U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

People Saving People
http://www.nhtsa.dot.gov

DOT HS 809 676 November 2003

Technical Report

The Relationship between Occupant Compartment Deformation and Occupant Injury

Published By:

NCSA

National Center for Statistics and Analysis
Research and Development

Technical Report Documentation Page

1. Report No. DOT HS 809 676	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Relationship between Occupant Compartment Deformation and Occupant Injury		5. Report Date November 2003 6. Performing Organization Code NPO - 121
7. Author(s) Eigen, Ana María; Glassbrenner, Donna		8. Performing Organization Report No.
9. Performing Organization Name and Address Mathematical Analysis Division, National Center for Statistics and Analysis National Highway Traffic Safety Administration U.S. Department of Transportation NPO-121, 400 Seventh Street, S.W. Washington, D.C. 20590		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Mathematical Analysis Division, National Center for Statistics and Analysis National Highway Traffic Safety Administration U.S. Department of Transportation NPO-121, 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered NHTSA Technical Report 14. Sponsoring Agency Code

15. Supplementary Notes

The authors wish to acknowledge the invaluable collaboration of John Hinch, Susan Partyka, and Randa Samaha for their problem identification, insight into problem development, and advisory role throughout the elaboration of this project.

Abstract

In collaboration with and at the request of the Federal Highway Administration (FHWA), this report examines the relationship between occupant compartment deformation and injury to the occupant. An evaluation criterion for roadside safety hardware is the extent of deformation and the accompanying intrusion into the occupant compartment. This is particularly an issue with pickup trucks in impacts with longitudinal barriers. For impacts with longitudinal barriers, deformation and intrusion are typically in the wheel well and floor pan areas. The FHWA has set a guideline of 15 cm (6 in.) as the pass/fail point providing the only quantitative threshold available for testing. Unfortunately, there is no established relationship between occupant compartment deformation and intrusion and injury severity. Thus, it is difficult to assess the guidelines set forth by FHWA. The subsequent work seeks to address this topic via data evaluation and statistical analyses.

In this report, The National Automotive Sampling System – Crashworthiness Data System was used to examine intrusion magnitude thresholds and their associated injury severities. Significance testing on the intrusion-injury relationship was performed for a variety of objects contacted and intruding components. It was found that lower limb injuries were the most prevalent for the toe pan, forward of the A-pillar, and floor pan intrusions. Additionally, the risk of moderate injury severity and greater increases as the intrusion magnitude increases.

17. Key Words occupant compartment deformation, passenger vehicles, toe pan, forward of A-pillar, and floor pan deformations, guardrails, bridge rails, roadside hardware	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161 http//:www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

1. Executive Summary 1
2. Introduction 2
   Summary 2
   Conclusions 3
3. Database Selection Rationale 4
4. CDS Definitions 5
   Unique Crash Identifiers 5
   Object Contacted Associated with the Highest Severity 5
   Intruded Component 5
   Intrusion Magnitude 5
   Intrusion Area 6
   Seating Position 6
   Age 6
   Injury Severity 6
   Body Region 7
5. Cases Selected from CDS 8
   Methodology 8
   Years of Study 8
   Relevant Vehicle Selection 8
   Occupant Demography 9
   Resultant Injury Dataset Merge Caveats 10
   Methodological Adjustments based Upon Limitations 10
6. Results 13
7. Significance Tests 14
   Background 14
   Struck Object Categorization for Significance Testing 14
   Component Categorization for Significance Testing 14
   Intrusion Categorization for Significance Testing 14
   Injury Categorization for Significance Testing 14
   Relationship between Intrusion and Injury Scenarios 14
   Sample Output 15
8. Analysis of Moderate to Maximum Injuries 19
   Results by Intruding Component 21
9. Summary of Results 24
   Vehicle Striking Vehicle 24
   Fixed Object Struck 24
10. Recommendations for Future Study 25
   Examine Several More Years of NASS - CDS 25
   Expand Search by Generalizing Scope to Include GES 25

Work with Anecdotal Data 25
Control for Vehicle Body Types 25
Examine All Toe Pan, Floor Pan, or Forward of the A-Pillar Cases 26
11. Appendix........ 27
A. Data Sets 27
B. Selected CDS Definitions 29
C. Number of Nearside Occupant, Age 13 Years and Older, Injuries that were Associated with a Relevant Intrusion 33
D. Relevant Intrusions Resulting from Impact with Other Vehicle 36
E. *Relevant crashes* 37
12. References 38

List of Tables and Figures

Table 1: Intrusion Magnitude as reported in NASS - CDS 6
Table 2: Abbreviated Injury Scale Definitions and Lower Extremity Injury Examples.....................7
Table 3: Number of Vehicles with Nearside Occupant Intrusion Pursuant to a Guardrail Impact, by Intrusion Magnitude (Sample size given in parenthesis.) 11
Table 4: Number of Vehicles with Nearside Occupant Intrusion Pursuant to a Toe Pan, Floor Pan, or Forward of the A-Pillar Intrusion, by Object Contacted and Intrusion Magnitude............12
(Sample size given in parenthesis.) 12
Table 5: Frequency of Levels of Nearside Occupant Injury at Two Intrusion Levels for Intrusion into Toe Pan, Floor Pan, or Forward of the A-Pillar 15
by a Fixed Object...15
Figure 1: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Other Vehicle with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusions 16
Figure 2: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Other Vehicle with Toe Pan Intrusion 17
Figure 3: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Non-Vehicle with Toe Pan, Forward of A-Pillar, and Floor Pan Intrusion..17
Figure 4: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Non-Vehicle with Toe Pan Intrusion 18
Table 6: P-values of the Significant Intrusion-Nearside Occupant Injury Relationships 18
for Toe Pan, Floor Pan, or Forward of the A-Pillar...18
Table 7: AIS 2+ Nearside Occupant Injuries by Object Contacted, Intruding Component............19
Table 8: AIS 3+ Nearside Occupant Injuries by Object Contacted, Intruding Component............20
and Injured Body Region 20
Figure 5: Distribution of AIS 2+ Nearside Occupant Injuries from Toe Pan, Floor Pan, and Forward of the A-Pillar Intrusion for Vehicles Striking a Fixed Object 20
Figure 6: Distribution of AIS 3+ Nearside Occupant Injuries from Toe Pan, Floor Pan, and Forward of the A-Pillar Intrusion for Vehicles Striking a Fixed Object 21
Figure 7: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 2 in Vehicles with Toe Pan Striking Vehicle...22
Figure 8: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 2 in Vehicles with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusion Striking Non-Vehicle 22
Figure 9: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 3 in Vehicles with Toe Pan Striking Vehicle...23
Figure 10: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 3 in Vehicles with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusion Striking Non-Vehicle 23
Table 9: Intrusion into Occupant Compartment by Intruding Component, AIS 1 33
Table 10: Intrusion into Occupant Compartment by Intruding Component, AIS 2 34
Table 11: Intrusion into Occupant Compartment by Intruding Component, AIS 3 35
Table 12: Intrusion into Occupant Compartment by Intruding Component, AIS 4 35
Table 13: Relative Frequency of Bifurcated Nearside Occupant Injury Levels Occurring at Bifurcated Intrusion Levels in Crashes with Impacts with Other Vehicles Inducing Toe Pan, Floor Pan, and/or Forward of the A-Pillar Damage...36
Table 14: Relative Frequency of Bifurcated Nearside Occupant Injury Levels Occurring at Bifurcated Intrusion Levels in Crashes with Impacts with Non-Vehicles (Fixed Objects) Inducing Toe Pan, Floor Pan, and/or Forward of the A-Pillar Damage 37

1. Executive Summary

This report is presented in response to a request from and in collaboration with the Federal Highway Administration (FHWA). In an effort to reduce the severity of single vehicle run-off-the-road crashes, the FHWA requires that all roadside features installed on the National Highway System be crashworthy, a determination based on satisfactory performance of the device under specified impact conditions. The specific tests that must be run and the evaluation criteria to be met for each category of roadside hardware are defined in the National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." This report sets forth many guidelines for systematically evaluating the safety performance of roadside hardware, one of which is the degree of intrusion into the occupant compartment of the vehicle used to test the device. Unfortunately, the current guidelines on allowable intrusion are very subjective and have lead to inconsistent conclusions regarding the acceptability of many types of roadside hardware. National Highway Traffic Safety Administration's (NHTSA) National Center for Statistics and Analysis (NCSA) has conducted an analysis using NASS-CDS data to evaluate the relationship between occupant compartment intrusion and occupant injury. FHWA and the roadside safety community can use these relationships to evaluate acceptable thresholds of intrusion resulting from crash tests. It should be noted that if a piece of guardrail or any other type of external roadside feature intrudes into the passenger compartment, the result is failure of the prescribed test. Finally, the information contained in this report may be incorporated into the revision to NCHRP Report 350 that is now underway.

