U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA
www.nhtsa.gov

DOT HS 811 731

May 2013

Description of Light-Vehicle Pre-Crash Scenarios for Safety Applications Based On Vehicle-to-Vehicle Communications

DISCLAIMER

This publication is distributed by the U.S. Department of Transportation, National Highway Traffic Safety Administration, in the interest of information exchange. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof. If trade names, manufacturers' names, or specific products are mentioned, it is because they are considered essential to the object of the publication and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2013	August 2009 – February 2011

4. TITLE AND SUBTITLE

Description of Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications

5. FUNDING NUMBERS

Intra-Agency Agreement
HS-60A1
DTNH22-09-V-00030

6. AUTHOR(S)

Wassim G. Najm*, Raja Ranganathan**, Gowrishankar Srinivasan**, John D. Smith*, Samuel Toma*, Elizabeth Swanson*, and August Burgett**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

* U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

** URC Enterprises Inc.
17106 Thatcher Court
Olney, MD 20832

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

John Harding
U.S. Department of Transportation
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE.
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DOT HS 811 731
DOT-VNTSC-NHTSA-xx-xx

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Document is available to the public from the National Technical Information Service
www.ntis.gov

12b. DISTRIBUTION CODE

13. ABSTRACT

This report describes pre-crash scenarios that might be addressed by vehicle-to-vehicle communications. The focus is on crashes involving at least 1 light vehicle with a gross vehicle weight rating of 10,000 pounds or less. The 2004-2008 General Estimates System crash databases were used to quantify the societal cost and describe the driving environment, driver characteristics, and crash contributing factors. The National Motor Vehicle Crash Causation Survey was queried to statistically portray crash causal factors. Data from Event Data Recorders drawn from model year 2000-2007 vehicles were analyzed to describe the kinematics of pre-crash scenarios in terms of travel speed, brake application, and deceleration level over a period of five seconds before the crash. Most crashes occurred on straight roads, dry surfaces, in clear weather, and during daylight hours. About 56 percent of drivers were male and 60 percent were of middle age. About 27 percent of all drivers were inattentive, 4 percent were under the influence of alcohol and/or drugs, and 10 percent were fatigued. Speeding was a factor in 13 percent of all crashes. The average effective deceleration level was over 0.6g in the 'lead vehicle moving' and 'lead vehicle decelerating' pre-crash scenarios, when braking was initiated 2 to 3 seconds before the crash.

14. SUBJECT TERMS

Safety Applications, Intelligent Transportation Systems, light vehicles, vehicle-to-vehicle communications, police-reported crashes, General Estimates System, National Motor Vehicle Crash Causation Survey, Event Data Recorder, pre-crash scenarios, crash causes, crash contributing factors, and kinematic data.

15. NUMBER OF PAGES
109

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

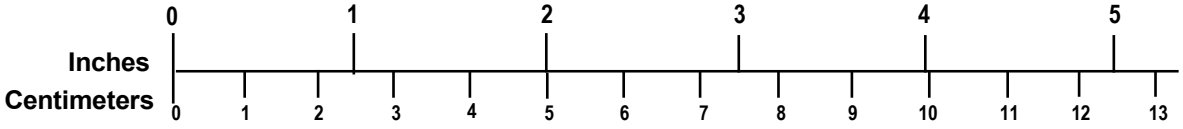


TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

	Abbreviated Injury Scale
AV	Autonomous Vehicle
CDS	Crashworthiness Data System
EDR	Event Data Recorder
FARS	Fatality Analysis Reporting System
FYL	Functional Years Lost
GES	General Estimates System
GM	General Motors
LTAP/OD	Left Turn Across Path/Opposite Directions
LVA	Lead Vehicle Accelerating
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped
MAIS	Maximum Abbreviated Injury Scale
NASS	National Automotive Sampling System
NMVCCS	National Motor Vehicle Crash Causation Survey
SCP	Straight Crossing Paths
TCD	Traffic Control Device
TTC	Time-to-Collision
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VSC-A	Vehicle Safety Communications – Applications
VSL	Value of Statistical Life

EXECUTIVE SUMMARY

The statistics of the 37 pre-crash scenarios' typology are updated using 2004-2008 General Estimates System (GES) data as well as additional data from the National Motor Vehicle Crash Causation Survey (NMVCCS) and Event Data Recorder (EDR) databases. Moreover, comprehensive economic costs based on 2007 economics are utilized to quantify their societal cost. This analysis focuses on pre-crash scenarios involving at least one light vehicle (e.g., passenger car, van, minivan, sport utility vehicle, or light pickup truck with gross vehicle weight rating less than or equal to 10,000 pounds). This research is performed in support of the Intelligent Transportation System initiative that calls for the use of vehicle-to-vehicle (V2V) communications to enhance the safety and mobility of motor vehicles. A crash scenario framework will be created to enable the development and deployment of effective crash-imminent warning systems based on V2V dedicated short-range communications. This report analyzes a total of 17 out of the 37 pre-crash scenarios as a target for V2V-based crash countermeasure systems. These pre-crash scenarios are statistically described in terms of their societal cost, driving environment, driver characteristics, contributing and causal factors, and kinematic information about travel speed, brake application, and deceleration level over a period of five seconds prior to the crash.

A set of five rear-end pre-crash scenarios account for the most harm at about 20 percent of the societal cost of all target V2V pre-crash scenarios. This is followed by a set of three crossing path pre-crash scenarios at junctions accounting for 16 percent of the total societal cost. The third most harmful pre-crash scenarios are the opposite direction at 12 percent.

The driving environment statistics reveal that most crashes occur on straight roads, dry surfaces, in clear weather, and during daylight hours. A large portion of crashes associated with changing lanes/drifting in same direction, lead vehicle moving, and lead vehicle decelerating pre-crash scenarios occur at speed limits greater than or equal to 55 mph. In contrast, a very large portion of crossing-path crashes are reported at speed limits less than or equal to 35 mph.

The breakdown of drivers of interest by age is about 31 percent by younger drivers, 60 percent by middle-age drivers, and 9 percent by older drivers. In terms of gender, the breakdown of drivers of interest is about 56 percent by male drivers and 44 percent by female drivers.

The 2004-2008 GES statistics show that inattention is noted for about 27 percent of all drivers of interest. Alcohol and drugs are reported for about 4 percent of all drivers. Obscured vision is reported by 5 percent of all drivers. Speeding is attributed to 13 percent of all vehicles of interest, mostly in rear-end pre-crash scenarios.

NMVCCS data indicate that about 15 percent of the drivers are inattentive, 10 percent are fatigued, and 13 percent are engaged in conversation. Inadequate surveillance is implicated in 55 percent of all drivers. Following too closely accounts for about 11 percent of the cases. Misjudgement of distance/speed is noted for 8 percent of all drivers. False assumption of other road users' actions is mentioned by 13 percent of all drivers. About 5 percent of all vehicles of interest have inadequate evasive action, with the highest rate reported in opposite-direction scenarios.

The analysis of EDR data reveals that 56 percent of the following vehicles in the 'lead vehicle decelerating' scenario do not brake up to 1 second prior to the crash. This statistic is 34 percent of the vehicles in 'opposite-direction/no maneuver' and 'straight crossing paths at non-signalized junction' pre-crash scenarios. The average effective deceleration level is over 0.6g in the 'lead vehicle moving' and 'lead vehicle decelerating' pre-crash scenarios, when braking was initiated between 2 and 3 seconds before the crash.

The results of this report feed into the crash scenario framework that will be used to identify intervention opportunities and define crash countermeasure profiles based on V2V communications. The statistical and kinematical depiction of target pre-crash scenarios will enable the development of countermeasure functional requirements and minimum performance specifications as well as the estimation of potential safety benefits.

I. INTRODUCTION

This report presents a detailed description of light-vehicle pre-crash scenarios to identify intervention opportunities for crash avoidance systems based on vehicle-to-vehicle (V2V) communications. This analysis is conducted in support of the Intelligent Transportation System's program for safety and mobility applications based on V2V and vehicle-to-infrastructure (V2I) communications [1]. Safety applications will be designed to increase situational awareness and reduce or eliminate crashes through V2V and V2I data transmission that supports driver advisories, driver warnings, and vehicle and/or infrastructure controls. It is envisioned that each vehicle on the roadway (inclusive of automobiles, trucks, transit vehicles, and motorcycles) 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. This report documents the results of a crash analysis that focuses on police-reported crashes involving at least 1 light vehicle (i.e., passenger car, van, minivan, sport utility vehicle, or pickup truck with a gross vehicle weight rating of 10,000 pounds or less). Such results provide a basis for the selection and development of V2V active safety applications that address the most critical crash scenarios.

Understanding pre-crash scenarios contributes to the evolution of advanced-technology safety systems that have been introduced to motor vehicles over the last decade such as brake assist, stability control, adaptive cruise control, and driver warning systems. Pre-crash scenarios depict vehicle movements and dynamics as well as the critical event that occur immediately prior to a crash. An enhanced knowledge database is needed to identify new intervention opportunities, set research priorities and direction in technology development, and evaluate the effectiveness of potential crash countermeasures. Statistical descriptions of pre-crash scenarios provide that knowledge to better define the functions, develop performance guidelines, set up test procedures, and estimate the benefits for active safety technologies such as crash avoidance and crash severity reduction systems based on V2V communications.

I.1. Study Objectives

This study seeks to address three main objectives:

1. Assess the severity of target pre-crash scenarios in terms of annual crash frequency, comprehensive economic costs, and functional years lost.
2. Characterize the crash circumstances, contributing factors, and causes.
3. Quantify the kinematics of pre-crash scenarios in terms of travel speed, brake application, and deceleration level.

The emphasis of the analysis is on crashes involving at least two vehicles in the pre-crash events so as to support V2V-based crash countermeasure concepts that assist drivers in avoiding imminent crashes. Such impending crashes usually arise within a relatively short period of time (i.e., under 10 seconds) from the driver's encounter with hazardous driving conditions. National crash databases are used including the National Automotive Sampling System (NASS) General Estimates System (GES) crash database [2], the National Motor Vehicle Crash Causation Survey (NMVCCS) [3], and the Event Data Recorder (EDR) database that contains a subset of crash cases from the 2000-2008 Crashworthiness Data System (CDS) crash databases [4, 5]. These

specific databases incorporate pre-crash variables that enable the identification of pre-crash scenarios.

I.2. Prior Analyses of Pre-Crash Scenarios

A number of crash typologies have been developed to provide a common foundation for public and private organizations to develop and estimate potential safety benefits of effective crash countermeasure systems. Two crash typologies were widely used for crash avoidance research in support of the Intelligent Vehicle Initiative within the Intelligent Transportation Systems program: "44-crashes" [6, 7] and "pre-crash scenarios" [8].

The "44-crashes" typology was developed by General Motors and adopted by automakers for the design, development, and benefits assessment of potential crash countermeasure technologies. Specific crash scenarios representing all collisions in the United States were identified, and causes associated with each crash scenario were investigated using the 1991 GES crash database and samples of 1990-1991 police-reported crashes from Michigan and North Carolina. Shortcomings of this method for typology generation include the limited study of State crash data and the amount of effort required to replicate the results using recent crash data.

The "pre-crash scenarios" typology was devised by the United States Department of Transportation based primarily on pre-crash variables in the NASS crash databases including the GES and CDS. This typology was utilized to identify intervention opportunities, develop performance guidelines and objective test procedures, and estimate the safety benefits for crash countermeasure systems. Single-vehicle and two-vehicle crashes of common crash types were analyzed to produce the list of representative pre-crash scenarios. Multi-vehicle (> 2) crashes were not included in the analysis. Some low-frequency crash types were also excluded such as vehicle failure, non-collision incidents, and evasive action scenarios. As a result, the "pre-crash scenarios" typology did not account for all police-reported crashes.

A third typology of pre-crash scenarios has been developed for crash avoidance research as shown in Table 1, which combines crash information from both typologies mentioned above [9]. This new typology consists of 37 pre-crash scenarios that depict vehicle movements and dynamics as well as the critical events occurring immediately prior to crashes involving at least 1 light vehicle. The goal of this typology was to establish a common vehicle safety research foundation for public and private organizations, which will allow researchers to prioritize traffic safety issues for further investigation and to develop concomitant crash avoidance systems.

Figure 1 summarizes and links the three crash typologies mentioned above. As seen in Figure 1, a subset of the 37 pre-crash scenarios was deemed applicable to V2V-based crash countermeasure applications. Table 2 lists the 22 target V2V pre-crash scenarios that are described in Section V of this report. The last five scenarios in Table 2, control loss (vehicle action & no vehicle action), backing, parking, and other, are not covered in this report since the scenario might be more efficiently addressed by autonomous vehicle-based systems or because additional V2V data about a vehicle losing control serves as input to advisory systems rather than crash-imminent warning systems.

Table 1. 37 Pre-Crash Scenario Typology

1	Vehicle Failure	21	Vehicle(s) Not Making a Maneuver – Opposite Direction
2	Control Loss with Prior Vehicle Action	22	Following Vehicle Making a Maneuver
3	Control Loss without Prior Vehicle Action	23	Lead Vehicle Accelerating
4	Running Red Light	24	Lead Vehicle Moving at Lower Constant Speed
5	Running Stop Sign	25	Lead Vehicle Decelerating
6	Road Edge Departure with Prior Vehicle Maneuver	26	Lead Vehicle Stopped
7	Road Edge Departure without Prior Vehicle Maneuver	27	Left Turn Across Path from Opposite Directions at Signalized Junctions
8	Road Edge Departure While Backing Up	28	Vehicle Turning Right at Signalized Junctions
9	Animal Crash with Prior Vehicle Maneuver	29	Left Turn Across Path from Opposite Directions at Non-Signalized Junctions
10	Animal Crash without Prior Vehicle Maneuver	30	Straight Crossing Paths at Non-Signalized Junctions
11	Pedestrian Crash with Prior Vehicle Maneuver	31	Vehicle(s) Turning at Non-Signalized Junctions
12	Pedestrian Crash without Prior Vehicle Maneuver	32	Evasive Action with Prior Vehicle Maneuver
13	Pedalcyclist Crash with Prior Vehicle Maneuver	33	Evasive Action without Prior Vehicle Maneuver
14	Pedalcyclist Crash without Prior Vehicle Maneuver	34	Non-Collision Incident
15	Backing Up into Another Vehicle	35	Object Crash with Prior Vehicle Maneuver
16	Vehicle(s) Turning – Same Direction	36	Object Crash without Prior Vehicle Maneuver
17	Vehicle(s) Parking – Same Direction	37	Other
18	Vehicle(s) Changing Lanes – Same Direction		
19	Vehicle(s) Drifting – Same Direction		
20	Vehicle(s) Making a Maneuver – Opposite Direction		

- Vehicle Action refers to a vehicle decelerating, accelerating, starting, passing, parking, turning, backing up, changing lanes, merging, or successful corrective action to a previous critical event.
- Vehicle Maneuver denotes passing, parking, turning, changing lanes, merging, or successful corrective action to a previous critical event.

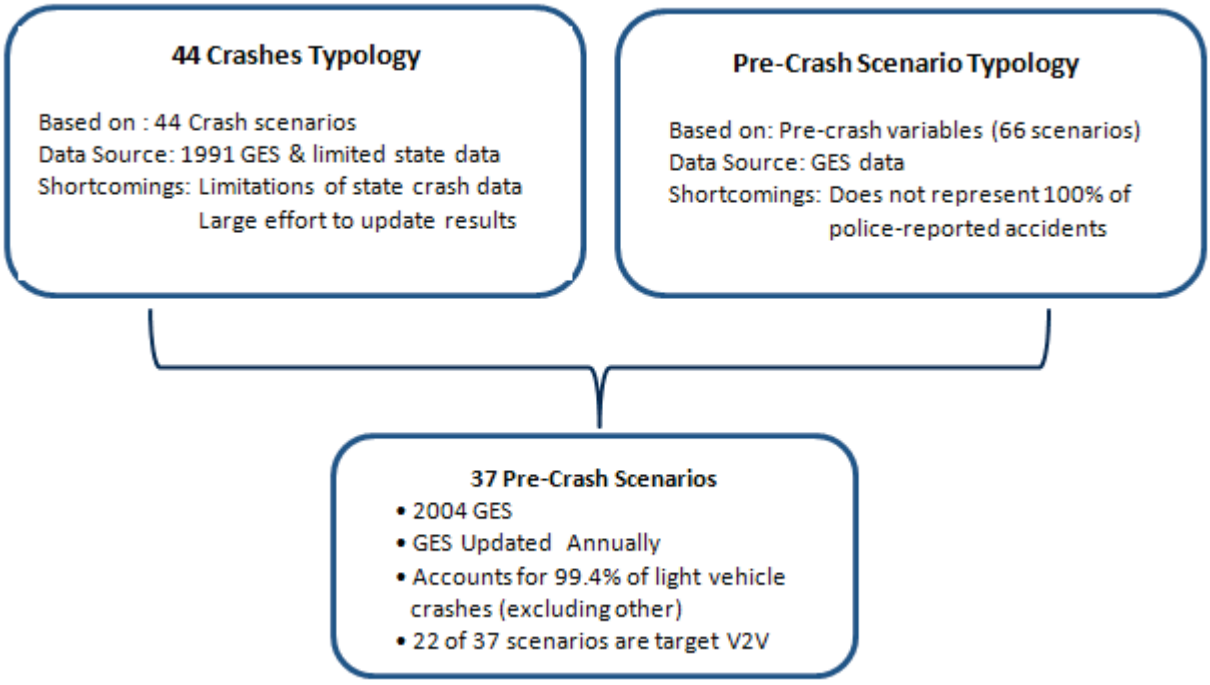


Figure 1. Pre-Crash Scenario Typologies

Table 2. Target V2V Pre-Crash Scenarios

Pre-Crash Scenarios	Used in Analysis
Running Red Light	✓
Running Stop Sign	✓
Turning/Same Direction	✓
Changing Lanes/Same Direction	✓
Drifting/Same Direction	✓
Opposite Direction/Maneuver	✓
Opposite Direction/No Maneuver	✓
Rear-End/Striking Maneuver	✓
Rear-End/Lead Vehicle Accelerating (LVA)	✓
Rear-End/Lead Vehicle Moving at Slower Constant Speed (LVM)	✓
Rear-End/Lead Vehicle Decelerating (LVD)	✓
Rear-End/Lead Vehicle Stopped (LVS)	✓
Left Turn Across Path (LTAP)/Opposite Direction (OD) at Signal	✓
Turn Right at Signal	✓
LTAP/OD at Non Signal	✓
Straight Crossing Path (SCP) at Non-Signal	✓
Turn at Non-Signal	✓
Control Loss/No Vehicle Action	✗
Control Loss/Vehicle Action	✗
Parking/Same Direction	✗
Backing Into Vehicle	✗
Other	✗

I.3. Annual Frequency of Target Pre-Crash Scenarios

Based on statistics from the 2005-2008 GES crash databases, V2V systems 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 [10]. V2V systems predominantly apply to crashes that involve vehicle-to-vehicle pre-crash scenarios. This criterion recognizes that, in general, V2V systems require two equipped vehicles in communication to be effective. The exception to that rule 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 in the Vehicle Safety Communications – Applications (VSC-A) project [11]. If considered as the primary countermeasure, V2V systems have the potential to deal with 76 percent of all crashes involving at least 1 light vehicle. Excluding drivers impaired by alcohol or drowsiness, these systems address 81 percent of all light-vehicle crashes involving unimpaired drivers. About 3 percent of the crashes were not assigned to any crash countermeasure due to the lack of information. The remaining 16 percent of the light-vehicle crashes can be addressed by either V2I or autonomous vehicle (AV) systems or both. Table 3 lists the different criteria used to map applicable crash data to V2V systems as the primary countermeasure and the remaining crashes to V2I and autonomous systems.

Table 3. Mapping of Pre-Crash Scenarios to V2V as Primary Systems

Pre-Crash Scenario	V2V	V2I	AV
No driver present	None	None	None
Vehicle failure	None	None	All Crashes
Control loss/vehicle action	All Crashes	None Remaining	None Remaining
Control loss/no vehicle action	All Crashes	None Remaining	None Remaining
Running red light	2+ Vehicle Crashes	All Remaining Crashes	None Remaining
Running stop sign	2+ Vehicle Crashes	All Remaining Crashes	All Remaining Crashes
Road edge departure/maneuver	None	Speeding Crashes	Conditional Speeding Crashes
Road edge departure/no maneuver	None	Speeding Crashes	All Crashes
Road edge departure/backing	None	None	All Crashes
Animal/maneuver	None	None	All Crashes
Animal/no maneuver	None	None	All Crashes
Pedestrian/maneuver	None	Crosswalk Crashes	All Crashes
Pedestrian/no maneuver	None	Crosswalk Crashes	All Crashes
Cyclist/maneuver	None	None	All Crashes
Cyclist/no maneuver	None	None	All Crashes
Backing into vehicle	All Crashes	None	None
Turning/same direction	All Crashes	None	None Remaining
Parking/same direction	All Crashes	None	None Remaining
Changing lanes/same direction	All Crashes	None	None Remaining
Drifting/same direction	All Crashes	None	None Remaining
Opposite direction/maneuver	All Crashes	None	None Remaining
Opposite direction/no maneuver	All Crashes	None	None Remaining
Rear-end/striking maneuver	All Crashes	None	None Remaining
Rear-end/lead vehicle accelerating	All Crashes	None	None Remaining
Rear-end/lead vehicle constant speed	All Crashes	None	None Remaining
Rear-end/lead vehicle decelerating	All Crashes	None	None Remaining
Rear-end/lead vehicle stopped	All Crashes	None	None Remaining
LTAP/OD @ signal	All Crashes	None Remaining	None
Turn right @ signal	All Crashes	None Remaining	None
LTAP/OD @ non signal	All Crashes	None Remaining	None
SCP @ non signal	All Crashes	None Remaining	None
Turn @ non signal	All Crashes	None Remaining	None
Evasive maneuver/maneuver	Uncertain	Uncertain	Uncertain
Evasive maneuver/no maneuver	Uncertain	Uncertain	Uncertain
Rollover	None	Speeding Crashes	Conditional Speeding Crashes
Noncollision -No impact	None	None	None
Object contacted/maneuver	None	Speeding Crashes	Conditional Speeding Crashes
Object contacted/no maneuver	None	Speeding Crashes	All Crashes
Hit and run	Uncertain	Uncertain	Uncertain
Other Rear-end	All Crashes	None	None Remaining
Other Sideswipe	All Crashes	None	None Remaining
Other - Turn Across Path	All Crashes	None Remaining	None
Other - Turn Into Path	All Crashes	None Remaining	None
Other	Uncertain	Uncertain	Uncertain

LTAP/OD: Left Turn Across Path/Opposite Directions, SCP: Straight Crossing Paths

II. DATA SOURCES

The 2004-2008 GES, NMVCCS, and EDR crash databases were utilized to identify and statistically describe target pre-crash scenarios for V2V-based safety applications.

II.1. General Estimates System

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. This report presents results based on an average annual estimate from yearly crashes over a 5-year period including 2004-2008 datasets. These crash estimates do not account for non-reported crashes. Thus, the national estimates produced from the GES data may differ from the true population values because they are based on a probability sample of police-reported crashes rather than a census of all crashes. The GES was selected for this study due to the following characteristics:

- Nationally representative
- Updated annually
- Variables about the crash type and pre-crash attributes that enable the identification of dynamically distinct scenarios
- Descriptive variables of the environmental and driving conditions at the time of the crash, driver and vehicle contributing factors, and injury levels of persons involved

II.1.a. Identification of Pre-Crash Scenarios

Appendix A presents the coding scheme to identify common pre-crash scenarios leading to all single-vehicle and multiple-vehicle crashes based on GES variables and codes. A total of 46 pre-crash scenarios are listed starting with scenarios associated with crash contributing factors such as vehicle control loss and driver violation of a red light or stop sign (numbers 2-6). The 46 scenarios were narrowed down to the core 37 pre-crash scenarios by combining the 7 "other" scenarios and eliminating the Rollover and Hit & Run scenarios. The remaining 37 scenarios result in different crash types. For example, loss of vehicle control due to excessive speed could lead to a vehicle running off the road, rear-ending another vehicle, or encroaching into another lane and side-swiping an adjacent vehicle. From a crash-avoidance perspective, the problem of vehicle control loss is identical in all three cases. A potential crash countermeasure function would detect the excessive speed or the imminent loss of control regardless of what crash type these conditions might lead to. Therefore, scenarios based on crash contributing factors in Appendix A supersede remaining scenarios that represent dynamically distinct driving situations based on vehicle movements and dynamic states. The 37 pre-crash scenario typology was created by deducting the scenarios in the same order listed in Appendix A using the process of elimination. The sum of the resulting frequency distribution adds to 100 percent, eliminating double counting of crashes in each of the scenarios.

The Accident Type, Movement Prior to Critical Event, and Critical Event variables from the GES Vehicle File were primarily used to identify dynamically-distinct pre-crash scenarios. The first event in a crash from the GES Event File helped to distinguish pre-crash scenarios in multi-

vehicle crashes. In addition to these variables, the coding schemes utilize the following GES variables:

- Traffic Control Device: what type of traffic control device, if any, was present?
- Violations Charged: any violations for which the drivers were cited.
- First Harmful Event: first property damaging or injury-producing event in the crash.
- Crash Event Sequence Number: number assigned to each harmful event in a crash, in chronological order.
- Vehicle Number-This Vehicle: number assigned to an in-transport motor vehicle involved in the event.
- Vehicle Number-Other Vehicle or Object Contacted: vehicle number of the other vehicle or object hit, or the type of non-collision involved in the event.
- Vehicle Role: vehicle role (e.g., striking, struck) in single or multiple vehicle crashes.
- Rollover Type: indicates if a rollover occurred and whether it was tripped or untripped. Rollover is defined as any vehicle rotation of 90 degrees or more about any true longitudinal or lateral axis. Rollover can occur at any time during the crash.
- Hit and Run: indicates that a motor vehicle in transport or its driver departed the scene; vehicles not in transport are excluded. It does not matter whether the hit-and-run vehicle was striking or struck.
- Number of Vehicles Involved: number of vehicles involved in the crash.

The following GES variables and codes were queried to identify the light vehicle:

- Body Type (Hot-Deck Imputed) = 01 – 22, 28 – 41, and 45 – 49
- Special Use: Indicates whether the vehicle has a special use (not necessarily emergency use).

II.1.b. Description of GES Descriptive Variables

Table 4 lists the GES descriptive variables used in this analysis. The descriptions of each variable are grouped according to driving environment, driver characteristics, and driver and vehicle contributing factors.

The descriptions of variables that are categorized into driving environment are as follows:

- ROADWAY ALIGNMENT (imputed): horizontal alignment of roadway.
    - Straight
    - Curve
- ROADWAY SURFACE CONDITION (imputed): condition of road surface at the time of the crash.
    - Dry
    - Wet/slippery – wet; snow or slush; ice; sand, dirt, and oil; and other.

Table 4. GES Descriptive 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

- ATMOSPHERIC CONDITIONS (imputed): general atmospheric conditions at the time of crash.
    - Clear – no adverse conditions
    - Adverse – rain; sleet; snow; fog; rain and fog; sleet and fog; and other (smog, smoke, blowing sand/dust/snow, crosswind, and hail).
- RELATION TO JUNCTION (imputed): indicates if the first harmful event is located within a junction or interchange area. If the first harmful event occurs off the roadway, the location classified is the point of departure. (Non-interchange area and interchange area are combined).
    - Non-junction
    - Intersection/intersection related
    - Driveway, alley access, etc.
    - Entrance/exit ramp
    - Rail grade crossing
    - On a bridge
    - Crossover related
    - Other

- TRAFFIC CONTROL DEVICE (imputed): indicates whether or not a traffic control device was present for the crash and the type of traffic control device.
    - No traffic controls

  Not at Railroad Grade Crossing

  Trafficway Traffic Signals:
    - 3 color traffic signal
    - Other traffic signal type - flashing traffic control signal or flashing beacon; other traffic signal; and unknown traffic signal.

  Regulatory, School Zone Signs:
    - Stop sign
    - Other sign type - yield sign; school zone related sign; other sign; unknown sign.

  Warning Signs:
    - Other sign type (cont.) - advisory speed sign; warning sign for road conditions (hill, steep grade, etc.); warning sign for road construction; warning sign for environment/traffic (fog ahead, wind, crash ahead, etc.); and unknown type warning.

  Miscellaneous, Not at Railroad Crossing:
    - Officer, crossing guard, flagman, etc.

  At Railroad Grade Crossing
    - RR crossing device - active devices (e.g., gates, flashing lights, traffic signal) and passive devices (e.g., stop sign, cross bucks).

  Other:
    - Other - traffic control present - no details and other traffic control (whether or not at RR grade crossing).
- LIGHTING CONDITION (imputed): general light conditions at the time of the crash, including light from external roadway illumination fixtures.
    - Daylight
    - Dark
    - Dark but lighted
    - Dawn/dusk
- SPEED LIMIT (imputed): posted speed limit in miles per hour.

The following two variables describe driver characteristics:

- AGE (imputed): indicates the person's age at the time of the crash, with respect to the person's last birthday.
- GENDER (imputed): indicates the police reported gender for this person.
    - Male
    - Female

Crash contributing factors attributed to the driver or vehicle are obtained from these variables:

- POLICE-REPORTED ALCOHOL INVOLVEMENT (imputed): indicates that the person (drivers of in-transport motor vehicles and non-motorists only) had consumed an alcoholic beverage. This variable does not indicate that alcohol was a cause of the crash.

If a police report indicates that opened or unopened alcohol bottles were found in the vehicle, then this information does not by itself constitute involvement.
    - No alcohol
    - Alcohol
- POLICE-REPORTED DRUG INVOLVEMENT*:* indicates that the person (drivers of in-transport motor vehicles and non-motorists only) had taken drugs. Involvement is not an indication that drugs were or were not a cause of the crash. If the police report indicates that drugs were found in the vehicle, then this information does not by itself constitute involvement.
    - No drugs
    - Drugs
    - Unknown - not on police report; not coded; and unknown (police reported)
- PERSON'S PHYSICAL IMPAIRMENT*:* Identifies physical impairments for all drivers and non-motorists which may have contributed to the cause of the crash.
    - None
    - Ill, blackout
    - Sleepy - drowsy, sleepy, fell asleep, fatigued
    - Other - requires cane or crutches, paraplegic or restricted to wheelchair, impaired due to previous injury, deaf, blind, physical impairment - no details, and other physical impairments.
    - Unknown - hit & run (and no information); not on police report; not coded; and unknown if physically impaired.
- VIOLATIONS CHARGED (imputed): indicates which violations are charged to drivers.
    - No – no violations
    - Yes - alcohol or drugs; speeding; alcohol or drugs and speeding; reckless driving; driving with a suspended or revoked license; failure to yield right-of-way; running a traffic signal or stop sign; violation charged-no details; and other violation.
- SPEED RELATED**:** indicates whether speed is a contributing factor to the cause of the crash.
    - No
    - Yes
    - Unknown
- DRIVER'S VISION OBSCURED BY*:* identifies visual circumstances that may have contributed to the cause of the crash.
    - No obstruction
    - Obstruction - rain, snow, smoke, sand, dust; reflected glare, bright sunlight, headlights; curve or hill; building, billboard, or other design features (includes signs embankment); trees, crops, vegetation; moving vehicle (including load); parked vehicle; splash or spray of passing vehicle; inadequate defrost or defog system; inadequate lighting system; obstruction interior to vehicle; external mirrors; head restraints; broken or improperly cleaned windshield; fog; vision obscured-no details; and other obstruction.
    - Unknown - hit & run vehicle (and no information); not on police report; not coded; and unknown whether vision was obstructed.

- DRIVER DISTRACTED BY: identifies all distractions which may have influenced driver performance and contributed to the cause of the crash. The distraction can be either inside the vehicle (internal) or outside the vehicle (external).
    - No distraction
    - Distraction - looked but did not see; by other occupants; by moving object in vehicle; while talking or listening to phone; while dialing phone; while adjusting climate control; while adjusting radio, cassette or CD; while using other devices integral to vehicle; while using or reaching for other devices; distracted by outside person or object; eating or drinking; smoking related; other cellular phone related; distraction or inattention, details unknown; inattentive or lost in thought; other distraction.
    - Sleepy - sleepy or fell asleep
    - Unknown - hit & run (and no information); not on police report; not coded; and unknown if distracted.
- VEHICLE CONTRIBUTING FACTORS: indicates vehicle factors that may have contributed to the cause of the crash.
    - No contributing factors
    - Vehicle contributing factors – tires, brake system, steering system-tie rod, kingpin, ball joint, etc.; suspension-springs, shock absorbers, McPherson struts, control arms, etc.; power train-universal joint, drive shaft, transmission, etc.; exhaust system; headlights; signal lights; other lights; wipers; wheels; mirrors; driver seating and control; body, doors; trailer hitch vehicle contributing factors-no details; and other vehicle contributing factors.
    - Unknown - hit-and-run vehicle and unknown if vehicle has contributing factors.

Driver action is obtained from this variable:

- CORRECTIVE ACTION ATTEMPTED: indicates the maneuver attempted by the driver of interest just prior to the crash.
    - No Avoidance Maneuver
    - Braking - braking with lockup, braking without lockup, braking with unknown lockup, releasing brakes
    - Steering - steering to right, steering to left
    - Braking and Steering - braking and steering right, braking and steering left
    - Accelerating - accelerating straight, accelerating to right, accelerating to left
    - Other action attempted.

It should be noted that imputed variables in the GES were used to account for unknown information, when available. The GES employs two different statistical procedures to identify values for unknown data: univariate imputation and hot-deck imputation. If imputed values were not available, the unknowns were imputed using the univariate method [12].

II.2. National Motor Vehicle Crash Causation Survey

The objective of NMVCCS was to collect on-scene information on the events and associated factors leading up to crashes that involve light vehicles. This information facilitates the statistical and clinical analyses that would help identify, develop, as well as evaluate current and

emerging crash avoidance technologies for the improvement of highway safety [13]. NMVCCS had strict guidelines for a crash to qualify for an on-scene investigation. Only crashes occurring between 6 a.m. and midnight were considered for possible investigation. Taking into consideration the operational and statistical issues, a crash must meet the following criteria in order to qualify for an investigation:

- Crash must have resulted in a harmful event associated with a vehicle in transport on a trafficway.
- Emergency medical services must have been dispatched to the crash scene.
- At least one of the first three crash-involved vehicles must be present at the crash scene when the NMVCCS researcher arrives.
- The police must be present at the scene of the crash when the NMVCCS researcher arrives.
- One of the first three vehicles involved in the crash was a light passenger vehicle that was towed.
- A completed police accident report for this crash must be available.

NMVCCS database contains over 600 data elements including narratives, diagrams, and schematics.

II.2.a. General NMVCCS Statistics

NMVCCS collected data on a total of 6,949 crashes during a three-year period, January 2005 to December 2007. Of these, 5,470 crashes comprised a nationally representative sample. The remaining 1,479 crashes were meant for clinical studies. Based on the weights attached to the sample of 5,470 crashes, at the national level, this sample represented an estimated 2,188,969 crashes involving 3,944,621 drivers and 4,031,075 vehicles.

The NMVCCS data provide detailed information about different aspects of the crash: pre-crash movement, critical pre-crash event, critical reason, and associated factors. About 41 percent of the driver-related critical reasons were recognition errors that include inattention, internal and external distractions, inadequate surveillance, etc. About 33 percent of the driver-related critical reasons were decision errors that included too fast for conditions, too fast for curve, false assumption of others' actions, illegal maneuver, and misjudgment of gap or others' speed. In about ten percent of the crashes, the critical reason was a performance error such as over-compensation, poor directional control, etc. Among the non-performance errors by drivers in about seven percent of the crashes, sleep was the most common critical reason.

II.2.b. Description of NMVCCS Variables

Table 5 lists the NMVCCS variables that were investigated in this study.

Table 5. Key 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 CRITICAL REASON FOR THE CRITICAL PRECRASH EVENT establishes the critical reason for the occurrence of the critical pre-crash event. The critical reason is the immediate reason for this event and is often the last failure in the causal chain (i.e., closest in time to the critical pre-crash event). Although the critical reason is an important part of the description of crash events, it is not the cause of the crash nor does it imply the assignment of fault:

- No critical reason
- Sleepy - sleeping, that is, actually asleep.
- Ill/blackout - heart attack or other physical impairment of the ability to act.
- Driver error - inattention (i.e., daydreaming); internal distraction; external distraction; inadequate surveillance (e.g., failed to look, looked but did not see); too fast for conditions; too fast to be able to respond to unexpected actions of others; too fast for curve/turn; misjudgment of gap or other's speed; following too closely to respond to unexpected actions; false assumption of other's actions; illegal maneuver; inadequate evasive action, e.g. braking only, not braking and steering; incorrect evasive action; aggressive driving behavior; turned with obstructed view; panic/freezing; overcompensation; poor directional control (e.g., failing to control vehicle with skill ordinarily expected); type of driver error unknown; other decision error; other performance error; unknown performance error; unknown decision error; other recognition error; unknown recognition error; other critical non-performance; and unknown critical non-performance.
- Vehicle issues - brakes failed; degraded braking capability; tires/wheels failed; steering failed; transmission/engine failure; vehicle related vision obstructions; other vehicle failure; and other tire degradation.
- Weather /road /sign-signal issues – signs/signals missing; signs/signals erroneous/defective; signs/signals inadequate; view obstructed by roadway design/furniture; view obstructed by other vehicles; slick roads (low friction road surface due to ice, loose debris, any other cause); rain, snow; fog; glare; blowing debris; and other highway-related condition.

