

Prioritization of Crash Scenarios for Pre-Crash Sensing Applications

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ABSTRACT

Crash scenarios are prioritized for crash-imminent braking and advanced restraint applications aimed at reducing injuries when the crash becomes unavoidable using forward-looking pre-crash sensors. Characteristics of priority crash scenarios will form a basis for the development of performance specifications and test procedures for these two applications. Target crashes involve at least one light vehicle (passenger car, van or minivan, light pickup truck, or sport utility vehicle) of model year 1998 or higher with frontal damage from the first impact. Crash prioritization is based on the number of fatalities and functional years lost. Data sources include the Fatality Analysis Reporting System, General Estimates System, and Crashworthiness Data System. Crash scenarios are broken down by vehicle-object and vehicle-vehicle crashes. Pedestrian, pole, or tree impacts prevail in vehicle-object crashes. Dominant vehicle-vehicle crash scenarios include opposite direction and rear-end pre-crash scenarios with front-to-front and front-to-back impacts, respectively.

INTRODUCTION

Vehicle safety technology has remarkably evolved in the last decade to realize the total safety of motor vehicles [1]. New safety systems have been fielded to mitigate crash severity and aid drivers in crash prevention [2, 3]. Such systems encompass enhanced brake assist, stability control, adaptive cruise control, driver advisory

systems such as blind spot monitors, and driver warning systems such as rear-end crash and lane departure warning. In addition, crash notification systems using cellular phone technology have been deployed to help emergency responders save crash victims.

Total vehicle safety incorporates crash countermeasures that address all parts of the crash scenario structure as illustrated in Figure 1. Crash prevention measures assist the driver to better control the vehicle such as stability control systems, or warn the driver of an impending crash such as lane departure warning systems. Crash severity reduction measures act to mitigate the impact severity of crashes deemed unavoidable by pre-crash sensing such as enhanced brake assist or last-second automatic braking systems. Occupant injury mitigation measures alleviate potential severe injuries of an imminent impact by preparing crashworthiness systems such as next-generation airbags and advanced seatbelts. Post crash is also part of total vehicle safety in which appropriate emergency assistance is automatically summoned to provide medical attention.

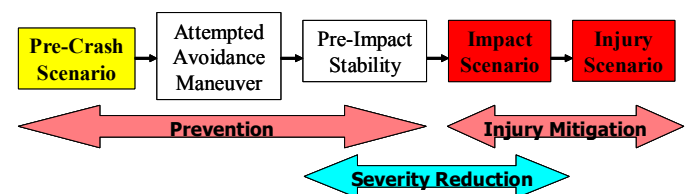


Figure 1. Crash scenario structure and countermeasures

This paper identifies and prioritizes crash scenarios for severity reduction and injury mitigation measures that are activated before impact when a crash becomes unavoidable based on environmental data collected by external sensors. Specifically, full-authority last-second crash-imminent braking (CIB) is considered to reduce impact severity by dissipating energy from the crash. Advanced restraint systems (ARS) are also examined to mitigate occupant injuries by improving the coupling of occupants to the vehicle, reducing firing times of airbags, among others. This analysis supports a joint research effort between the United States Department of Transportation and the automotive industry to develop performance guidelines, test procedures, and safety benefits estimates for CIB and ARS applications.

The focus of this paper is on a top-down analysis of crash data from historical crash databases, which links pre-crash scenarios to the impact scenario crash modes.

Pre-crash scenarios depict vehicle movements and dynamics as well as the critical event occurring immediately prior to a crash, excluding attempted avoidance maneuver and pre-impact vehicle stability. Impact scenarios involve vehicle-object and vehicle-vehicle impact crash events. Only crash modes of the impact scenario (e.g., front-to-back impact) are considered in this particular analysis. Detailed statistical descriptions of crash scenarios as shown in Figure 1 are reported in [4] and [5] respectively for ARS and CIB applications. Target crash population encompasses light vehicles of model year 1998 or higher (MY98⁺) that sustained frontal damage from the first impact. Light vehicles include passenger cars, sport utility vehicles, minivans, vans, and light pickup trucks with gross vehicle weight rating at 4,536 Kg or less. The model year serves as the surrogate for modern restraint systems including three-point lap and shoulder belts, presence of pretensioners, load limiters, the advent of the second generation de-powered airbags, and more advanced seatbelt and airbag technology. Frontal damage from the first harmful event of the crash, as opposed to the most harmful event in multi-impact crashes, is selected to accommodate the development of functional requirements for forward-looking pre-crash sensors that would enable ARS and CIB applications.

First, this paper describes the crash analysis framework. After the framework, results of the vehicle-object crash analysis are presented. Results of the vehicle-vehicle crash analysis follow. After that, this paper lists the priority crash scenarios for ARS and CIB applications. Finally, this paper concludes with a summary of the analysis and remarks about next research steps.

ANALYSIS FRAMEWORK

Figure 2 illustrates a crash analysis approach dealing with two major crash types: vehicle-object and vehicle-vehicle crashes. They are distinguished by the type of obstacle struck during the first harmful event based on whether or not the obstacle is a vehicle in transport. Vehicle-object crashes are characterized by a vehicle in transport contacting a “not vehicle in transport” obstacle. Obstacle categories include tree, pole, ground, structure, person, vehicle, animal, not-fixed object, non-collision, and unknown. Attention is paid to whether the target vehicle is involved in a single- or multi-impact crash. In single-vehicle crashes, the target vehicle does not hit a vehicle in transport. However, in a multi-impact crash, it is important to identify the object type that was contacted during the first harmful event. In multi-vehicle crashes, the target vehicle contacts a vehicle in transport. In a multi-impact crash, it is possible for the target vehicle to strike an object first before hitting another vehicle in transport. Thus, the analysis separates multi-vehicle crashes based on the first harmful event into vehicle-object and vehicle-vehicle crashes as seen in Figure 2.