2. *Introduction*

There are many types of roadside hardware located along the edge of the nation's highway system. These items included guardrails and bridge rails, sign and luminaire supports, and crash cushions, to name a few. These systems are designed to reduce the severity of a crash or to shield a motorist from a more hazardous object or feature. The role of selecting appropriate devices typically lies with the individual State Departments of Transportation. The States often work together, sponsoring research to develop safe systems and installation methodologies, and methods to evaluate the performance of new roadside safety systems. The definitive guidelines for evaluating roadside systems are contained in the National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." This methodology was developed based on the needs identified by chief administrators of the highway and transportation departments, by committees of American Association of State Highway and Transportation Officials (AASHTO), and the Federal Highway Administration (FHWA). The FHWA requires that all roadside features installed on the National Highway System meet the evaluation criteria contained in Report 350.

Although most of the evaluation criteria recommended in NCHRP Report 350 are specific and unambiguous, some are highly subjective. In particular, Chapter 5 of NCHRP Report 350, Table 5.1, evaluation criteria "D," states, in part, "Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted." The location and extent of occupant compartment intrusion that might cause "serious injury" is not quantified, nor is a definition of "serious injury" offered. There are no uniform guidelines that a researcher or highway agency can use to assess whether deformation or intrusion resulting from crash damage will result in serious injury. To provide some degree of uniformity among the various testing agencies, FHWA has arbitrarily set 15 cm deformation of the occupant compartment as the threshold beyond which serious injury may result. This determination does not specifically address the location of the deformation or the size of the vehicle involved in the crash.

The highway safety community is in the process of updating NCHRP Report 350 (Powers, 2003), and is interested in quantifying the current deformation and intrusion evaluation criteria. For this reason, the National Center for Statistics and Analysis (NCSA) has worked in conjunction with FHWA to undertake this study. The results of this study can be directly applicable to that goal.

Summary

The study seeks to:

- **Examine the 15 centimeter floor pan/wheel well intrusion guideline used to evaluate roadside safety and occupant injury.**

NCSA undertook an examination of the National Automotive Sampling System (NASS) – Crashworthiness Data System (CDS) to review real world crash experience in response to a request from the FHWA. Passenger vehicles with damage to the toe pan, forward of the A-pillar, and floor pan were isolated for analysis, without regard to the object struck, as surrogates for occupant compartment deformation induced by longitudinal roadside hardware intrusion.

Crashes in which a vehicle contacted another vehicle were also examined because of the sample size issues.

Conclusions listed below were based on analysis of the following NASS – CDS variables:

Vehicle Type: Passenger vehicles (passenger cars and light trucks).
Occupant Ages: Greater than or equal to 13 years old.
Seating Positions: Driver and front right passenger seat.
Intruding Component: Toe pan, forward of the A-pillar, and floor pan. These are referenced throughout this report as **relevant intrusion**. In CDS, forward of the A-pillar and front side panel are used to describe the attribute of interest, therefore, these are used interchangeably in the text.
Relevant Crashes: Crashes in which the case vehicle strikes a fixed (non-vehicle) object resulting in toe pan, forward of the A-pillar, or floor pan intrusion.
Intrusion: Occupant compartment deformation induced by **relevant intrusion**.
Injury Severity: Abbreviated Injury Scale (AIS) ranging from AIS 1, minor, through AIS 6, maximum (untreatable).
Object Contacted: No limitation. Selected **Intruding Components** acted as roadside hardware object struck surrogate.
Years: Crashes occurring during the years 1991 – 2000 and recorded in NASS - CDS.

Conclusions

Based on Chi-Square tests, the data indicates that many moderate to maximum injuries occur at intrusions into the occupant compartment that are less deep than the 15 centimeter threshold set forth by the FHWA. Sample size issues preclude a more detailed analysis and obviate controlling for other factors, such as belt use, age of vehicle occupant, or vehicle body type. The analysis is also based on an aggregation of fixed objects that may exhibit different deformation characteristics, which upon aggregation disappear. Finally, these results are based upon an assessment of life-impairment, consistent with lower limb injuries, rather than risk of mortality; however, impairment and mortality are addressed when interpreting the results.

3. *Database Selection Rationale*

A comprehensive crash report was required for this study. An integrated examination of the vehicle, roadway environment, and occupant demography was necessary to address the possible improvement to the current guardrail intrusion guideline. NCSA compiles and maintains two databases under the aegis of NASS. NASS - General Estimates System (GES) is a representative sample of crashes occurring in the United States. The NASS - CDS is a nationally representative database concentrating on crashes of greatest concern to the highway safety community and the public.

GES and CDS are based on the police accident report (PAR). GES, however, relies only on the police officer's interpretation of the event. A NASS researcher does not examine the vehicle or interview occupants. For these reasons, a more subjective and less detailed account is compiled. This is not conducive to addressing questions specific to crashworthiness performance of roadside hardware. Additionally, the question of injury severity is assessed on a non-medical scale (KABCO), whose score is assigned by the law enforcement official on the scene.

The NASS – CDS is a comprehensive description of approximately 4,500 nationally representative crash events each year. This data set is based on the PAR only in so far as the selection criteria. Upon selection, the work of the investigation staff begins. The comprehensive crash scene and vehicle review combines with the occupant demography and injury accounts. The CDS was chosen owing to its: thorough tow-away vehicle inspection, inclusive injury-specific data for occupants of towed vehicle, and multi-variable link of occupant injury to vehicle damage. By examining the complete crash file, the study can encompass the most general crash environment components to the most specific occupant injury attributes via the continuity of the year, primary sampling unit (PSU, a geographical area dictated by the sample design), case identification number, occupant number, and injury number. An additional refinement which links the occupant to the injury occurs with the intrusion area, that is equivalent to the seating position, and the intrusion number, that links to the injury record.

CDS was chosen for this analysis for several reasons. The weightiest was the thorough vehicle inspection undertaken by NASS researcher. Further, deformations into the occupant compartment are defined and linked to occupant injury and injury severity. GES, although a superior research tool, did not meet the needs of this study. By providing, substantial data on general transportation safety trends, its strength and one of its purposes, it sacrifices the ability to provide an in-depth study of the crash, the strength of CDS and one of its purposes. In this regard, both were designed to perform different functions. For the sake of uniformity of the data set compiled for this study, the entire analysis contained in this paper was performed using the CDS data.

4. CDS Definitions

Several variables unique to CDS are included and adapted for this study. Their definitions and contribution to the study are outlined in this section.

Unique Crash Identifiers

Each crash in CDS is uniquely identified by three elements: year, primary sampling unit (PSU), and case identification (caseid) number. The year in which the crash occurs is reported by the year variable. The PSU is a geographical subdivision inherent to the sampling plan of the CDS. The caseid is a combination of the case number assigned to the crash and the stratum. The stratum is a classification based on the sampling plan generated by the Automated Case Selection System. Additional elements exist to link vehicles, occupants, and injuries to the appropriate crash. A unique vehicle number (vehno) is assigned to each vehicle in a crash. Further, occupants are linked to a vehicle, uniquely numbered, and assigned to a seat within the vehicle. Each occupant sustaining injuries has a numbered listing of injuries, which can be associated with the injury source, body region, and injury severity.

Object Contacted Associated with the Highest Severity

The objects contacted retained were those with impacts occurring at the highest delta-v. Delta-v is the change in velocity experienced by the case vehicle during an impact and used as a severity measure in planar crashes. In general, these objects were categorized as vehicle and non-vehicle. Vehicle identifies any multi-vehicular crashes whose most severe crash is attributable to contact with another vehicle. Non-vehicle contacts are those impacts with manmade and naturally occurring roadside hardware.

Intruded Component

The intruding object is said to reduce the occupant space for a specified vehicle sector. In response to the guardrail surrogate definition, toe pan, forward of the A-pillar, and floor pan were selected. The toe pan is defined as the front portion of the floor that angles up to meet the dash panel. The side panel forward of the A1/A2 pillar refers to the interior panel located on the side of the vehicle and forward of the front doors. This includes areas directly below the instrument panel sometimes referred to as a "kick panel." Finally, the floor pan, including the sill, refers to the floor of the vehicle. This includes the lower portion of the passenger compartment. Damage to the three components was used to represent damage from collisions with guardrails.

Intrusion Magnitude

The intrusion magnitude is defined by a categorical variable that establishes ranges of values for intrusion induced by impact. These range from three centimeters through 61 centimeters or greater of recorded intrusion. Those cases defined as 61 centimeters and greater are quantifiable events measured by the NASS researcher. For this reason, these cases are retained. The unquantifiable events are grouped owing to the high severity and rarity of occurrence. The term catastrophic is reserved for deformations with severity beyond codification. An unknown category exists to indicate intrusions of unspecified magnitude. For purposes of statistical analysis, the catastrophic and unknown cases were eventually excluded. These cases were not assigned numeric values by which to assess the deformation because the damage was considered immeasurable or the vehicle may no longer have been available for measurement by the researcher. It should also be noted, as stated above, these represent ranges and not the precise values allowing for larger cell sizes when performing analysis. Please reference Table 1.