The FATIGUE variable assesses if the driver was fatigued at the time of the crash based on an evaluation of the driver's current and preceding sleep schedules, current and preceding work schedules, and a variety of other fatigue related factors including recreational and non-work activities:

- Driver not fatigued
- Driver fatigued

The variables of driver recognition errors are:

- DRIVER INATTENION: documents if the driver was inattentive due to focusing on concerns and the nature of those concerns:
  - No inattention factors
  - Inattention factors - personal problem; family problem; financial problem; preceding argument; future event (e.g., vacation, wedding, etc.); inattentive, thought focus unknown; and other.
  - Unknown
- DRIVER CONVERSING: establishes if the driver was participating in conversation during the pre-crash phase:
  - Not conversing
  - Conversing - conversing with passenger; talking on phone; talking on CB radio; and other.
  - Unknown
- INADEQUATE SURVEILLANCE: identifies inadequate surveillance actions on the part of the driver:
  - No inadequate surveillance factors
  - Inadequate surveillance factors - failed to look far enough ahead; failed to look either side ahead; failed to look to side; failed to look to rear (mirrors); failed to look-other; looked, but did not see; failed to see traffic control device; and other.
  - Unknown
- OTHER DRIVER RECOGNITION FACTOR: establishes the occurrence of other recognition factors related to this driver:
  - No other recognition factors
  - Other recognition factors - impending problem masked by traffic flow pattern; driver focused on extraneous vehicle; and other recognition error.
  - Unknown

Driver decision errors are described by the following variables:

- MISJUDGEMENT OF DISTANCE OR SPEED OF OTHER VEHICLE: identifies the involvement of a decision error in which the driver either misjudged the gap distance to the other vehicle or misjudged the velocity of the other vehicle:
  - No misjudgment factors
  - Misjudgment factors - misjudgment of gap distance; misjudgment of velocity of other vehicle; and misjudgment of both factors.
  - Unknown

- FALSE ASSUMPTION OF OTHER ROAD USER'S ACTION: establishes if and how the driver made a false assumption about the other driver's action:
    - No false assumption factors
    - False assumption factors - assumed that other driver would merge without stopping; assumed that other driver would turn without stopping; assumed that other driver would continue to proceed; assumed that other driver would yield right-of-way; assumed that other driver would turn; and other false assumption factors.
    - Unknown
- FOLLOWING TOO CLOSELY: documents reasons given by the driver for traveling with less than the recommended gap interval to traffic forward of the driver's position:
    - No following too closely factors
    - Following too closely factors - congested traffic; keeping up with traffic; did not realize he/she was too close to forward vehicle; always drive at this gap distance; and other.
    - Unknown
- OTHER DRIVER DECISION FACTOR: identifies driver decision errors relevant to the crash that are not captured by other variables that deal with driver decision factors (e.g., Following Too Closely):
    - No other decision factors
    - Other decision factors - crossed with obstructed view; turned with obstructed view; stopped when not required; proceeded with insufficient clearance; turned without signaling; and other decision error.
    - Unknown

As for driver action, the INADEQUATE/INCORRECT EVASIVE ACTION variable identifies inadequate evasive actions on the part of the driver. This variable does not deal with legal requirements and the final assessment may be subjective:

- No inadequate evasive action factors
- Inadequate evasive action factors - insufficient steering inputs; insufficient braking inputs; combination of insufficient steering and braking inputs; chose inappropriate/unsuccessful evasive action; and other insufficient evasive action.
- Unknown

II.3. Event Data Recorder Dataset

This study analyzed records from EDRs to quantify driver speed and braking response to an imminent crash in a quantitative way from five seconds before the crash. Available EDR pre-crash variables of travel speed and brake switch were utilized. A sample of vehicle cases from the 2000-2007 CDS databases with available EDR data was included in the analysis. All these vehicles were made by General Motors (GM). Comparative assessment was conducted to evaluate the goodness of data for some similar variables recorded by EDRs and reported by the CDS [5]. The accuracy of EDR data was examined in a range of crash test scenarios for model year 2004-2007 cars and light trucks [14]. EDR data were downloaded from 48 crash-tested vehicles with test speeds ranging from 25 mph to 40 mph. This study found that the average time between the impact and the time of EDR algorithm wakeup was 17.7 milliseconds.

Moreover, the pre-crash speed of the vehicle as recorded by the EDR was always within three percent of the test speed.

EDRs from GM vehicles record and store pre-crash data such as brake switch status and vehicle speed at one second increments for five seconds from the start of a triggering event (i.e., crash). The analysis in this report assumes that the start of this triggering event coincides with the exact instant of the collision; i.e., time-to-collision (TTC) equals to zero. Thus, brake and speed data are recorded at TTC from five seconds to one second. The EDR variables included in the analysis are:

- PRE-CRASH BRAKE STATUS: documents the status of the brake switch activation prior to the crash at one second interval as recorded by the EDR:
    - On
    - Off
    - Unknown
- CRASH VEHICLE SPEED READING: documents the pre-crash vehicle speed reading in mph at one second interval as recorded by the EDR.

The intensity of braking exerted by the vehicles is 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.

Quantitative crash data on speed, driver braking response, and brake intensity support the development of crash countermeasure system performance guidelines and objective test procedures, 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. System effectiveness is typically estimated for each target pre-crash scenario based on different travel speed ranges. In order to predict the national number of crashes that these systems might avoid, system effectiveness in a specific speed range is multiplied with the number of target crashes that occur at that speed range. Due to deficient data on pre-crash travel speed in national crash databases, posted speed limit information was used as a surrogate for travel speed. This led to a rough approximation of safety benefits estimates. Availability of reliable speed information in national crash databases will enhance the full understanding of safety benefits.

III. LIGHT-VEHICLE PRE-CRASH SCENARIO STATISTICS

Target V2V pre-crash scenarios are statistically described in terms of their societal cost, driving environment, driver characteristics, crash contributing factors, and causes based on the 2004-2008 GES and NMVCCS crash databases.

III.1. Societal Cost

Societal cost of target pre-crash scenarios is estimated from the 2004-2008 GES data by two harm measures: comprehensive economic costs and functional years lost. The functional years lost harm measure was selected for this analysis over other measures such as "equivalent lives" in order to harmonize with automakers who have been using this measure in their crash avoidance research. These harm measures are derived from the maximum injury severity of all injured people involved in a specific crash scenario according to the Abbreviated Injury Scale (AIS). The AIS is a classification system for assessing impact injury severity developed by the Association for the Advancement of Automotive Medicine. It provides the basis for stratifying the economic costs and functional years lost of crashes by injury severity. The Maximum Abbreviated Injury Scale (MAIS) is a function of AIS on a single injured person, which measures overall maximum injury severity.

III.1.a. Injury Severity Scale Conversion

The GES does not provide detailed information regarding injury severity based on the AIS coding scheme. Instead, the GES records injury severity by crash victim on the KABCO scale from police crash reports. Police reports in almost every state use KABCO to classify crash victims as K – killed, A – incapacitating injury, B – non-incapacitating injury, C – possible injury, O – no apparent injury, or ISU – Injury Severity Unknown. The KABCO coding scheme allows non-medically trained persons to make on-scene injury assessments without a hands-on examination. However, KABCO ratings are imprecise and inconsistently coded between states and over time. To estimate injuries based on the MAIS coding structure, a translator derived from 1982–1986 NASS and 2000-2007 CDS data was applied to the GES police-reported injury profile as shown in Table 6 [15].

Table 6. MAIS-KABCO Conversion Matrix

	Police-Reported Injury Severity System						
MAIS	O	C	B	A	K	U	
	No Injury	Possible Injury	Non Incapacitating	Incapacitating	Fatality	Injured, Severity Unknown	Unknown
0	0.92458	0.23203	0.06995	0.03341	0	0.22274	0.42883
1	0.07329	0.69145	0.78039	0.55819	0	0.61725	0.41108
2	0.00201	0.06413	0.11026	0.20748	0	0.10289	0.08667
3	0.00009	0.01061	0.0308	0.1407	0	0.04072	0.04748
4	0	0.00148	0.0063	0.03859	0	0.00418	0.00609
5	0.00003	0.00012	0.0009	0.01702	0	0.01174	0.00277
Killed	0	0.00018	0.0014	0.00461	1	0.00048	0.01708
Total	1	1	1	1	1	1	1

Source: 1982-1986 Old NASS and 2000-2007 CDS

It should be noted that the National Highway Traffic Safety Administration recommends that fatal crashes and fatalities be extracted from the Fatality Analysis Reporting System (FARS), not GES, since it contains records on all fatal traffic crashes and thus provides a more accurate representation of fatal crashes and fatalities than the sample contained in the GES. This report, however, counts fatalities from the GES because FARS does not contain the Accident Type and Critical Event variables needed to identify pre-crash scenarios.

III.1.b. Comprehensive Costs and Functional Years Lost

Comprehensive economic costs account for goods and services that must be purchased or productivity that is lost as a result of motor vehicle crashes [16]. Intangible consequences of these events to individuals and families, such as pain and suffering or loss of life, are not included. Comprehensive costs encompass medical, emergency medical service, market productivity, household productivity, insurance administration, workplace productivity, legal and court, travel delay, and property damage costs. In addition, comprehensive costs include the value of quality-adjusted life-years. Figure 2 illustrates the values of comprehensive cost associated with each MAIS level based on 2007 economics.

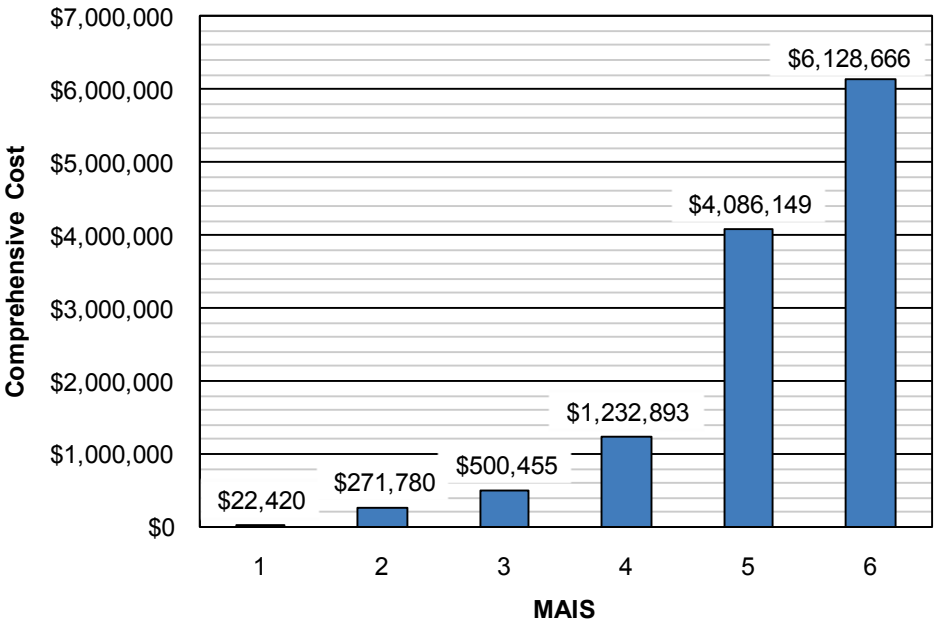


Figure 2. Values of Comprehensive Cost by MAIS Level

Functional years lost is a non-monetary measure that sums the years of life lost to fatal injury and the years of functional capacity lost to nonfatal injury [17]. This measure does not mirror the monetary economic cost. It assigns a different value to the relative severity of injuries suffered from motor vehicle crashes. Figure 3 shows the values of functional years lost associated with each MAIS level.

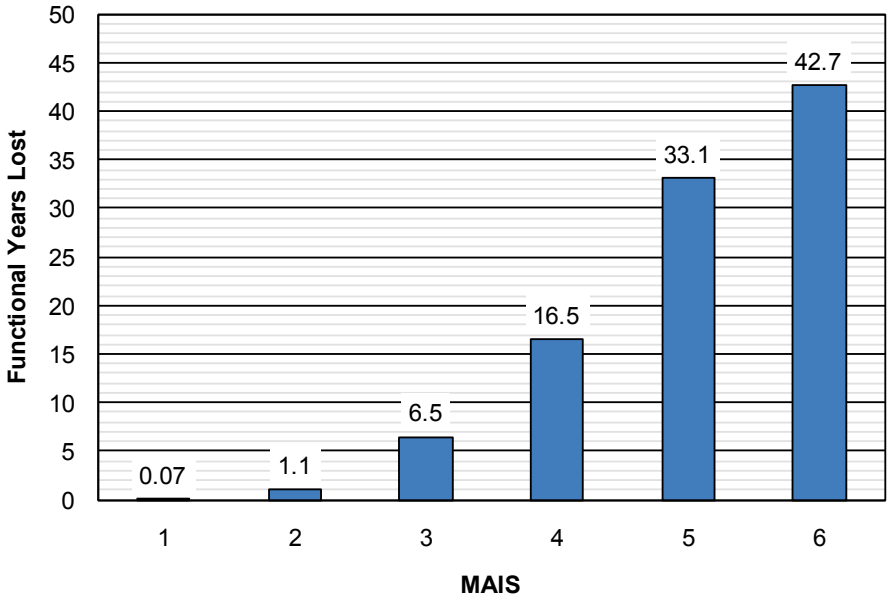


Figure 3. Values of Functional Years Lost by MAIS Level

III.1.c. Crash Severity Statistics

Table 7 provides the annual values of comprehensive costs and functional years lost for 22 target pre-crash scenarios involving at least 1 light vehicle based on 2004-2008 GES crash statistics of injured persons. It is noteworthy that these cost estimates reflect the injury levels of persons involved in police-reported crashes only. This analysis excludes the cost of crashes that were not reported to the police. The top four pre-crash scenarios that individually account for over ten percent of the total cost are listed below in a descending order by the comprehensive cost:

1. Control loss without any vehicle action in the pre-event movement
2. Straight crossing paths at non-signalized junctions
3. Lead vehicle stopped
4. Opposite direction without any vehicle attempting a maneuver in the pre-event movement

Collectively, the top four most harmful pre-crash scenarios comprise about 60 percent of the total comprehensive costs and functional years lost. Figure 4 illustrates the ranking of the 22 pre-crash scenarios based on comprehensive costs. The top ten pre-crash scenarios, each accounting for over three percent of the total cost, result in 89 percent of the total comprehensive costs and functional years lost.

The two control loss pre-crash scenarios account for slightly over a quarter of the total comprehensive costs (26.1%) and functions years lost (26.7%). These scenarios are currently addressed by stability control systems. In addition, the VSC-A project investigated a crash countermeasure that provides an advisory message to the vehicles surrounding the vehicle experiencing the control loss. Since the crash risk to the surrounding vehicles may or may not be imminent, this report does not consider these control loss pre-crash scenarios for V2V-based crash-imminent warning applications and, therefore, does not statistically describe their driving environment and crash contributing factors and causes.

Table 7. Societal Cost and Ranking of Target Light-Vehicle Pre-Crash Scenarios

PRE_CRASH SCENARIO	Light Vehicles V2V Crashes					
	Comprehensive Cost			Functional Years Lost		
	Total	Percentage	Rank	Total	Percentage	Rank
Control loss/no vehicle action	$ 64,744,000,000	23.5%	1	469,000	24.1%	1
SCP @ non signal	$ 41,095,000,000	14.9%	2	292,000	15.0%	2
Rear-end/LVS	$ 29,716,000,000	10.8%	3	198,000	10.2%	4
Opposite direction/no maneuver	$ 29,558,000,000	10.8%	4	213,000	11.0%	3
Running red light	$ 18,274,000,000	6.6%	5	129,000	6.6%	5
LTAP/OD @ non signal	$ 15,481,000,000	5.6%	6	111,000	5.7%	6
LTAP/OD @ signal	$ 14,777,000,000	5.4%	7	105,000	5.4%	7
Rear-end/LVD	$ 12,215,000,000	4.4%	8	82,000	4.2%	8
Rear-end/LVM	$ 10,342,000,000	3.8%	9	72,000	3.7%	9
Changing lanes/same direction	$ 8,414,000,000	3.1%	10	60,000	3.1%	10
Control loss/vehicle action	$ 7,148,000,000	2.6%	11	51,000	2.6%	11
Turning/same direction	$ 6,176,000,000	2.2%	12	43,000	2.2%	12
Opposite direction/maneuver	$ 3,500,000,000	1.3%	13	25,000	1.3%	13
Drifting/same direction	$ 3,483,000,000	1.3%	14	25,000	1.3%	13
Running stop sign	$ 3,075,000,000	1.1%	15	22,000	1.1%	15
Rear-end/striking maneuver	$ 2,381,000,000	0.9%	16	16,000	0.8%	16
Parking/same direction	$ 1,095,000,000	0.4%	17	8,000	0.4%	17
Turn @ non signal	$ 930,000,000	0.3%	18	6,000	0.3%	18
Turn right @ signal	$ 908,000,000	0.3%	19	6,000	0.3%	18
Backing into vehicle	$ 874,000,000	0.3%	20	6,000	0.3%	18
Rear-end/LVA	$ 667,000,000	0.2%	21	5,000	0.3%	21
Other	$ 76,000,000	0.0%	22	-	0.0%	22
All	**$ 274,929,000,000**	**100.0%**		**1,944,000**	**100.0%**	

SCP: Straight Crossing Paths, LVS: Lead Vehicle Stopped, LVD: Lead Vehicle Decelerating, LTAP/OD: Left Turn Across Path/Opposite Directions, LVM: Lead Vehicle Moving, LVA: Lead Vehicle Accelerating

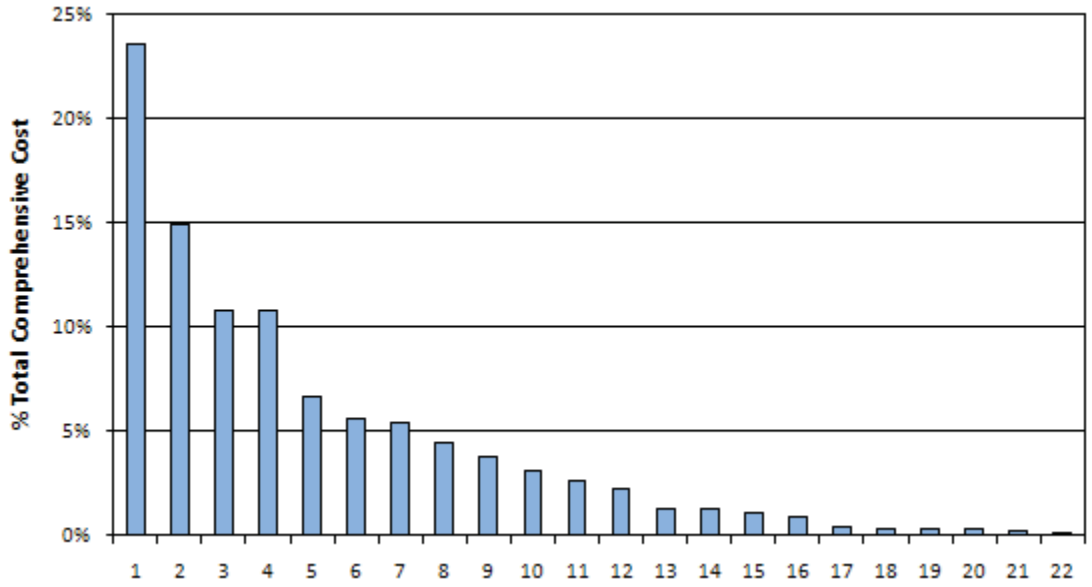


Figure 4. Relative Comprehensive Costs of Target Light-Vehicle Pre-Crash Scenarios by Rank

III.2. Driving Environment

The driving environment of target pre-crash scenarios was described by four categories comprised of different variables in the GES Accident Data Set:

- Roadway alignment × roadway surface condition × atmospheric condition
- Relation to junction × traffic control device
- Lighting condition
- Posted speed limit

Table 8 provides the relative frequency of crashes occurring under main conditions of the driving environment for each of the target V2V pre-crash scenarios. The list of pre-crash scenarios in Table 8 excludes the control loss pre-crash scenarios for reasons provided earlier in this section of the report. Also excluded are the "parking/same direction", "backing into vehicle", and "other" pre-crash scenarios due to their very low contribution to the comprehensive costs (0.74%) and functional years lost (0.72%).

The following are key observations from Table 8:

- Most crashes occur on a straight road and dry surface in clear weather. The opposite direction/no maneuver pre-crash scenario happens more on a curved road and dry surface under clear weather than any other target pre-crash scenario.
- Many rear-end pre-crash scenarios are reported at intersections controlled by 3-color signals, especially lead vehicle stopped and lead vehicle accelerating scenarios. A large portion of the left turn across path/opposite direction (LTAP/OD) at non-controlled junction pre-crash scenario happens at driveways or alleyways.
- Most crashes occur in daylight. Opposite direction pre-crash scenarios happen more in dark conditions than any other scenario. Moreover, a large portion of the LTAP/OD at controlled junction pre-crash scenario is occurring in non-daylight conditions.
- A large portion of crashes associated with changing lanes/same direction, drifting/same direction, lead vehicle moving, and lead vehicle decelerating pre-crash scenarios occurs at speed limits greater than or equal to 55 mph. In contrast, a very large portion of crashes tied to running stop sign, turning/same direction, and LTAP/OD, straight crossing paths, and turning at non-controlled junction pre-crash scenarios is reported at speed limits less than or equal to 35 mph.

Table 8. Statistical Description of Driving Environment in Target Light-Vehicle V2V Pre-Crash Scenarios

Pre-Crash Scenario	Road Alignment x Surface Condition x Atmospheric Condition			Relation to Junction x Traffic Control Device						Lighting Condition			Posted Speed Limit (MPH)		
	Straight, Dry, Clear	Straight, Slippery, Adverse	Curved, Dry, Clear	Non-Junction, No traffic Controls	Intersection, No traffic Controls	Intersection, RGY Traffic Signal	Intersection, Stop Sign	Driveway, Alley Access, etc., No traffic Controls	Other, Other Sign Type	Day light	Dark	Dark but Lit	≤ 35	35 to 55	≥ 55
Running Red Light	79%	12%	2%	-	-	94%	-	-	-	74%	3%	21%	53%	47%	<1%
Running Stop Sign	79%	11%	3%	-	-	-	98%	-	-	76%	8%	13%	70%	28%	2%
Turning/Same Direction	78%	9%	6%	6%	25%	26%	4%	25%	1%	80%	4%	13%	59%	39%	2%
Changing Lanes/Same Direction	78%	9%	6%	65%	6%	11%	<1%	<1%	<1%	75%	6%	15%	36%	42%	23%
Drifting/Same Direction	71%	12%	8%	60%	7%	15%	<1%	2%	<1%	71%	8%	18%	38%	39%	23%
Opposite Direction/Maneuver	60%	15%	13%	70%	9%	7%	2%	<1%	-	62%	17%	18%	43%	52%	5%
Opposite Direction/No Maneuver	47%	10%	26%	78%	4%	4%	<1%	<1%	-	67%	16%	13%	49%	47%	3%
Rear-End/Striking Maneuver	65%	8%	19%	28%	7%	25%	3%	3%	11%	79%	4%	14%	40%	47%	12%
Rear-End/LVA	79%	8%	6%	16%	4%	56%	7%	<1%	2%	80%	3%	14%	40%	55%	5%
Rear-End/LVM	76%	12%	5%	58%	7%	18%	1%	2%	<1%	75%	8%	14%	35%	45%	21%
Rear-End/LVD	74%	13%	5%	47%	11%	19%	2%	5%	<1%	82%	5%	10%	33%	50%	17%
Rear-End/LVS	74%	13%	5%	29%	9%	37%	5%	2%	<1%	81%	4%	12%	42%	51%	7%
LTAP/OD at Signal	81%	11%	2%	-	-	97%	-	-	-	66%	3%	26%	50%	50%	<1%
LTAP/OD at Non Signal	80%	8%	5%	<1%	41%	-	9%	35%	<1%	79%	4%	13%	55%	44%	<1%
Turn Right at Signal	74%	16%	3%	-	-	90%	-	-	-	70%	3%	25%	51%	49%	<1%
SCP at Non Signal	77%	11%	4%	<1%	9%	-	52%	25%	<1%	80%	4%	12%	60%	38%	1%
Turn at Non Signal	78%	10%	5%	7%	21%	-	31%	22%	<1%	78%	5%	13%	61%	38%	2%

III.3. Driver Characteristics

Driver characteristics were obtained for drivers of interest who were charged with traffic control device violation, attempted a maneuver, or were in the following vehicles in rear-end pre-crash scenarios. Table 9 provides the codes to identify the vehicle/driver of interest from the GES, NMVCCS, and CDS (EDR data). In addition to driver characteristics, crash contributing factors and causes were also obtained from the vehicle/driver of interest.

Table 9. Vehicle/Driver of Interest Identification Codes

Pre-Crash Scenario	Vehicle Criteria
Running red light	AND MVIOLATN = 7
Running stop sign	AND MVIOLATN = 7
Turning/same direction	AND (MANEUV_I = 10 - 12 OR ACC_TYPE = 70, 72)
Changing lanes/same direction	AND (MANEUV_I = 6, 15, 16 OR ACC_TYPE = 46, 47)
Drifting/same lane	AND P_CRASH2 = 10-14
Opposite direction/maneuver	
Opposite direction/no maneuver	AND (P_CRASH2 = 10-14 OR ACC_TYPE = 01, 06, 50, 64)
Rear-end/striking maneuver	AND VROLE_I = 1
Rear-end/LVA	AND VROLE_I = 1
Rear-end/LVM	AND (VROLE_I = 1 OR ACC_TYPE = 24)
Rear-end/LVD	AND (VROLE_I = 1 OR ACC_TYPE = 28)
Rear-End/LVS	AND (VROLE_I = 1 OR ACC_TYPE = 20)
LTAP/OD @ signal	AND (MANEUV_I = 11 OR P_CRASH2 = 15 OR ACC_TYPE = 68)
LTAP/OD @ signal	AND not (MANEUV_I = 11 OR P_CRASH2 = 15 OR ACC_TYPE = 68)
Turn right @ signal	AND (MANEUV_I = 10 OR P_CRASH2 = 16 OR ACC_TYPE = 78, 80)
Turn right @ signal	AND not (MANEUV_I = 10 OR P_CRASH2 = 16 OR ACC_TYPE = 78, 80)
LTAP/OD @ non signal	AND (MANEUV_I = 11 OR P_CRASH2 = 15 OR ACC_TYPE = 68)
LTAP/OD @ non signal	AND not (MANEUV_I = 11 OR P_CRASH2 = 15 OR ACC_TYPE = 68)
SCP @ non signal	
Turn @ non signal	AND (MANEUV_I = 10 - 12 OR P_CRASH2 = 15-16)
Turn @ non signal	AND not (MANEUV_I = 10 - 12 OR P_CRASH2 = 15-16)

Table 10 shows the relative frequency statistics of driver characteristics for age and gender in each of the target V2V pre-crash scenarios based on the average values of 2004-2008 GES data. From age statistics:

- Overall, the breakdown of drivers of interest by age is 31.6 percent by younger drivers, 59.7 percent by middle-age drivers, and 8.7 percent by older drivers.
- Higher rates of involvement by younger drivers appear in running stop sign, opposite direction, rear-end, and turning left in LTAP/OD at signalized junction pre-crash scenarios as compared to other scenarios.
- Higher rates of involvement by middle-age drivers emerge in turning/same direction, drifting/same direction, and non-turning in LTAP/OD and right turn pre-crash scenarios as compared to other scenarios.

- Higher rates of involvement by older drivers show up in running red light, running stop sign, and turning in LTAP/OD and turn pre-crash scenarios as compared to other scenarios.

The following observations are gleaned from gender statistics:

- Overall, the breakdown of drivers of interest by gender is about 56 percent by male drivers and 44 percent by female drivers.
- Higher rates of involvement by male drivers appear in changing lanes/same direction, drifting/same lane, opposite direction, and lead vehicle moving pre-crash scenarios as compared to other scenarios.
- Higher rates of involvement by female drivers emerge in running red light, turning left in LTAP/OD at signalized junction, and straight crossing path at non-signalized junction pre-crash scenarios as compared to other scenarios.

Table 10. Statistical Description of Driver Characteristics in Target Light-Vehicle V2V Pre-Crash Scenarios

Pre-Crash Scenario	Age (Years)			Gender	
	≤ 24	25 - 64	≥ 65	Male	Female
Running Red Light	32%	57%	11%	53%	47%
Running Stop Sign	35%	53%	12%	56%	44%
Turning/Same Direction	26%	65%	10%	55%	45%
Changing Lanes/Same Direction	32%	59%	10%	59%	41%
Drifting/Same Direction	27%	63%	9%	66%	34%
Opposite Direction/Maneuver	38%	56%	7%	70%	30%
Opposite Direction/No Maneuver	33%	60%	7%	65%	35%
Rear-End/Striking Maneuver	34%	60%	6%	58%	42%
Rear-End/LVA	36%	59%	5%	54%	46%
Rear-End/LVM	36%	59%	5%	61%	39%
Rear-End/LVD	38%	58%	4%	58%	42%
Rear-End/LVS	35%	59%	7%	56%	44%
LTAP/OD at Signal - Left Turning	34%	52%	14%	52%	48%
LTAP/OD at Signal - Non Left Turning	28%	64%	7%	56%	44%
LTAP/OD at Non Signal - Left Turning	30%	55%	15%	54%	46%
LTAP/OD at Non Signal - Non Left Turning	26%	67%	7%	55%	45%
Turn Right at Signal - Right Turning	29%	55%	16%	54%	46%
Turn Right at Signal - Non Right Turning	24%	67%	9%	54%	46%
SCP at Non Signal	28%	61%	10%	53%	47%
Turn at Non Signal	29%	60%	11%	57%	43%

III.4. Crash Contributing and Causal Factors

Crash contributing and causal factors were obtained for drivers/vehicles of interest as defined in Table 9. Table 11 shows 2004-2008 GES statistics about crash contributing and causal factors in each of the target V2V pre-crash scenarios, including alcohol and drug involvement, physical impairment, violation, vision obscuration, inattention, and vehicle factors. The following observations are made from the average GES data for overall target V2V pre-crash scenarios:

- Alcohol is involved in 3.4 percent of all drivers of interest. Higher alcohol involvement rates are coded in running stop sign, drifting/same direction, opposite direction, lead vehicle moving, and turning in turn right at signalized junction pre-crash scenarios as compared to other scenarios.
- Drugs are implicated in only 4 percent of all drivers of interest.
- Violations are cited to about 42 percent of all drivers of interest.
- Speeding is attributed to 13 percent of all vehicles of interest. Vehicles of interest in rear-end pre-crash scenarios account for 89 percent of all speeding vehicles.
- Obscured vision is reported by 4.9 percent of all drivers of interest. Higher rates of obscured vision appear in opposite direction/maneuver, LTAP/OD, and straight crossing paths at non signalized junction pre-crash scenarios as compared to other scenarios.
- Inattention is noted by 27.2 percent of all drivers of interest. 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 only 0.6 percent of all vehicles of interest.

Table 11. Light-Vehicle Crash Contributing and Causal Factors Based on 2004-2008 GES Statistics

Pre Crash Scenario	Alcohol Involved	Drugs Involved	Physical Impairment	Violation Cited	Speeding	Vision Obscured	Distracted	Vehicle Factors
Running Red Light	3%	< 1%	< 1%	100%	3%	3%	35%	< 1%
Running Stop Sign	6%	< 1%	< 1%	100%	4%	6%	33%	< 1%
Turning/Same Direction	2%	< 1%	< 1%	27%	< 1%	1%	17%	< 1%
Changing Lanes/Same Direction	4%	< 1%	< 1%	38%	4%	2%	28%	< 1%
Drifting/Same Direction	9%	< 1%	< 1%	29%	6%	2%	28%	< 1%
Opposite Direction/Maneuver	13%	2%	< 1%	33%	7%	7%	19%	1%
Opposite Direction/No Maneuver	12%	2%	< 1%	36%	9%	5%	24%	1%
Rear-End/Striking Maneuver	5%	< 1%	< 1%	43%	22%	2%	44%	< 1%
Rear-End/LVA	4%	< 1%	< 1%	49%	26%	3%	51%	< 1%
Rear-End/LVM	7%	< 1%	< 1%	47%	30%	2%	36%	< 1%
Rear-End/LVD	2%	< 1%	< 1%	49%	33%	2%	38%	< 1%
Rear-End/LVS	4%	< 1%	< 1%	52%	30%	2%	47%	1%
LTAP/OD at Signal - Left Turning	3%	< 1%	< 1%	50%	< 1%	6%	21%	< 1%
LTAP/OD at Signal - Non Left Turning	1%	< 1%	< 1%	13%	2%	3%	4%	< 1%
LTAP/OD at Non Signal - Left Turning	3%	< 1%	< 1%	55%	< 1%	18%	29%	< 1%
LTAP/OD at Non Signal - Non Left Turning	< 1%	< 1%	< 1%	10%	2%	9%	4%	< 1%
Turn Right at Signal - Right Turning	6%	< 1%	< 1%	37%	5%	4%	24%	< 1%
Turn Right at Signal - Non Right Turning	1%	< 1%	< 1%	9%	< 1%	2%	3%	< 1%
SCP at Non Signal	2%	< 1%	< 1%	27%	2%	8%	13%	< 1%
Turn at Non Signal	2%	< 1%	< 1%	22%	2%	4%	18%	< 1%

Tables 12 and 13 present results from the analysis of NMVCCS data, which describe the statistics of the critical reason behind the pre-crash critical event and crash contributing and causal factors in each of the target V2V pre-crash scenarios. The critical reason refers to the immediate reason for the critical pre-crash event and is often the last failure in the causal chain. The contributing and causal factors covered in this analysis include fatigue, inattention, conversing, inadequate surveillance, following too closely, misjudgement of distance/speed and vehicle approach, false assumption of others' actions, inadequate evasive action, and other decision and recognition factors. Due to the low number of NMVCCS cases available for some target pre-crash scenarios, a smaller set of target V2V scenarios was analyzed as seen in Tables 12 and 13. Notable observations about critical reason statistics are:

- Sleepy driver is cited in over two percent of the cases in individual scenarios only in two pre-crash scenarios: opposite direction (5.9 percent) and changing lanes/turning/drifting – same direction (2.2 percent).
- Ill/blackout is the most reported critical reason in opposite direction pre-crash scenarios (6.8 percent) among other scenarios.
- Driver error is the most cited critical reason in every target pre-crash scenario. It is reported in over 90 percent of the cases in LTAP/OD, turn right at signalized junctions, and lead vehicle stopped pre-crash scenarios.
- Vehicle issues are implicated in over two percent of the cases in individual scenarios only in two pre-crash scenarios: changing lanes/turning/drifting – same direction (2.1 percent) and turn right at signalized junctions (2.0 percent).
- Weather, road, or traffic control device issues are mentioned in over two percent of the cases in opposite direction (2.2 percent), running stop sign (2.2 percent), and straight crossing paths or turning at non signalized junctions (2.1 percent).

Table 12. Light-Vehicle Critical Reason Statistics Based on NMVCCS Data

Pre-Crash Scenario	No Critical Reason	Sleepy	Ill/ Blackout	Driver Error	Vehicle Issues	Weather /Road /TCD Issues
Running Red Light	29.8%	0.9%	0.1%	67.9%	0.9%	0.4%
Running Stop Sign	22.6%	0.0%	0.1%	75.0%	0.1%	2.2%
Changing Lanes/Turning/Drifting	6.1%	2.2%	2.0%	87.7%	2.1%	0.0%
Opposite Direction	0.5%	5.9%	6.8%	84.1%	0.5%	2.2%
Rear-End/LVM	60.4%	0.9%	1.1%	36.8%	0.2%	0.7%
Rear-End/LVD	51.5%	0.3%	0.7%	46.6%	0.0%	1.0%
Rear-End/LVS	4.1%	1.3%	1.0%	90.7%	1.4%	1.5%
LTAP/OD at Signal - Left Turning	0.3%	0.0%	0.2%	98.8%	0.0%	0.7%
LTAP/OD at Signal - Non Left Turning	0.7%	0.0%	1.7%	97.6%	0.0%	0.0%
LTAP/OD at Non Signal	0.6%	0.0%	0.0%	98.2%	0.0%	1.3%
Turn right at Signal	0.0%	0.0%	0.0%	98.0%	2.0%	0.0%
SCP/Turn at Non Signal	21.0%	0.0%	0.0%	75.9%	1.0%	2.1%

TCD: Traffic Control Device

From Table 13, key results from the NMVCCS data analysis about crash causal factors are:

- Fatigue is a factor in 9.5 percent of all drivers of interest. Higher fatigue rates are noted in opposite direction (26.5 percent), changing lanes/turning/drifting – same direction (14.9 percent), lead vehicle decelerating (13.1 percent), and lead vehicle stopped (12.9 percent) pre-crash scenarios as compared to other scenarios.
- Inattention is cited in 14.5 percent of all drivers of interest. Higher inattention rates are observed in lead vehicle stopped (23.3 percent), running red light (22.9 percent), and lead vehicle decelerating (18.3 percent) pre-crash scenarios as compared to other scenarios.
- Engaging in conversation is reported in 13.4 percent of all drivers of interest. Higher rates of driver conversing emerge in changing lanes/turning/drifting – same direction (17.5 percent), lead vehicle moving (17.2 percent), and straight crossing paths/turning at non signalized junction (16.3 percent) pre-crash scenarios as compared to other scenarios.
- Inadequate surveillance is implicated in 54.8 percent of all drivers of interest. Rates over 65 percent show up in running red light/stop sign, LTAP/OD, and straight crossing paths/turning at non signalized junction pre-crash scenarios.
- Following too closely is relevant in rear-end pre-crash scenarios. It is reported at 19.6 percent in lead vehicle decelerating, 9.0 percent in lead vehicle moving, and 8.5 percent in lead vehicle stopped.
- Misjudgement of distance/speed is indicated by 7.7 percent of all drivers of interest. Its highest rate of 44.8 percent appears in the turn right at signalized junction pre-crash scenario. This rate is 13.6 percent for all LTAP/OD pre-crash scenarios and 10.1 percent for all rear-end pre-crash scenarios.
- False assumption of other road user's action is mentioned by 13.1 percent of all drivers of interest. The rate of this driver decision error amounts to 25.8 percent in LTAP/OD at signalized junction by left turning and other vehicles, 29.5 percent in turn right at signalized junction, and 25.1 percent in lead vehicle stopped pre-crash scenarios.
- Inadequate evasive action by all vehicles of interest is 5.1 percent. This rate is highest in opposite direction pre-crash scenarios at 23.5 percent, followed by the lead vehicle stopped pre-crash scenario at 12.5 percent.
- "Other" driver decision errors are cited by 15.2 percent of all drivers of interest. This is most dominant in all LTAP/OD pre-crash scenarios at 30.0 percent. This factor also emerges in the straight crossing paths/turn at non-signalized junction pre-crash scenarios at 29.3 percent.
- "Other" driver recognition errors are reported by 9.5 percent of all drivers of interest. This is most dominant in the running stop sign pre-crash scenario at 17.6 percent, followed by crossing paths (LTAP/OD, SCP, and turn) at non-signalized junction pre-crash scenarios at 13.7 percent.

