. Moreover, the front or rear offset of target vehicles must be considered. V2V-based safety applications must be able to ascertain each vehicle's relative position including elevation, velocity, heading, range rate, position in lane, acceleration (longitudinal and lateral), and yaw rate.

Supporting Demographic Data

Pre-crash scenario depictions included supporting demographic data from the GES and NMVCCS databases, where available. Such information provides insight into the most common crash contributing factors and primary causes.

Kinematic Crash Representations

Kinematic representations consist of three elements: scenario configuration, timeline, and mathematical description. The scenario configuration is depicted by a generic diagram, similar to Figure 2, to represent each pre-crash scenario.

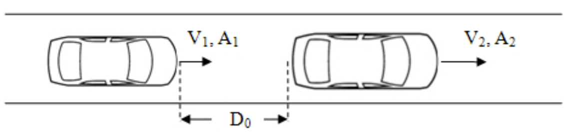

Figure 2. Rear-End Pre-Crash Scenario Diagram

The timeline of each pre-crash scenario illustrates the behavior of each vehicle involved in the scenario to highlight the speeds and distance between vehicles as a function of time. Figure 3 shows the crash timeline for the rear-end LVS scenario.

Each kinematic depiction concludes with a mathematical description of the ttc equation for each scenario. Equation (1) illustrates a sample ttc equation for the rear-end LVS scenario:

$$ttc = \frac{D_0}{V_1} \quad (1)$$

ttc = Time-to-collision
D_0 = Distance between vehicles
V_i = Vehicle i speed

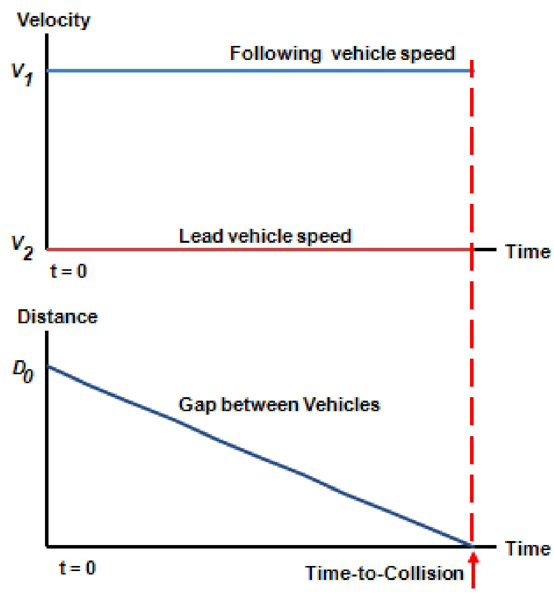

Figure 3. Timeline of Rear-End LVS Scenario

Crash Avoidance Needs

From the kinematic crash depictions and time-to-collision equations, various crash avoidance needs were identified for each priority pre-crash scenario group. The information needs were organized by crash kinematic, driver intent, and demographic needs. Vehicles in all pre-crash scenarios must collect the following information:

- Vehicle position
- Velocity
- Longitudinal acceleration
- Lateral acceleration
- Heading
- Position in lane
- Yaw rate
- Turn signal use
- Brake activation
- Throttle position
- Wiper state, temperature, etc.
- Vehicle size

Driver intent could be deduced from the use of vehicle controls and signals such as turn signal use, brake activation, and/or throttle position. Each vehicle must also compute different variables such as range, range rate, and time-to-collision to all vehicles in close proximity.

PRIORITY PRE-CRASH SCENARIO COUNTERMEASURES

The VSC-A project developed and tested six safety applications for autonomous vehicles to work in conjunction with vehicle communications and positioning systems [2]. The following is a brief description of five of these related safety applications that were selected for a test bed in the VSC-A project:

- Emergency Electronic Brake Light (EEBL): This application enables a host vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and provides a warning to the driver if appropriate.
- Forward Collision Warning (FCW): This application warns the driver of the host vehicle in case of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel.
- Intersection Movement Assist (IMA): This application warns the driver of a host vehicle when it is not safe to enter an intersection due to high collision probability with other remote vehicles at stop sign controlled and uncontrolled intersections.
- Blind Spot Warning (BSW) + Lane Change Warning (LCW): This application warns the driver of the host vehicle during a lane change attempt if the blind spot zone into which the host vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction. The application also provides the driver of the host vehicle with advisory information that a vehicle in an adjacent lane is positioned in the blind spot zone when a lane change is not being attempted.
- Do Not Pass Warning (DNPW): This application warns the driver of the host vehicle during a passing maneuver attempt when a slower moving vehicle, ahead and in the same lane, cannot be safely passed using a passing zone that is occupied by vehicles in the opposite direction of travel. The application also provides the driver of the host vehicle with advisory information that the passing zone is occupied when a passing maneuver is not being attempted.