Table 1: Intrusion Magnitude as reported in NASS - CDS	
CDS Code	**Intrusion Magnitude Ranges**
1	3 through 7 centimeters
2	8 through 14 centimeters
3	15 through 29 centimeters
4	30 through 45 centimeters
5	46 through 60 centimeters
6	61 centimeters or greater
7	Catastrophic
.U	Unknown
Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000	

Intrusion Area

This area is defined by occupied row and position affected by the intrusion. The definitions correspond to those set forth by the seating position described below.

Seating Position

Seating positions adjacent to the selected intruded components were retained for this study. These were the front left (driver) and the front right (passenger) seats. Rear and center seating positions were omitted owing to their lack of proximity to the intruding components.

Age

The age variable is reported in one-year increments from zero (less than one year old) through 96 years old. Ages of 97 years and greater are subsumed within a single code. Owing to their rare occurrence, this does not misstate the analysis. The exclusion of those children less than 13 years old was deemed necessary owing to their developing state. This issue is discussed more precisely in subsequent sections.

Injury Severity

The CDS offers injury classification on two scales. The first is the KABCO scale, which is a visual classification based on a police officer's observation and reported on the PAR. The ranking is in descending order with: killed (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and no injury (O). The Abbreviated Injury Scale (AIS), the second scale, is a medically assessed classification of injuries based on hospital records. Occupants with multiple injuries receive a rating for each injury. This ranking measures threat to life induced by injuries sustained over six levels. For completeness, "unknown" and "not collected" categories exist. A variant of this is the MAIS that shares the ranking, however, reports the level of maximum injury severity. The absence of an injury is understood to be defined by an AIS 0 rating, however, this is not recorded in CDS. MAIS 0, however, exists to describe those occupants who do not sustain injury. It has been noted in the CDS that occupants with injuries of severity less than 6 have expired. It should also be noted that AIS 6 injuries generally result in fatality; however, CDS uses a treatment variable to assess the outcome of an occupant. To put these rating into a physiological context Table 2 offers an example of injuries to the body regions most frequently injured in ***relevant crashes***. These examples are also meant to accentuate the life threatening nature of these injuries predicated on the increasing risk of fatality as one ascends the AIS scale. It should be noted, however, that life threatening injuries to the lower limb are extremely rare. For this reason, the AIS 6 example may seem somewhat generic. Table 2 suggests the life devastating rather than life threatening nature of lower extremity injuries.

Table 2: Abbreviated Injury Scale Definitions and Lower Extremity Injury Examples

AIS Code	Injury Severity Description	Lower Extremity Example of Injury by AIS Level
0	Uninjured	No body region listed in absence of an injury.
1	Minor	Ankle Sprain
2	Moderate	Hip Dislocation
3	Serious	Femur Fracture
4	Severe	Major Laceration of Femoral Artery
5	Critical	Pelvic Fracture, substantial deformation and displacement with associated vascular disruption or with major retroperitoneal hematoma; "open book" fracture, blood loss greater than 20 % by volume.
6	Maximum	2° or 3° (or charring to head or trunk or incineration with ≥ 90 % of total body surface.
7	Unknown	Traumatic lower extremity injury died without further evaluation; no autopsy.

Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000

Body Region

The body region variable classifies the injured segment of the body. This allows an injured body region to be associated with interior or exterior sources of contact. Additionally, the body region may be linked to an intruding component. The distinction between injury sources and intruding components lies with the file in which it is reported and the matching with the occupant injury. The injury source resides in the occupant injury file and corresponds to a specific injury. The intruding component is reported in the vehicle interior file and is linked to a seating position. An occupant is reported to occupy a seating position thereby linking an intrusion location with an occupant and his injuries. The intruding component is a condensed listing of injury sources and associated with seating position. The occupant injuries are attributed to the expanded listing of injury sources. If relevant, the intruding component may be linked to one or more injuries and may correspond to more than one injury source.

5. *Cases Selected from CDS*

Methodology

Nearside occupant experience was examined. The parameters by which cases were selected varied without sacrificing injury reporting. Based on the intruded areas, an association of the nearside occupant injuries attributable to these intruding components was drawn to populate the data set.

Years of Study

The study spanned the crash reporting years 1991 through 2000 because the fleet age is generally accepted to be about ten years and the technology specific to guardrail intrusion present in these vehicles would be comparable owing to the CDS selection criteria. The fleet age is unattainable using CDS owing to the sample design and case selection criteria. Instead, the selection of crash data reported over the ten most recent years is intended to serve as a surrogate for the stipulated fleet age. It should also be noted that the ten year time frame is used to ensure an adequate sample size.

Relevant Vehicle Selection

The vehicle data was restricted to CDS case vehicles (towed passenger vehicles) in non-rollover crashes with toe pan, forward of A-Pillar, and/or floor pan intrusion. For reference, this report will identify crashes where the case vehicle strikes a fixed object resulting in intrusion to the toe pan, floor pan, or forward of the A-Pillar ***relevant crashes***. Cases in which another vehicle is struck are also retained for comparative purposes to establish potential common features in intrusion threshold evaluation.

CDS case vehicles are further defined as those, which are involved in, tow away passenger vehicle crashes on United States public roadways and reported in NASS selected PARs. Although general vehicle and crash environment data may exist for vehicles other than the case vehicle in multi-crash environments, specific vehicle and occupant level data will be absent.

Passenger vehicles are considered in this study because: CDS intrusion and injury data are limited to towed light vehicles and the FHWA guideline is relevant only to light vehicles. The adequacy of guardrails protecting the entire vehicle fleet mix is the ultimate goal of these guardrail guidelines.

The tow-away vehicle restriction was imposed on the query (forming the basis for this work) because of the investigation that ensues. Upon reaching the tow yard, a NASS investigator is deployed to examine the vehicle and compile all quantitative data relevant to the crash. From this data, other more subtle inferences, based upon experience, may be drawn which are very useful in crash reconstruction.

A restriction based upon the crash configuration is imposed to assure true surrogates in the research. Non-planar crashes are excluded owing to the uniqueness of the event, the lack of repeatability in laboratory settings, and to their aberrant nature. Additionally, distinguishing nearside impact from rollover damage may be difficult, especially following a series of quarter turns.

From the object contacted listing, two categories were created. These were meant to isolate vehicle impacts and non-vehicle impacts. Since over 50 attributes are associated with the object contacted, small cell sizes were pervasive. For this reason, any impact for which object contacted was considered vehicle was retained as such. Among the selected intruding components, the impact with another vehicle accounted for slightly more than half of the reported impacts. The remaining struck objects were considered non-vehicle impacts.

The intruded areas were selected upon the FHWA test guideline. These areas also correspond with the prevalence in lower limb injuries typically occurring with lower occupant compartment deformations. Toe pan and floor pan strikes may be the most obvious selections, however, the rationale for forward of the A-pillar is compelling; although upper body injury may be found, the majority of the interactions occur with the lower limb. Since the three relevant intrusions are considered surrogates for the intrusion and injury patterns caused by a guardrail, these formed one of two categories describing intruding components. The second group contemplates the toe pan only. The frequency with which this intrusion appears and the damage profile for the roadside hardware with respect to the vehicle dictate this selection.

The intrusion levels were devised based upon the categorical variables defined in CDS (per Table 1.) Each level is designed to describe greater intrusion thereby discarding the lower levels of intrusion. The groups will, therefore, consist of ever shrinking sample size.

Occupant Demography

The occupant data restrictions included are: occupied front right and/or left seating positions, age 13 years and greater, seating position matches intrusion location (near-side), intrusion linked to an injury, and MAIS.

The front right and/or left seating positions are specified for several reasons. First, these occupants are in vehicle-specified seats equipped with manual and possibly passive restraints. The rear seat occupants, as well as any center seating positions, are not generally vulnerable to the occupant compartment deformation induced by guardrails, based upon CDS data. Further, most of the guardrail crashes with occupant compartment intrusion were frontal or frontal offset endangering the lower frontal portion of the vehicle thereby reasserting the selection of the intruding components. Structurally, the rear seat occupants are protected from frontal and side impact induced by guardrails (10, 11, 12, 1, and 2 o'clock directions of force) by the B-pillar and components forward of the B-pillar. The center seating positions should be shielded from this type of intrusion owing to their distance from any of the affected sides.

An age restriction was imposed upon the occupants to address the majority of occupants within the vehicle, especially the front seat. Additionally, the physiological development of those occupants less than 13 years old might tend to distort the injury patterns of the overall population affected by the nearside guardrail impact. NHTSA also recommends that children, ages zero through 12 years old, be placed in a rear seating position. As mandated by CDS categorization of the age variable, occupant age is coded to 96 years old. If the occupant has reached 97 years or older, the age is recorded as 97. Few occupants are categorized with the code of 97. For this reason, the demography retains age representation and no cases are sacrificed owing to their advanced, yet unspecified age.

Intrinsic to the coding of CDS, the seating position is set equal to the intrusion area to ensure nearside contacts. The intrusion area is assigned an intrusion number that is referenced in the occupant injury file. This reference is a linking variable between the relevant intrusion and the associated injury.