Table 13. Light-Vehicle Crash Contributing and Causal Factors Based on NMVCCS Data

Pre-Crash Scenario	Fatigue	Inattention	Conversing	Inadequate Surveillance	Following Too Closely	Misjudgment of Distance/Speed	False Assumption	Inadequate Evasive Action	Other Decision Factors	Other Recognition Factors
Running Red Light	7.4%	22.9%	12.8%	66.0%	0.0%	0.2%	6.1%	3.3%	7.4%	7.7%
Running Stop Sign	5.2%	14.0%	14.1%	66.2%	0.0%	6.8%	11.8%	1.8%	23.8%	17.6%
Changing Lanes/Turning/Drifting	14.9%	14.1%	17.5%	59.0%	2.9%	8.0%	16.7%	4.7%	13.8%	4.8%
Opposite Direction	26.5%	10.0%	14.5%	20.2%	0.1%	0.2%	1.8%	23.5%	3.2%	6.1%
Rear-End/LVM	4.9%	7.6%	17.2%	15.4%	9.0%	5.0%	5.0%	2.2%	2.4%	4.2%
Rear-End/LVD	13.1%	18.3%	7.7%	29.2%	19.6%	8.1%	12.0%	3.3%	3.1%	3.0%
Rear-End/LVS	12.9%	23.3%	11.0%	52.3%	8.5%	15.2%	25.1%	12.5%	3.8%	8.3%
LTAP/OD at Signal - Left Turning	6.3%	7.8%	13.4%	68.5%	0.0%	12.8%	22.7%	1.1%	25.3%	10.0%
LTAP/OD at Signal - Non Left Turning	5.4%	5.0%	10.3%	49.4%	0.0%	10.7%	44.1%	0.9%	24.4%	4.3%
LTAP/OD at Non Signal	6.2%	8.3%	9.5%	77.2%	0.0%	15.8%	4.7%	0.4%	40.3%	13.5%
Turn right at Signal	0.0%	3.6%	8.2%	52.8%	0.0%	44.8%	29.5%	0.0%	50.0%	5.3%
SCP/Turn at Non Signal	8.9%	12.8%	16.3%	69.2%	0.0%	6.0%	13.0%	3.7%	29.3%	13.8%

III.5. Corrective Action Attempted

The corrective action attempted statistics were obtained from drivers/vehicles of interest as defined in Table 9. Table 14 presents the 2004-2008 GES statistics about corrective action in each of the target V2V pre-crash scenarios including braking, steering, and combinations of both actions. The following observations are made from the average GES data for overall target V2V pre-crash scenarios:

- No avoidance maneuver was recorded for 58 percent of all drivers of interest. This was most prevalent in turning in the same direction, LTAP/OD (left turning vehicle), and turning right at signal (turning vehicle) pre-crash scenarios.
- Applying brakes was reported for just nine percent of all drivers of interest. Higher rates of braking were reported for rear-end: LVA, LVM, LVD, and LVS scenarios when compared against all pre-crash scenarios.
- Braking with lockup was seen to be charateristic of eight percent of all drivers of interest.
- Seventy-five percent of drivers of interest involved in opposite drection/maneuver crashes were reported steering to avoid a crash. In addition, across all scenarios, steering was reported by 20 percent of drivers of interest especially in oppposite direction/no maneuver, changing lanes in the same direction, and turn at non-signalized junction pre-crash scenarios.
- Combined braking and steering was coded for just three percent of all drivers of interest.
- Less than two percent of drivers reported an attempted avoidance manuever other than braking or steering.

Table 14. Light-Vehicle Corrective Action Attempted Based on 2004-2008 GES Statistics

Pre-Crash Scenario	No Avoidance Maneuver	Braking (No Lockup)	Braking (Lockup)	Steering*	Braking and Steering	Other Action**
Running red light	68.3 %	5.3 %	17.5 %	7.1 %	1.0 %	0.7 %
Running stop sign	71.6 %	8.2 %	16.1 %	2.5 %	0.4 %	1.2 %
Turning/same direction	93.7 %	2.0 %	0.6 %	2.7 %	0.0 %	1.0 %
Changing lanes/same direction	52.0 %	1.3 %	2.1 %	40.0 %	4.4 %	0.3 %
Drifting/same direction	65.1 %	2.4 %	3.5 %	25.1 %	2.6 %	1.4 %
Opposite direction/maneuver	14.8 %	0.1 %	3.7 %	75.0 %	4.1 %	2.3 %
Opposite direction/no maneuver	17.8 %	2.8 %	6.5 %	66.6 %	5.1 %	1.2 %
Rear-end/striking maneuver	48.5 %	10.8 %	4.3 %	30.8 %	3.6 %	2.1 %
Rear-end/LVA	61.2 %	20.0 %	10.2 %	5.8 %	0.0 %	2.8 %
Rear-end/LVM	28.9 %	40.4 %	13.9 %	10.2 %	4.9 %	1.7 %
Rear-end/LVD	35.1 %	30.0 %	18.4 %	10.6 %	5.2 %	0.7 %
Rear-end/LVS	41.9 %	27.0 %	18.4 %	7.9 %	2.6 %	2.2 %
LTAP/OD @ signal (left turning)	88.9 %	4.1 %	2.2 %	1.4 %	0.3 %	3.0 %
LTAP/OD @ signal (non left turning)	43.6 %	17.3 %	17.8 %	14.8 %	4.2 %	2.2 %
Turn right @ signal (right turning)	88.9 %	5.2 %	3.3 %	0.1 %	1.3 %	1.3 %
Turn right @ signal (non right turning)	74.4 %	4.7 %	4.5 %	14.2 %	1.1 %	1.2 %
LTAP/OD @ non signal (left turning)	91.0 %	3.4 %	0.9 %	1.9 %	0.1 %	2.7 %
LTAP/OD @ non signal (non left turning)	41.6 %	18.3 %	17.7 %	15.3 %	5.4 %	1.7 %
SCP @ non signal	56.6 %	8.7 %	12.5 %	16.7 %	3.4 %	2.1 %
Turn @ non signal	53.5 %	2.5 %	1.3 %	37.8 %	3.7 %	1.1 %

*includes categories: "accelerating and steering left" and "accelerating and steering right"

**includes categories: "releasing brakes" and "accelerating"

III.6. Light Vehicle Pre-Crash Scenario Groups

The seventeen target V2V pre-crash scenarios listed in Table 8 are arranged into six groups as shown in Table 15. This arrangement is devised based mostly on vehicle movements and orientations prior to the occurrence of the crash critical event. Six safety applications may be developed to implement these pre-crash scenario groups as individual or integrated crash countermeasure systems based on V2V communications. The rear-end pre-crash scenarios involve at least two vehicles following each other in the same direction, same lane. The lane change pre-crash scenarios comprise of two vehicles traveling in the same direction, in adjacent lanes, and at close proximity. 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. This group typically occurs away from 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. This group of scenarios happens at junctions. The junction crossing group incorporates all crossing path pre-crash scenarios in which the two vehicles approach each other from perpendicular directions at mostly non-signalized junctions. The last group, TCD violation, is different from

the other five groups since it accounts for a driver error at signed or signalized junctions rather than vehicle movements.

Table 15 lists the six pre-crash scenario groups and provides their societal cost in terms of comprehensive economic cost and functional years lost. Values for individual scenarios are drawn from Table 7. Figure 5 illustrates the ranking of these target V2V pre-crash scenario groups based on comprehensive cost. Their total amounts to 73.1 percent of the overall comprehensive economic cost provided in Table 7. The remaining cost of 26.9 percent is due mostly to control loss pre-crash scenarios. As seen in Figure 5, the rear-end pre-crash scenario group is the most dominant among the six groups. The junction crossing, opposite direction, and LTAP/OD pre-crash scenario groups account for over 10 percent of the overall comprehensive cost individually.

Table 15. Groups of Target Light-Vehicle V2V Pre-Crash Scenarios and Associated Societal Cost

Pre-Crash Scenario		Comprehensive Cost			Functional Years Lost		
		Total	Percentage	Rank	Total	Percentage	Rank
Rear End	Rear-end/LVS	$ 29,716,000,000	10.8%	3	198,000	10.2%	4
	Rear-end/LVD	$ 12,215,000,000	4.4%	8	82,000	4.2%	8
	Rear-end/LVM	$ 10,342,000,000	3.8%	9	72,000	3.7%	9
	Rear-end/striking maneuver	$ 2,381,000,000	0.9%	16	16,000	0.8%	16
	Rear-end/LVA	$ 667,000,000	0.2%	21	5,000	0.3%	21
	Total	**$ 55,321,000,000**	**20.1%**		**373,000**	**19.2%**	
Lane Change	Changing lanes/same direction	$ 8,414,000,000	3.1%	10	60,000	3.1%	10
	Turning/same direction	$ 6,176,000,000	2.2%	12	43,000	2.2%	12
	Drifting/same direction	$ 3,483,000,000	1.3%	14	25,000	1.3%	13
	Total	**$ 18,073,000,000**	**6.6%**		**128,000**	**6.6%**	
Opposite Direction	Opposite direction/no maneuver	$ 29,558,000,000	10.8%	4	213,000	11.0%	3
	Opposite direction/maneuver	$ 3,500,000,000	1.3%	13	25,000	1.3%	13
	Total	**$ 33,058,000,000**	**12.0%**		**238,000**	**12.2%**	
LTAP/OD	LTAP/OD @ non signal	$ 15,481,000,000	5.6%	6	111,000	5.7%	6
	LTAP/OD @ signal	$ 14,777,000,000	5.4%	7	105,000	5.4%	7
	Total	**$ 30,258,000,000**	**11.0%**		**216,000**	**11.1%**	
Junction Crossing	SCP @ non signal	$ 41,095,000,000	14.9%	2	292,000	15.0%	2
	Turn @ non signal	$ 930,000,000	0.3%	18	6,000	0.3%	18
	Turn right @ signal	$ 908,000,000	0.3%	19	6,000	0.3%	18
	Total	**$ 42,933,000,000**	**15.6%**		**304,000**	**15.6%**	
TCD Violation	Running red light	$ 18,274,000,000	6.6%	5	129,000	6.6%	5
	Running stop sign	$ 3,075,000,000	1.1%	15	22,000	1.1%	15
	Total	**$ 21,349,000,000**	**7.8%**		**151,000**	**7.8%**	

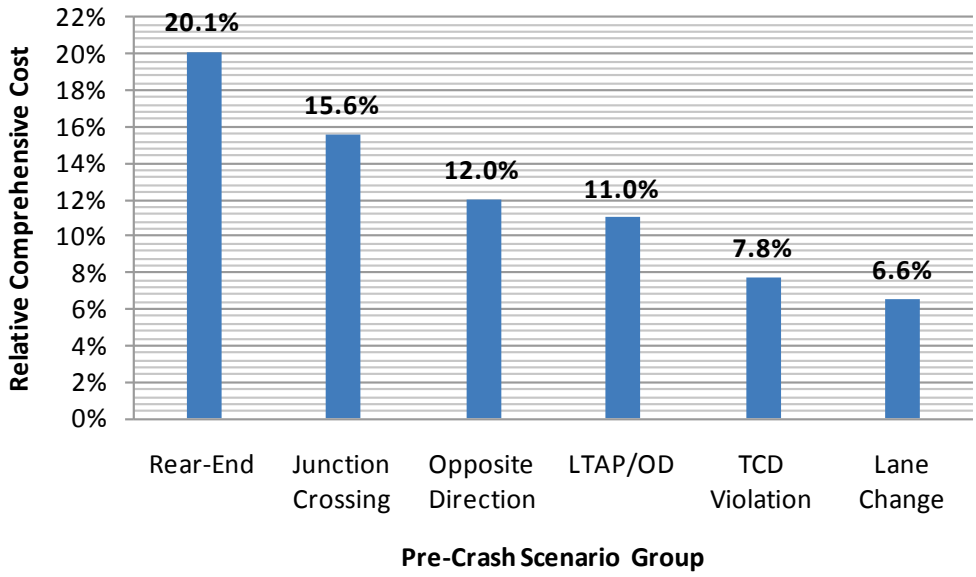


Figure 5. Relative Comprehensive Cost of Target Light-Vehicle V2V Pre-Crash Scenario Groups

IV. DETAILED DESCRIPTION OF LIGHT-VEHICLE PRE-CRASH SCENARIOS

This section provides a detailed description of each of the 17 target light-vehicle V2V pre-crash scenarios based on data from the 2004-2008 GES, NMVCCS, and EDR databases.

The following descriptions are obtained from 2004-2008 GES statistics:

- Societal Cost
    - Total number of crashes
    - Total number of vehicles involved
    - Number of vehicles with injured occupants
    - Number of people injured in and outside the vehicles
    - Total comprehensive cost, referred to by the Value of Statistical Life (VSL)
    - Total number of functional years lost (FYL)
    - Total number of persons injured at MAIS 2 or higher (MAIS 2^{+})
    - Total number of persons injured at MAIS 3 or higher (MAIS 3^{+})
- Driving Environment
    - Roadway Alignment × Roadway Surface Condition × Atmospheric Condition
    - Relation to Junction × Traffic Control Device
    - Lighting Condition
    - Cumulative distribution of Posted Speed Limit
- Driver of interest Characteristics
    - Age
    - Gender
- Driver of interest Contributing Factors
    - Alcohol
    - Drugs
    - Physical Impairment
    - Violation Cited
    - Speeding
    - Vision Obscured
    - Distraction
- Vehicle of interest Contributing Factors

Crash causal factors for drivers of interest are derived from NMVCCS statistics:

    - Driver fatigued
    - Inattention
    - Driver conversing
    - Misjudgment of Distance/Speed
    - False Assumption
    - Inadequate Evasive Action
    - Critical Reason
    - Inadequate Surveillance
    - Other Driver Recognition Factors
    - Following Too Closely

- Other Driver Decision Factors

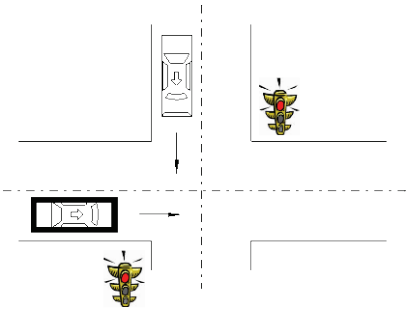
EDR data are analyzed to provide quantitative kinematic information about some target V2V pre-crash scenarios. Since these EDR cases are available in the CDS crash database, their concomitant weights are used to generate the statistics. Results of EDR analysis using non-weighted values are provided in Appendix B. Five plots of the EDR analysis results are presented along with one plot from the 2004-2008 GES showing the cumulative distribution of the posted speed limit for the vehicles of interest:

- Vehicle Travel Speed (mph): five cumulative distributions are presented for each second starting from five to one second before the crash. A corresponding plot of the posted speed limit is also presented for comparison purposes.
- Brake Frequency at Time-To-Collision (s): this plot shows the cumulative distribution of vehicles that initiated braking at each second starting from five to one second before the crash. The values shown on the plot include some vehicles that initially initiated braking and then stopped braking later on prior to the crash (e.g., brake switch is ON at -5 and -4, and OFF at -3, -2, and -1 second).
- Detailed Brake Application Frequency: a bar chart is provided showing the percentage of vehicles by the 5-second brake profile (e.g., bottom – 00011 – top refers to a brake switch being OFF at -5, -4, and -3 second, and being ON at -2 and -1 second before the crash).
- Braking Deceleration (g): four cumulative distributions are provided showing the percentage of vehicles by the deceleration level as derived from the difference in travel speeds over 1-second period.
- Effective Deceleration at TTC (s) with Frequency: a bar chart is presented showing the average effective deceleration value along with the standard deviation marks for the different TTC values. The frequency of the weighted cases is also provided. Effective deceleration represents the braking level from brake onset until the -1 second record of the travel speed. The TTC labels of the horizontal axis use x.5 to indicate that braking might have been initiated any time between the two time records.

It should be noted that not all 17 target V2V pre-crash scenarios are described using EDR data due to the lack of sufficient number of cases in some scenarios.

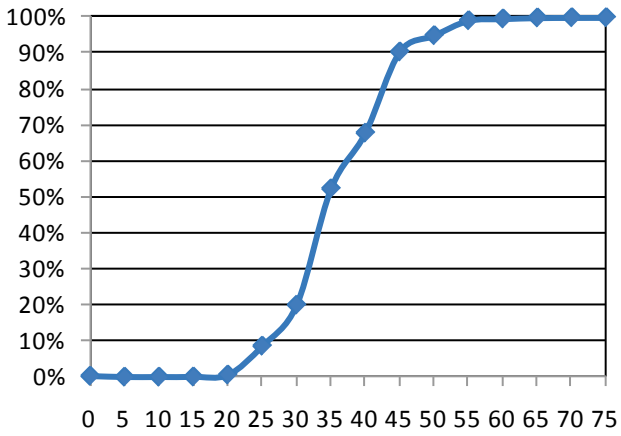
IV.1. Running Red Light

Typical Scenario: Vehicle is going straight, and then runs a red light while straight crossing an intersection and collides with another straight crossing vehicle from a lateral direction.



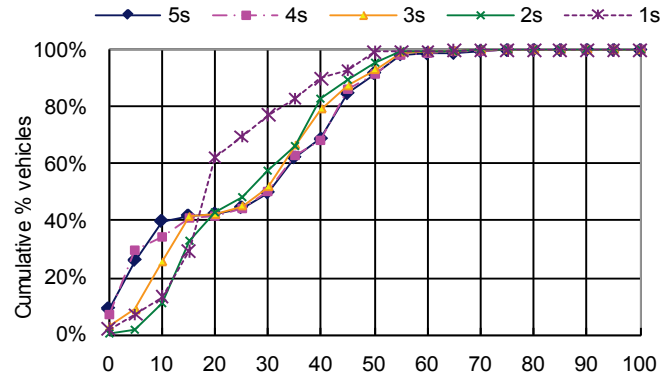
Societal Cost

Total No. of Crashes	237,000
Total No. of Vehicles Involved	494,000
No. of Vehicles with Injuries	146,000
No. of People Injured	232,000
VSL	$ 18,274,000,000
FYL	129,000
MAIS 2+ Injuries	24,000
MAIS 3+ Injuries	8,000

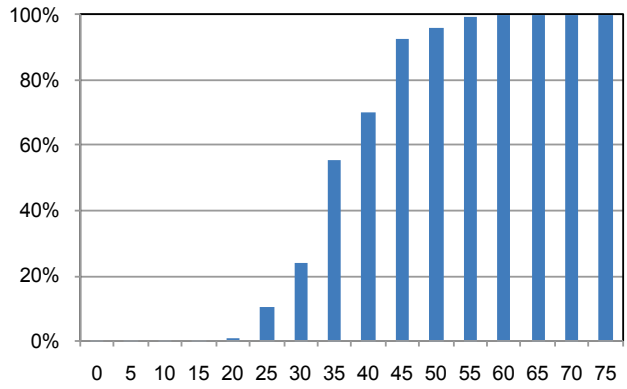
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	79% - Straight, dry road surface with no adverse weather 12% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	94% - Intersection or intersection related at 3-color traffic signal
Lighting Condition	74% - Daylight 21% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	32% - ≤ 24 years 57% - 25 to 64 years 11% - ≥ 65 years
Gender	53% - Male 47% - Female

tributing Factors	Running Red Light
Alcohol	3% - Alcohol use
Drugs	< 1% - Drug use
Physical Impairment	< 1%
Violation Cited	100% - Violation cited
Speeding	3% - Speeding
Vision Obscured	3% - Obscured
Distraction	35% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	4% - Braking (No lockup) 13% - Braking (Lockup) 6% - Braking (Lockup Unknown) 4% - Steering Left 3% - Steering Right
Causal Factors (NMVCCS)	
Driver Fatigued	7% - Driver fatigued
Inattention	23% - Inattention factors
Driver Conversing	13% - Conversing
Misjudgment of Distance/Speed	0% - Misjudgment of distance/speed factors
False Assumption	6% - False assumption factors
Inadequate Evasive Action	3% - Inadequate evasive action factors
Critical Reason	30% - No critical reason 1% - Sleepy 0% - Ill/blackout 68% - Driver error 1% - Vehicle issues 0% - Weather /road /sign-signal issues
Inadequate Surveillance	66% - Inadequate surveillance factors
Other Driver Recognition Factors	8% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	7% - Other decision factors

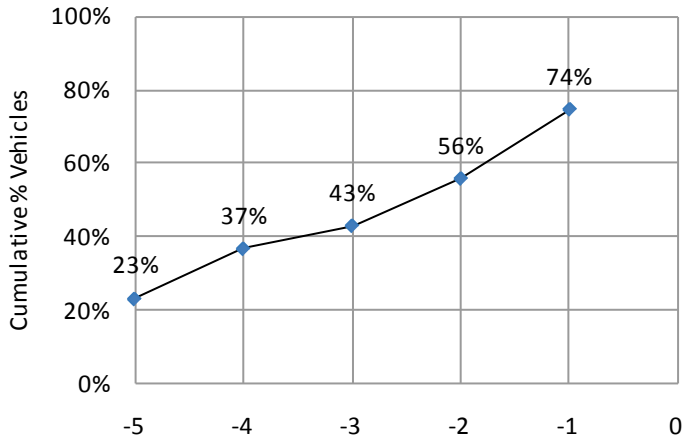
Kinematic Data (207 EDR Cases) **Running Red Light**



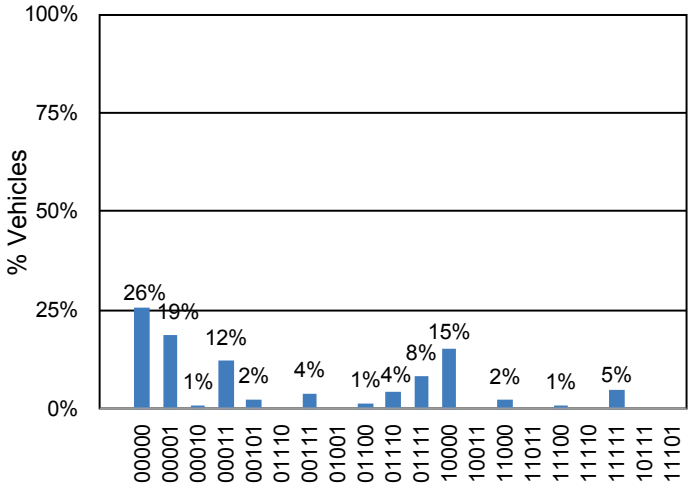
Vehicle Travel Speed (mph)



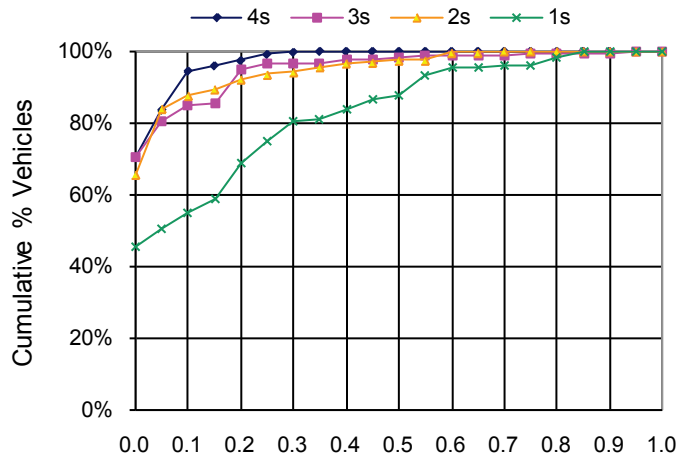
Vehicle Speed Limit (mph), 04-08 GES [1]



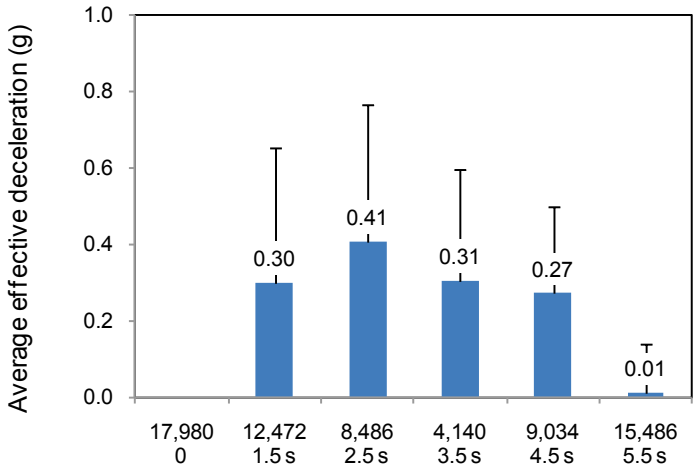
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



Braking Deceleration (g)

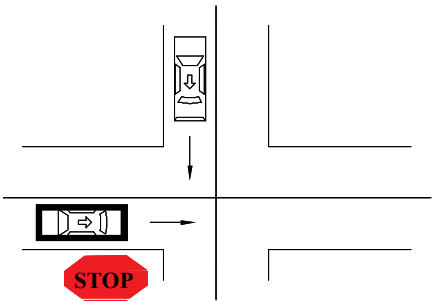


Effective Deceleration at TTC (s) with Frequency

[1] The Vehicle Speed Limit plot presents data taken from the 2004-2008 GES databases. The five remaining plots present EDR data.

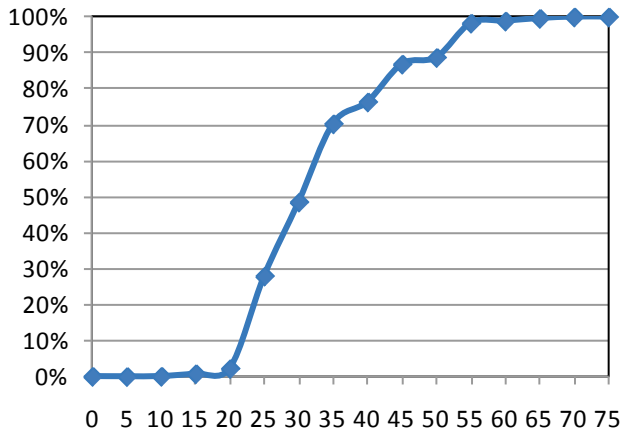
IV.2. Running Stop Sign

Typical Scenario: Vehicle is going straight; and then runs a stop sign at an intersection.



Societal Cost

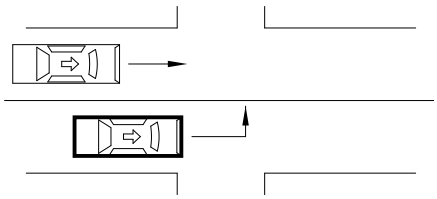
Total No. of Crashes	41,000
Total No. of Vehicles Involved	84,000
No. of Vehicles with Injuries	26,000
No. of People Injured	42,000
VSL	$ 3,075,000,000
FYL	22,000
MAIS 2+ Injuries	4,000
MAIS 3+ Injuries	1,0

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	79% - Straight, dry road surface with no adverse weather 11% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	98% - Intersection or intersection related at stop sign
Lighting Condition	76% - Daylight 13% - Dark but lighted
Posted Speed Limit	
Driver Characteristics	
Age	35% - ≤24 years 53% - 25 to 64 years 12% - 65 years or above
Gender	56% - Male 44% - Female

Driver Contributing Factors	**Running Stop Sign**
Alcohol	6% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical impairment
Violation Cited	100% - Violation cited
Speeding	4% - Speeding
Vision Obscured	6% - Obstruction
Distraction	33% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	6% - Braking (No lockup) 12% - Braking (Lockup) 7% - Braking (Lockup Unknown) 2% - Steering Left
Causal Factors (NMVCCS)	
Driver Fatigued	5% - Driver fatigued
Inattention	14% - Inattention factors
Driver Conversing	14% - Conversing
Misjudgment of Distance/Speed	7% - Misjudgment of distance/speed factors
False Assumption	12% - False assumption factors
Inadequate Evasive Action	2% - Inadequate evasive action factors
Critical Reason	23% - No critical reason 0% - Sleepy 0% - Ill/blackout 75% - Driver error 0% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	66% - Inadequate surveillance factors
Other Driver Recognition Factors	18% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	24% - Other decision factors

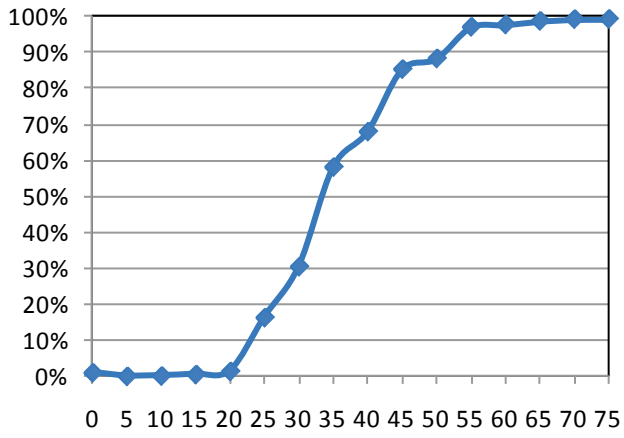
IV.3. Turning/Same Direction

Typical Scenario: Vehicle is turning left at an intersection, and then cuts across the path of another vehicle initially traveling in the same direction.



Societal Cost

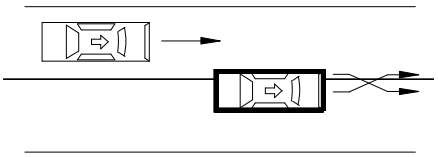
Total No. of Crashes	202,000
Total No. of Vehicles Involved	407,000
No. of Vehicles with Injuries	45,000
No. of People Injured	76,000
VSL	$ 6,176,000,000
FYL	43,000
MAIS 2+ Injuries	7,000
MAIS 3+ Injuries	2,00

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	78% - Straight, dry road surface with no adverse weather 9% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	26% - Intersection or intersection related at RGY traffic signal 25% - Intersection or intersection related without traffic controls 25% - Driveway, alley, etc. without traffic controls
Lighting Condition	80% - Daylight 13% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	26% - ≤24 years 65% - 25 to 64 years 10% - 65 years or above
Gender	55% - Male 45% - Female

Driver Contributing Factors	**Turning / Same Direction**
Alcohol	2% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical Impairment
Violation Cited	28% - Violation cited
Speeding	1% - Speeding
Vision Obscured	1% - Obstruction
Distraction	17% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	2% - Braking (No lockup) 2% - Steering Right
Causal Factors (NMVCCS)	
(Combined values for Changing Lanes, Turning and Drifting Same Direction)	
Fatigue	15% - Driver fatigued
Inattention	14% - Inattention factors
Conversing	17% - Conversing
Misjudgment of distance/speed	8% - Misjudgment of distance/speed factors
False assumption of others' action	17% - False assumption factors
Inadequate evasive action	5% - Inadequate evasive action factors
Critical reason	6% - No critical reason 2% - Sleepy 2% - Ill/blackout 88% - Driver error 2% - Vehicle issues 0% - Weather /road /sign-signal issues
Inadequate surveillance	59% - Inadequate surveillance factors
Other recognition factors	5% - Other recognition factors
Following too close	3% - Following too closely factors
Other decision errors	14% - Other decision factors

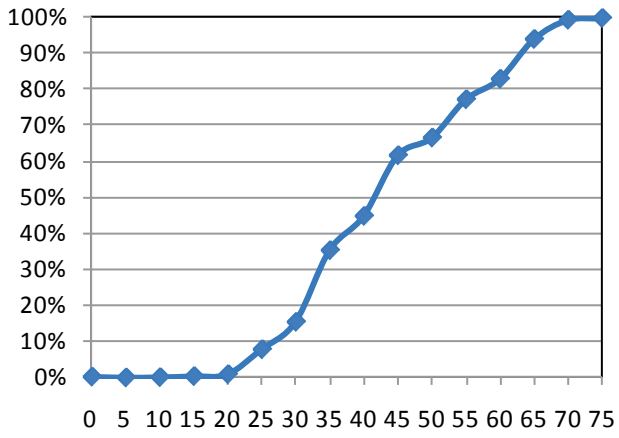
IV.4. Changing Lanes/Same Direction

Typical Scenario: Vehicle is changing lanes, and then encroaches into another vehicle traveling in the same direction.



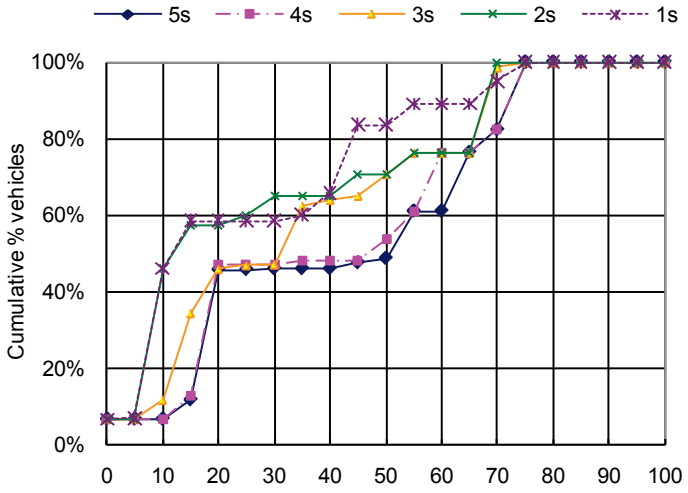
Societal Cost

Total No. of Crashes	336,000
Total No. of Vehicles Involved	659,000
No. of Vehicles with Injuries	60,000
No. of People Injured	98,000
VSL	$ 8,414,000,000
FYL	60,000
MAIS 2+ Injuries	10,000
MAIS 3+ Injuries	3,00

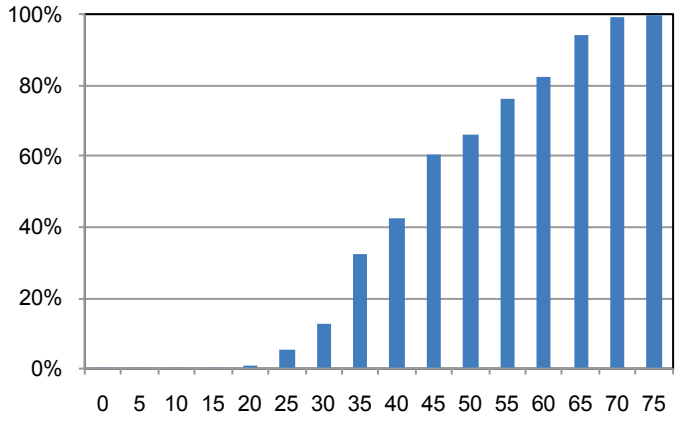
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	78% - Straight, dry road surface with no adverse weather 9% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	65% - Non-Junction without traffic controls 11% - Intersection or intersection related at RGY traffic signal
Lighting Condition	75% - Daylight 15% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	32% - ≤24 years 59% - 25 to 64 years 10% - 65 years or above
Gender	59% - Male 41% - Female

Driver Contributing Factors	**Changing Lanes / Same Direction**
Alcohol	4% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical Impairment
Violation Cited	42% - Violation cited
Speeding	4% - Speeding
Vision Obscured	2% - Obstruction
Distraction	28% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	2% - Braking (Lockup) 20% - Steering Left 20% - Steering Right 2% - Braking and Steering Left 2% - Braking and Steering Right
Causal Factors (NMVCCS)	
(Combined values for Changing Lanes, Turning and Drifting Same Direction)	
Driver Fatigued	15% - Driver fatigued
Inattention	14% - Inattention factors
Driver Conversing	17% - Conversing
Misjudgment of Distance/Speed	8% - Misjudgment of distance/speed factors
False Assumption	17% - False assumption factors
Inadequate Evasive Action	5% - Inadequate evasive action factors
Critical Reason	6% - No critical reason 2% - Sleepy 2% - Ill/blackout 88% - Driver error 2% - Vehicle issues 0% - Weather /road /sign-signal issues
Inadequate Surveillance	59% - Inadequate surveillance factors
Other Driver Recognition Factors	5% - Other recognition factors
Following Too Closely	3% - Following too closely factors
Other Driver Decision Factors	14% - Other decision factors

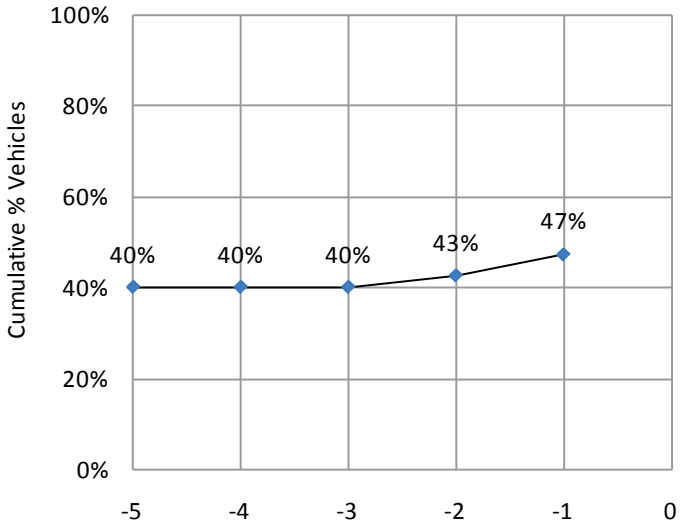
Kinematic Data (16 EDR Cases) **Changing Lanes / Same Direction**



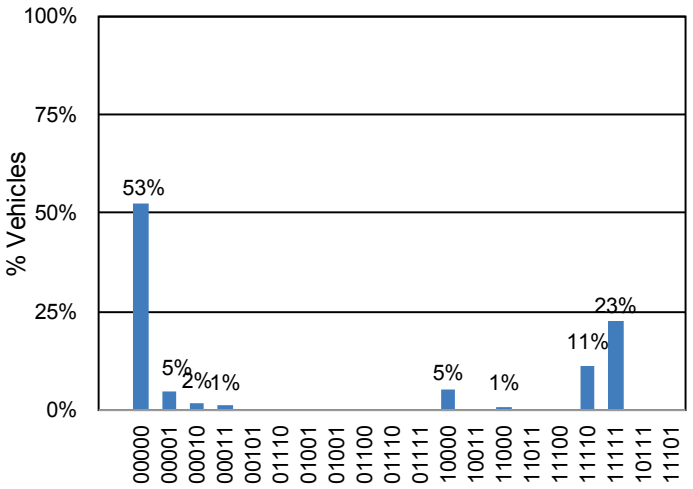
Vehicle Travel Speed (mph)



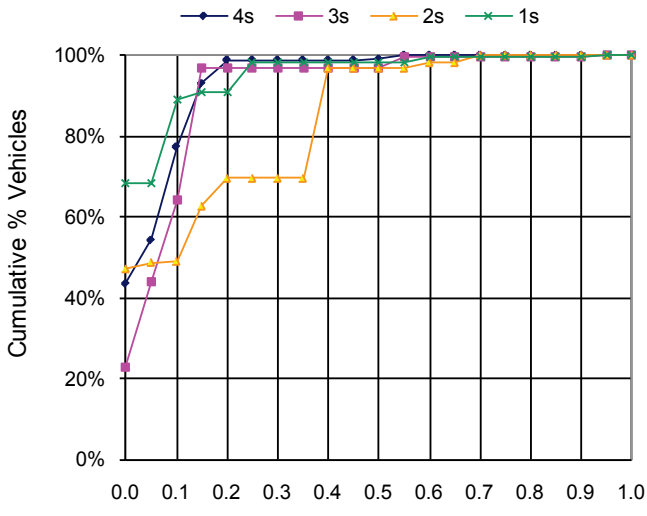
Vehicle Speed Limit (mph), 04-08 GES



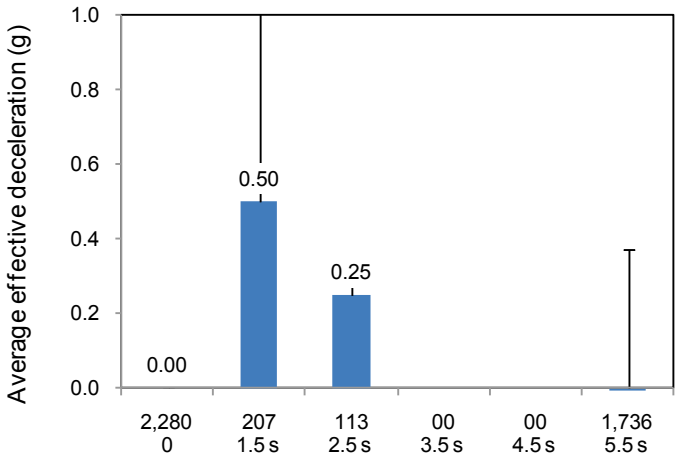
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



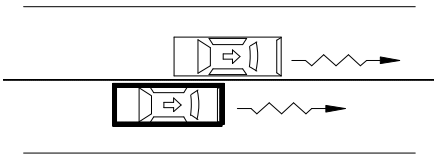
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

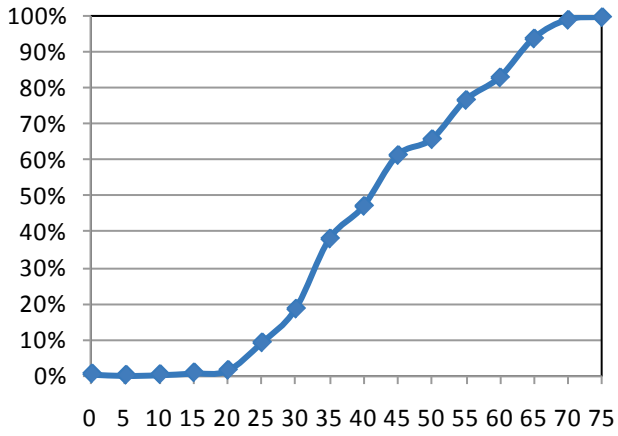
IV.5. Drifting/Same Direction

Typical Scenario: Vehicle is going straight, and then drifts into an adjacent vehicle traveling in the same direction.