Table 5 highlights potential crash countermeasures by mapping VSC-A's V2V-based safety applications to the 10 priority pre-crash scenarios [11].

Table 5. Mapping Priority Pre-Crash Scenarios to VSC-A Safety Applications

Priority Pre-Crash Scenarios		VSC-A Safety Applications				
		EEBL	FCW	IMA	DNPW	BSW+ LCW
Rear-End	Lead Vehicle Stopped		✓			
	Lead Vehicle Moving		✓			
	Lead Vehicle Decelerating	✓	✓			
Junction Crossing	SCP @ Non Signal			✓		
LTAP/OD	LTAP/OD					
Opposite Direction	Opposite Direction/ No Maneuver					
	Opposite Direction/ Maneuver				✓	
Lane Change	Changing Lanes/ Same Direction					✓
	Turning/Same Direction					✓
	Drifting/Same Direction					✓

As seen in Table 5, VSC-A safety applications address 8 of the 10 priority pre-crash scenarios. Two scenarios, LTAP/OD and opposite direction/no vehicle maneuver, would require the development of new applicable crash countermeasures. VSC-A safety applications would still require some further development to deal with the different crash characteristics and kinematics of the pre-crash scenarios already addressed by these applications, especially in the alert decision making area by considering distinct dynamic states of the vehicles.

CONCLUSIONS

This paper delineated a pre-crash scenario framework for the development and evaluation of crash avoidance systems based on V2V communications. Crash statistics were provided for 17 target pre-crash scenarios based on national crash data in the 2004-2008 GES and NMVCCS databases. The crash analysis focused on multiple-vehicle, police-reported crashes that involved at least one light vehicle. Moreover, comprehensive economic costs based on 2007 economic values were utilized to quantify and rank the societal cost of the 17 pre-crash scenarios. The pre-crash scenario framework statistically described the 17 target pre-crash scenarios in terms of their driving environment, driver characteristics, contributing and causal factors, and kinematic information about travel speed, brake application, and deceleration level over a period of 5 seconds prior to the crash.

This paper identified 10 priority pre-crash scenarios that were arranged into five pre-crash scenario groups as a basis for the development of future V2V-based crash avoidance systems. The five pre-crash groups included rear-end, lane change, opposite direction, LTAP/OD, and junction crossing pre-crash scenarios. The rear-end and lane change groups consisted of pre-crash scenario groups traveling in the same direction, in the same or adjacent lanes and are differentiated by their crash modes, rear or side-impacts respectively. The opposite direction group involved vehicles moving in the opposite direction in the same or adjacent lanes. The LTAP/OD and junction crossing pre-crash groups occurred at junctions such as intersections or driveways, differentiated by the primary other vehicle's initial orientation, opposite and parallel versus perpendicular to the subject vehicle.

Crash avoidance needs for the V2V-based crash countermeasures were derived from kinematic equations that represent the time-to-collision and suitable avoidance maneuver for each target pre-crash scenario. These equations incorporated key parameters that the countermeasures must measure to decide on whether a crash is imminent in a specific scenario and to determine when to assist the driver.

CAMP's VSC-A project investigated and built V2V-based safety application prototypes that addressed rear-end, lane change, junction crossing SCP, and opposite direction/vehicle making a maneuver pre-crash scenarios. The remaining two priority pre-crash scenarios, opposite direction/no vehicle maneuver and LTAP/OD, were not directly addressed by the VSC-A project. Thus, further development is recommended to build V2V-based safety applications that address these two remaining scenarios.

This paper presented a pre-crash scenario framework that will be used to identify intervention opportunities and define crash countermeasure profiles based on V2V communications. The statistical and kinematical depictions of priority pre-crash scenarios will enable the development of countermeasure functional requirements and minimum performance specifications, objective test procedures, and the estimation of potential safety benefits.

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