The injury data was also qualified to ensure the most accurate intrusion data. Any case with a maximum injury severity of abbreviated injury scale (MAIS) 0 through 6 was retained. The MAIS is a measurement of risk to life with zero accounting for no injury though six yielding a maximum risk to life. The intervening scores are of ascending order and are used to determine the severity of injuries sustained as a result of the crash.

Resultant Injury Dataset Merge Caveats

As with any data system, cautions must be issued when interpreting the vehicle and occupant records within the injury dataset. The following discussion should ensure that any attempt of replication would yield the same results.

Within the data set, an occupant appears as many times as: a qualifying injury record exists or a qualifying intruding component record exists. These are inherent to the CDS. This flexibility is allowed owing to the unique link existing upon stipulating the year, PSU, case identification number, vehicle number, occupant number, and injury number.

Methodological Adjustments based Upon Limitations

A study of roadside hardware crashes was impossible owing to the inadequate sample size. From 1991 through 2000, 69 cases were reported in which a vehicle striking the guardrail was the most severe event in the crash. CDS subsumes guardrails within a category known as other guardrail, however, guardrails are presumed to comprise the majority of this subset. The disaggregation of this category is unavailable without review of photographs and case records. An interim report prepared by the George Washington University's, NHTSA/FHWA National Crash Analysis Center (NCAC) for the NCHRP Project 22-15 on compatibility of vehicles and roadside hardware, identified and studied the other barrier category. The study concluded that the majority of crashes truly involved guardrails impacts including: guardrails, their end treatments, and/or their transitions. By way of photographic and case review, the researchers were not only able to disaggregate the various guardrail types, they were able to identify whether end treatments and/or transitions played a part in the impact. In the absence of sufficient guardrail cases, ***relevant crashes*** were proposed and outlined below.

Roadside hardware crashes could not be studied because of their inadequate sample size. A natural enlargement of other types of fixed objects that was similar to roadside hardware did not exist. Crashes into fixed objects of any kind that resulted in occupant compartment deformation into a location where roadside hardware was likely to intrude were aggregated. For comparison, the relationship for crashes into other vehicles that intruded into these components was examined.

The relevant case attributes were selected based upon biomechanical grounds. First, the intrusions into the passenger compartment inflicted by the guardrails generally occurred in the lower regions of the vehicle. As a corollary to this argument, the intrusion into the lower regions of the vehicle placed the lower limbs at greater risk for injury. Finally, guardrail impacts had the potential for intrusion in the front section of the vehicle. For this reason, the front left and right occupants were chosen owing to their proximity to this intrusion. The intruding components, most closely addressing the above concerns, were selected: toe pan, floor pan, and forward of the A-Pillar. Sample size concerns obligate the FHWA method of examining guardrail intrusion compartment into the occupant compartment to be substituted by this method considered complementary. As seen in CDS, the majority of guardrail impacts and their possible intrusions result in frontal and frontal offset general areas of damage. If any deformation occurs, these crashes will generally result in lower occupant compartment deformation, which in the event of injury, generally affect the lower extremities.

It was necessary to determine whether many crashes into roadside hardware sustained intrusions into the passenger compartment of less than 15 centimeters. As seen in Tables 3 and 4, this became evident for both guardrail and relevant intrusions. It should be noted that this study focuses on occupant compartment intrusion and injuries induced by this occurrence. This study is meant to examine the interaction between occupant compartment deformation and occupant injury, therefore, guardrail impact crashes in which no resultant occupant compartment intrusion occurs are excluded because these fall outside of the scope suggested by FHWA during the preparation of the analysis. Further, the 15 centimeter threshold will be tested above and below these recorded intrusion points because all of the ***relevant crashes*** were selected on based upon intruding component. It should also be noted that uninjured occupant data for ***relevant crashes*** in which occupant compartment deformation occurs are retained.

Table 3: Number of Vehicles with Nearside Occupant Intrusion Pursuant to a Guardrail Impact, by Intrusion Magnitude (Sample size given in parenthesis.)

Object Contacted	Intrusion Magnitude						Total
	3-7 CM	8-14 CM	15-29 CM	30-45 CM	46-60 CM	61 OR MORE CM	
Other Barrier*	5,800 (n = 20)	965 (n = 14)	2,790 (n = 20)	562 (n = 11)	68 (n = 2)	155 (n = 2)	10,339 (n = 69)

*No specific category exists in CDS to capture guardrails only, however, they are subsumed within the Other Barrier category and comprise a substantial number of these cases.

Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000

Table 4: Number of Vehicles with Nearside Occupant Intrusion Pursuant to a Toe Pan, Floor Pan, or Forward of the A-Pillar Intrusion, by Object Contacted and Intrusion Magnitude (Sample size given in parenthesis.)							
Object Contacted	Intrusion Magnitude						Total
	3-7 CM	8-14 CM	15-29 CM	30-45 CM	46-60 CM	61 OR MORE CM	
Vehicle	91,143	86,478	37,264	8,388	4,051	1,235	228,559
	(n = 305)	(n = 254)	(n = 269)	(n = 115)	(n = 46)	(n = 24)	(n = 1013)
Non-Vehicle	46,912	36,859	27,034	9,711	3,453	2,385	126,353
	(n = 118)	(n = 136)	(n = 173)	(n = 95)	(n = 54)	(n = 36)	(n = 612)
Total	138,055	123,337	64,298	18,099	7,504	3,620	354,912
	(n = 423)	(n = 390)	(n = 442)	(n = 210)	(n = 100)	(n = 60)	(n = 1625)
*No specific category exists in CDS to capture guardrails only, however, they are subsumed within the Other Barrier category and comprise a substantial number of these cases.							
Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000							

Over the period 1991 through 2000, 1,567 crashes and 1,625 vehicles involved with relevant intrusions were captured, per Table 4. These represented approximately 349,000 crashes and 354,912 vehicles when the case weighting factors were applied. Of these crashes, the most severe event attributable to: fixed object impacts, ***relevant crashes*** were 612 (126,000) cases and other vehicles were 955 (223,000) cases with their respective vehicle counts reported in Table 4.

It was acknowledged that factors such as restraint use and occupant age would affect injury patterns, however, control for these factors was impossible because of the sample sizes. It was assessed whether these factors confounded the data enough to mask a relationship between intrusion and injury rather than controlling for them.

As a final preliminary note, it is generally accepted that high severity injuries aid in identifying problem areas. In CDS, however, injury severity is based upon risk of death rather than impairment. Of the relevant intrusions, 98 percent of the resulting injuries were attributable to lower limb injuries. In general, these injuries are of low risk of mortality, therefore the injury severity is low. For this reason, AIS 4 injuries produced in relevant intrusions account for 0.08 percent of all the injuries produced in relevant intrusions.

Based on the relevant CDS crashes, it is suggested that mortality may not be the most suitable measure for occupant outcome. Lower limb injuries, although of low severity, have the potential to produce incapacitating injuries. For this reason it is proposed that the study of injuries greater than or equal to AIS 2 should be undertaken. In keeping with the spirit of the guideline rather than the corresponding AIS 3 definition of serious injury, a shift from life ending to life devastating injuries might better capture the nature of guardrail intrusion into the occupant compartment.

6. Results

Based on the methodology established for the current phase of research, the resultant data set was summarized and subsequently tested for significance. These results are based on injury outcomes and crash parameters.

The injury distribution attributable to the selected intruding components was concentrated at the AIS 1 and 2 severities. A small number of injuries were found with injury severity AIS 3 and 4. The lower injury severities are consistent with lower limb injuries, as few are life threatening. As expected from intrusions in the lower regions of the vehicle, lower limb injuries were the most prevalent. Ninety-eight percent of injuries resulting in toe pan, forward of the A-pillar, or floor pan intrusions induced lower extremity injuries. Injuries of maximum severity zero were retained to adequately represent the crash population, since these were the uninjured segment of the intrusion population.

Contacts with other vehicles tended to induce the majority of the toe pan, forward of A-pillar, and floor pan intrusions. These contacts are based on the injuries carrying the highest injury severity for each occupant. For this reason, in the event of contact inducing more than one injury at the maximum injury level, there may exist more than one entry per contact. This is calculated to be approximately 1.9 AIS 2+ injuries per occupant for this data set. Approximately, 53 percent of intrusions involved another vehicle. By definition, these are generally multi-vehicular crashes (non-parked vehicles). Among moderate to maximum occupant injuries occurring in vehicles striking trees (small and large, aggregated) with toe pan intrusion, these accounted for 42 percent of this subset. In contrast, within the same injury severity group but for occupants affected by any of the three components, the prevalence of tree contact drops to 24 percent. For the selected components, the majority of intrusions were of magnitude 8 through 29 centimeters. By components, the toe pan was found to experience the majority of intrusions (80 percent) when compared to forward of the A-pillar (6 percent) and floor pan (14 percent) intrusions.