Societal Cost

Total No. of Crashes	105,000
Total No. of Vehicles Involved	218,000
No. of Vehicles with Injuries	21,000
No. of People Injured	34,000
VSL	$ 3,483,000,000
FYL	25,000
MAIS 2+ Injuries	3,000
MAIS 3+ Injuries	1,0

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	71% - Straight, dry road surface with no adverse weather 12% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	60% - Non-Junction without traffic controls 15% - Intersection or intersection related at RGY traffic signal
Lighting Condition	71% - Daylight 18% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	27% - ≤24 years 63% - 25 to 64 years 9% - 65 years or above
Gender	66% - Male 34% - Female

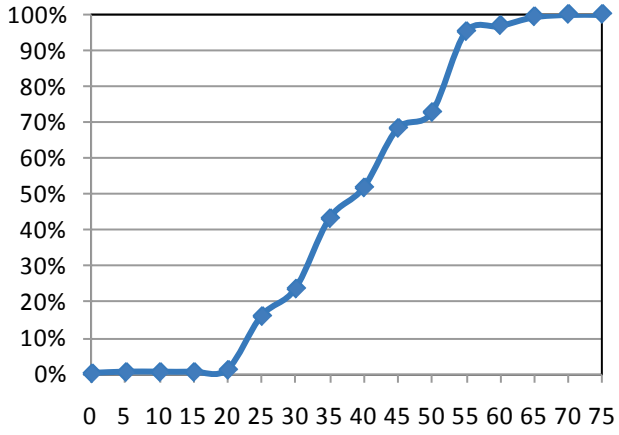
Driver Contributing Factors	**Drifting / Same Direction**
Alcohol	9% - Alcohol use
Drugs	1% - Drug use
Physical Impairment	2% - Sleepy
Violation Cited	33% - Violation cited
Speeding	7% - Speeding
Vision Obscured	2% - Obstruction
Distraction	28% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	2% - Braking (No lockup) 3% - Braking (Lockup) 1% - Braking (Lockup Unknown) 9% - Steering Left 16% - Steering Right 2% - Braking and Steering Left 1% - Unspecified action
Causal Factors (NMVCCS)	
(Combined values for Changing Lanes, Turning and Drifting Same Direction)	
Driver Fatigued	15% - Driver fatigued
Inattention	14% - Inattention factors
Driver Conversing	17% - Conversing
Misjudgment of Distance/Speed	8% - Misjudgment of distance/speed factors
False Assumption	17% - False assumption factors
Inadequate Evasive Action	5% - Inadequate evasive action factors
Critical Reason	6% - No critical reason 2% - Sleepy 2% - Ill/blackout 88% - Driver error 2% - Vehicle issues 0% - Weather /road /sign-signal issues
Inadequate Surveillance	59% - Inadequate surveillance factors
Other Driver Recognition Factors	5% - Other recognition factors
Following Too Closely	3% - Following too closely factors
Other Driver Decision Factors	14% - Other decision factors

IV.6. Opposite Direction/Maneuver

Typical Scenario: Vehicle is passing another vehicle, and encroaches into another vehicle traveling in the opposite direction.

Societal Cost

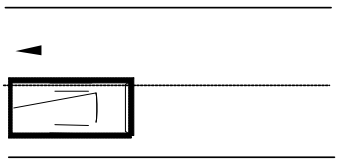
Total No. of Crashes	11,000
Total No. of Vehicles Involved	21,000
No. of Vehicles with Injuries	7,000
No. of People Injured	11,000
VSL	$ 3,500,000,000
FYL	25,000
MAIS 2+ Injuries	2,000
MAIS 3+ Injuries	1,00

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	60% - Straight, dry road surface with no adverse weather 15% - Straight, slippery road surface with adverse weather 13% - Curve, dry road surface with no adverse weather
Relation to Junction × Traffic Control Device	70% - Non-Junction without traffic controls
Lighting Condition	62% - Daylight 18% - Dark but lighted 17% - Dark
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	38% - ≤24 years 56% - 25 to 64 years 7% - 65 years or above
Gender	70% - Male 30% - Female

Driver Contributing Factors	**Opposite Direction / Maneuver**
Alcohol	13% - Alcohol use
Drugs	2% - Drug use
Physical Impairment	<1% - Physical Impairment
Violation Cited	39% - Violation cited
Speeding	8% - Speeding
Vision Obscured	7% - Obstruction
Distraction	19% - Distracted
Vehicle Contributing Factors	
Contributing Factors	1% - Contributing Factor
Corrective Action Attempted	
Corrective Action	3% - Braking (Lockup) 36% - Steering Left 38% - Steering Right 3% - Braking and Steering Left 1% - Braking and Steering Right 1% - Accelerating
Causal Factors (NMVCCS)	
(Combined values for Opposite Direction/Maneuver and No Maneuver)	
Driver Fatigued	26% - Driver fatigued
Inattention	10% - Inattention factors
Driver Conversing	14% - Conversing
Misjudgment of Distance/Speed	0% - Misjudgment of distance/speed factors
False Assumption	2% - False assumption factors
Inadequate Evasive Action	24% - Inadequate evasive action factors
Critical Reason	1% - No critical reason 6% - Sleepy 7% - Ill/blackout 84% - Driver error 1% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	20% - Inadequate surveillance factors
Other Driver Recognition Factors	6% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	3% - Other decision factors

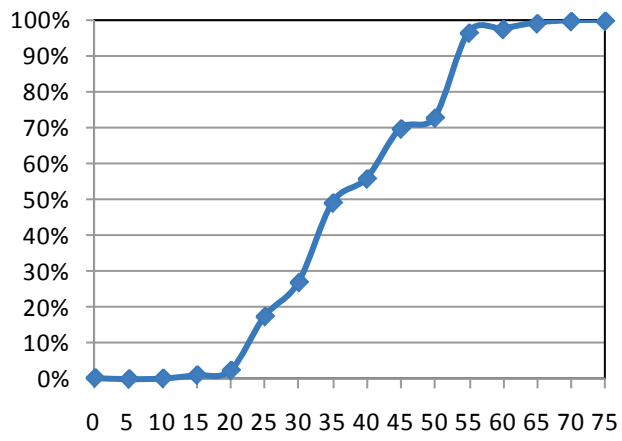
IV.7. Opposite Direction/No Maneuver

Typical Scenario: Vehicle is going straight, and then drifts and encroaches into another vehicle traveling in the opposite direction.



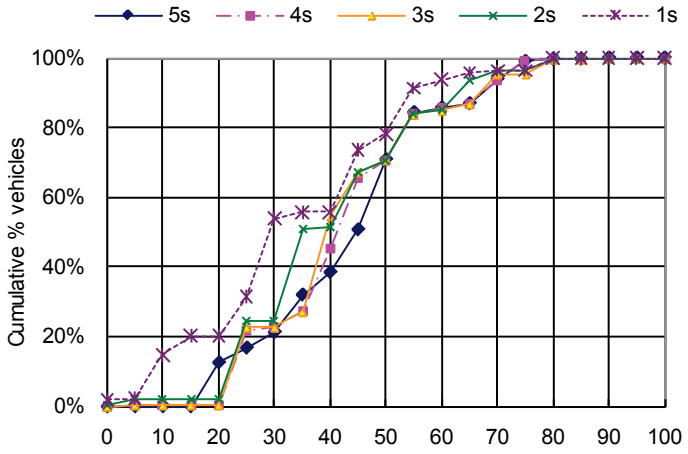
Societal Cost

Total No. of Crashes	118,000
Total No. of Vehicles Involved	219,000
No. of Vehicles with Injuries	66,000
No. of People Injured	102,000
VSL	$ 29,558,000,000
FYL	213,000
MAIS 2+ Injuries	17,000
MAIS 3+ Injuries	8,00

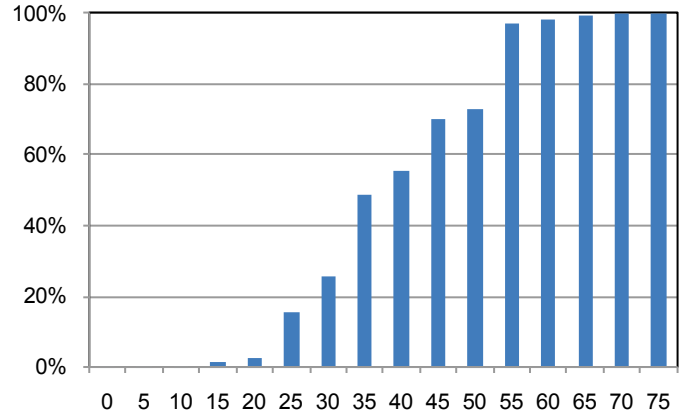
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	47% - Straight, dry road surface with no adverse weather 26% - Curve, dry road surface with no adverse weather 10% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	78% - Non-Junction without traffic controls
Lighting Condition	67% - Daylight 16% - Dark 13% - Dark but lighted
Posted Speed Limit	
Driver Characteristics	
Age	33% - ≤24 years 60% - 25 to 64 years 7% - 65 years or above
Gender	65% - Male 35% - Female

Driver Contributing Factors	**Opposite Direction / No Maneuver**
Alcohol:	12% - Alcohol use
Drugs	2% - Drug use
Physical Impairment	4% - Sleepy 1% - Ill, blackout
Violation Cited	39% - Violation cited
Speeding	10% - Speeding
Vision Obscured	5% - Obstruction
Distraction	24% - Distracted
Vehicle Contributing Factors	
Contributing Factors	1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	2% - Braking (No lockup) 5% - Braking (Lockup) 3% - Braking (Lockup Unknown) 17% - Steering Left 49% - Steering Right 2% - Braking and Steering Left 3% - Braking and Steering Right 1% - Unspecified action
Causal Factors (NMVCCS)	
(Combined values for Opposite Direction/Maneuver and No Maneuver)	
Driver Fatigued	26% - Driver fatigued
Inattention	10% - Inattention factors
Driver Conversing	14% - Conversing
Misjudgment of Distance/Speed	0% - Misjudgment of distance/speed factors
False Assumption	2% - False assumption factors
Inadequate Evasive Action	24% - Inadequate evasive action factors
Critical Reason	1% - No critical reason 6% - Sleepy 7% - Ill/blackout 84% - Driver error 1% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	20% - Inadequate surveillance factors
Other Driver Recognition Factors	6% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	3% - Other decision factors

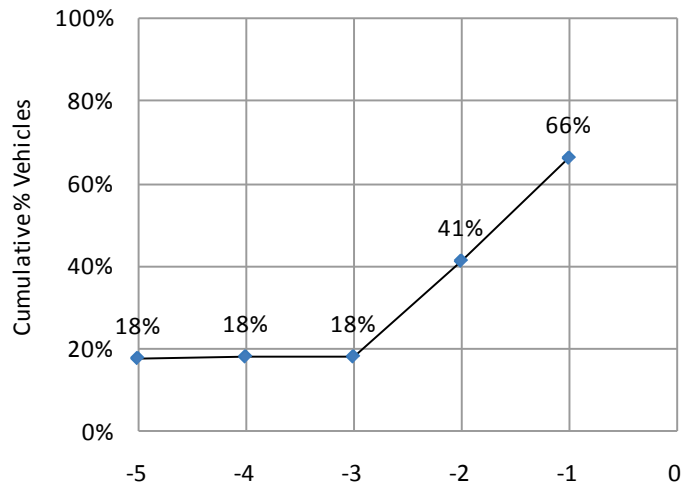
Kinematic Data (40 EDR Cases) **Opposite Direction/No Maneuver**



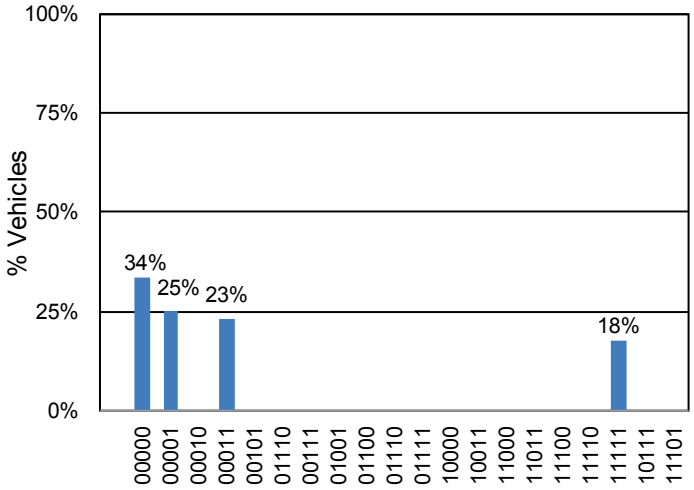
Vehicle Travel Speed (mph)



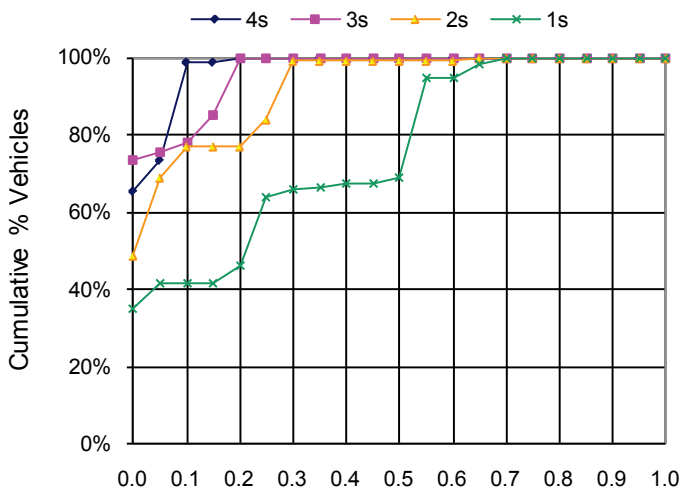
Vehicle Speed Limit (mph), 04-08 GES



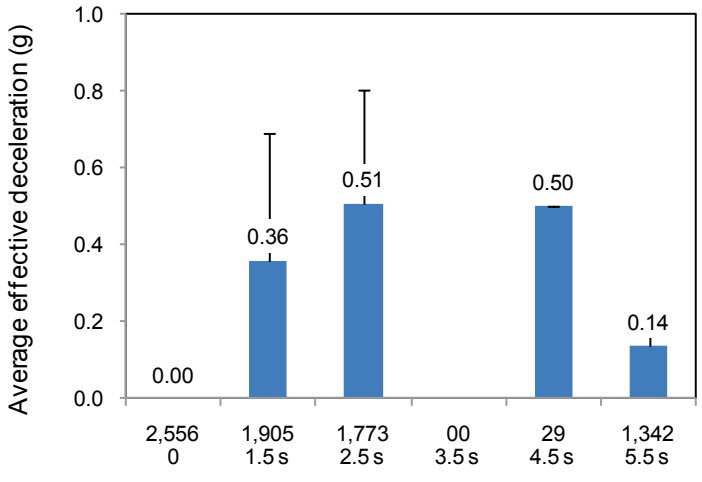
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



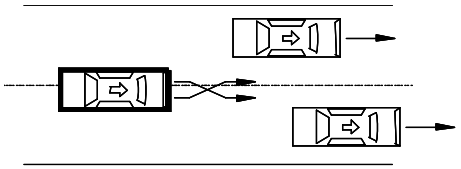
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

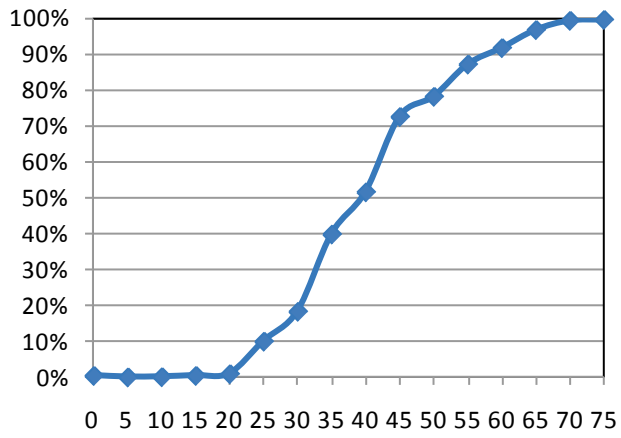
IV.8. Rear-End/Striking Maneuver

Typical Scenario: Vehicle is changing lanes or passing, and then closes in on a lead vehicle.



Societal Cost

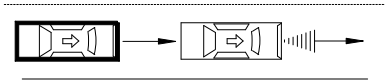
Total No. of Crashes	83,000
Total No. of Vehicles Involved	171,000
No. of Vehicles with Injuries	22,000
No. of People Injured	35,000
VSL	$ 2,381,000,000
FYL	16,000
MAIS 2+ Injuries	3,000
MAIS 3+ Injuries	1,000

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	65% - Straight, dry road surface with no adverse weather 19% - Curve, dry road surface with no adverse weather
Relation to Junction × Traffic Control Device	28% - Non-Junction without traffic controls 25% - Intersection or intersection related at RGY traffic signal
Lighting Condition	79% - Daylight 14% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	34% - ≤24 years 60% - 25 to 64 years 6% - 65 years or above
Gender	58% - Male 42% - Female

Driver Contributing Factors	Rear End / Striking Maneuver
Alcohol	5% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical Impairment
Violation Cited	48% - Violation cited
Speeding	24% - Speeding
Vision Obscured	2% - Obstruction
Distraction	44% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	8% - Braking (No lockup) 3% - Braking (Lockup) 3% - Braking (Lockup Unknown) 15% - Steering Left 15% - Steering Right 2% - Braking and Steering Left 2% - Braking and Steering Right 1% - Accelerating

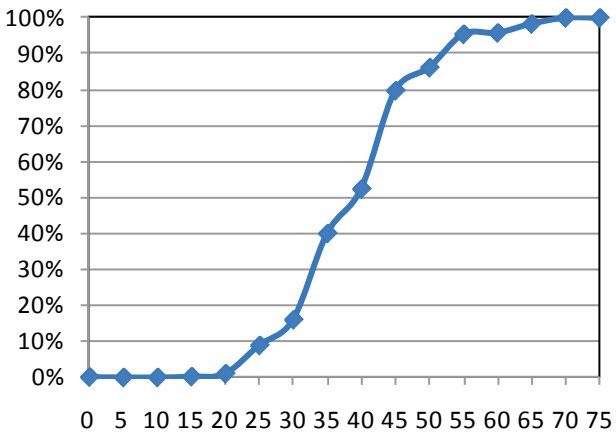
IV.9. Rear-End/Lead Vehicle Accelerating

Typical Scenario: Vehicle is going straight, and then closes in on an accelerating lead vehicle.



Societal Cost

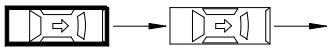
Total No. of Crashes		21,000
Total No. of Vehicles Involved		45,000
No. of Vehicles with Injuries		7,000
No. of People Injured		12,000
VSL	$	667,000,000
FYL		5,000
MAIS 2+ Injuries		1,000
MAIS 3+ Injuries		

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	79% - Straight, dry road surface with no adverse weather
Relation to Junction × Traffic Control Device	56% - Intersection or intersection related at RGY traffic signal 16% - Non-Junction without traffic controls
Lighting Condition	80% - Daylight 14% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	36% - ≤24 years 59% - 25 to 64 years 5% - 65 years or above
Gender	54% - Male 46% - Female

Driver Contributing Factors	**Rear-End/Lead Vehicle Accelerating**
Alcohol	4% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	1% - Sleepy
Violation Cited	51% - Violation cited
Speeding	27% - Speeding
Vision Obscured	3% - Obstruction
Distraction	51% - Distracted 1% - Sleepy
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	15% - Braking (No lockup) 8% - Braking (Lockup) 8% - Braking (Lockup Unknown) 4% - Steering Left 1% - Steering Right 3% - Accelerating

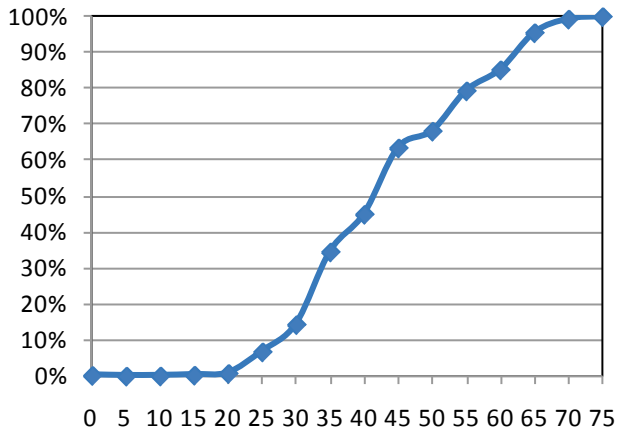
IV.10. Rear-End/Lead Vehicle Moving at Slower Constant Speed

Typical Scenario: Vehicle is going straight, and then closes in on a lead vehicle moving at lower constant speed.



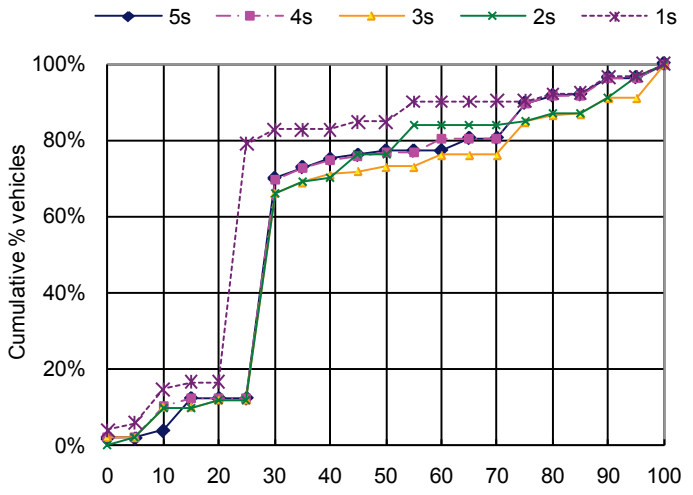
Societal Cost

Total No. of Crashes	202,000
Total No. of Vehicles Involved	430,000
No. of Vehicles with Injuries	75,000
No. of People Injured	121,000
VSL	$ 10,342,000,000
FYL	72,000
MAIS 2+ Injuries	12,000
MAIS 3+ Injuries	4,000

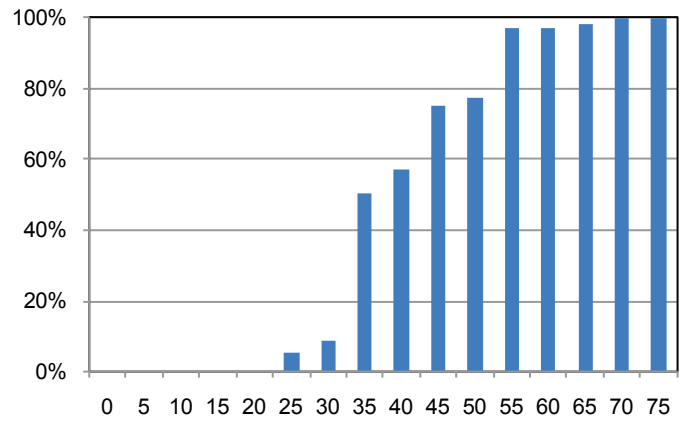
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	76% - Straight, dry road surface with no adverse weather 12% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	58% - Non-Junction without traffic controls 18% - Intersection or intersection related at RGY traffic signal
Lighting Condition	75% - Daylight 14% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	36% -≤24 years 59% - 25 to 64 years 5% - 65 years or above
Gender	61% - Male 39% - Female

Driver Contributing Factors	**Rear-End/Lead Vehicle Moving**
Alcohol	7% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	2% - Sleepy
Violation Cited	51% - Violation cited
Speeding	32% - Speeding
Vision Obscured	2% - Obstruction
Distraction	36% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	31% - Braking (No lockup) 11% - Braking (Lockup) 13% - Braking (Lockup Unknown) 5% - Steering Left 5% - Steering Right 2% - Braking and Steering Left 3% - Braking and Steering Right
Causal Factors (NMVCCS)	
Driver Fatigued	5% - Driver fatigued
Inattention	8% - Inattention factors
Driver Conversing	17% - Conversing
Misjudgment of Distance/Speed	5% - Misjudgment of distance/speed factors
False Assumption	5% - False assumption factors
Inadequate Evasive Action	2% - Inadequate evasive action factors
Critical Reason	60% - No critical reason 1% - Sleepy 1% - Ill/blackout 37% - Driver error 0% - Vehicle issues 1% - Weather /road /sign-signal issues
Inadequate Surveillance	15% - Inadequate surveillance factors
Other Driver Recognition Factors	4% - Other recognition factors
Following Too Closely	9% - Following too closely factors
Other Driver Decision Factors	2% - Other decision factors

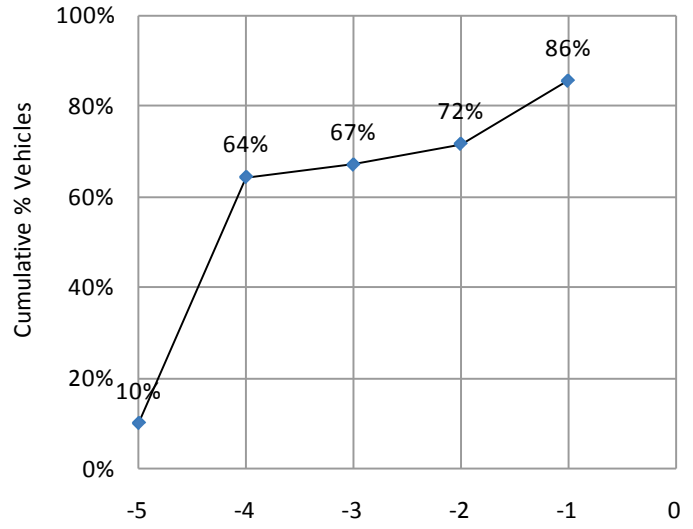
Kinematic Data (21 EDR Cases) **Rear-End/Lead Vehicle Moving**



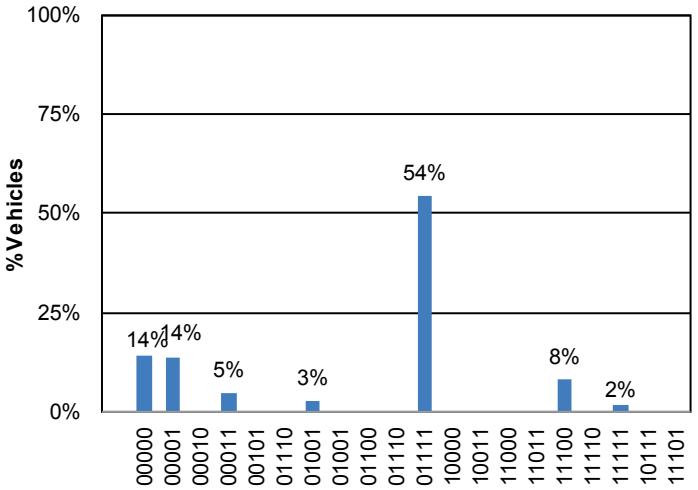
Vehicle Travel Speed (mph)



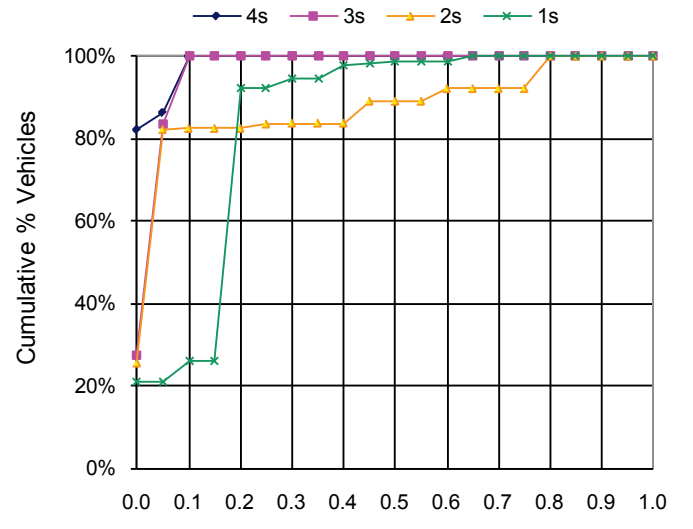
Vehicle Speed Limit (mph), 04-08 GES



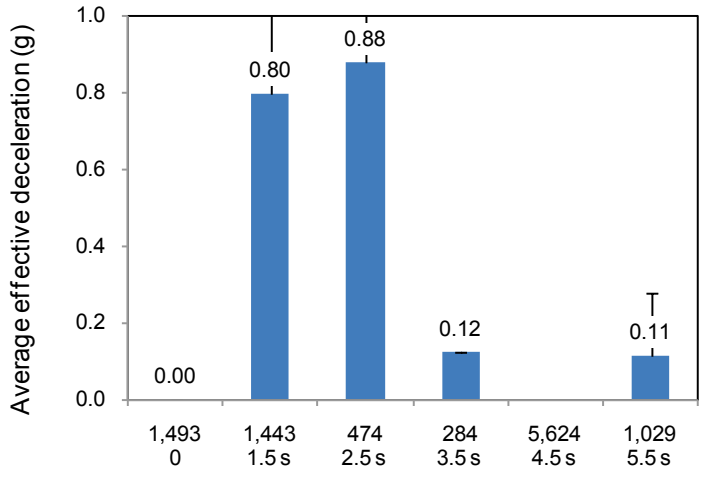
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



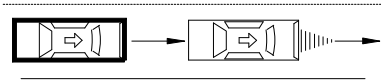
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

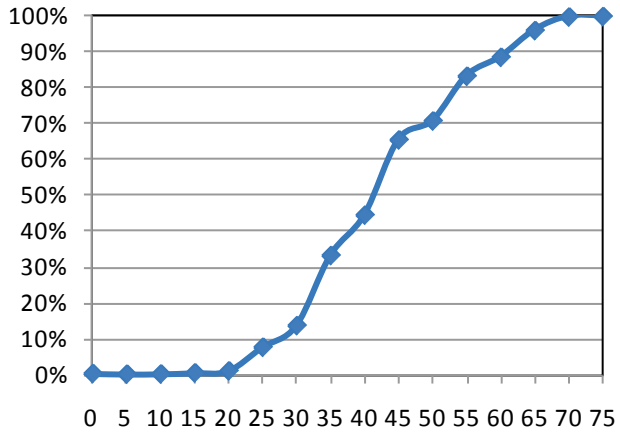
IV.11. Rear-End/Lead Vehicle Decelerating

Typical Scenario: Vehicle is going straight and following another lead vehicle, and then the lead vehicle suddenly decelerates.