DATA SOURCES - A top-down analysis was conducted using the 2002-2006 Fatality Analysis Reporting System (FARS), 2006 General Estimates System (GES), and 1997-2006 Crashworthiness Data System (CDS) crash databases. The GES and CDS databases comprise the National Automotive Sampling System (NASS).

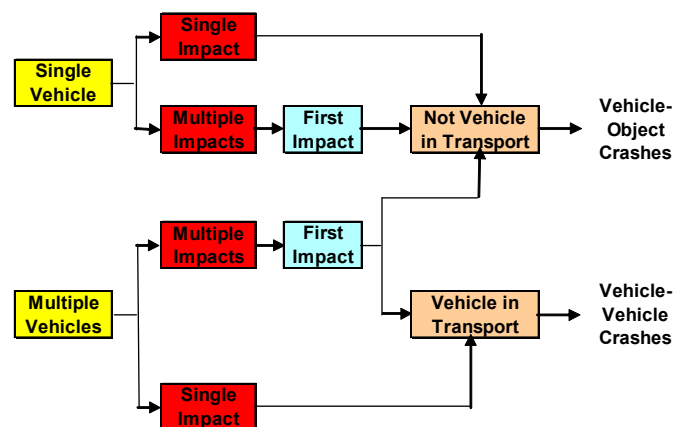


Figure 2. Crash analysis framework

FARS - This database is a census of fatal crashes occurring on roadways in the United States. At least one crash participant must expire as a result of a motor vehicle crash within 30 days of the incident. In addition to vehicle occupants, FARS also accounts for pedestrians, pedalcyclists, or other conveyances involved in fatal crashes. The crash detail, however, is limited to the information furnished by the police officer during the course of writing the incident report.

GES - This database estimates the national crash population based on police crash reports by sampling approximately 55,000 crashes annually. These crashes involve all vehicle types and all injury levels. This provides a broad overview of vehicle and occupant involvement and the general crash environment.

CDS - This database samples about 4,500 crashes per year and is designed to fill the comprehensive crash void of the GES. It includes light vehicles towed from the crash scene due to damage. On-scene investigators collect forensic evidence relevant to crash location, vehicle deformation, occupant kinematics, demography, and injury outcomes. A crash timeline chronology is established, although not quantitative, thereby defining a crash into unique events with injuries reported at the crash unit level.

HARM MEASURES - Target crashes for ARS and CIB applications are identified and prioritized based on the number of fatalities and functional years lost (FYL). The latter measure quantifies the societal harm of motor vehicle crashes by weighing and integrating the injury level of all people involved. This 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 [6]. This measure does not mirror the monetary economic cost [7]. It assigns a different value to the relative severity of injuries suffered from motor vehicle crashes based on the maximum abbreviated injury scale (MAIS) as listed in Table 1. This measure was selected over other measures such as equivalent lives in order to harmonize with automakers who have adopted this measure in their crash avoidance research [8].

Table 1. Functional years lost by MAIS

MAIS	Severity	Functional Years Lost
1	Minor	0.07
2	Moderate	1.1
3	Serious	6.5
4	Severe	16.5
5	Critical	33.1
6	Fatal	42.7

The GES does not provide information on 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. To estimate injuries based on the MAIS coding structure, a

translator derived from 1982-1986 NASS data was applied to the GES police-reported injury profile [9].

TARGET OCCUPANTS - Crash analysis for ARS applications is focused on understanding the injury suffered by the driver and the front seat passenger of 13 years of age or older (FSP13⁺) in target vehicles. The age restriction placed upon the front seat occupant conforms to a mandate by the National Highway Traffic Safety Administration (NHTSA) for child passengers to ride in the rear seating positions until they are older than 12 years. In addition, the FYL harm measure for ARS only counts MAIS levels 3 through 6 by the driver and FSP13⁺ occupants in the target vehicle corresponding respectively to serious, severe, critical, and fatal injuries. On the other hand, the FYL harm measure for CIB incorporates MAIS levels 2 through 6 by all occupants in the target vehicle and all other persons who are involved in the crash (i.e., occupants of other vehicles or other road users). This study supports a cooperative research project between NHTSA and a team from different auto makers and suppliers. The project objective is to develop ARS and CIB applications that address serious or higher level injuries MAIS 3⁺ for ARS and moderate or higher level injuries MAIS 2⁺ for CIB. Thus, these injury filters were applied accordingly to ensure that the development of these two applications is based on the target crash and injury characteristics.

VEHICLE-OBJECT CRASH SCENARIOS

Analysis results of vehicle-object crashes are presented based on data respectively from FARS, GES, and CDS.

FARS VEHICLE-OBJECT CRASHES - The 2002-2006 FARS crash databases were queried to identify target vehicle-object crashes for ARS and CIB applications. Target vehicles included all MY98⁺ light vehicles that experienced front damage from the first harmful event. Target crashes for ARS involved at least one fatal injury in target vehicles by the driver or FSP13⁺. Target crashes for CIB comprised at least one fatal injury by any person who was associated with a target vehicle-involved crash. Tables 2 and 3 list the number of fatalities in target vehicle-object crashes by obstacle category, from 2002 through 2006, respectively for ARS and CIB applications. The number of fatalities increased in almost each category over time due to the greater number of MY98⁺ vehicles in the vehicle fleet in the United States. The “ground” category in Table 2 includes embankment, ditch, culvert, or curb. The “structure” category consists of guardrail, fence, concrete barrier, bridge, wall, building, boulder, snowbank, or fire hydrant.