Not surprisingly, a relationship was found to exist between occupant compartment intrusion and injury, even without controlling for important, and seemingly confounding, variables such as safety belt usage, age of vehicle occupant, or vehicle body type. This relationship was true for fixed objects and vehicles. This suggested that factors were not substantially confounding the data. Statistically significant relationships were found for non-minor injuries with intrusions of 8 to 15 centimeters. This suggested that there was an association between intrusions lower than the NCHRP guideline and injury. It was found that 34 percent of ***relevant crashes*** into roadside hardware had intrusion greater than 15 centimeters, 61 percent had intrusion greater than 8 centimeters, and 35 percent had intrusion 8 to 15 centimeters.

The most important result was found to be that the data indicated that many moderate to maximum injuries occurred at intrusions less than 15 centimeters. However, the analysis was performed without controlling for important variables, such as safety belt usage and age of injured occupant. In addition, the result was based on crashes into fixed objects and other vehicles, and so might not apply to roadside hardware, per se.

7. *Significance Tests*

Background

The injury dataset consisted of MAIS 0 through 4 injuries. Significance testing was conducted on impact (vehicle or non-vehicle) and component (aggregate of three components or toe pan) by intrusion (six categories of magnitude) and injury severity (four combinations of AIS values). This operation was performed using SUDAAN (Survey Data Analysis, Software for Statistical Analysis of Correlated Data), in conjunction with SAS (Statistical Analysis System).

Struck Object Categorization for Significance Testing

The struck objects were separated into two levels, vehicle and non-vehicle, based on CDS data. The vehicle category was defined as any vehicle-to-vehicle contact related to injury via intrusion. The non-vehicle category subsumed any other object contacted. These included poles, posts, natural and man-made roadside hardware, or miscellaneous struck objects related to injury via intrusion.

Component Categorization for Significance Testing

Two levels of intruding component were devised based on CDS data. The first was an aggregate of toe pan, forward of the A-Pillar, and floor pan. The second was comprised solely of the toe pan.

Intrusion Categorization for Significance Testing

The intrusion magnitude was separated into six categories based on the CDS data. These are as follow: 3 centimeters and greater, 8 centimeters and greater, 15 centimeter and greater, 30 centimeters and greater, 46 centimeters and greater, greater than 61 centimeters. Catastrophic and unknown levels of intrusion were omitted owing to their non-numeric and qualitative nature.

Injury Categorization for Significance Testing

Four levels of injury severity were used based on CDS data. These are as follow: from AIS 1 through AIS 6, from AIS 2 through AIS 6, from AIS 3 through AIS 6, from AIS 4 through AIS 6. The unknown injury level was omitted from the data set.

Relationship between Intrusion and Injury Scenarios

In Table 5, the output tests the relations for an impact with a non-vehicle, a fixed object, resulting in occupant compartment intrusion from the floor pan, toe pan, or forward of the A-Pillar at intrusion magnitudes above and below 15 centimeters were analyzed for moderate to maximum injury severities (AIS $\geq$ 2) and minor injury severities (AIS $\leq$ 1). When comparing the p-value resulting from the chi square test with the established p-value of 0.05, the relationship was found to be significant. This test criterion was applied to all p-values to determine significance. (Please reference Section 11, Subsection D for vehicle impacts and Subsection E for the output governing fixed object impacts.

For example in Table 5, AIS $\geq$ 2, when intrusion is greater than or equal to 15 centimeters in ***relevant crashes***, 36 percent of the injuries were of moderate to maximum severity while 64 percent were of minor severity or the occupant was uninjured. When the intrusion was less than 15 centimeters, 9 percent of the occupant injuries were of moderate to maximum and 91 percent sustained minor injuries or were uninjured. These data indicate a relationship between intrusion and injury that is significant with 99.97, (100 %– p-value for the χ^2 test), percent confidence. Again, this analysis does not take into account other factors that are related to injury, such as safety belt usage.

Table 5, AIS ≥ 3 also yields a 99.97, (100 %– p-value for the χ^2 test), percent confidence in the relationship, however, this is based on a very small sample size. It should be noted that intrusion greater than 15 centimeters is present. The zero percent is a minute, rounded value.

Sample Output

Table 5: Frequency of Levels of Nearside Occupant Injury at Two Intrusion Levels for Intrusion into Toe Pan, Floor Pan, or Forward of the A-Pillar by a Fixed Object

Injury Severity	Intrusion ≥ 15 cm	Intrusion < 15 cm
AIS ≥ 2	36%	9%
AIS < 2	64%	91%
p-value for χ^2 test: **0.0269**		
AIS ≥ 3	5 %	0 %
AIS < 3	95 %	100 %
p-value for χ^2 test: **0.0284**		
Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000		

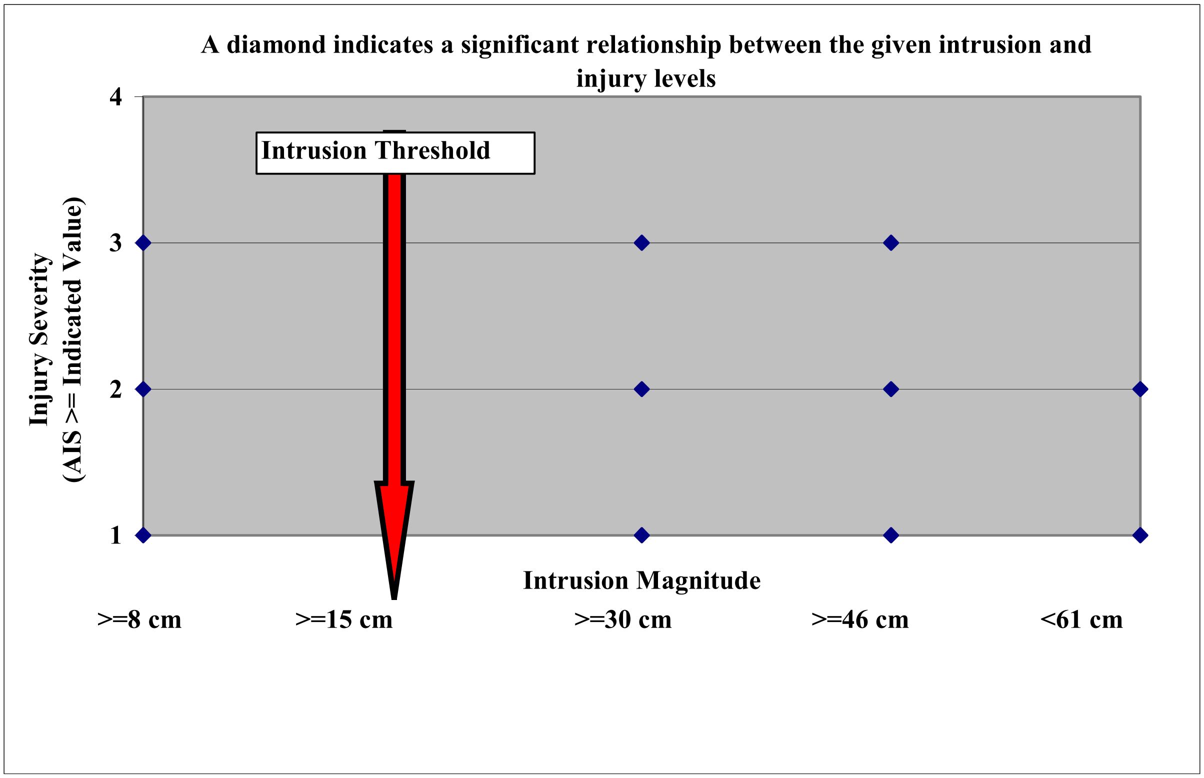
Vehicle data has been retained in Appendix 11, Subsection D; however, non-vehicular intrusion into the occupant compartment is considered a more adequate surrogate for the guardrail intrusion. First, vehicles are geometrically different in mass and design from a guardrail. Further, these will deform in a different fashion than the guardrail. Second, the vehicle inflicting the intrusion may be moving thereby causing a damage profile unlike that of a stationary object. Figures 1 through 4 depict the distribution of significant values of intrusion magnitude and injury severity. A concentration of values is evident from 15 centimeters through 61 centimeters. For non-vehicle impacts, however, the significant injury severity is consistently distributed from 15 centimeters through 46 centimeters. As expected, few extreme cases above 61 centimeters exist. For vehicle impacts with other vehicles inducing toe pan intrusion, cases are concentrated from 15 through 61 centimeters. Table 6 accompanies these charts for greater clarity of distribution and relevant p-values. The arrows are included in each figure as a reminder of the threshold dictated by the current guideline.

Figures 1 through 4 graphically depict the significant intrusion and injury relationships. For example, the significant relationship from Table 5 is indicated by the dot in Figure 3 at the point where intrusion is greater than or equal to 15 centimeters and AIS greater than or equal to 2. However, in Figure 3, no relationship was found when, for example, intrusion is greater than or equal to 15 centimeters and AIS greater than or equal to 4. This might be because of the small number of cases.

Taken together, Figures 1 through 4 indicate a relationship between occupant compartment intrusion and injury. They also indicate that many moderate to maximum injuries occur below the current NCHRP intrusion threshold of 15 centimeters. These are graphic representation of the data presented in Table 6 and may be used interchangeably. It is considered that each representation method appeals to different styles of data assimilation.