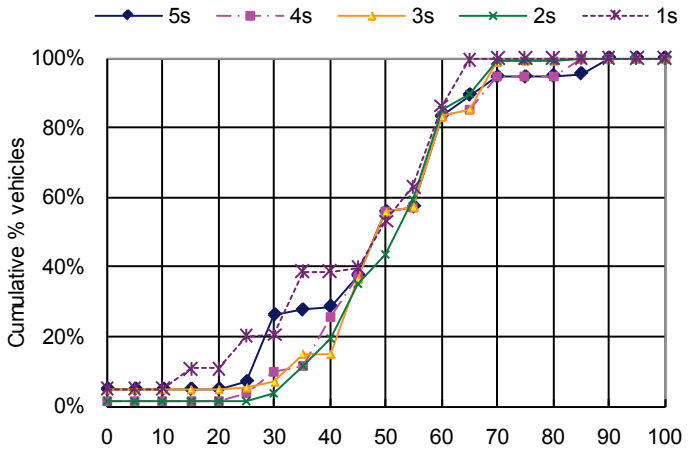
Societal Cost

Total No. of Crashes	398,000
Total No. of Vehicles Involved	873,000
No. of Vehicles with Injuries	133,000
No. of People Injured	212,000
VSL	$ 12,215,000,000
FYL	82,000
MAIS 2+ Injuries	18,000
MAIS 3+ Injuries	5,000

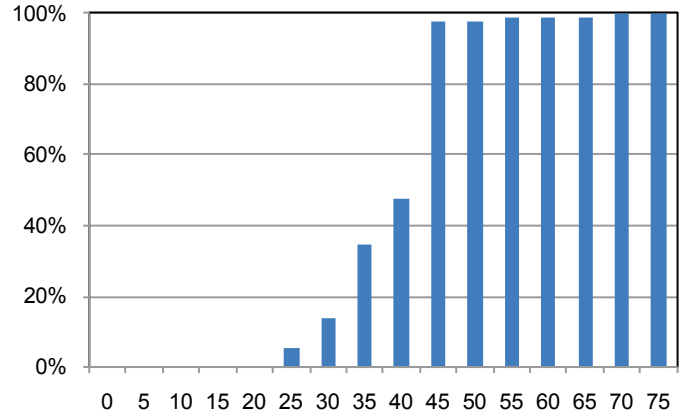
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	74% - Straight, dry road surface with no adverse weather 13% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	47% - Non-Junction without traffic controls 19% - Intersection or intersection related at RGY traffic signal 11% - Intersection or intersection related without traffic controls
Lighting Condition	82% - Daylight 10% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	38% - ≤24 years 58% - 25 to 64 years 4% - 65 years or above
Gender	58% - Male 42% - Female

Driver Contributing Factors	**Rear-End/Lead Vehicle Decelerating**
Alcohol	2% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical impairment
Violation Cited	51% - Violation cited
Speeding	34% - Speeding
Vision Obscured	2% - Obstruction
Distraction	38% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	23 % - Braking (No lockup) 14 % - Braking (Lockup) 12 % - Braking (Lockup Unknown) 4 % - Steering Left 6 % - Steering Right 2 % - Braking and Steering Left 3 % - Braking and Steering Right
Causal Factors (NMVCCS)	
Driver Fatigued	13% - Driver fatigued
Inattention	18% - Inattention factors
Driver Conversing	8% - Conversing
Misjudgment of Distance/Speed	8% - Misjudgment of distance/speed factors
False Assumption	12% - False assumption factors
Inadequate Evasive Action	3% - Inadequate evasive action factors
Critical Reason	51% - No critical reason 0% - Sleepy 1% - Ill/blackout 47% - Driver error 0% - Vehicle issues 1% - Weather /road /sign-signal issues
Inadequate Surveillance	29% - Inadequate surveillance factors
Other Driver Recognition Factors	3% - Other recognition factors
Following Too Closely	20% - Following too closely factors
Other Driver Decision Factors	3% - Other decision factors

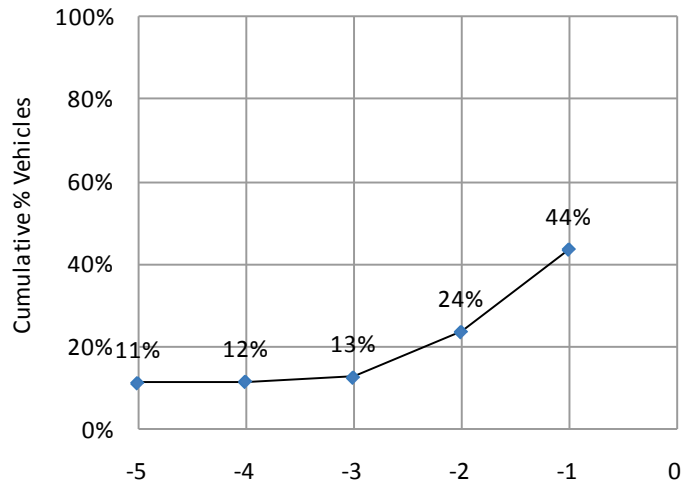
Kinematic Data (27 EDR Cases) **Rear-End/Lead Vehicle Decelerating**



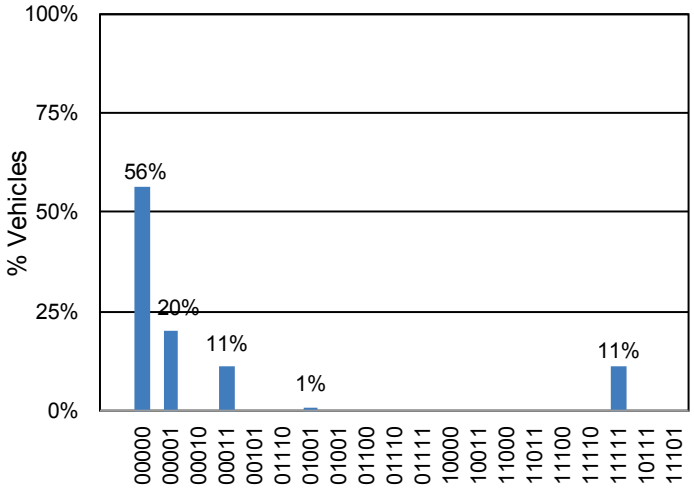
Vehicle Travel Speed (mph)



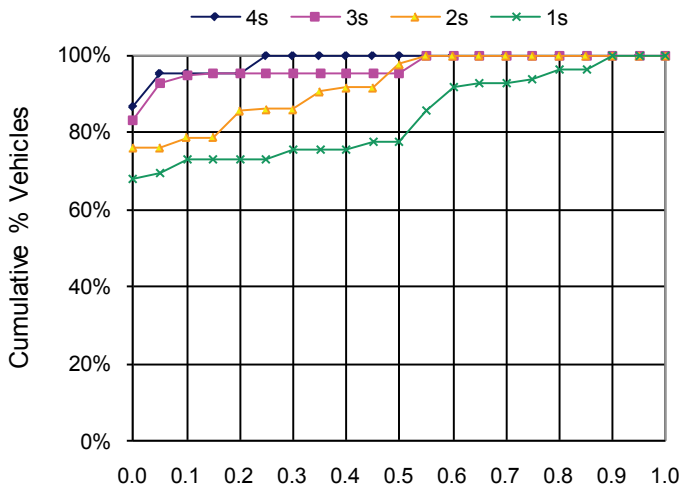
Vehicle Speed Limit (mph), 04-08 GES



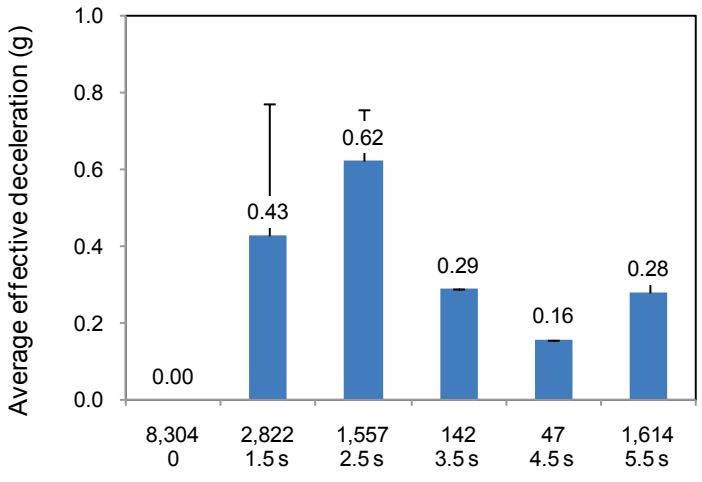
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



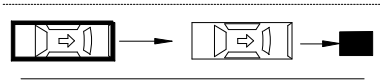
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

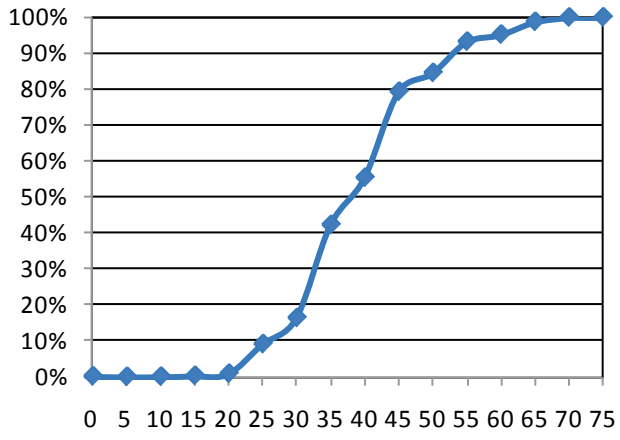
IV.12. Rear-End/Lead Vehicle Stopped

Typical Scenario: Vehicle is going straight, and then closes in on a stopped lead vehicle.



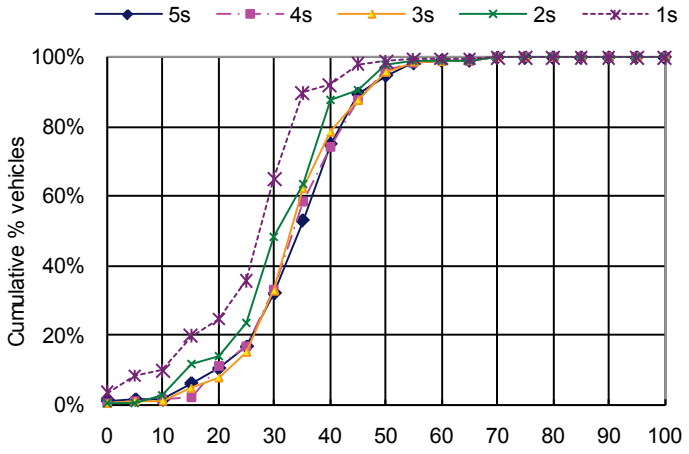
Societal Cost

Total No. of Crashes	942,000
Total No. of Vehicles Involved	2,067,000
No. of Vehicles with Injuries	342,000
No. of People Injured	550,000
VSL	$ 29,716,000,000
FYL	198,000
MAIS 2+ Injuries	45,000
MAIS 3+ Injuries	12,000

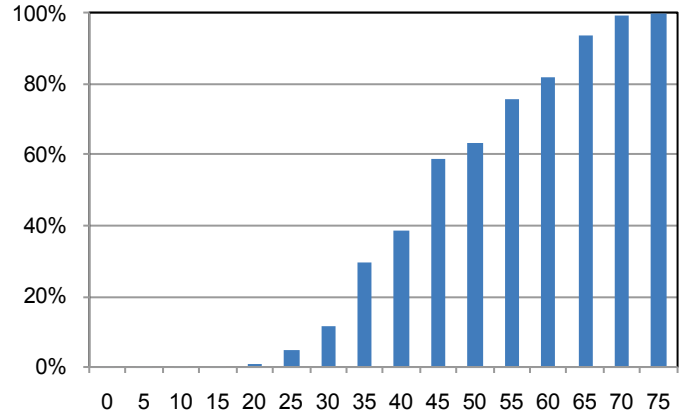
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	74% - Straight, dry road surface with no adverse weather 13% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	37% - Intersection or intersection related at RGY traffic signal 29% - Non-Junction without traffic controls
Lighting Condition	81% - Daylight 12% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	35% - ≤24 years 59% - 25 to 64 years 7% - 65 years or above
Gender	56% - Male 44% - Female

Driver Contributing Factors	**Rear-End/Lead Vehicle Stopped**
Alcohol	4% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical impairment
Violation Cited	55% - Violation cited
Speeding	31% - Speeding
Vision Obscured	2% - Obstruction
Distraction	47% - Distracted 1% - Sleepy
Vehicle Contributing Factors	
Contributing Factors	1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	20% - Braking (No lockup) 13% - Braking (Lockup) 13% - Braking (Lockup Unknown) 3% - Steering Left 5% - Steering Right 2% - Braking and Steering Right 2% - Accelerating
Causal Factors (NMVCCS)	
Driver Fatigued	13% - Driver fatigued
Inattention	23% - Inattention factors
Driver Conversing	11% - Conversing
Misjudgment of Distance/Speed	15% - Misjudgment of distance/speed factors
False Assumption	25% - False assumption factors
Inadequate Evasive Action	13% - Inadequate evasive action factors
Critical Reason	4% - No critical reason 1% - Sleepy 1% - Ill/blackout 91% - Driver error 1% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	52% - Inadequate surveillance factors
Other Driver Recognition Factors	8% - Other recognition factors
Following Too Closely	9% - Following too closely factors
Other Driver Decision Factors	4% - Other decision factors

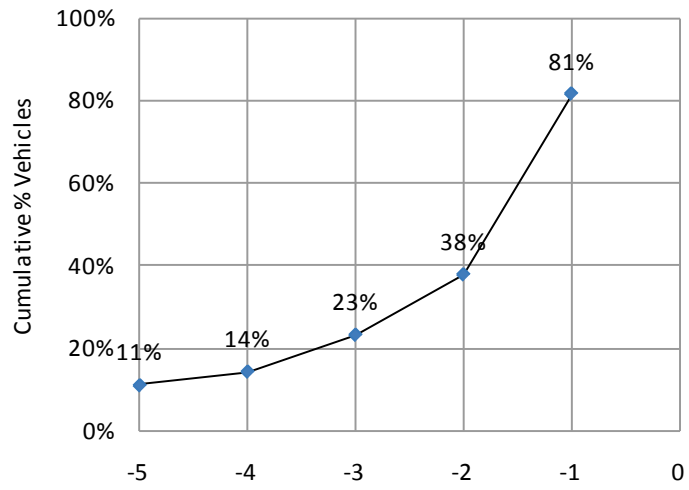
Kinematic Data (99 EDR Cases) **Rear-End/Lead Vehicle Stopped**



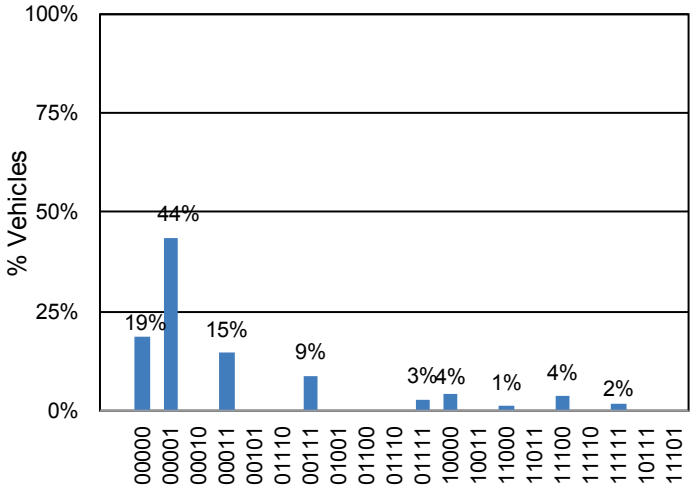
Vehicle Travel Speed (mph)



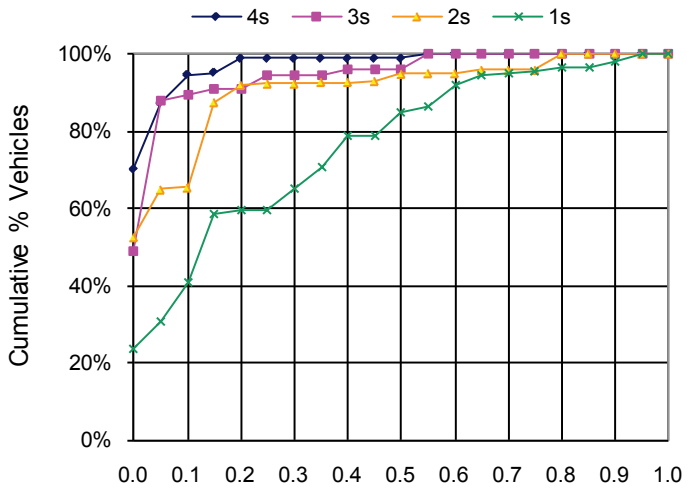
Vehicle Speed Limit (mph), 04-08 GES



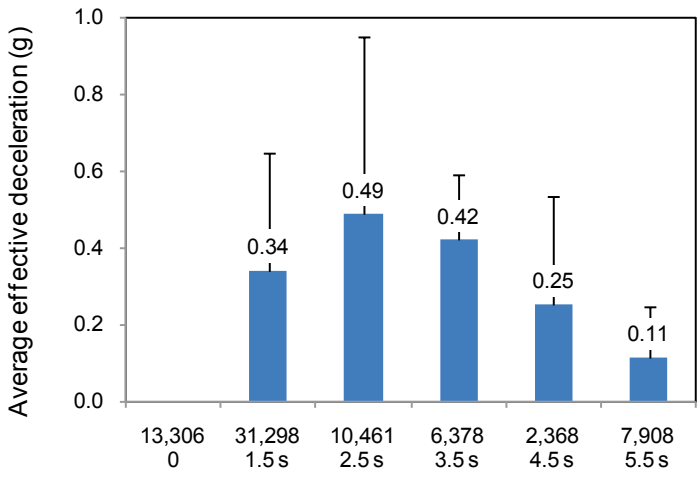
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



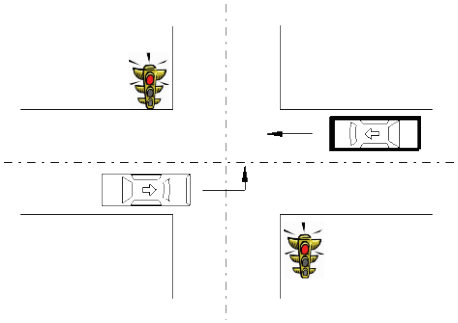
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

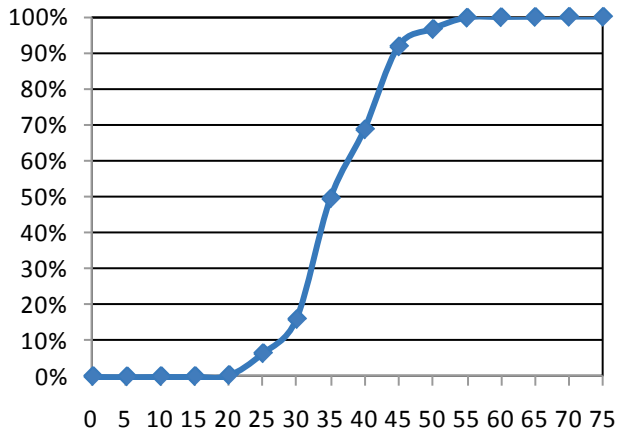
IV.13. LTAP/OD at Signal

Typical Scenario: Vehicle is turning left at a signalized intersection, and then cuts across the path of another vehicle straight crossing from an opposite direction.



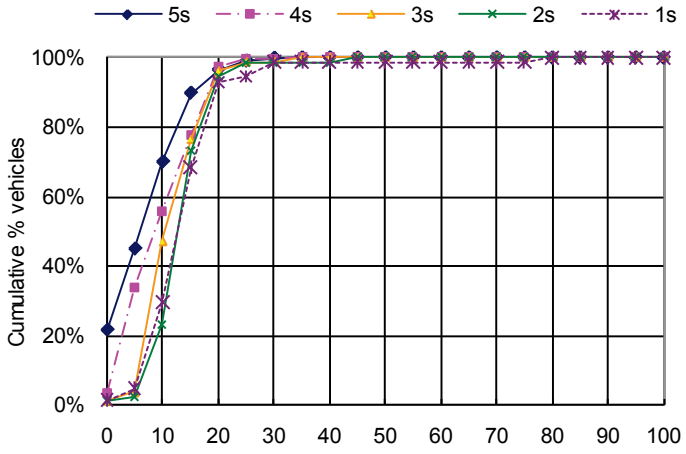
Societal Cost

Total No. of Crashes	204,000
Total No. of Vehicles Involved	424,000
No. of Vehicles with Injuries	120,000
No. of People Injured	191,000
VSL	$ 14,777,000,000
FYL	105,000
MAIS 2+ Injuries	20,000
MAIS 3+ Injuries	6,000

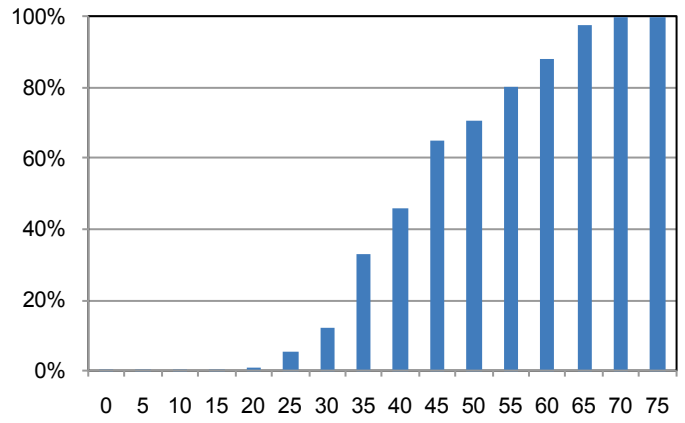
Driving Environment		
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	81% - Straight, dry road surface with no adverse weather 11% - Straight, slippery road surface with adverse weather	
Relation to Junction × Traffic Control Device	97% - Intersection or intersection related at RGY traffic signal	
Lighting Condition	66% - Daylight 26% - Dark but lighted	
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)	
Driver Characteristics		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Age	34% - ≤24 years 52% - 25 to 64 years 14% - 65 years or above	28% - ≤24 Years 64% - 25 to 64 Years 7% - 65 Years or above
Gender	52% - Male 48% - Female	56% - Male 44% - Female

Driver Contributing Factors	**LTAP/OD at Signal**	
	Left Turning Driver	**Non-Left Turning Driver**
Alcohol	3% - Alcohol use	1% - Alcohol use
Drugs	<1% - Drug use	<1% - Drug use
Physical Impairment	<1% - Physical impairment	<1% - Physical impairment
Violation Cited	51% - Violation cited	13% - Violation cited
Speeding	1% - Speeding	2% - Speeding
Vision Obscured	6% - Obstruction	3% - Obstruction
Distraction	21% - Distracted	4% - Distracted
Vehicle Contributing Factors		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Contributing Factors	<1% - Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Corrective Action	3% - Braking (No lockup) 2% - Braking (Lockup) 1% - Braking (Lockup Unknown) 1% - Steering Left 3% - Accelerating	12% - Braking (No lockup) 13% - Braking (Lockup) 10% - Braking (Lockup Unknown) 5% - Steering Left 10% - Steering Right 1% - Braking and Steering Left 3% - Braking and Steering Right 2% - Unspecified action
Causal Factors (NMVCCS)		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Driver Fatigued	6% - Driver fatigued	5% - Driver fatigued
Inattention	8% - Inattention factors	5% - Inattention factors
Driver Conversing	13% - Conversing	10% - Conversing
Misjudgment of Distance/Speed	13% - Misjudgment of distance/speed factors	11% - Misjudgment of distance/speed factors
False Assumption	23% - False assumption factors	44% - False assumption factors
Inadequate Evasive Action	1% - Inadequate evasive action factors	1% - Inadequate evasive action factors
Critical Reason	0% - No critical reason 0% - Sleepy 0% - Ill/blackout 99% - Driver error 0% - Vehicle issues 1% - Weather /road /sign-signal issues	1% - No critical reason 0% - Sleepy 2% - Ill/blackout 98% - Driver error 0% - Vehicle issues 0% - Weather /road /sign-signal issues
Inadequate Surveillance	69% - Inadequate surveillance factors	49% - Inadequate surveillance factors
Other Driver Recognition Factors	10% - Other recognition factors	4% - Other recognition factors
Following Too Closely	0% - Following too closely factors	0% - Following too closely factors
Other Driver Decision Factors	25% - Other decision factors	24% - Other decision factors

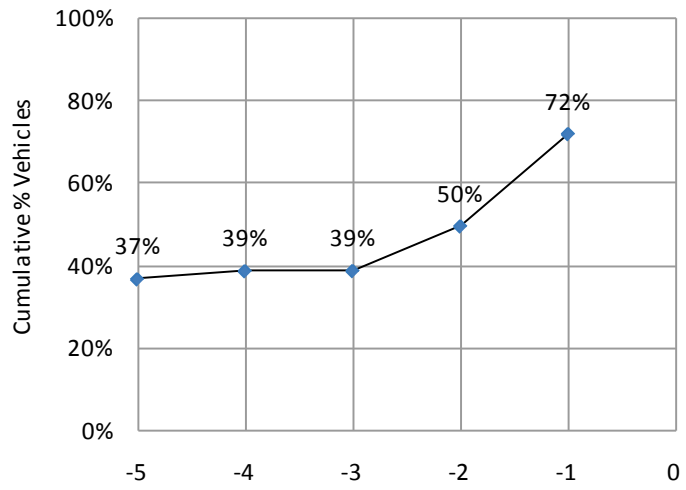
Kinematic Data of Turning Vehicle (89 EDR Cases) | **LTAP/OD at Signal**



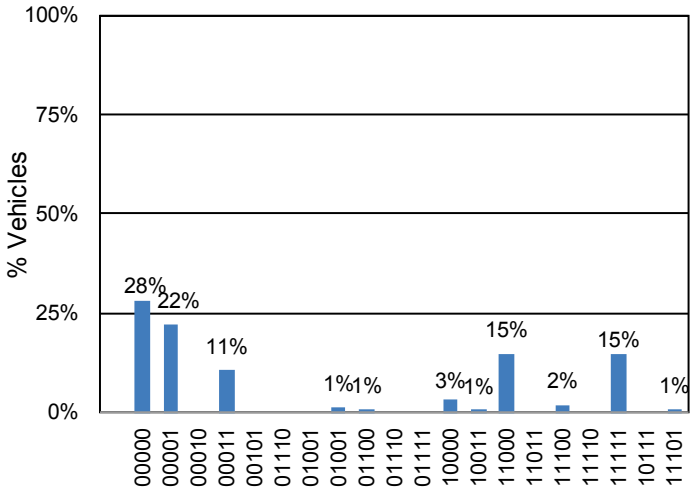
Vehicle Travel Speed (mph)



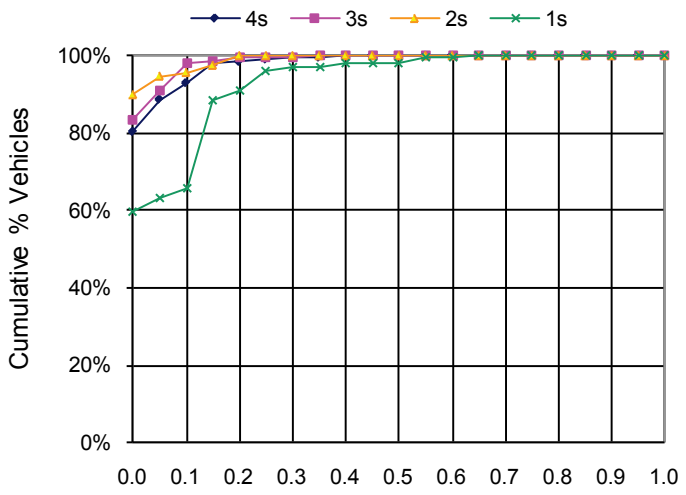
Vehicle Speed Limit (mph), 04-08 GES



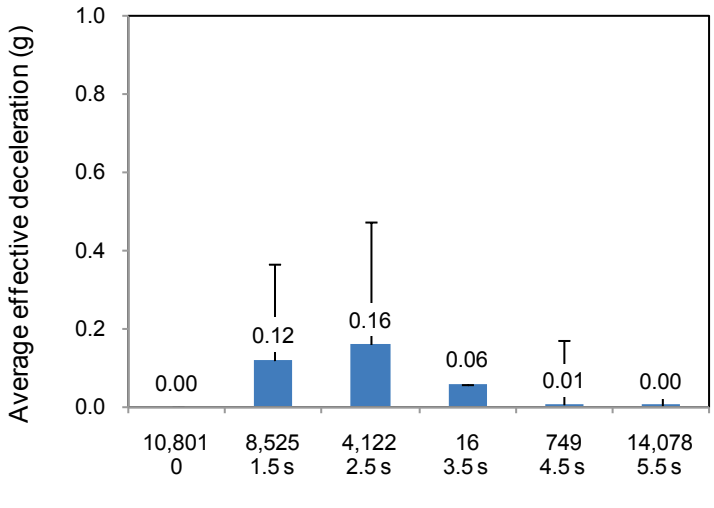
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

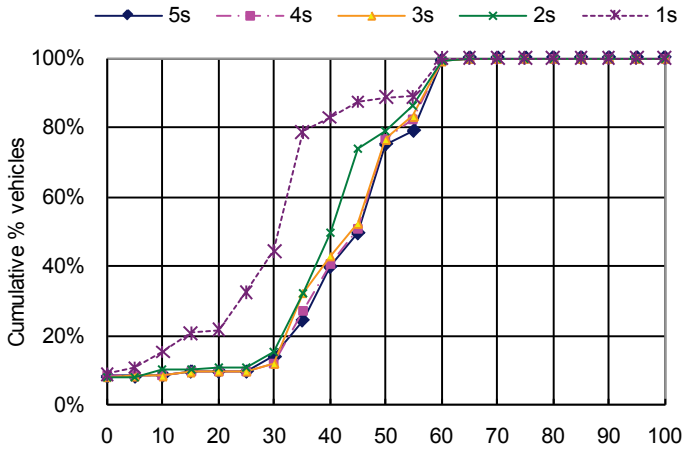


Braking Deceleration (g)

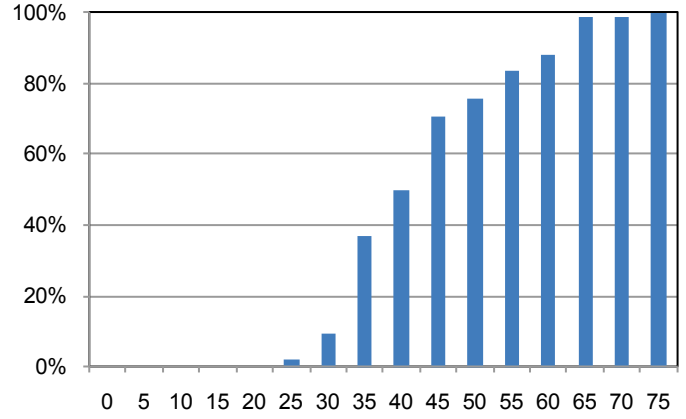


Effective Deceleration at TTC (s) with Frequency

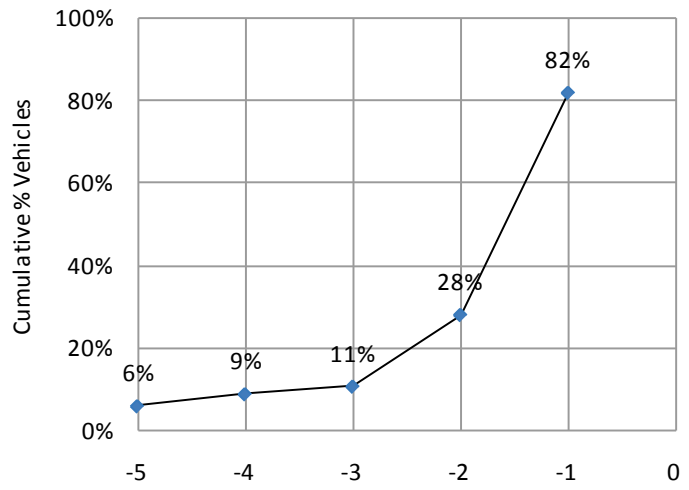
Kinematic Data of Non-Turning Vehicle (78 EDR) **LTAP/OD at Signal**



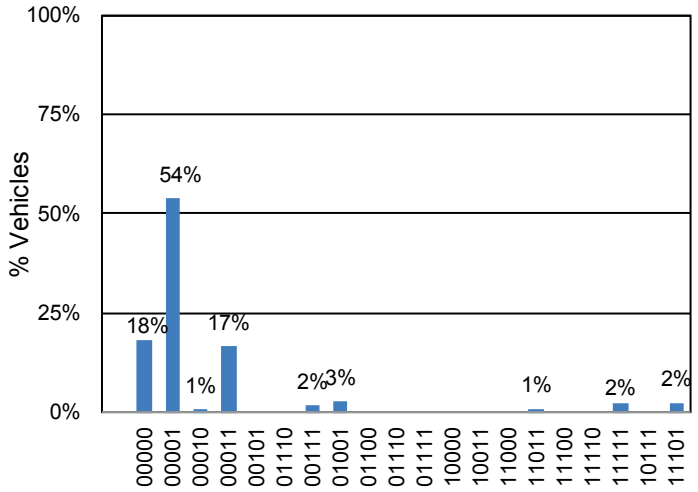
Vehicle Travel Speed (mph)



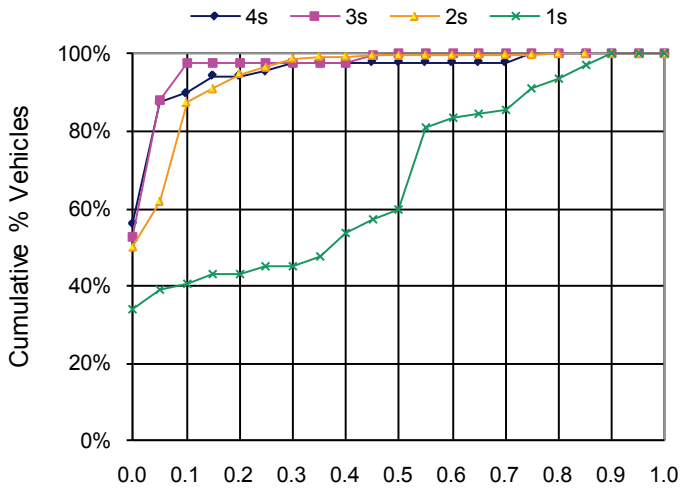
Vehicle Speed Limit (mph), 04-08 GES



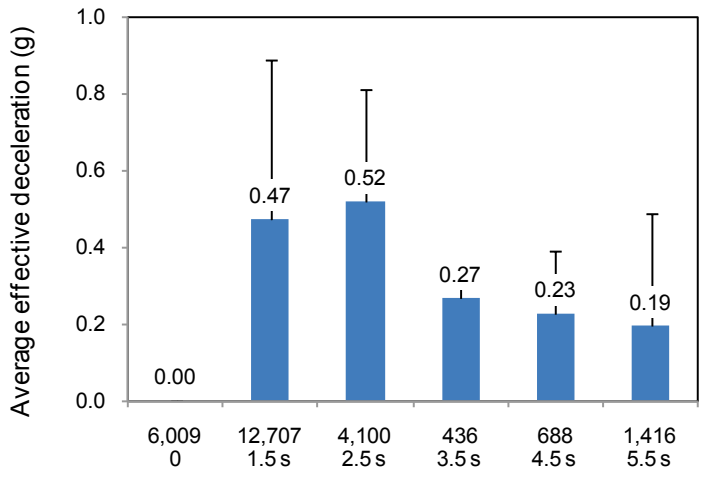
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



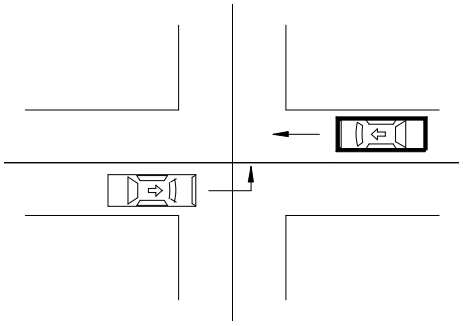
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

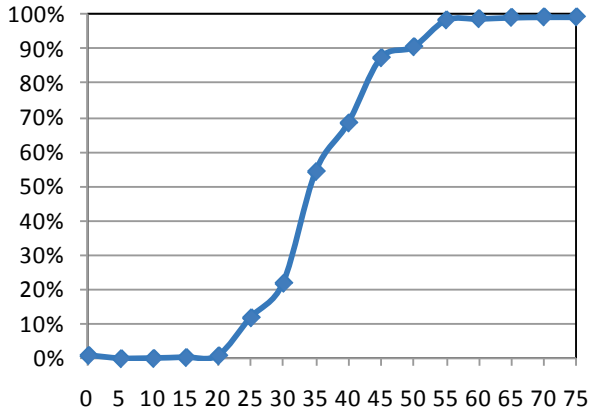
IV.14. LTAP/OD at Non-Signal

Typical Scenario: Vehicle is turning left at an intersection without traffic controls, and then cuts across the path of another vehicle traveling from the opposite direction.