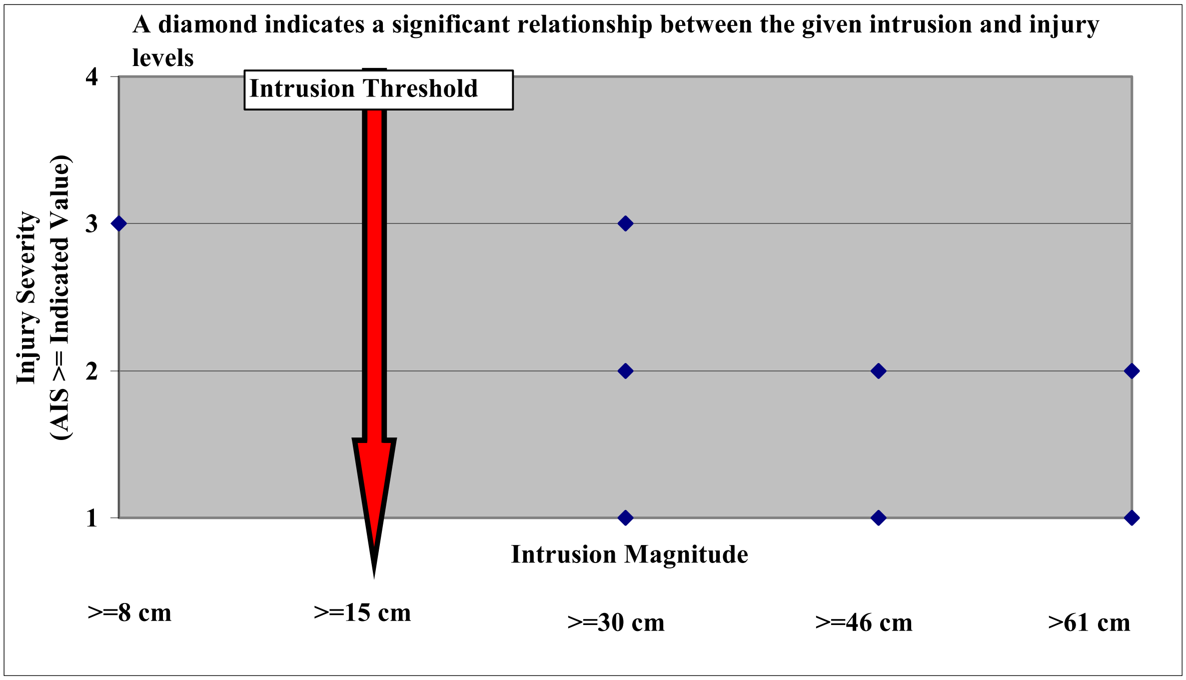
The data points on the graphs indicate a significant relationship between the given intrusion and injury levels. Based on the outcomes shown in Figures 1 through 4, an indication of relationship between intrusion and injury is evident for injuries with as little as eight centimeters of intrusion. It should be noted that lack of significance should not be interpreted as zero but instead it may indicate an absence of data.

Figure 1: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Other Vehicle with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusions



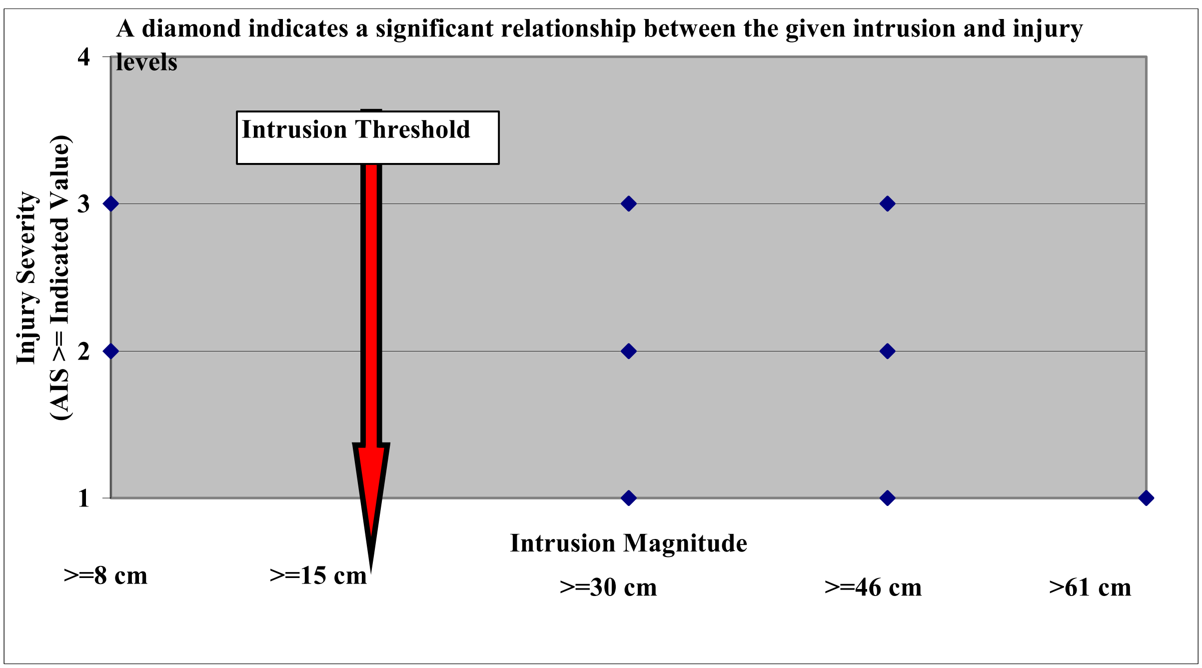
Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Figure 2: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Other Vehicle with Toe Pan Intrusion



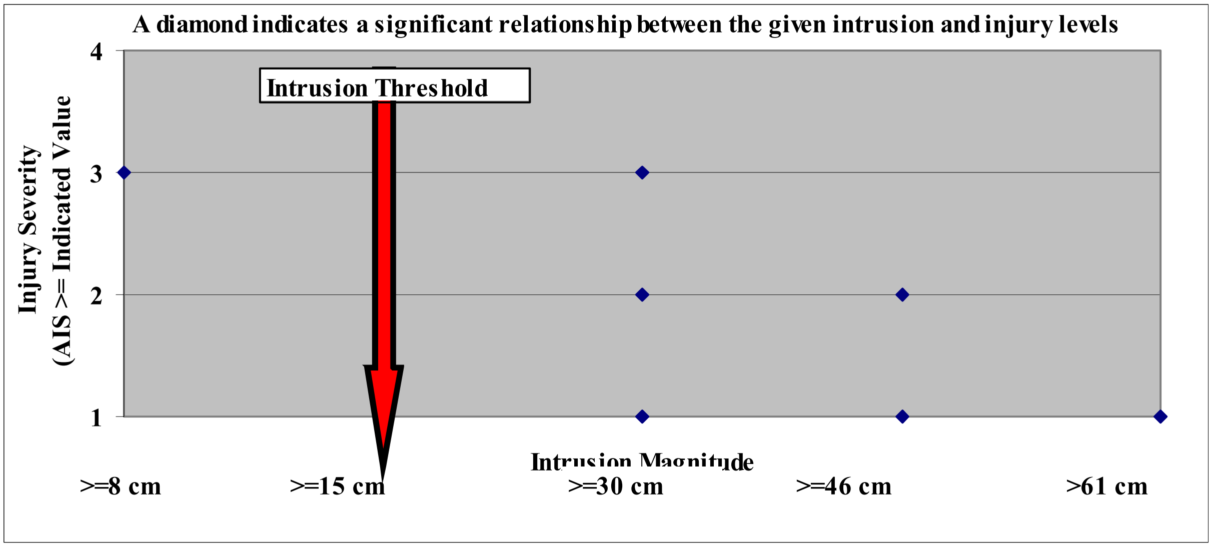
Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Figure 3: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Non-Vehicle with Toe Pan, Forward of A-Pillar, and Floor Pan Intrusion



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Figure 4: Significant Intrusion-(Nearside Occupant) Injury Relationship for Contact by Non-Vehicle with Toe Pan Intrusion



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Table 6 presents a numeric summarization of Figures 1 through 4. Each dot in Figures 1 through 4 may represent more than one significant relationship, as seen in Table 6. Relevant are the many significant relationships found at the various intrusion and injury levels. Also, the significant values of intrusion exist as of eight centimeters and greater, as dictated by the current guardrail intrusion guideline, and are consistently persistent through 46 centimeters.