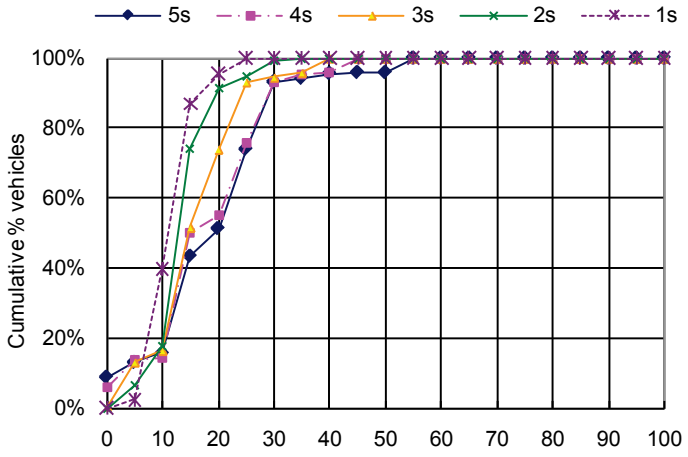
Societal Cost

Total No. of Crashes	184,000
Total No. of Vehicles Involved	376,000
No. of Vehicles with Injuries	100,000
No. of People Injured	158,000
VSL	$ 15,481,000,000
FYL	111,000
MAIS 2+ Injuries	18,000
MAIS 3+ Injuries	6,000

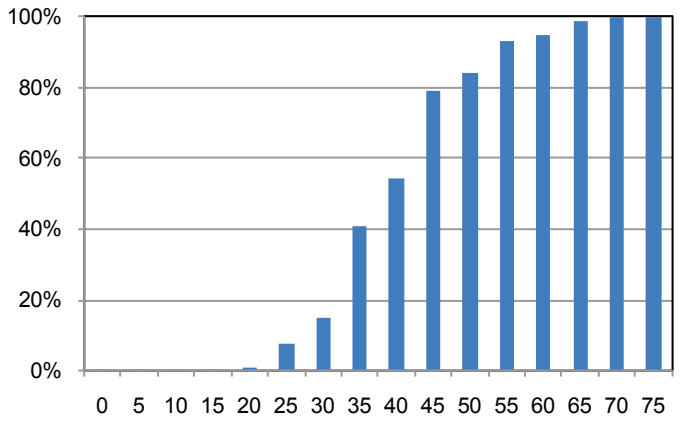
Driving Environment		
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	80% - Straight, dry road surface with no adverse weather	
Relation to Junction × Traffic Control Device	41% - Intersection or intersection related without traffic controls 35% - Driveway, alley, etc. without traffic controls	
Lighting Condition	79% - daylight 13% - dark but lighted	
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)	
Driver Characteristics		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Age	30% - ≤24 years 55% - 25 to 64 years 15% - 65 years or above	26% - ≤24 years 67% - 25 to 64 years 7% - 65 years or above
Gender	54% - Male 46% - Female	55% - Male 45% - Female

Driver Contributing Factors	**LTAP/OD at Non-Signal**	
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Alcohol:	3% - Alcohol use	1% - Alcohol use
Drugs	<1% - Drug use	<1% - Drug use
Physical Impairment	<1% - Physical impairment	<1% - Physical impairment
Violation Cited	56% - Violation cited	10% - Violation cited
Speeding	1% - Speeding	2% - Speeding
Vision Obscured	18% - Obstruction	9% - Obstruction
Distraction	29% - Distracted	4% - Distracted
Vehicle Contributing Factors		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Contributing Factors	<1% - Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted		
	Left Turning Vehicle	**Non-Left Turning Vehicle**
Corrective Action	3% - Braking (No lockup) 2% - Accelerating	13% - Braking (No lockup) 12% - Braking (Lockup) 11% - Braking (Lockup Unknown) 6% - Steering Left 9% - Steering Right 1% - Braking and Steering Left 4% - Braking and Steering Right 1% - Unspecified action
Causal Factors (NMVCCS)		
Driver Fatigued	6% - Driver fatigued	
Inattention	8% - Inattention factors	
Driver Conversing	9% - Conversing	
Misjudgment of Distance/Speed	16% - Misjudgment of distance/speed factors	
False Assumption	5% - False assumption factors	
Inadequate Evasive Action	0% - Inadequate evasive action factors	
Critical Reason	1% - No critical reason 0% - Sleepy 0% - Ill/blackout 98% - Driver error 0% - Vehicle issues 1% - Weather /road /sign-signal issues	
Inadequate Surveillance	77% - Inadequate surveillance factors	
Other Driver Recognition Factors	14% - Other recognition factors	
Following Too Closely	0% - Following too closely factors	
Other Driver Decision Factors	40% - Other decision factors	

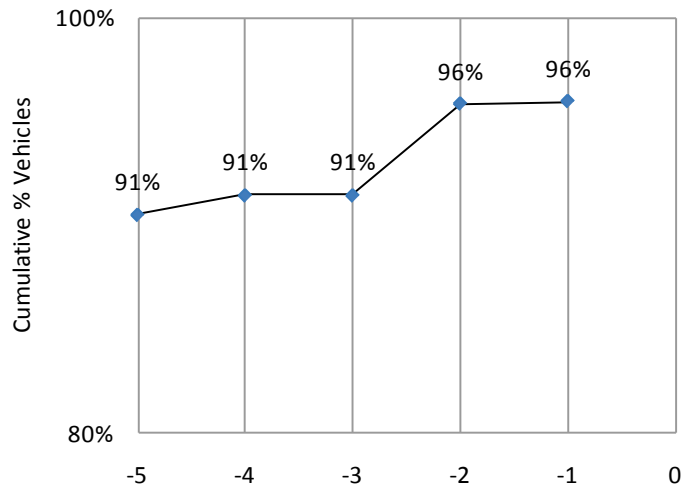
Kinematic Data of Turning Vehicle (44 EDR Cases) **LTAP/OD at Non-Signal**



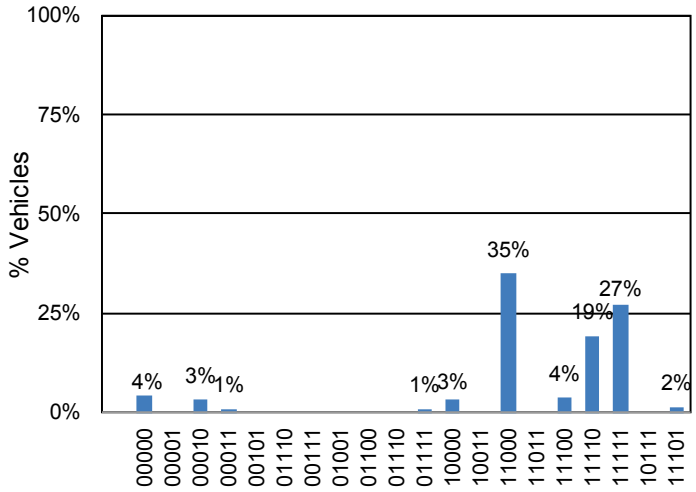
Vehicle Travel Speed (mph)



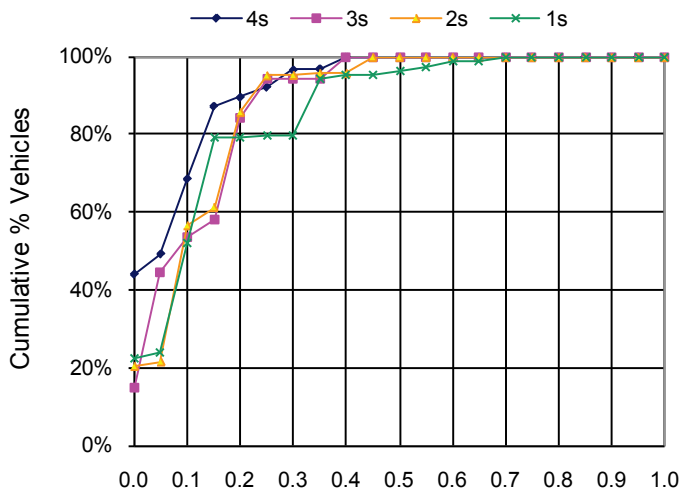
Vehicle Speed Limit (mph), 04-08 GES



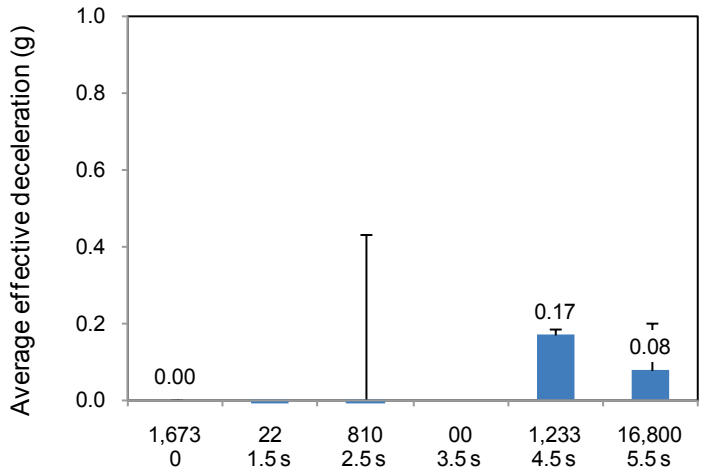
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

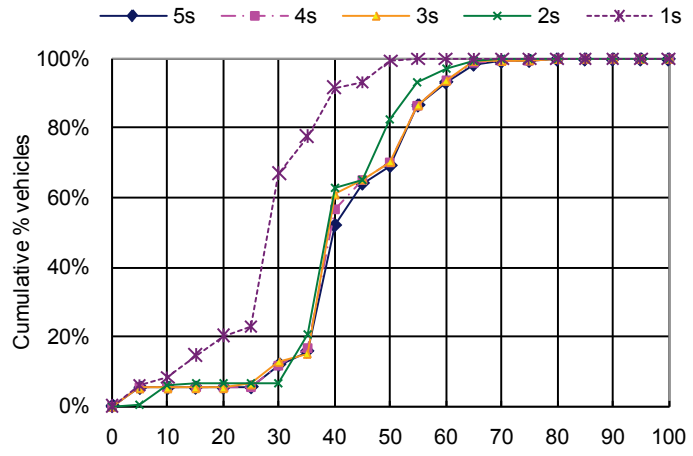


Braking Deceleration (g)

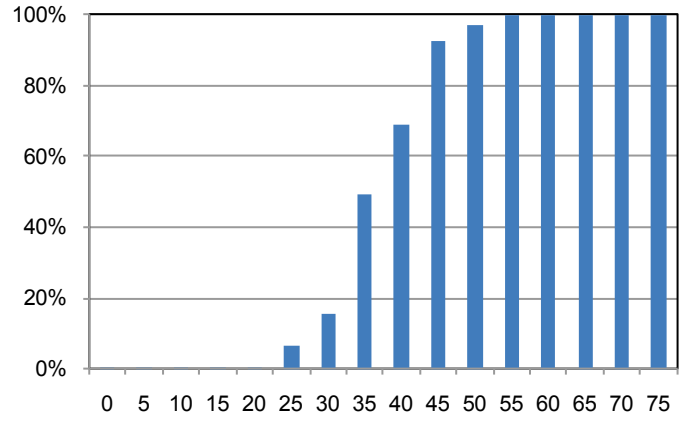


Effective Deceleration at TTC (s) with Frequency

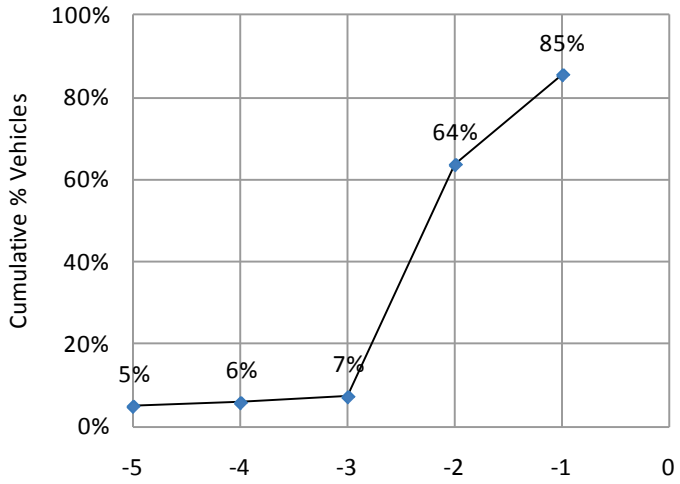
Kinematic Data of Non-Turning Vehicle (44 EDR Cases) | **LTAP/OD at Non-Signal**



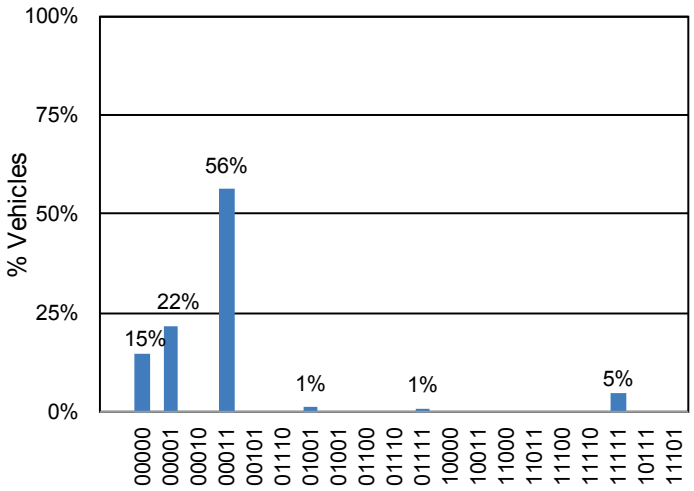
Vehicle Travel Speed (mph)



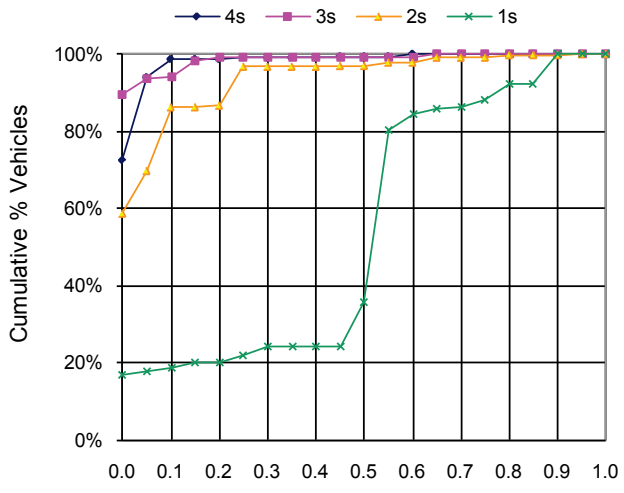
Vehicle Speed Limit (mph), 04-08 GES



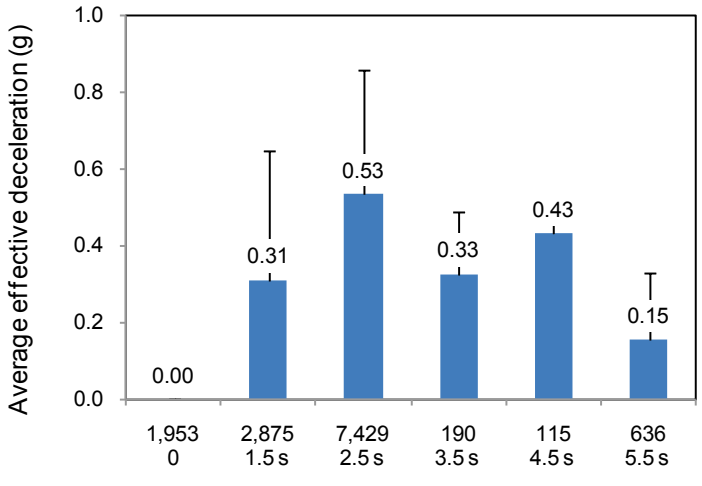
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



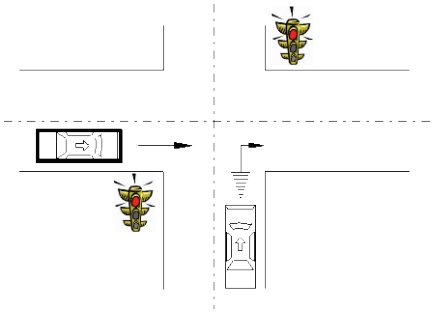
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

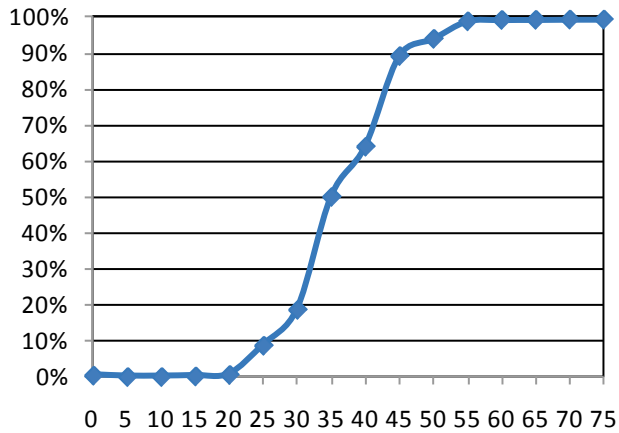
IV.15. Turn Right at Signal

Typical Scenario: Vehicle is turning right at a signalized intersection, and then turns into the same direction of another vehicle crossing straight initially from a lateral direction.



Societal Cost

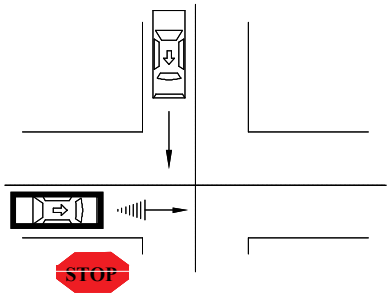
Total No. of Crashes		31,000
Total No. of Vehicles Involved		64,000
No. of Vehicles with Injuries		6,000
No. of People Injured		10,000
VSL	$	908,000,000
FYL		6,000
MAIS 2+ Injuries		1,000
MAIS 3+ Injuries		

Driving Environment		
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	74% - Straight, dry road surface with no adverse weather 16% - Straight, slippery road surface with adverse weather	
Relation to Junction × Traffic Control Device	90% - Intersection or intersection related at RGY traffic signal	
Lighting Condition	70% - Daylight 25% - Dark but lighted	
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)	
Driver Characteristics		
	Right Turning Vehicle	**Non-Right Turning Vehicle**
Age	29% - ≤24 years 55% - 25 to 64 years 16% - 65 years or above	24% - ≤24 years 67% - 25 to 64 years 9% - 65 years or above
Gender	54% - Male 46% - Female	54% - Male 46% - Female

Driver Contributing Factors	**Turn Right at Signal**	
	Right Turning Vehicle	**Non-Right Turning Vehicle**
Alcohol	6% - Alcohol use	1% - Alcohol use
Drugs	<1% - Drug use	<1% - Drug use
Physical Impairment	<1% - Physical impairment	0% - Physical impairment
Violation Cited	40% - Violation cited	9% - Violation cited
Speeding	5% - Speeding	<1% - Speeding
Vision Obscured	4% - Obstruction	2% - Obstruction
Distraction	24% - Distracted	3% - Distracted
Vehicle Contributing Factors		
	Right Turning Vehicle	**Non-Right Turning Vehicle**
Contributing Factors	<1% - Contributing Factors	0% - Contributing Factors
Corrective Action Attempted		
	Right Turning Vehicle	**Non-Right Turning Vehicle**
Corrective Action	3% - Braking (No lockup) 2% - Braking (Lockup) 4% - Braking (Lockup Unknown) 1% - Braking and Steering Right	4% - Braking (No lockup) 4% - Braking (Lockup) 12% - Steering Left 2% - Steering Right 1% - Braking and Steering Left 1% - Unspecified action
Causal Factors (NMVCCS)		
Driver Fatigued	0% - Driver fatigued	
Inattention	4% - Inattention factors	
Driver Conversing	8% - Conversing	
Misjudgment of Distance/Speed	45% - Misjudgment of distance/speed factors	
False Assumption	29% - False assumption factors	
Inadequate Evasive Action	0% - Inadequate evasive action factors	
Critical Reason	0% - No critical reason 0% - Sleepy 0% - Ill/blackout 98% - Driver error 2% - Vehicle issues 0% - Weather /road /sign-signal issues	
Inadequate Surveillance	53% - Inadequate surveillance factors	
Other Driver Recognition Factors	5% - Other recognition factors	
Following Too Closely	0% - Following too closely factors	
Other Driver Decision Factors	50% - Other decision factors	

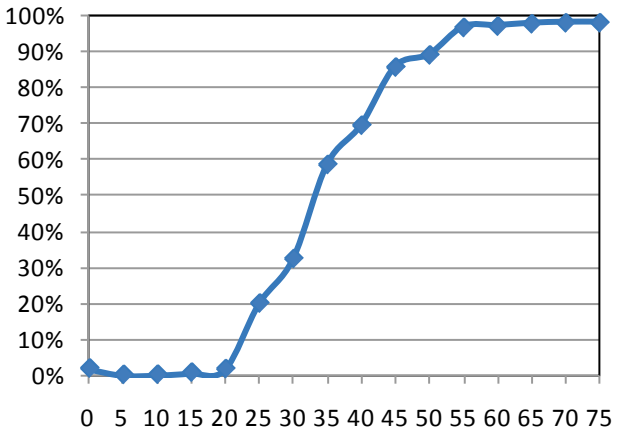
IV.16. SCP at Non-Signal

Typical Scenario: Vehicle stops at a stop sign, and then proceeds against lateral crossing traffic.



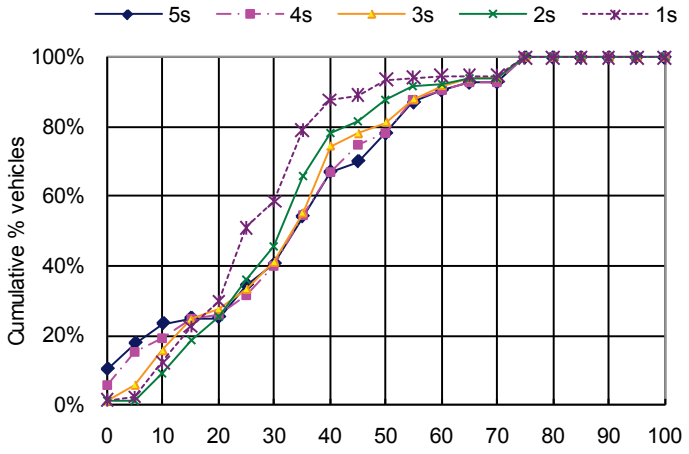
Societal Cost

Total No. of Crashes	647,000
Total No. of Vehicles Involved	1,308,000
No. of Vehicles with Injuries	273,000
No. of People Injured	443,000
VSL	$ 41,095,000,000
FYL	292,000
MAIS 2+ Injuries	47,000
MAIS 3+ Injuries	16,000

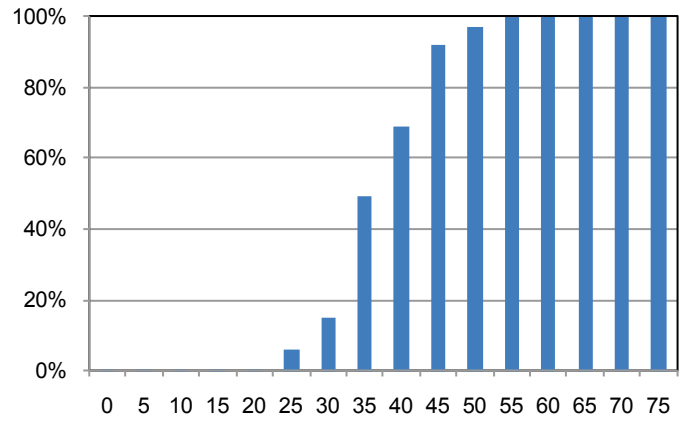
Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	77% - Straight, dry road surface with no adverse weather 11% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	52% - Intersection or intersection related at stop sign 25% - Driveway, alley, etc. without traffic controls
Lighting Condition	80% - Daylight 12% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	28% - ≤24 years 61% - 25 to 64 years 10% - 65 years or above
Gender	53% - Male 47% - Female

Driver Contributing Factors	**SCP at Non-Signal**
Alcohol	2% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical impairment
Violation Cited	27% - Violation cited
Speeding	2% - Speeding
Vision Obscured	8% - Obstruction
Distraction	13% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	6% - Braking (No lockup) 9% - Braking (Lockup) 7% - Braking (Lockup Unknown) 11 % - Steering Left 6% - Steering Right 2% - Braking and Steering Left 1% - Braking and Steering Right 1% - Unspecified action
Causal Factors (NMVCCS)	
	(Combined SCP & Turn at Non-Signal)
Driver Fatigued	9% - Driver fatigued
Inattention	13% - Inattention factors
Driver Conversing	16% - Conversing
Misjudgment of Distance/Speed	6% - Misjudgment of distance/speed factors
False Assumption	13% - False assumption factors
Inadequate Evasive Action	4% - Inadequate evasive action factors
Critical Reason	21% - No critical reason 0% - Sleepy 0% - Ill/blackout 76% - Driver error 1% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	69% - Inadequate surveillance factors
Other Driver Recognition Factors	14% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	29% - Other decision factors

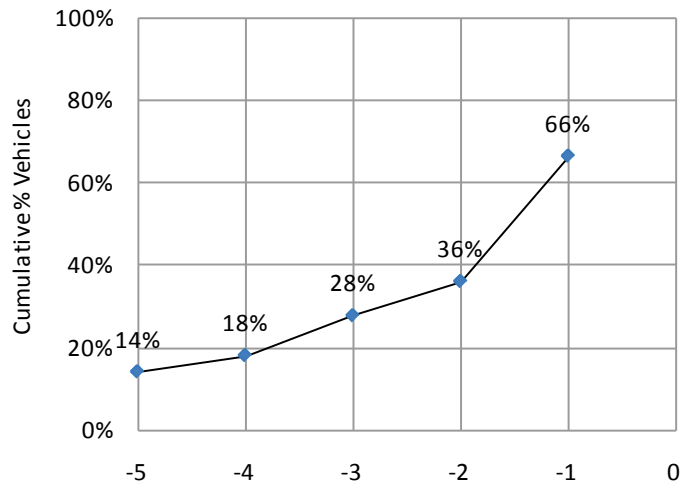
Kinematic Data (126 EDR Cases) **SCP at Non-Signal**



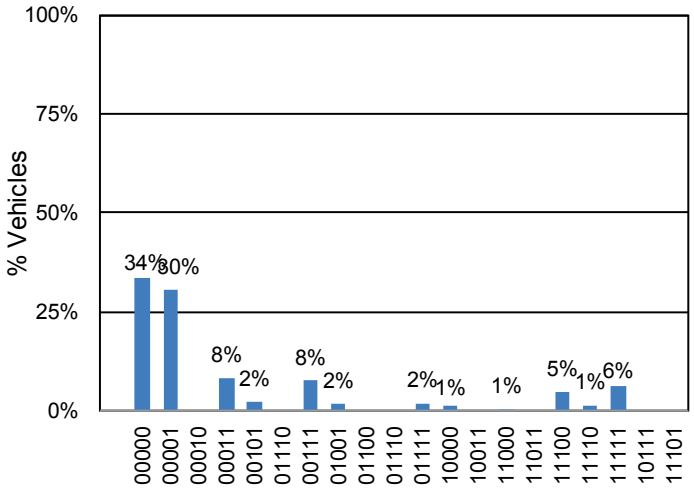
Vehicle Travel Speed (mph)



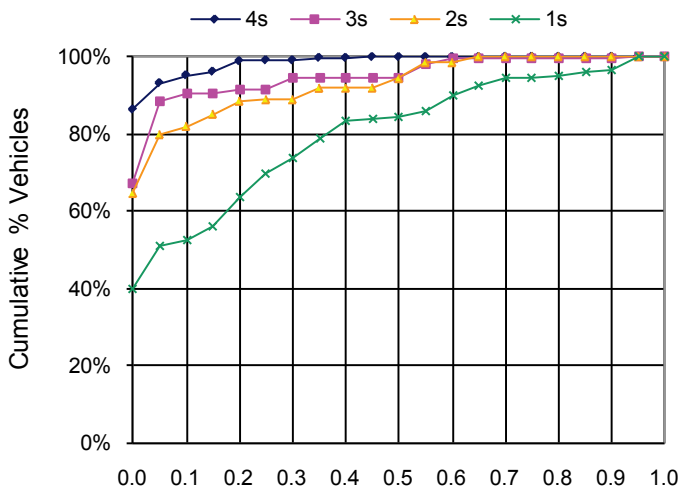
Vehicle Speed Limit (mph), 04-08 GES



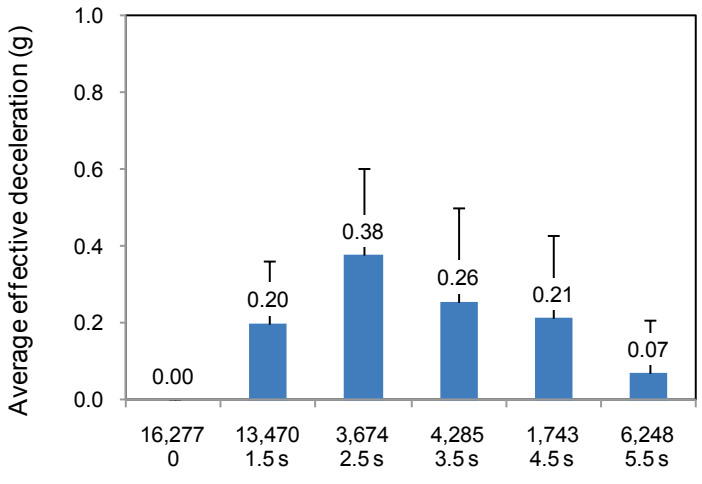
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



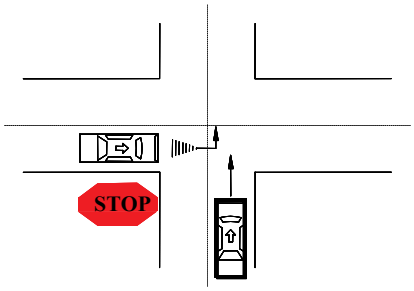
Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

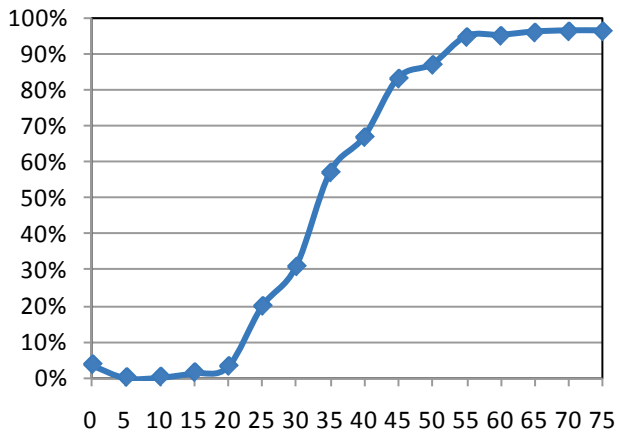
IV.17. Turn at Non-Signal

Typical Scenario: Vehicle stops at a stop sign, and then proceeds to turn left against lateral crossing traffic.



Societal Cost

Total No. of Crashes		45,000
Total No. of Vehicles Involved		83,000
No. of Vehicles with Injuries		9,000
No. of People Injured		15,000
VSL	$	930,000,000
FYL		6,000
MAIS 2+ Injuries		1,000
MAIS 3+ Injuries		-

Driving Environment	
Roadway Alignment × Roadway Surface Condition × Atmospheric Condition	78% - Straight, dry road surface with no adverse weather 10% - Straight, slippery road surface with adverse weather
Relation to Junction × Traffic Control Device	31% - Intersection or intersection related at stop sign 22% - Driveway, alley, etc. without traffic controls 21% - Intersection or intersection related without traffic controls
Lighting Condition	78% - Daylight 13% - Dark but lighted
Posted Speed Limit	 Cumulative Posted Speed Limit (MPH)
Driver Characteristics	
Age	29% - ≤24 years 60% - 25 to 64 years 11% - 65 years or above
Gender	57% - male 43% - female

Driver Contributing Factors	**Turn at Non-Signal**
Alcohol	2% - Alcohol use
Drugs	<1% - Drug use
Physical Impairment	<1% - Physical impairment
Violation Cited	23% - Violation cited
Speeding	2% - Speeding
Vision Obscured	4% - Obstruction
Distraction	18% - Distracted
Vehicle Contributing Factors	
Contributing Factors	<1% - Contributing Factors
Corrective Action Attempted	
Corrective Action	2% - Braking (No lockup) 1% - Braking (Lockup Unknown) 12% - Steering Left 25% - Steering Right 1% - Braking and Steering Left 2% - Braking and Steering Right 1% - Unspecified action
Causal Factors (NMVCCS)	
	(Combined SCP & Turn at Non-Signal)
Driver Fatigued	9% - Driver fatigued
Inattention	13% - Inattention factors
Driver Conversing	16% - Conversing
Misjudgment of Distance/Speed	6% - Misjudgment of distance/speed factors
False Assumption	13% - False assumption factors
Inadequate Evasive Action	4% - Inadequate evasive action factors
Critical Reason	21% - No critical reason 0% - Sleepy 0% - Ill/blackout 76% - Driver error 1% - Vehicle issues 2% - Weather /road /sign-signal issues
Inadequate Surveillance	69% - Inadequate surveillance factors
Other Driver Recognition Factors	14% - Other recognition factors
Following Too Closely	0% - Following too closely factors
Other Driver Decision Factors	29% - Other decision factors

V. CONCLUSION

This report updates the statistics of the 37 pre-crash scenario typology for crash avoidance research, which was developed in the past based on 2004 GES data involving at least 1 light vehicle in police-reported crashes. The update consists of the use of 2004-2008 GES data as well as additional data from NMVCCS and EDR databases. Moreover, comprehensive economic costs based on 2007 economics, instead of 2000, are utilized to quantify the societal cost of pre-crash scenarios. This new analysis focuses on pre-crash scenarios that may be addressed with crash countermeasure systems based on V2V communications. Thus, target pre-crash scenarios must involve at least two vehicles. As a result, a total of 22 out of the 37 pre-crash scenarios are analyzed. By taking into account that the crash countermeasure systems must warn the driver in imminent crash situations, 17 pre-crash scenarios remain as target V2V scenarios. These 17 pre-crash scenarios are statistically described in terms of their societal cost, 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.

A set of 5 rear-end pre-crash scenarios account for the most harm at about 20 percent of the societal cost of all 22 applicable V2V pre-crash scenarios. This is followed by a set of 3 junction-crossing pre-crash scenarios at 16 percent of the total societal cost, which includes straight crossing paths and turning (other than LTAP/OD) at non-signalized junctions and turning right at signalized junctions. The third most harmful pre-crash scenarios are the opposite direction at 12 percent.

The driving environment statistics reveal that most crashes occur on a straight road, dry surface, in clear weather, during daylight. The opposite direction pre-crash scenarios happen more on a curved road during dark conditions than any other target pre-crash scenario. A large portion of crashes associated with changing lanes/drifting in same direction, lead vehicle moving, and lead vehicle decelerating pre-crash scenarios occurs at speed limits greater than or equal to 55 mph. In contrast, a very large portion of crossing path crashes is reported at speed limits less than or equal to 35 mph.

The breakdown of drivers of interest by age is 31.6 percent by younger drivers, 59.7 percent by middle-age drivers, and 8.7 percent by older drivers. In terms of gender, the breakdown of drivers of interest is about 56 percent by male drivers and 44 percent by female drivers. Higher rates of involvement by older drivers show up in TCD violation pre-crash scenarios. Younger drivers are more involved in running stop sign, opposite direction, rear-end, and turning left in LTAP/OD at signalized junction pre-crash scenarios than in other scenarios.

The 2004-2008 GES statistics show that inattention is noted by 27.2 percent of all drivers of interest, with higher rates emerging in running red light, running stop sign, rear-end, and turning in LTAP/OD at non signalized junction pre-crash scenarios. Alcohol and drugs are involved in about four percent of all drivers of interest. Speeding is attributed to 13 percent of all vehicles of interest, mostly in rear-end pre-crash scenarios. Obscured vision is reported by 4.9 percent of all drivers of interest mostly in opposite direction/maneuver, LTAP/OD, and straight crossing paths at non signalized junction pre-crash scenarios.

NMVCCS data show that inattention is cited in 14.5 percent of all drivers of interest with higher rates showing in lead vehicle stopped, running red light, and lead vehicle decelerating. Fatigue is a factor in 9.5 percent of all drivers with higher rates observed in opposite direction, changing lanes/turning/ drifting, and lead vehicle stopped. Engaging in conversation is reported in 13.4 percent of all drivers with higher rates in changing lanes/turning/drifting, lead vehicle moving, and straight crossing paths/turning at non signalized junctions. Inadequate surveillance is implicated in 54.8 percent of all drivers of interest. Following too closely is relevant in rear-end pre-crash scenarios, accounting for about 11 percent of the cases. Misjudgement of distance/speed is indicated by 7.7 percent of all drivers with the highest rate of 44.8 percent appearing in the turn right at signalized junction pre-crash scenario. False assumption of other road user's action is mentioned by 13.1 percent of all drivers with higher rates observed in LTAP/OD at signalized junctions, turn right at signalized junctions, and lead vehicle stopped. Finally, inadequate evasive action by all vehicles of interest is 5.1 percent, with the highest rate reported in opposite direction scenarios.

The analysis of EDR data shows that 56 percent of the following vehicles in the lead vehicle decelerating scenario do not brake up to one second prior to the crash. This statistic is 53 percent of the vehicles making a lane change and 34 percent of the vehicles in opposite direction/no maneuver and straight crossing paths at non-signalized junction pre-crash scenarios. The average effective deceleration level is over 0.6g in lead vehicle moving and lead vehicle decelerating pre-crash scenarios when braking was initiated between 2 and 3 seconds before the crash. This statistic is below 0.4g in straight crossing path vehicles at non-signalized junctions and in vehicles making a lane change.

The 2004-2008 GES data enabled the detailed description of all 17 target V2V pre-crash scenarios. Data from the NMVCCS and EDR databases were limited in some pre-crash scenarios but were sufficient to describe the majority of the target V2V pre-crash scenarios.

The results of this report feed into the crash scenario framework that will to used to identify intervention opportunities and define crash countermeasure profiles based on V2V communications. The statistical and kinematical depiction of target pre-crash scenarios will enable the development of countermeasure functional requirements and minimum performance specifications as well as the estimation of potential safety benefits.

VI. REFERENCES

[1] ITS Joint Program Office. (2010). *ITS Strategic Research Plan, 2010-2014 - Executive Summary*. (Report No. FHWA-JPO-10-028). Washington, DC: U.S. Department of Transportation, Research and Innovative Technology Administration.

[2] National Center for Statistics and Analysis. (2009). *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-2008*. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[3] Bellis, E., & Page, J. (2008, December). *National Motor Vehicle Crash Causation Survey - SAS Analytical User's Manual*. (Report No. DOT HS 811 053). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[4] ftp://ftp.nhtsa.dot.gov/NASS/EDR_Reports/

[5] DaSilva, M. P. (2008, April). *Analysis of Event Data Recorder Data for Vehicle Safety Improvement*. (Report No. DOT HS 810 935). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[6] NAO Engineering, Safety & Restraints Center, Crash Avoidance Department. (1997, January). *44 Crashes, Version 3.0*. Warren, MI: General Motors Corporation..

[7] Crash Avoidance Metrics Partnership. (2004, November). *Enhanced Digital Mapping Project – Final Report*. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[8] Najm, W. G., Sen, B., Smith, J. D., & Campbell, B. N. (2003, February). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System*. (Report No. DOT HS 809 573). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[9] Najm, W. G., Smith, J., & Yanagisawa, M. (2007, April). *Pre-Crash Scenario Typology for Crash Avoidance Research*. (Report No. DOT HS 810 767). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[10] Najm, W. G., Koopmann, J., Smith, J., &Brewer, J. (2010, October). *Frequency* of *Target* Crashes *for IntelliDrive^{SM} Safety Systems*. (Report No. DOT HS 811 381). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[11] Ahmed-Zaid, F., & Carter, A. (2009, January). *Vehicle Safety Communications – Applications First Annual Report*. (Report No. DOT HS 811 073). Washington, DC: U. S. Department of Transportation, National Highway Traffic Safety Administration.

[12] Shelton, T. (1993, June). *Imputation in the NASS General Estimates System.* (Report No. DOT HS 807 985). Washington, DC: U. S. Department of Transportation, National Highway Traffic Safety Administration.

[13] National Center for Statistics and Analysis. (2008, December). *Traffic Safety Facts, Research Note, The National Motor Vehicle Crash Causation Survey*. (Report No. DOT HS 811 057). Washington, DC: U. S. Department of Transportation, National Highway Traffic Safety Administration.

[14] Gabler, H. C., Thor, C. P., & Hinch, J. (2008). *Preliminary Evaluation of Advanced Air Bag Field Performance Using Event Data Recorders.* (Report No. DOT HS 811 015). Washington, DC: U. S. Department of Transportation, National Highway Traffic Safety Administration.

[15] Willke, D., Summers, S., Wang, J., Lee, J., Partyka, S., &Duffy, S. (1999, August). *Ejection Mitigation Using Advanced Glazing: Status Report II*. East Liberty, OH: Transportation Research Center.

[16] Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romano, E., Luchter, S., &Spicer, R. (2002, May). *The Economic Impact of Motor Vehicle Crashes 2000*. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[17] Miller, T., Viner, J., Rossman, S., Pindus, N., Gellert, W., Douglass, J., Dillingham, A., &Blomquist, G. (1991, October). *The Costs of Highway Crashes*. (Report No. FHWA-RD-91-055). Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

Appendix A. GES Coding Schematic for Pre-Crash Scenarios

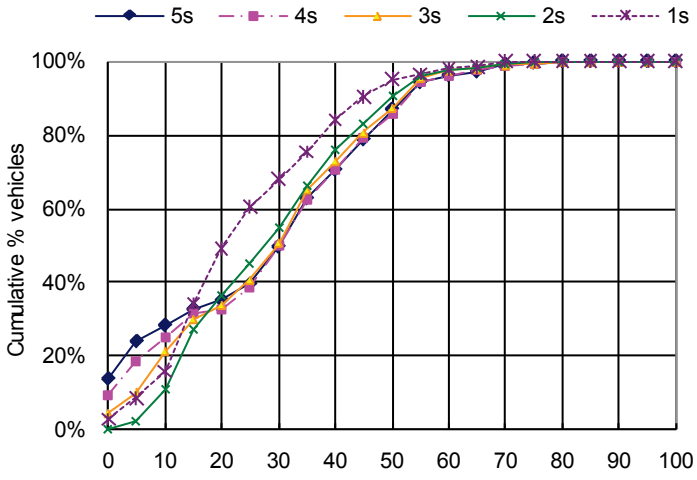
No	Scenario	Single-Vehicle Crashes (VEH_INVL = 1)	Multi-Vehicle Crashes (VEH_INVL >= 2), First Event
1	No driver present	MANEUV_I = 0	
2	Vehicle failure	P_CRASH2 = 1 - 4	P_CRASH2 = 1 - 4 (at least one vehicle)
3	Control loss/vehicle action	P_CRASH2 = 5 - 9 AND MANEUV_I = 2 - 4, 6, 8 - 13, 15 - 97 ACC_TYPE = 2, 7 AND MANEUV_I = 2 - 4, 6, 8 - 13, 15 - 97	Vx_P_CRASH2 = 5 - 9 AND Vx_MANEUV_I = 2 - 4, 6, 8 - 13, 15 - 97 Vx_ACC_TYPE = 34, 36, 54, 56 AND Vx_MANEUV_I = 2 - 4, 6, 8 - 13, 15 - 97 Vx_ACC_TYPE = 2, 7 AND Vx_MANEUV_I = 2 - 4, 6, 8 - 13, 15 - 97
4	Control loss/no vehicle action	P_CRASH2 = 5 - 9 AND MANEUV_I = 1, 14 ACC_TYPE = 2, 7 AND MANEUV_I = 1, 14	Vx_P_CRASH2 = 5 - 9 AND Vx_MANEUV_I = 1, 14 Vx_ACC_TYPE = 34, 36, 54, 56 AND Vx_MANEUV_I = 1, 14 Vx_ACC_TYPE = 2, 7 AND Vx_MANEUV_I = 1, 14
5	Running red light	TRAF_CON = 1, 4 AND MVIOLATN = 7	TRAF_CON = 1 AND ACC_TYPE = 76, 77, 82, 83, 86 - 91 TRAF_CON = 1, 4 AND MVIOLATN = 7
6	Running stop sign	TRAF_CON = 21 AND MVIOLATN = 7	TRAF_CON = 21 AND MVIOLATN = 7
7	Road edge departure/maneuver	P_CRASH2 = 10 - 14 AND MANEUV_I = 6, 8 - 12, 15 - 97 ACC_TYPE = 1, 6, 14 AND MANEUV_I = 6, 8 - 12, 15 - 97	Vx_ACC_TYPE = 1, 6, 14 AND Vx_MANEUV_I = 6, 8 - 12, 15 - 97
8	Road edge departure/no maneuver	P_CRASH2 = 10 - 14 AND MANEUV_I = 1 - 5, 7, 14 ACC_TYPE = 1, 6, 14 AND MANEUV_I = 1 - 5, 7, 14	Vx_ACC_TYPE = 1, 6, 14 AND Vx_MANEUV_I = 1 - 5, 7, 14
9	Road edge departure/backing	P_CRASH2 = 10 - 14 AND MANEUV_I = 13 ACC_TYPE = 1, 6, 14 AND MANEUV_I = 13 ACC_TYPE = 92	Vx_ACC_TYPE = 1, 6, 14 AND Vx_MANEUV_I = 13
10	Animal/maneuver	EVENT1_I = 24 AND MANEUV_I = 6, 8 - 13, 15 - 97 P_CRASH2 = 87 - 89 AND MANEUV_I = 6, 8 - 13, 15 - 97	Vx_P_CRASH2 = 87 - 89 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 124 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97
11	Animal/no maneuver	EVENT1_I = 24 AND MANEUV_I = 1 - 5, 7, 14 P_CRASH2 = 87 - 89 AND MANEUV_I = 1 - 5, 7, 14	Vx_P_CRASH2 = 87 - 89 AND Vx_MANEUV_I = 1 - 5, 7, 14 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 124 AND Vx_MANEUV_I = 1 - 5, 7, 14
12	Pedestrian/maneuver	EVENT1_I = 21 AND MANEUV_I = 6, 8 - 13, 15 - 97 P_CRASH2 = 80 - 82 AND MANEUV_I = 6, 8 - 13, 15 - 97	Vx_P_CRASH2 = 80 - 82 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 121 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97
13	Pedestrian/no maneuver	EVENT1_I = 21 AND MANEUV_I = 1 - 5, 7, 14 P_CRASH2 = 80 - 82 AND MANEUV_I = 1 - 5, 7, 14	Vx_P_CRASH2 = 80 - 82 AND Vx_MANEUV_I = 1 - 5, 7, 14 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 121 AND Vx_MANEUV_I = 1 - 5, 7, 14
14	Cyclist/maneuver	EVENT1_I = 22 AND MANEUV_I = 6, 8 - 13, 15 - 97 P_CRASH2 = 83 - 85 AND MANEUV_I = 6, 8 - 13, 15 - 97	Vx_P_CRASH2 = 83 - 85 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 122 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97
15	Cyclist/no maneuver	EVENT1_I = 22 AND MANEUV_I = 1 - 5, 7, 14 P_CRASH2 = 83 - 85 AND MANEUV_I = 1 - 5, 7, 14	Vx_P_CRASH2 = 83 - 85 AND Vx_MANEUV_I = 1 - 5, 7, 14 EVENTNUM = 1 AND VEHNUM = x AND OBJCONT = 122 AND Vx_MANEUV_I = 1 - 5, 7, 14
16	Backing into vehicle	P_CRASH2 = 56	ACC_TYPE = 92, 93 AND EVENT1_I = 25
17	Turning/same direction		ACC_TYPE = 44 - 49, 70 - 73 AND MANEUV_I = 10 - 12 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 10 - 12 MANEUV_I = 10 -12 AND P_CRASH2 = 60, 61
18	Parking/same direction	P_CRASH2 = 64	ACC_TYPE = 44 - 49, 70 - 73 AND MANEUV_I = 8, 9 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 8, 9 MANEUV_I = 8, 9 AND P_CRASH2 = 60, 61 P_CRASH2= 64
19	Changing lanes/same direction	P_CRASH2 = 60, 61	ACC_TYPE = 44 - 49, 70 - 73 AND MANEUV_I = 6, 15, 16 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 6, 15, 16 MANEUV_I = 6, 15, 16 AND P_CRASH2 = 60, 61
20	Drifting/same lane		ACC_TYPE = 44 - 49, 70 - 73 AND MANEUV_I = 1 - 5, 7, 14 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_P_CRASH2 = 10, 11

No	Scenario	Single-Vehicle Crashes (VEH_INVL = 1)	Multi-Vehicle Crashes (VEH_INVL >= 2), First Event
21	Opposite direction/maneuver	P_CRASH2 = 54, 62, 63 AND MANEUV_I = 6, 8 - 13, 15 - 97	ACC_TYPE = 50 - 67 AND MANEUV_I = 6, 8 - 13, 15 - 97
22	Opposite direction/no maneuver	P_CRASH2 = 54, 62, 63 AND MANEUV_I = 1 - 5, 7, 14	ACC_TYPE = 50 - 67 AND MANEUV_I = 1 - 5, 7, 14
23	Rear-end/striking maneuver	P_CRASH2 = 50 - 52 AND MANEUV_I = 6, 8 - 13, 15 - 97	ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 1 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97 Vx_VROLE_I = 1 AND Vx_MANEUV_I = 6, 8 - 13, 15 - 97 AND Vx_P_CRASH2 = 50, 51, 52
24	Rear-end/LVA		ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 3, 4 Vx_MANEUV_I = 3, 4 AND Vx_P_CRASH2 = 53
25	Rear-end/LVM	P_CRASH2 = 51	ACC_TYPE = 25 - 27 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 1, 14 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 1 AND Vx_P_CRASH2 = 51 P_CRASH2 = 51 Vx_MANEUV_I = 1, 14 AND Vx_P_CRASH2 = 53
26	Rear-end/LVD	P_CRASH2 = 52	ACC_TYPE = 29 - 31 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 2 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 1 AND Vx_P_CRASH2 = 52 P_CRASH2 = 52 Vx_MANEUV_I = 2 AND Vx_P_CRASH2 = 53
27	Rear-end/LVS	P_CRASH2 = 50	ACC_TYPE = 21 - 23 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 2 AND Vx_MANEUV_I = 5, 7 ACC_TYPE = 20 - 43 AND Vx_VROLE_I = 1 AND Vx_P_CRASH2 = 50 P_CRASH2 = 50 Vx_MANEUV_I = 5, 7 AND Vx_P_CRASH2 = 53 ACC_TYPE = 20 - 43 AND Vx_MANEUV_I = 1 AND Vy_MANEUV_I = 0
28	LTAP/OD @ signal		TRAF_CON = 1 AND ACC_TYPE = 68, 69 TRAF_CON = 1 AND MANEUV_I = 11 AND P_CRASH2 = 54, 62, 63 TRAF_CON = 1 AND Vx_P_CRASH2 = 15 AND Vy_P_CRASH2 = 54, 62, 63 TRAF_CON = 1 AND Vx_MANEUV_I = 11 AND Vy_MANEUV_I not 10 AND ACC_TYPE = 74, 75
29	Turn right @ signal		TRAF_CON = 1 AND ACC_TYPE = 78 - 81 TRAF_CON = 1 AND MANEUV_I = 10 AND P_CRASH2 = 65 - 68 TRAF_CON = 1 AND Vx_P_CRASH2 = 16 AND Vy_P_CRASH2 = 65 - 68 TRAF_CON = 1 AND V_MANEUV_I = 10 AND ACC_TYPE = 74, 75, 84, 85
30	LTAP/OD @ non signal		TRAF_CON not 1 AND ACC_TYPE = 68, 69 TRAF_CON not 1 AND MANEUV_I = 11 AND P_CRASH2 = 54, 62, 63 TRAF_CON not 1 AND Vx_P_CRASH2 = 15 AND Vy_P_CRASH2 = 54, 62, 63
31	SCP @ non signal	TRAF_CON not 1 AND P_CRASH2 = 66, 71	TRAF_CON not 1 AND ACC_TYPE = 86 - 91 TRAF_CON not 1 AND MANEUV_I not 10 -12 AND P_CRASH2 = 65 - 68, 70 - 78 TRAF_CON not 1 AND Vx_P_CRASH2 not 15, 16 AND Vy_P_CRASH2 = 65 - 68, 70 - 78
32	Turn @ non signal	TRAF_CON not 1 AND P_CRASH2 = 65, 67, 68, 70, 72, 73	TRAF_CON not 1 AND ACC_TYPE = 74 - 85 TRAF_CON not 1 AND MANEUV_I = 10 -12 AND P_CRASH2 = 65 - 68, 70 - 78 TRAF_CON not 1 AND Vx_P_CRASH2 = 15, 16 AND Vy_P_CRASH2 = 65 - 68, 70 - 78

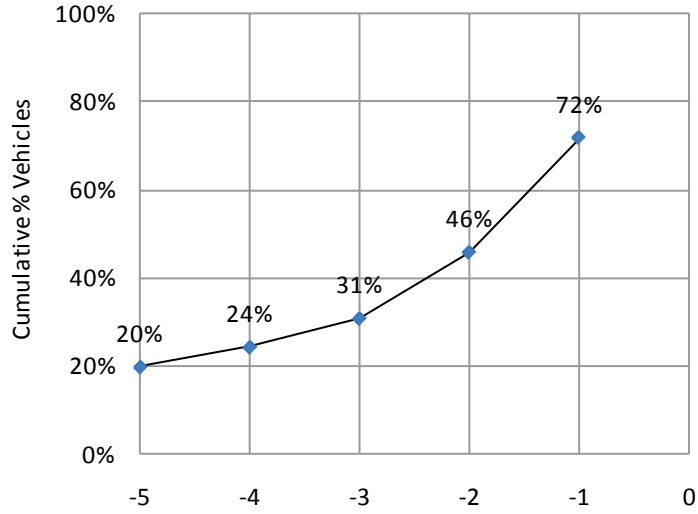
No	Scenario	Single-Vehicle Crashes (VEH_INVL = 1)	Multi-Vehicle Crashes (VEH_INVL >= 2), First Event
33	Avoidance/maneuver	ACC_TYPE = 3, 8 AND MANEUV_I = 6, 8 - 13, 15 - 97 P_CRASH2 = 50 - 78 AND MANEUV_I = 6, 8 - 13, 15 - 97	
34	Avoidance/no maneuver	ACC_TYPE = 3, 8 AND MANEUV_I = 1 - 5, 7, 14 P_CRASH2 = 50 - 78 AND MANEUV_I = 1 - 5, 7, 14	
35	Rollover	ROLLOVER=10 OR EVENT1_I=1	
36	Noncollision - No Impact	EVENT1_I=2 - 10 ACC_TYPE = 00	
37	Object/maneuver	P_CRASH2 = 90, 91, 92 AND MANEUV_I = 6, 8 - 13, 15 - 97 ACC_TYPE = 12 AND MANEUV_I = 6, 8 - 13, 15 - 97 ACC_TYPE = 11 AND MANEUV_I = 6, 8 - 13, 15 - 97 EVENT1_I = 21 - 29, 31 - 59 AND MANEUV_I = 6, 8 - 13, 15 - 97	
38	Object/no maneuver	P_CRASH2 = 90, 91, 92 AND MANEUV_I = 1 - 5, 7, 14 ACC_TYPE = 12 AND MANEUV_I = 1 - 5, 7, 14 ACC_TYPE = 11 AND MANEUV_I = 1 - 5, 7, 14 EVENT1_I = 21 - 29, 31 - 59 AND MANEUV_I = 1 - 5, 7, 14	
39	Hit and run	HITRUN_I = 1	
40	Other - Rear-End		ACC_TYPE = 20 - 43
41	Other - Sideswipe		ACC_TYPE = 44 - 49
42	Other - Opposite Direction		ACC_TYPE = 50 - 67
43	Other - Turn Across Path		ACC_TYPE = 68 - 75
44	Other - Turn Into Path		ACC_TYPE = 76 - 85
45	Other - Straight Paths		ACC_TYPE = 86 - 91
46	Other		

Appendix B. Results of Non-Weighted EDR Cases

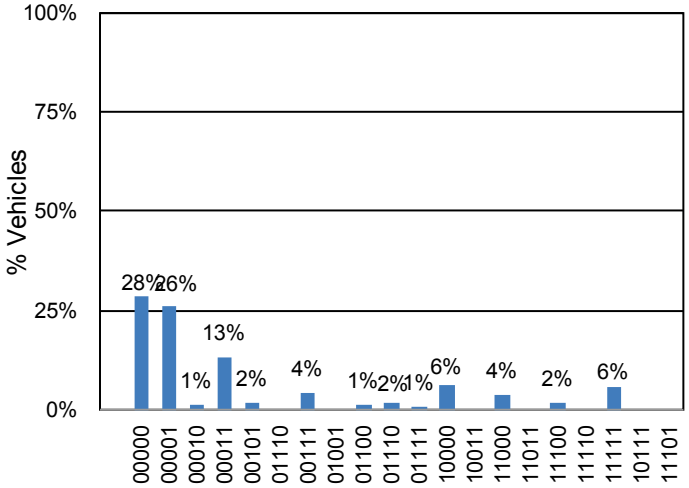
Kinematic Data (207 EDR Cases) **Running Red Light**



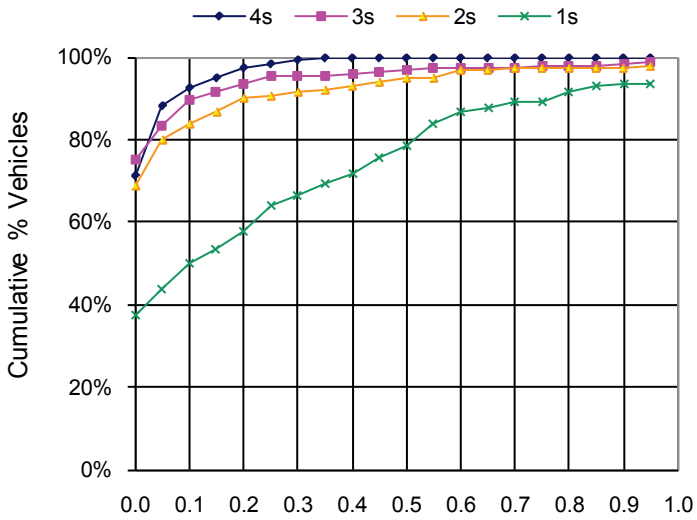
Vehicle Travel Speed (mph)



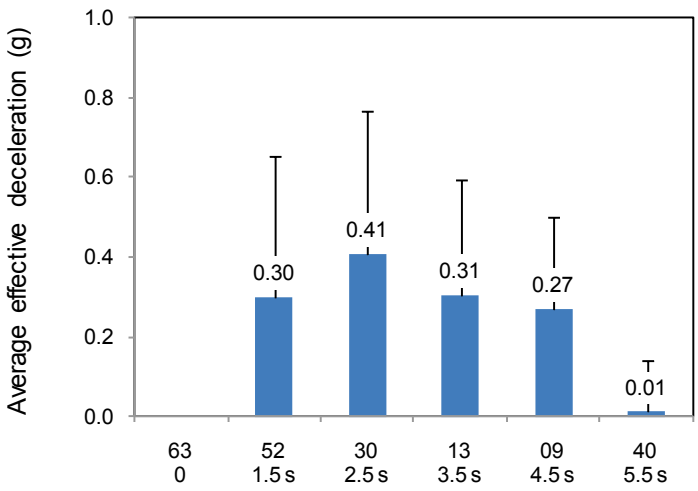
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

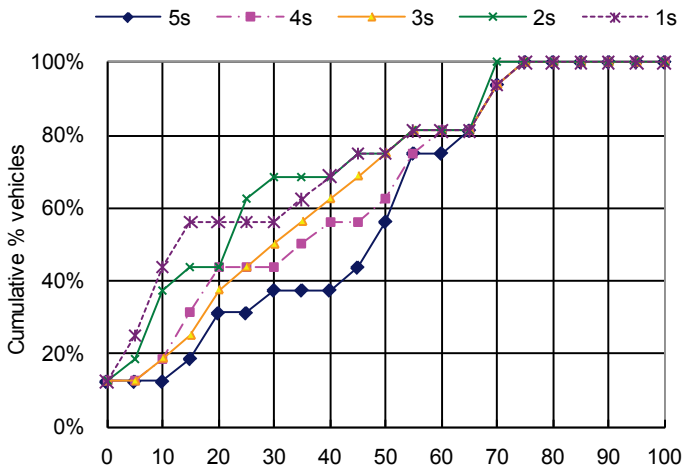


Braking Deceleration (g)

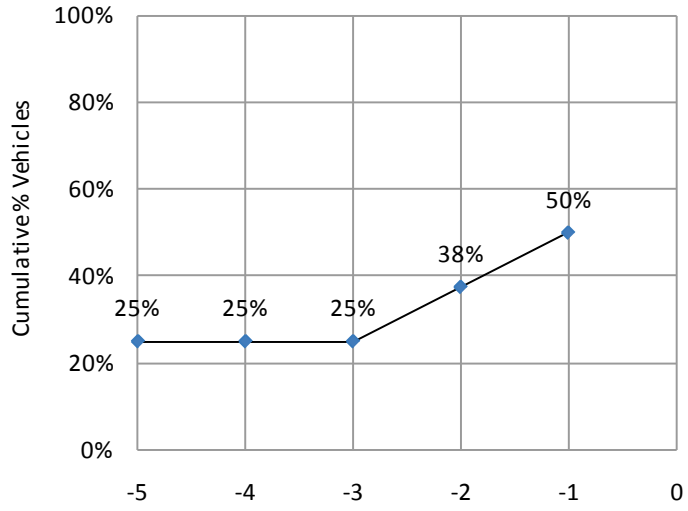


Effective Deceleration at TTC (s) with Frequency

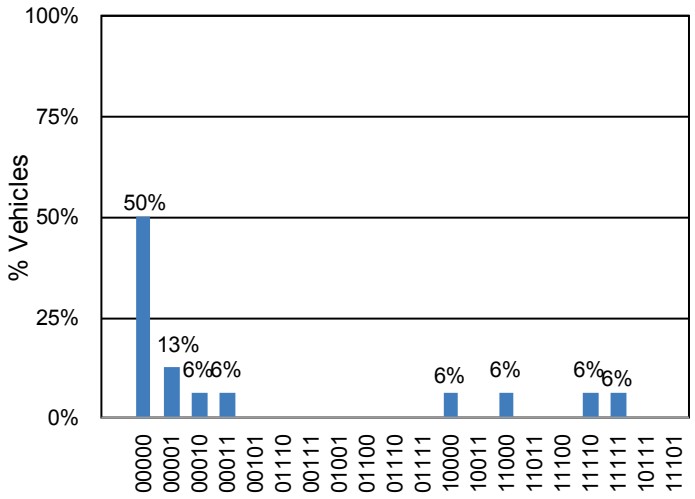
Kinematic Data (16 EDR Cases) **Changing Lanes / Same Direction**



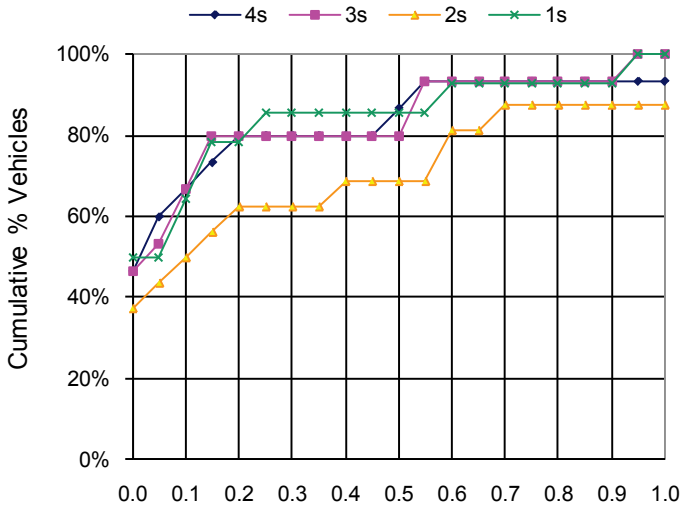
Vehicle Travel Speed (mph)



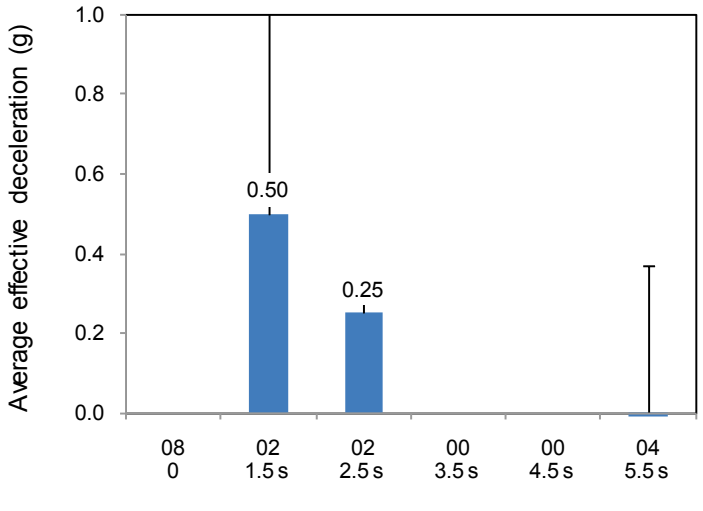
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

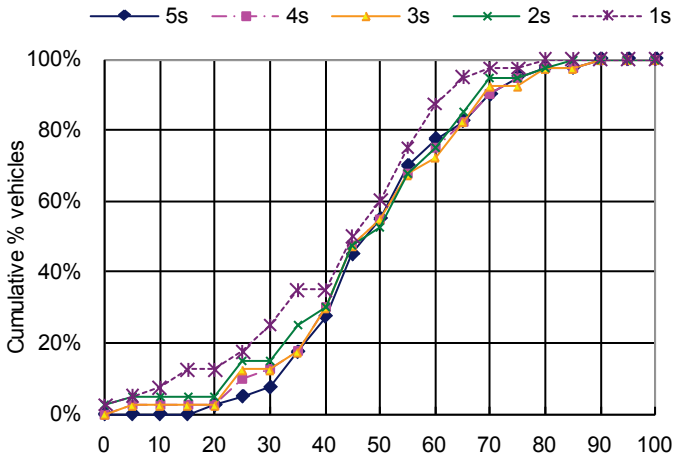


Braking Deceleration (g)

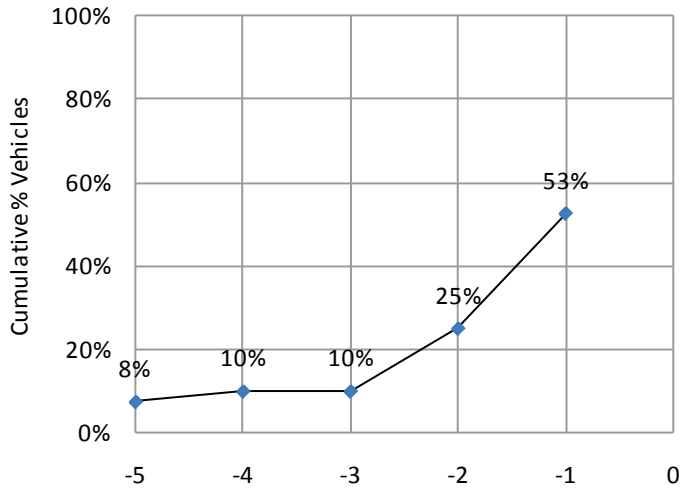


Effective Deceleration at TTC (s) with Frequency

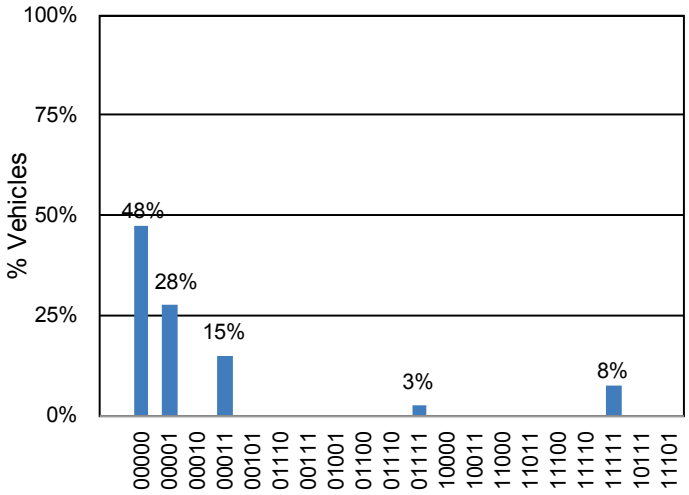
Kinematic Data (40 EDR Cases) **Opposite Direction/No Maneuver**



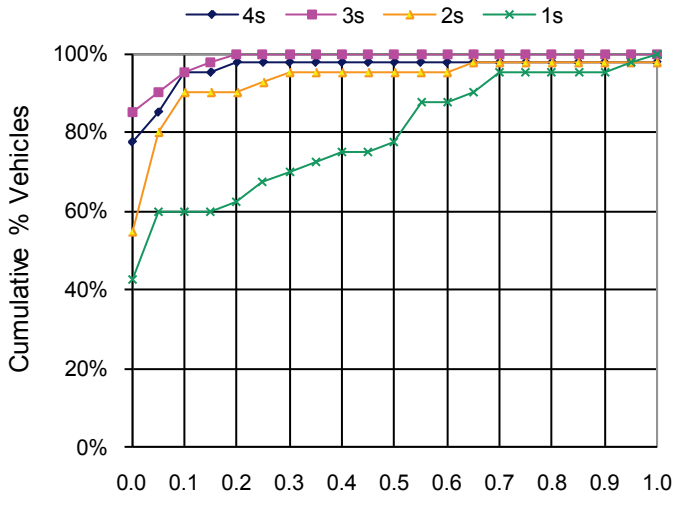
Vehicle Travel Speed (mph)



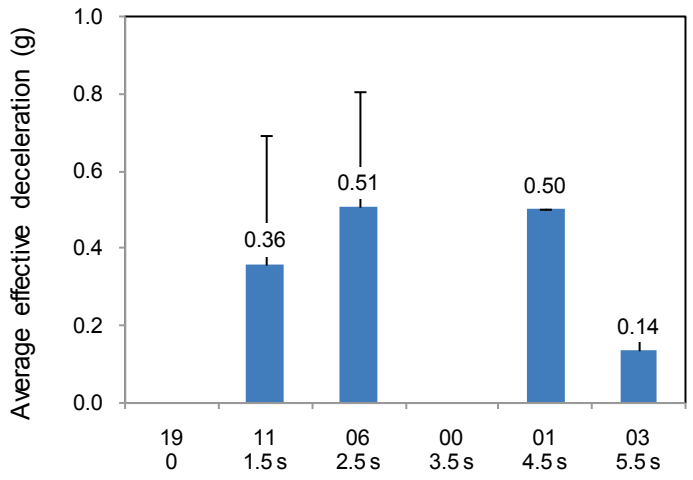
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

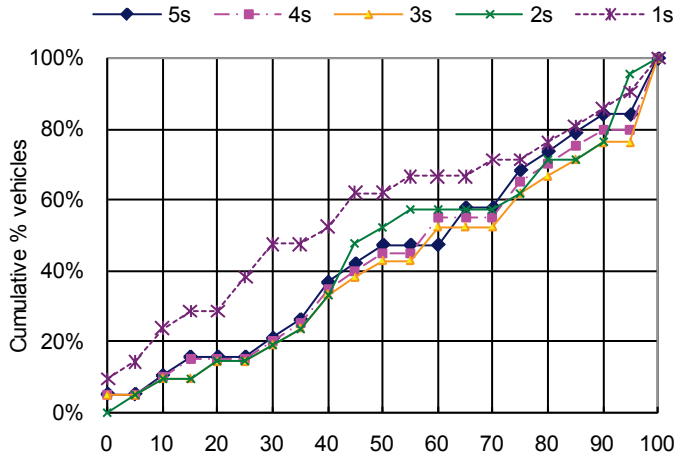


Braking Deceleration (g)

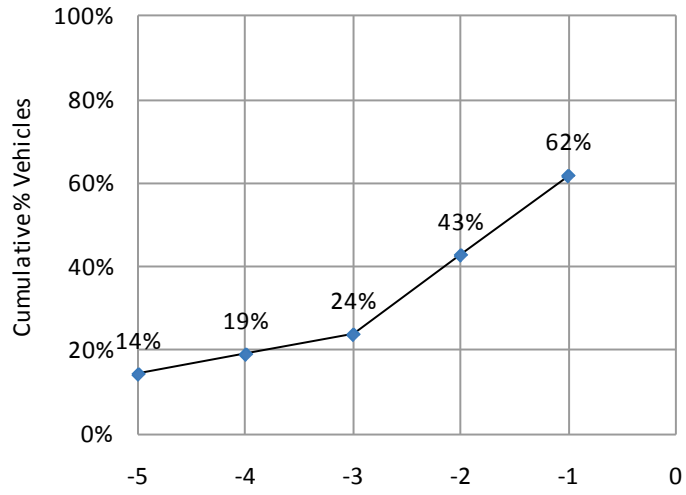


Effective Deceleration at TTC (s) with Frequency

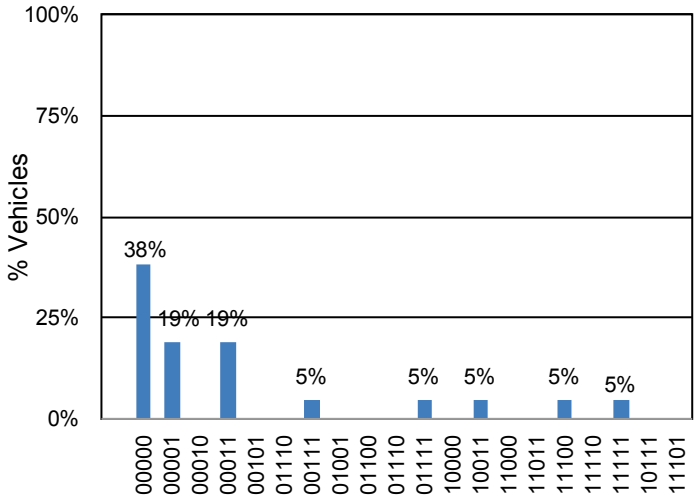
Kinematic Data (21 EDR Cases) **Rear-End/Lead Vehicle Moving**



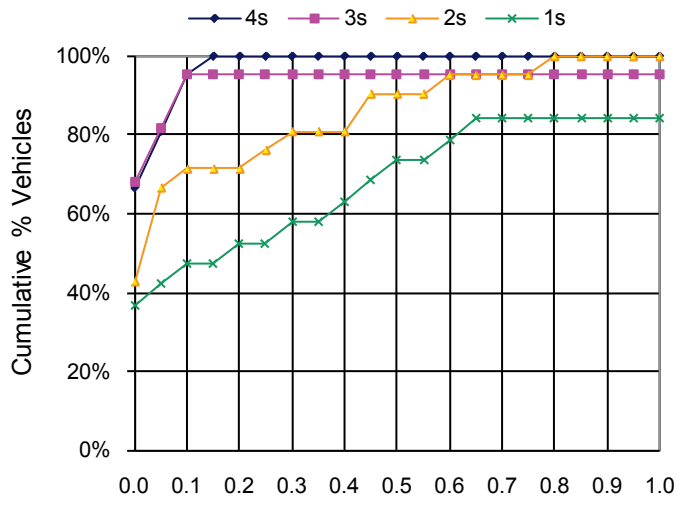
Vehicle Travel Speed (mph)



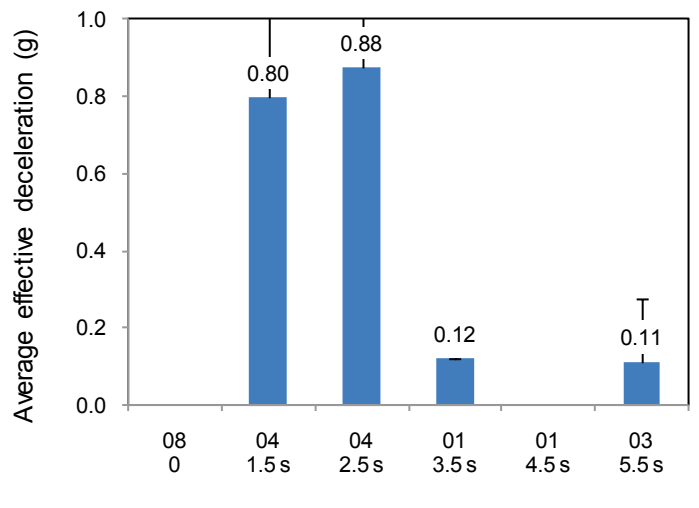
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

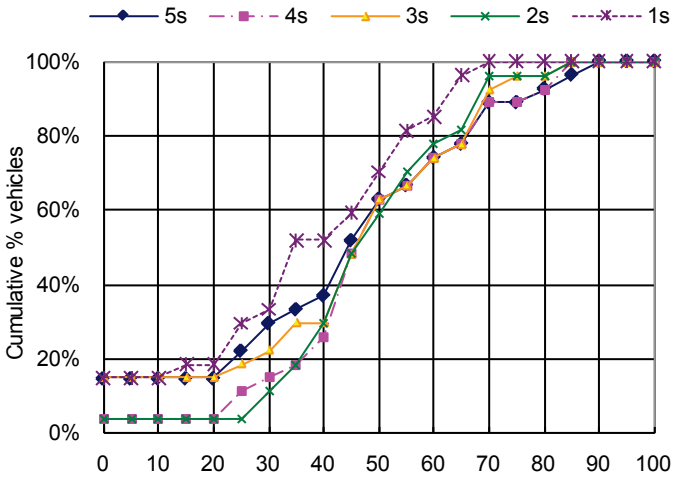


Braking Deceleration (g)

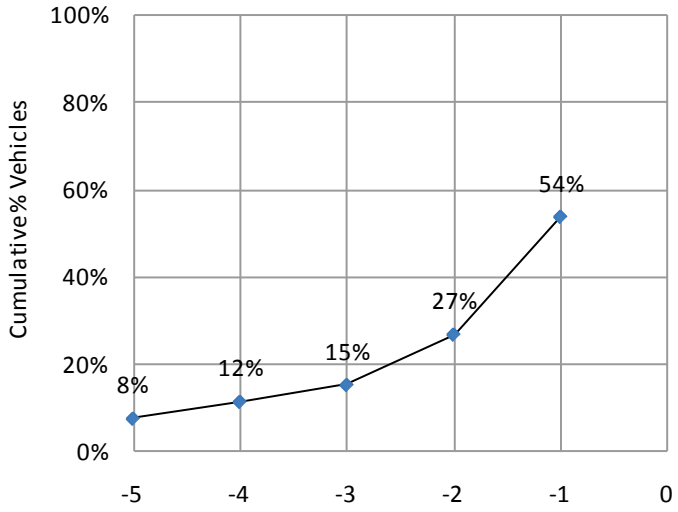


Effective Deceleration at TTC (s) with Frequency

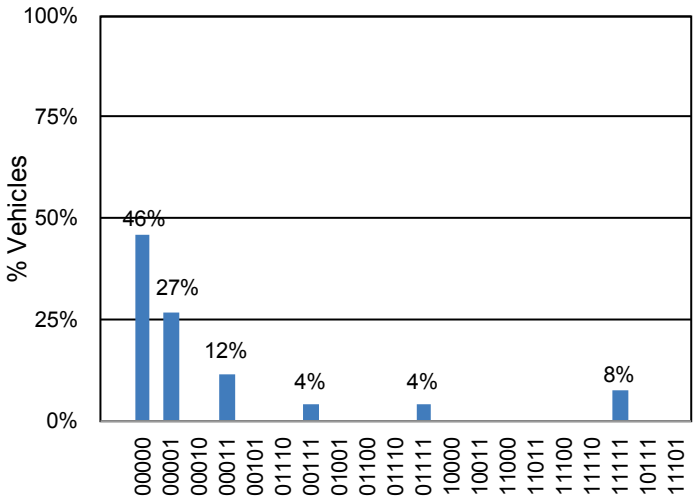
Kinematic Data (21 EDR Cases) **Rear-End/Lead Vehicle Decelerating**