Table 6: P-values of the Significant Intrusion-Nearside Occupant Injury Relationships for Toe Pan, Floor Pan, or Forward of the A-Pillar

Contact by Other Vehicle with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusions			Contact by Other Vehicle with Toe Pan Intrusion			Contact by Non-vehicle with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusions			Contact by Non-vehicle with Toe Pan Intrusion		
Intrusion	**Injury**	**p-value**	**Intrusion**	**Injury**	**p-value**	**Intrusion**	**Injury**	**p-value**	**Intrusion**	**Injury**	**p-value**
≥8 cm	AIS ≥ 1	0.0007	≥8 cm	AIS ≥ 3	0.0330	≥8 cm	AIS ≥ 2	0.0269	≥8 cm	AIS ≥ 3	0.0363
≥8 cm	AIS ≥ 2	0.0129	≥15 cm	AIS ≥ 1	0.0008	≥8 cm	AIS ≥ 3	0.0284	≥15 cm	AIS ≥ 1	0.0100
≥8 cm	AIS ≥ 3	0.0040	≥15 cm	AIS ≥ 2	0.0000	≥15 cm	AIS ≥ 1	0.0036	≥15 cm	AIS ≥ 2	0.0172
≥15 cm	AIS ≥ 1	0.0000	≥15 cm	AIS ≥ 3	0.0002	≥15 cm	AIS ≥ 2	0.0159	≥15 cm	AIS ≥ 3	0.0131
≥15 cm	AIS ≥ 2	0.0000	≥30 cm	AIS ≥ 1	0.0025	≥15 cm	AIS ≥ 3	0.0175	≥30 cm	AIS ≥ 1	0.0190
≥15 cm	AIS ≥ 3	0.0001	≥30 cm	AIS ≥ 2	0.0035	≥30 cm	AIS ≥ 1	0.0014	≥30 cm	AIS ≥ 2	0.0012
≥30 cm	AIS ≥ 1	0.0009	≥30 cm	AIS ≥ 3	0.0113	≥30 cm	AIS ≥ 2	0.0005	≥30 cm	AIS ≥ 3	0.0409
≥30 cm	AIS ≥ 2	0.0003	≥46 cm	AIS ≥ 1	0.0190	≥30 cm	AIS ≥ 3	0.0254	≥46 cm	AIS ≥ 1	0.0102
≥30 cm	AIS ≥ 3	0.0007	≥46 cm	AIS ≥ 2	0.0107	≥46 cm	AIS ≥ 1	0.0015	≥46 cm	AIS ≥ 2	0.0171
≥46 cm	AIS ≥ 1	0.0053	≥61 cm	AIS ≥ 1	0.0003	≥46 cm	AIS ≥ 2	0.0049	≥61 cm	AIS ≥ 1	0.0472
≥46 cm	AIS ≥ 2	0.0037	≥61 cm	AIS ≥ 2	0.0004	≥46 cm	AIS ≥ 3	0.0485			
≥46 cm	AIS ≥ 3	0.0286				≥61 cm	AIS ≥ 1	0.0079			
≥61 cm	AIS ≥ 1	0.0001									
≥61 cm	AIS ≥ 2	0.0001									

Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

8. *Analysis of Moderate to Maximum Injuries*

Based on the significance tests, it was concluded that injuries of severity (AIS) 2 and greater merited further study. This is also consistent with the spirit of the NCHRP's "serious injury" stipulation, as applied to lower limb injuries. It should be noted that the roadside safety community also contemplates the traditional AIS definition when defining serious injury resulting from occupant compartment deformation pursuant to a guardrail intrusion. For this reason, both definitions are presented in this section. In Section 11, Subsection C, injury concentrations were evident in the band of occupants sustaining AIS 2 injuries. This is consistent with lower limb injuries and dictated by their prevalence in this crash type. Further, occupant compartment intrusion magnitudes 8 through 29 centimeters posed greatest AIS 2 injury frequency. AIS 1 injury, as in all crash types with injured occupants, are the most prevalent (121,000) but nearly equivalent to the AIS 2 injuries (108,000.)

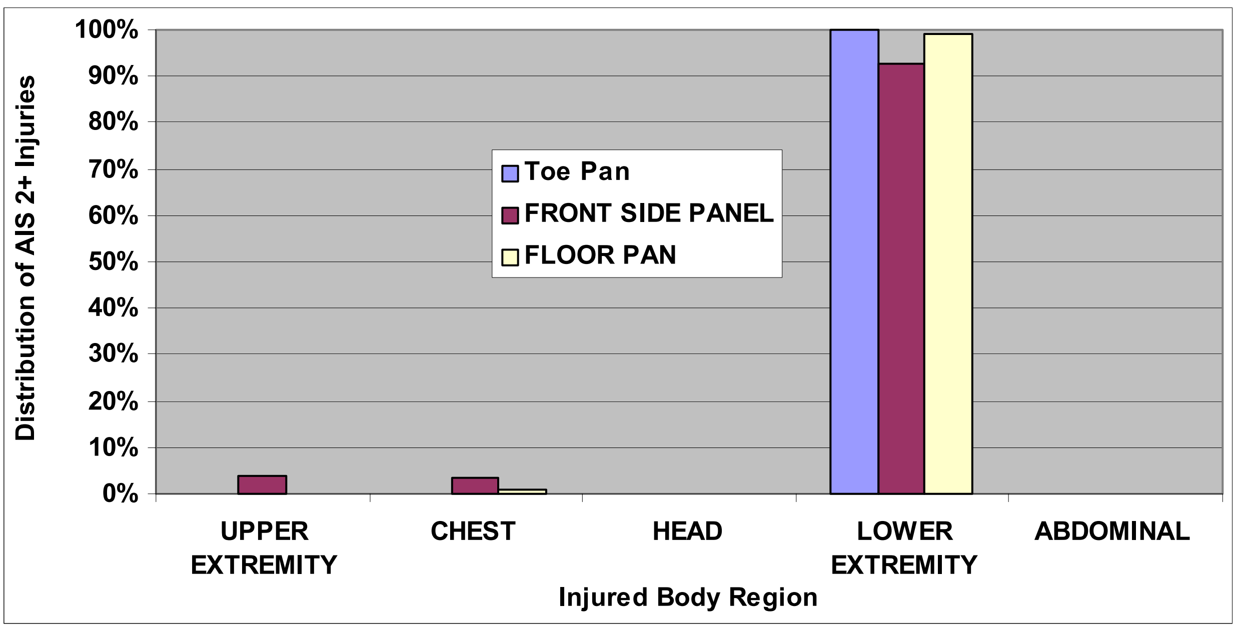
Tables 7 and 8 describe intrusion magnitude associated with nearside occupant injury distribution based on categories of object contacted and intruding component, for AIS 2+ and AIS 3+ severities. Figures 5 and 6 describe nearside occupant injury distribution, for AIS 2+ and AIS 3+ severities. The overwhelming representation of lower limb injury is of particular interest in each figure, as is its prevalence among the **relevant intrusion**. It should be noted that the extremely low frequencies might represent as few as one case indicating a potentially rare situation. (Please recall that CDS is a weighted sample of tow away crashes.)

Table 7: AIS 2+ Nearside Occupant Injuries by Object Contacted, Intruding Component and Injured Body Region

Non-Vehicle	UPPER EXTREMITY	CHEST	HEAD	LOWER EXTREMITY	ABDOMINAL
Toe Pan	0	0	0	48,166	48
Forward of A-Pillar	54	47	0	1,260	0
Floor Pan	0	55	0	8,200	0
Selected Intruding Components	54	102	0	57,626	48
Vehicle	**UPPER EXTREMITY**	**CHEST**	**HEAD**	**LOWER EXTREMITY**	**ABDOMINAL**
Toe Pan	66	0	16	50,057	0
Forward of A-Pillar	185	1,517	65	3,822	603
Floor Pan	0	0	0	8,358	0
Selected Intruding Components	251	1,517	81	62,237	603
Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000					