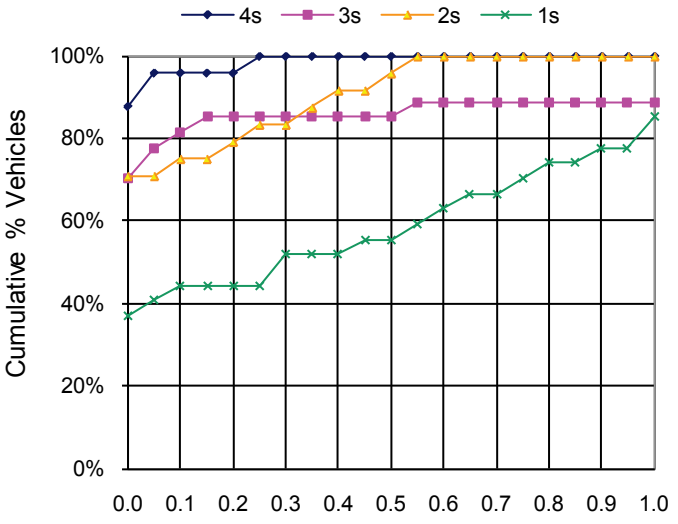
Vehicle Travel Speed (mph)



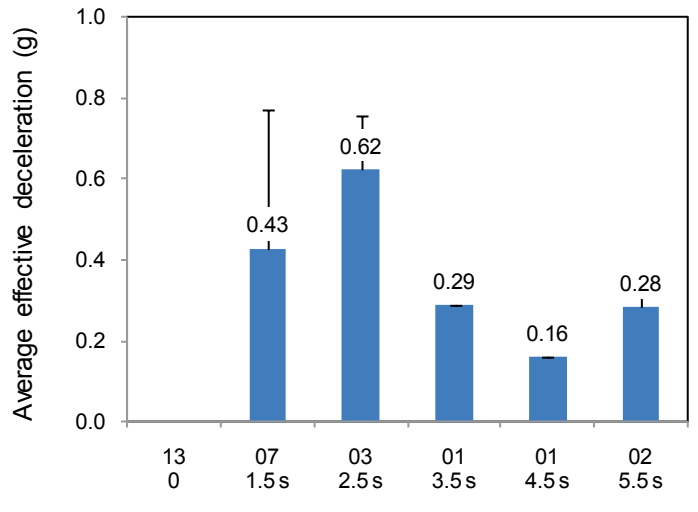
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

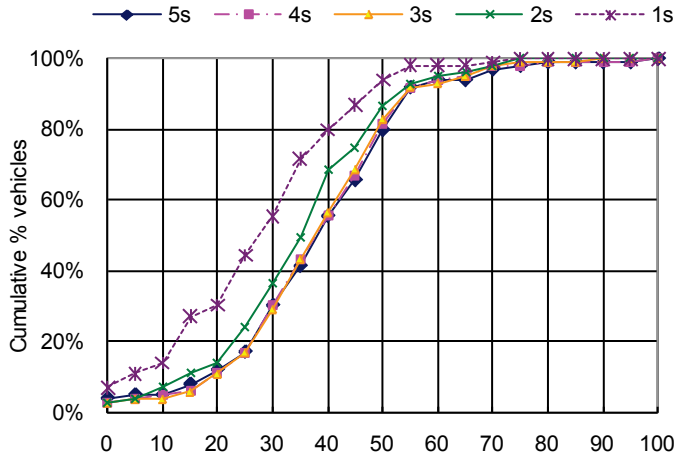


Braking Deceleration (g)

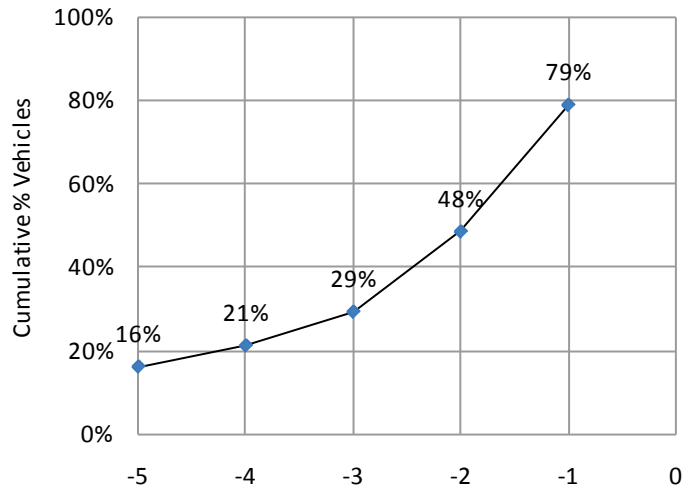


Effective Deceleration at TTC (s) with Frequency

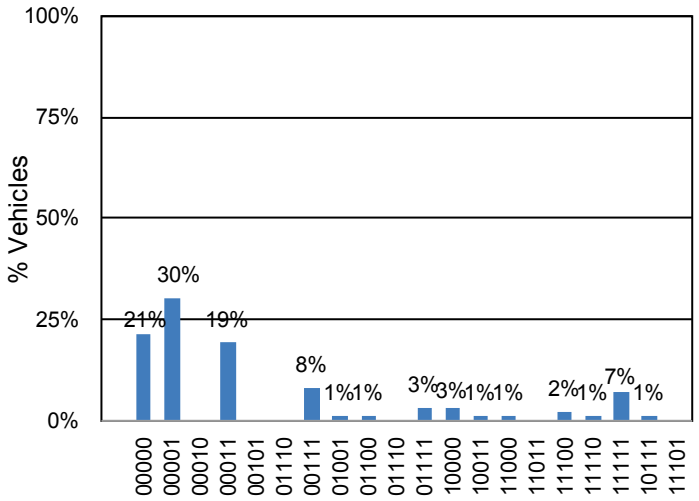
Kinematic Data (99 EDR Cases) **Rear-End/Lead Vehicle Stopped**



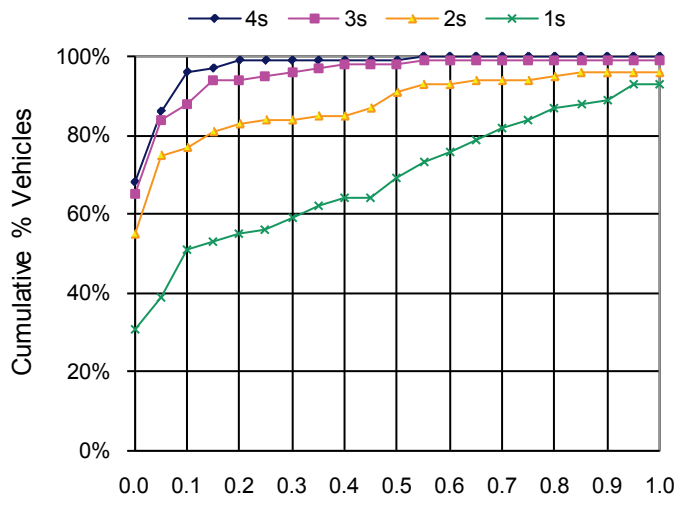
Vehicle Travel Speed (mph)



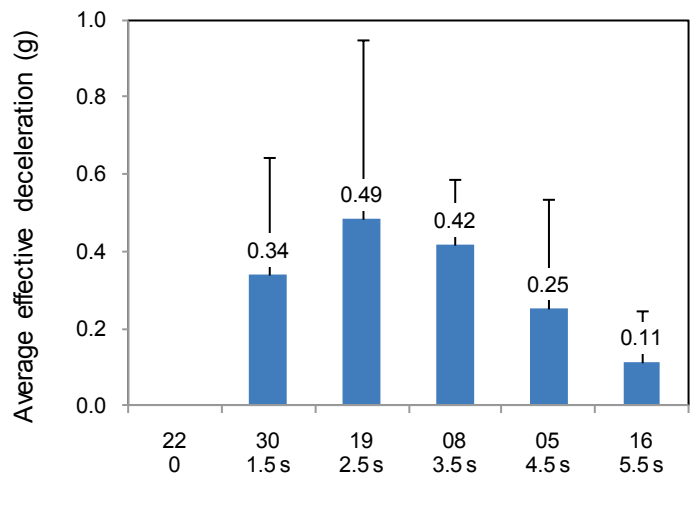
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

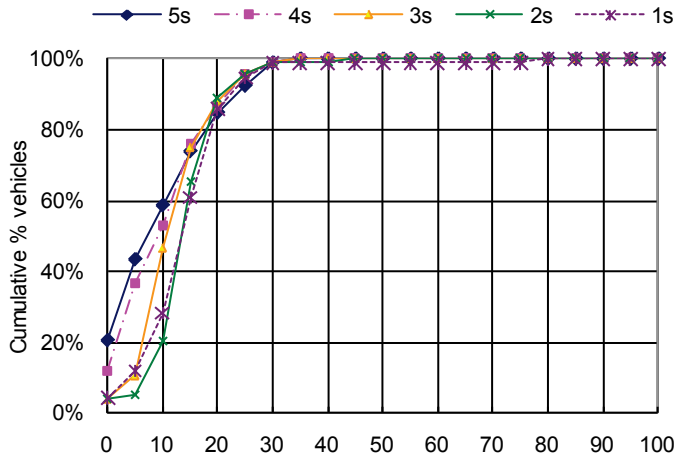


Braking Deceleration (g)

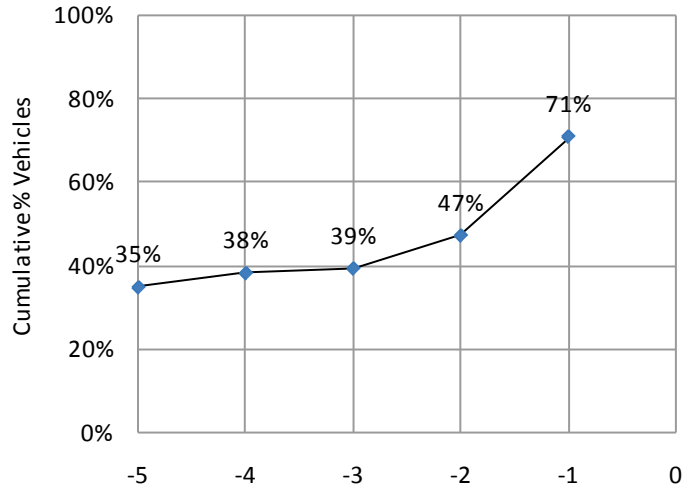


Effective Deceleration at TTC (s) with Frequency

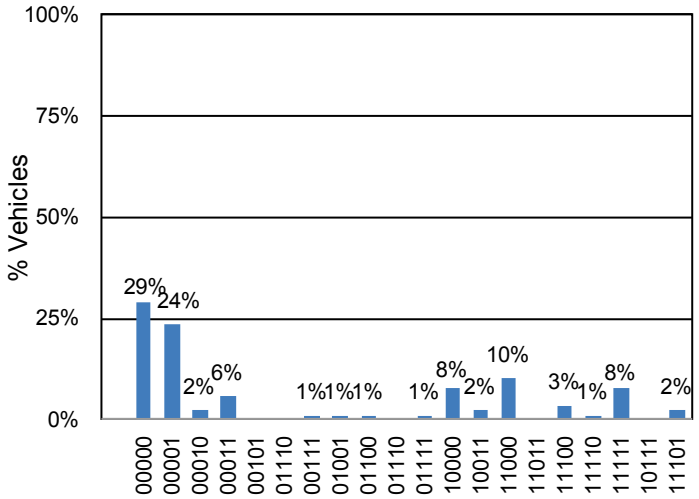
Kinematic Data of Turning Vehicle (89 EDR Cases)	**LTAP/OD at Signal**



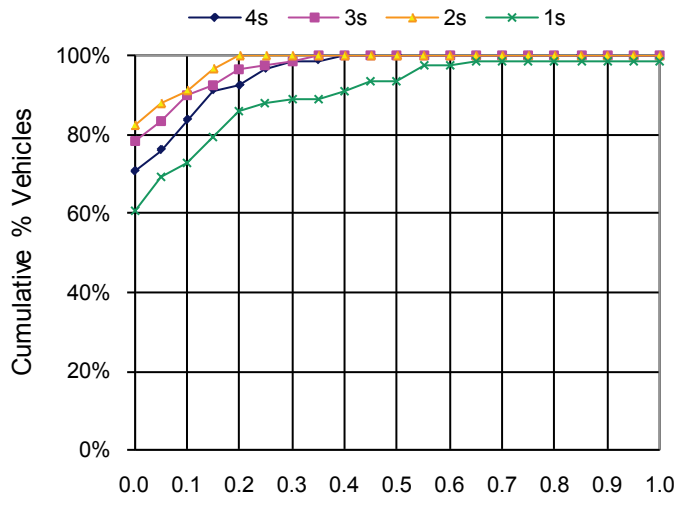
Vehicle Travel Speed (mph)



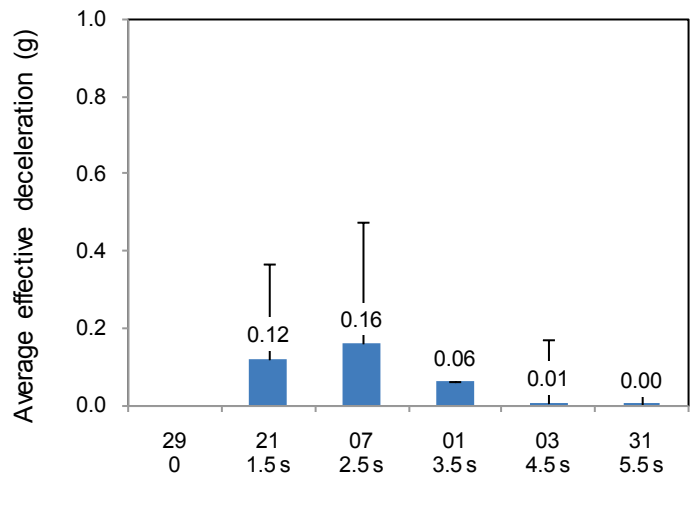
Brake Frequency at Time to Collision (s)



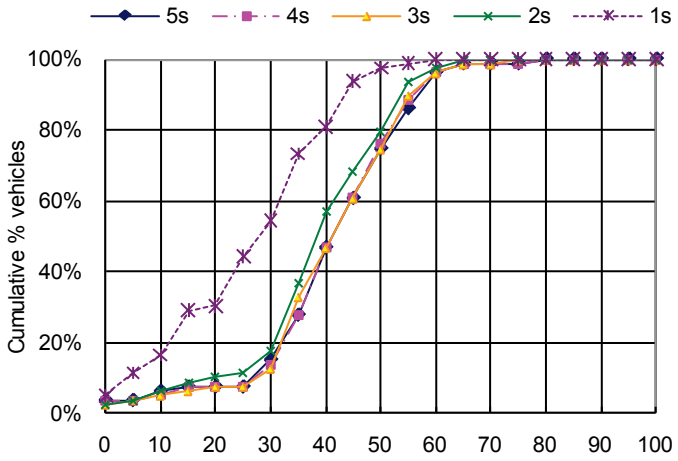
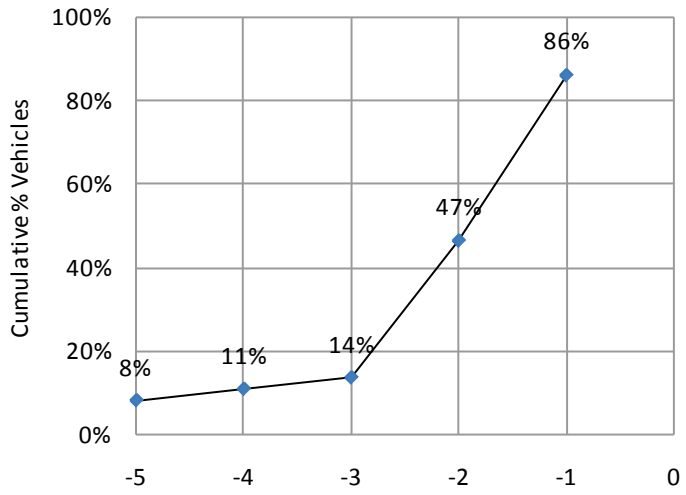
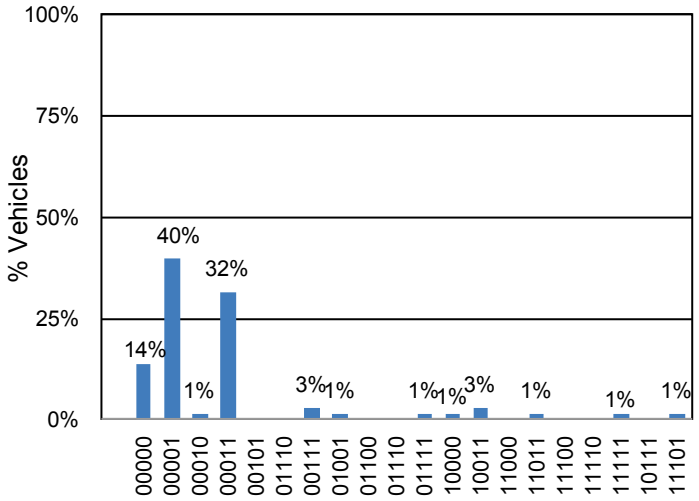
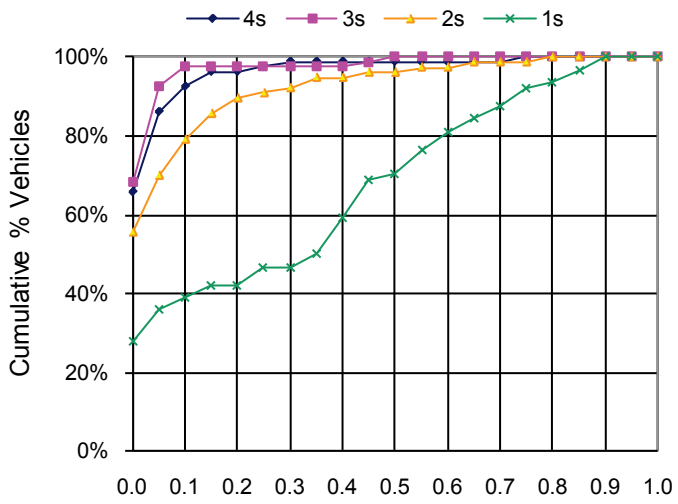
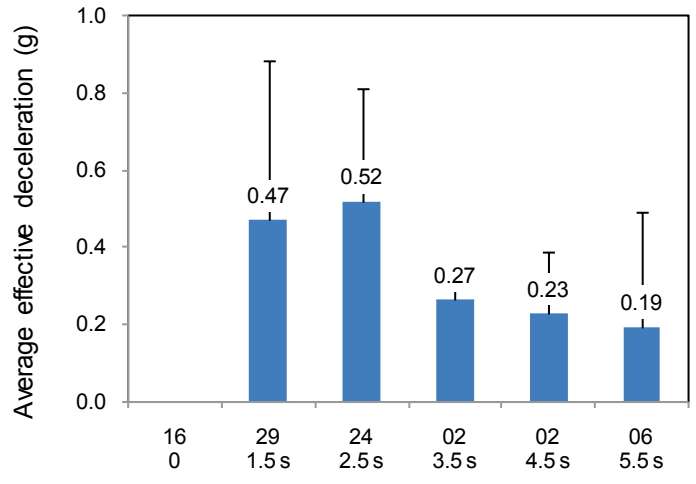
Detailed Brake Application Frequency



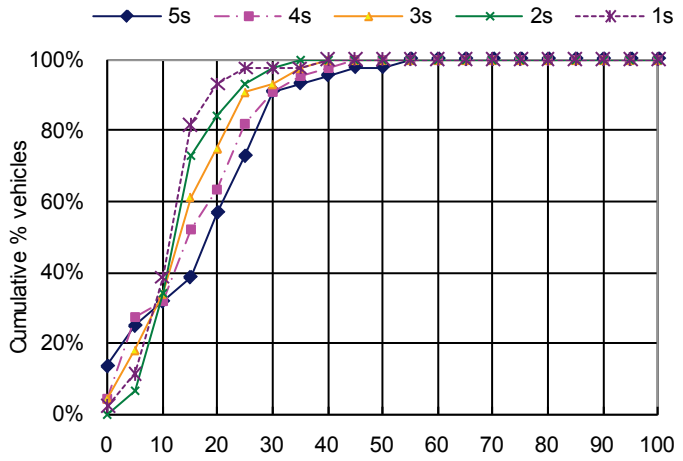
Braking Deceleration (g)



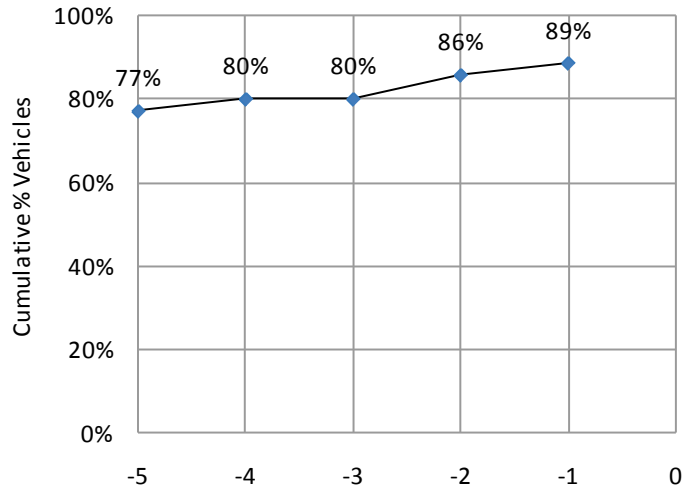
Effective Deceleration at TTC (s) with Frequency

Kinematic Data of Non-Turning Vehicle (78 EDR)	LTAP/OD at Signal
 Vehicle Travel Speed (mph)	
 Brake Frequency at Time to Collision (s)	 Detailed Brake Application Frequency
 Braking Deceleration (g)	 Effective Deceleration at TTC (s) with Frequency

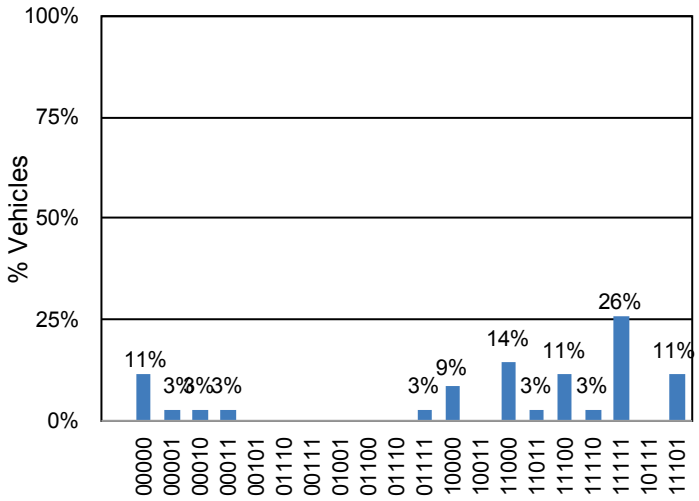
Kinematic Data of Turning Vehicle (44 EDR Cases) **LTAP/OD at Non-Signal**



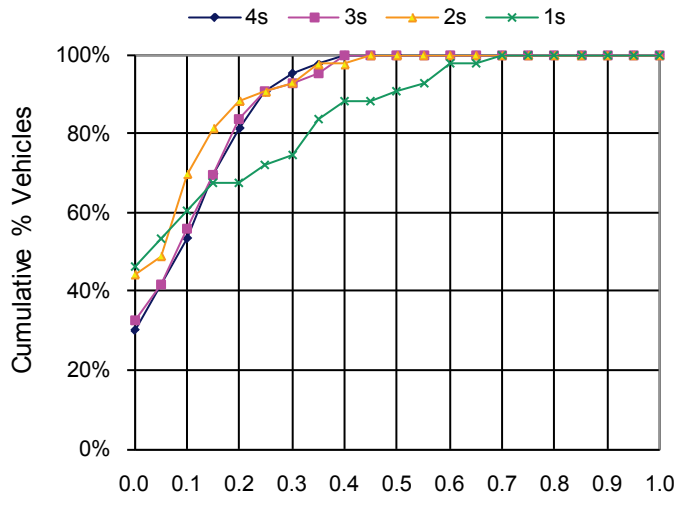
Vehicle Travel Speed (mph)



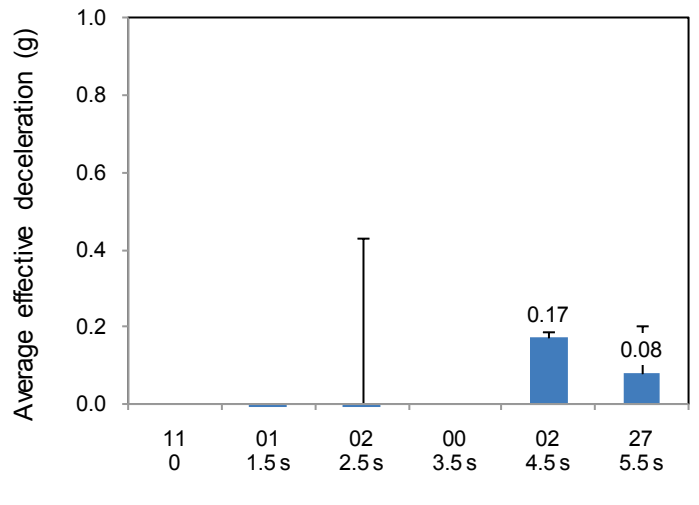
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

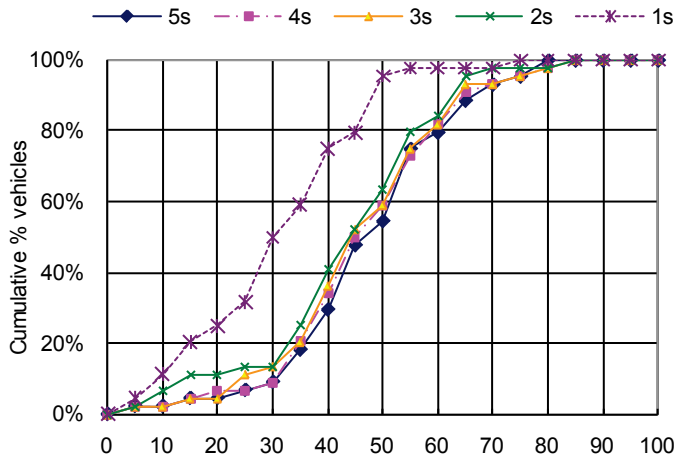


Braking Deceleration (g)

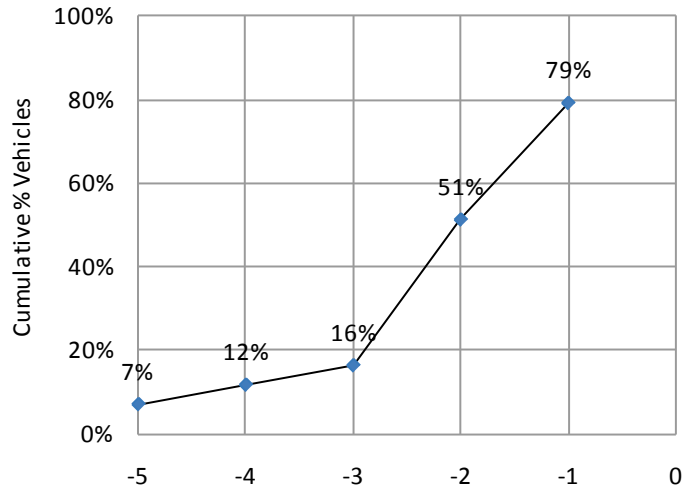


Effective Deceleration at TTC (s) with Frequency

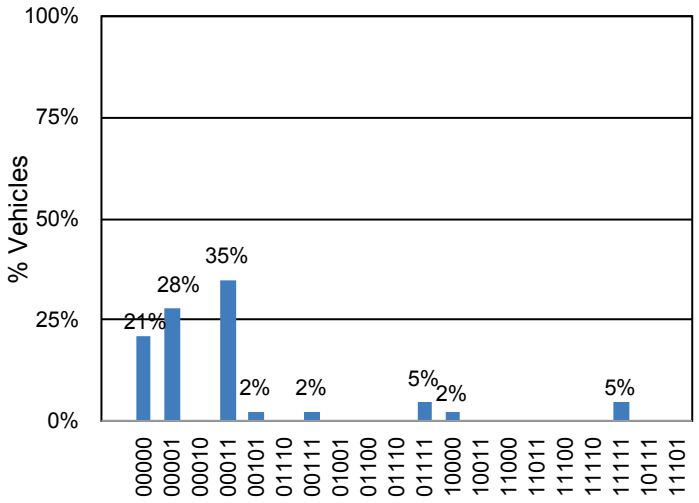
Kinematic Data of Non-Turning Vehicle (44 EDR Cases) **LTAP/OD at Non-Signal**



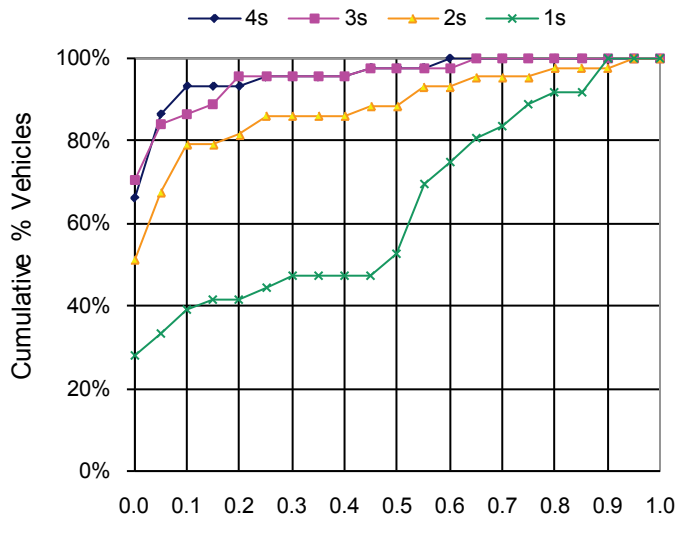
Vehicle Travel Speed (mph)



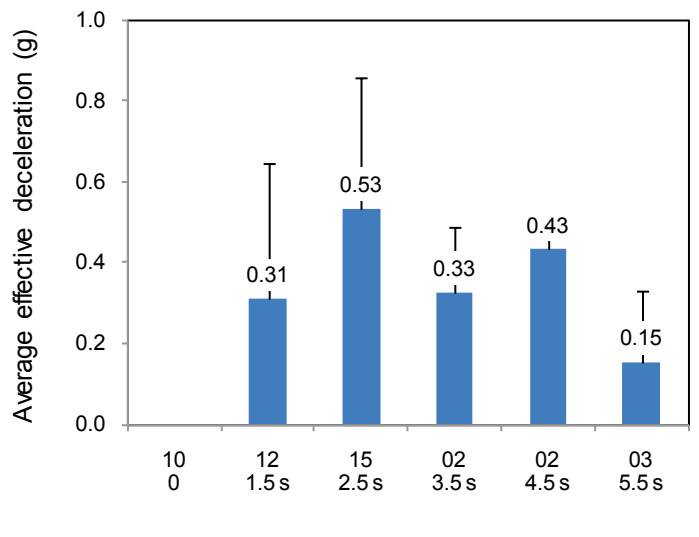
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency

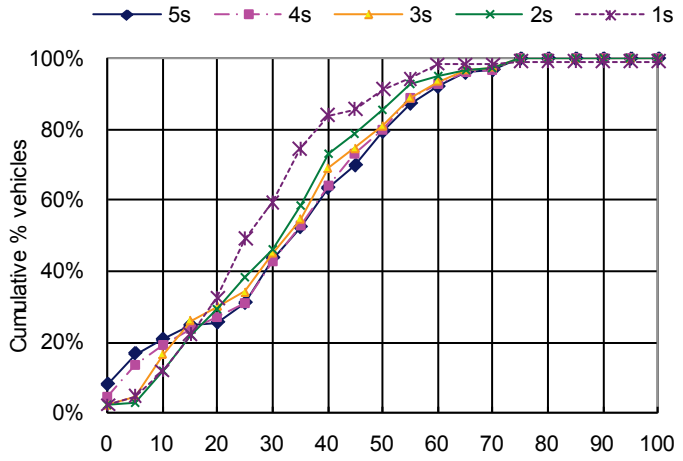


Braking Deceleration (g)

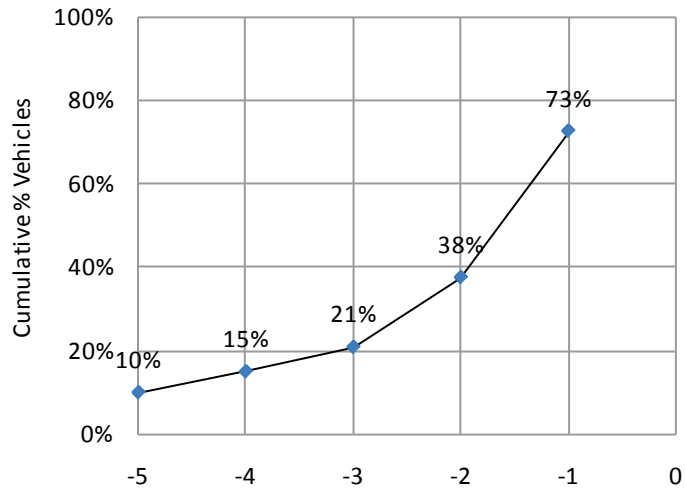


Effective Deceleration at TTC (s) with Frequency

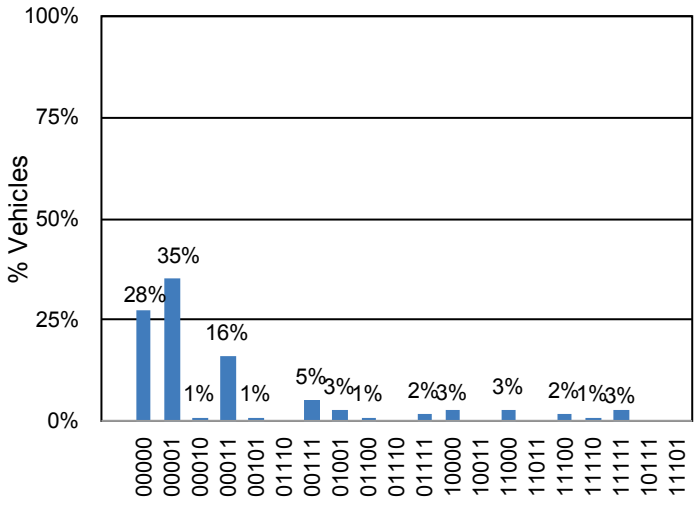
Kinematic Data (126 EDR Cases) **SCP at Non-Signal**



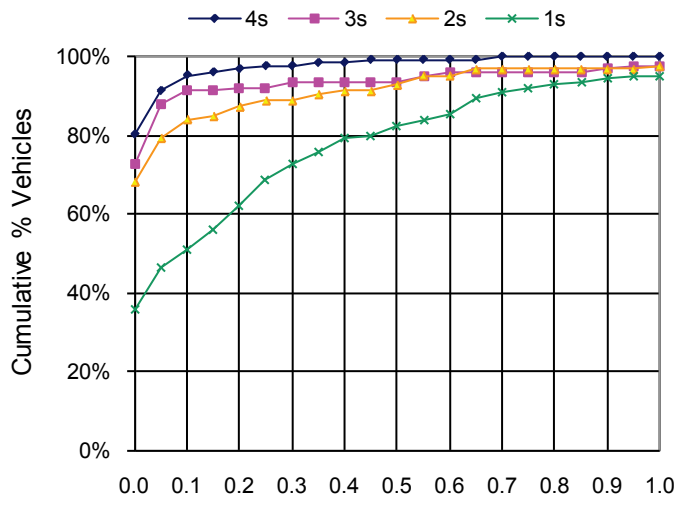
Vehicle Travel Speed (mph)



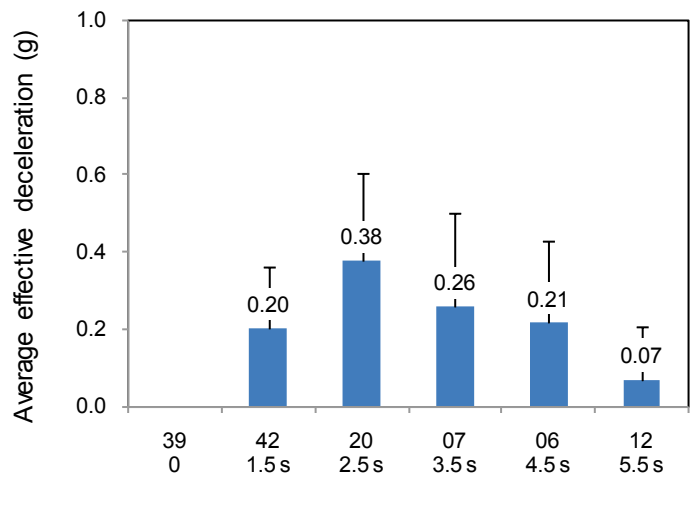
Brake Frequency at Time to Collision (s)



Detailed Brake Application Frequency



Braking Deceleration (g)



Effective Deceleration at TTC (s) with Frequency

DOT HS 811 731
May 2013

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

9358-052913-v2