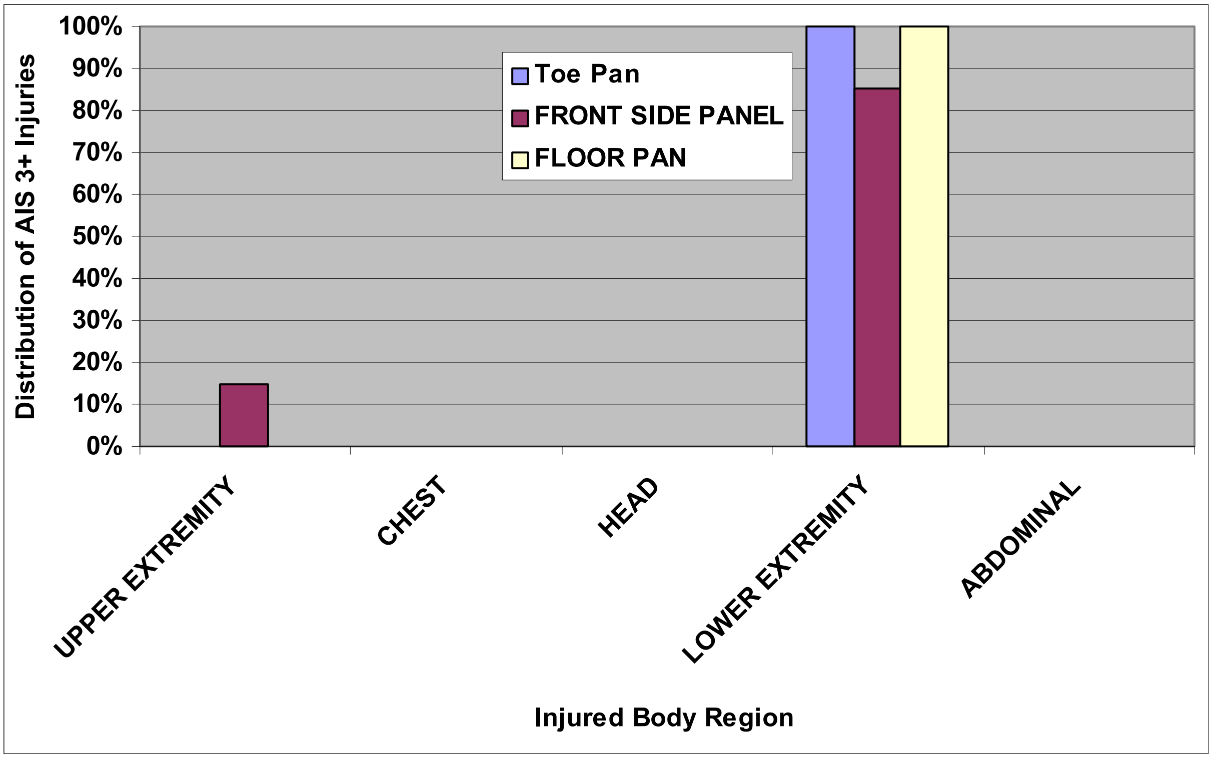
Table 8: AIS 3+ Nearside Occupant Injuries by Object Contacted, Intruding Component and Injured Body Region					
Non-Vehicle	**UPPER EXTREMITY**	**CHEST**	**HEAD**	**LOWER EXTREMITY**	**ABDOMINAL**
Toe Pan	0	0	0	4,266	0
Forward of A-Pillar	54	0	0	317	0
Floor Pan	0	0	0	676	0
Selected Intruding Components	54	0	0	5,259	0
Vehicle	**UPPER EXTREMITY**	**CHEST**	**HEAD**	**LOWER EXTREMITY**	**ABDOMINAL**
Toe Pan	66	0	16	7,350	0
Forward of A-Pillar	0	826	22	471	90
Floor Pan	0	0	0	425	0
Selected Intruding Components	66	826	38	8,246	90
Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000					

Figure 5: Distribution of AIS 2+ Nearside Occupant Injuries from Toe Pan, Floor Pan, and Forward of the A-Pillar Intrusion for Vehicles Striking a Fixed Object



Source: NCSA, NHTSA, NASS – CDS, 1991 - 2000

Figure 6: Distribution of AIS 3+ Nearside Occupant Injuries from Toe Pan, Floor Pan, and Forward of the A-Pillar Intrusion for Vehicles Striking a Fixed Object



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Based on Tables 7 and 8, it is evident that the lower limb is the most vulnerable. Nearly 100 percent of the AIS 2 through 6 injuries for occupants in vehicles with toe pan intrusion induced by a fixed object affects the lower limb. Intrusion from forward of the A-pillar inflicts injuries upon upper body regions, as well as lower extremities. The floor pan induces lower limb injury patterns similar to the other intruding components. The aggregate, **relevant intrusion** yields the same result with regard to the probability of injury.

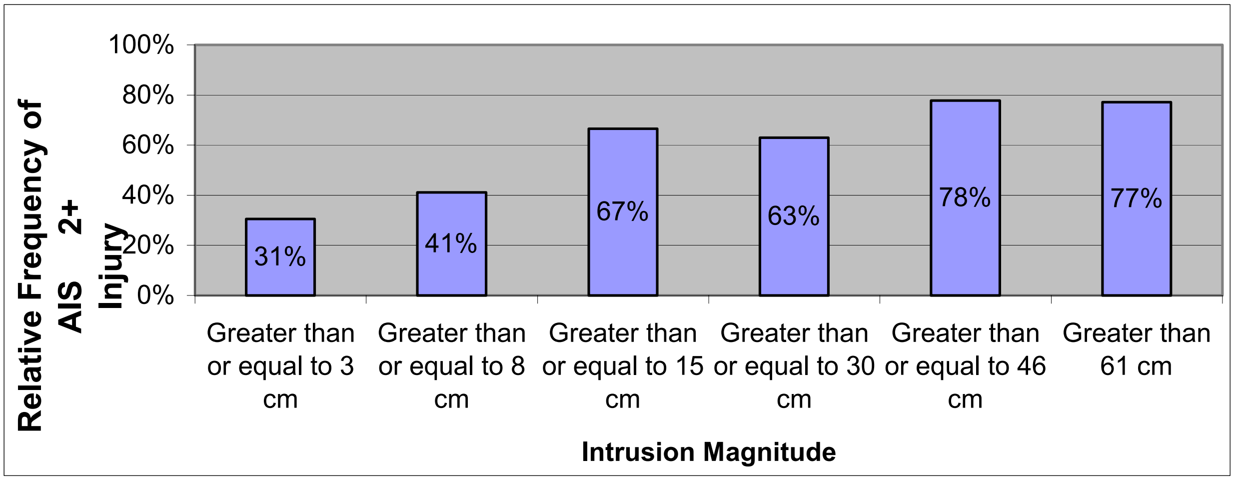
Vehicle-to-vehicle contacts are retained in view of their prevalence; however, the focus of this work has been the non-vehicle contact. It is surmised that non-vehicle intrusion more closely resembles the geometry of a guardrail as described in the previous section.

Results by Intruding Component

The intruding components were divided into toe pan and all components combined (**relevant intrusion.**) The toe pan was found to pose a greater risk of injury. A caveat must be issued with regard to several confounding factors. These factors may include but are not restricted to delta-v, crash conditions, and restraint use.

As expected, the risk of injuries of moderate severity and greater resulting from nearside toe pan intrusion increases as the intrusion magnitude increases, per Figure 7. The greater the deformation of the occupant compartment the more vulnerable the nearside occupant becomes. The percentages represent the likelihood that an AIS 2 through 6 injury will occur at each of the six intrusion magnitude levels. It should be noted that severe injuries, AIS 4, are the highest reported for the previously defined intrusion configurations. Since the lower injury severities are culpable for irreparable orthopedic damage, these injuries may be interpreted as life devastating, as opposed to life threatening.

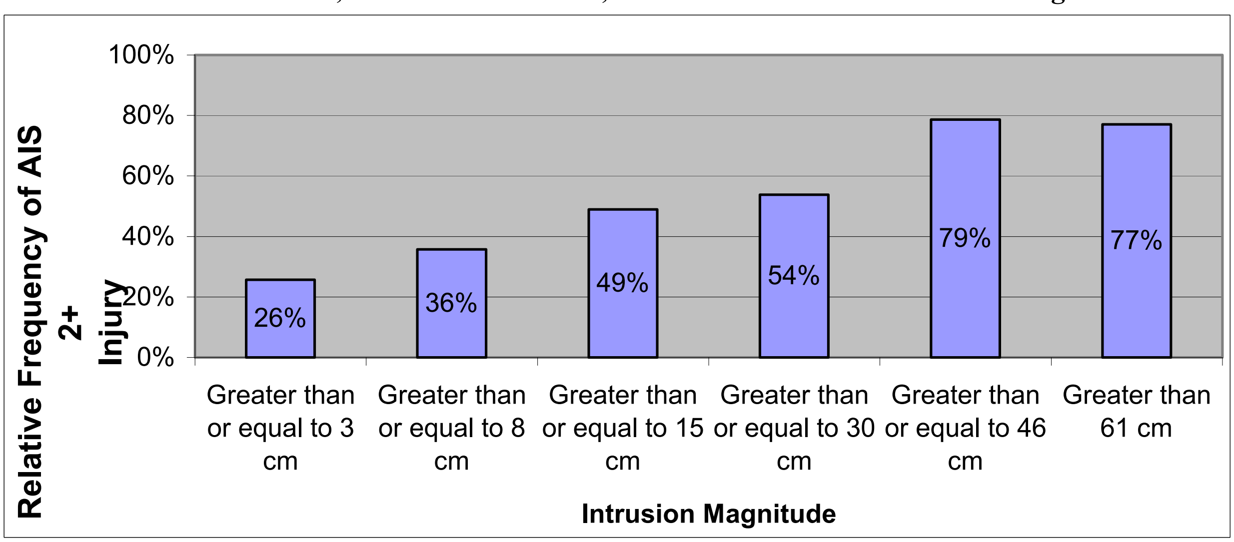
Figure 7: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 2 in Vehicles with Toe Pan Striking Vehicle



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Upon combining the **relevant intrusion** in Figure 8, the results are found to be consistent but not statistically significant. The p-values yielded from the Chi-Square testing were used to determine the lack of significance. Although, yielding values above the 0.05 confidence level, the patterns were seen to be consistent with those found in the toe pan only scenario. One possible explanation for the consistent results is that strengthening the guideline may benefit toe pan more than other components.

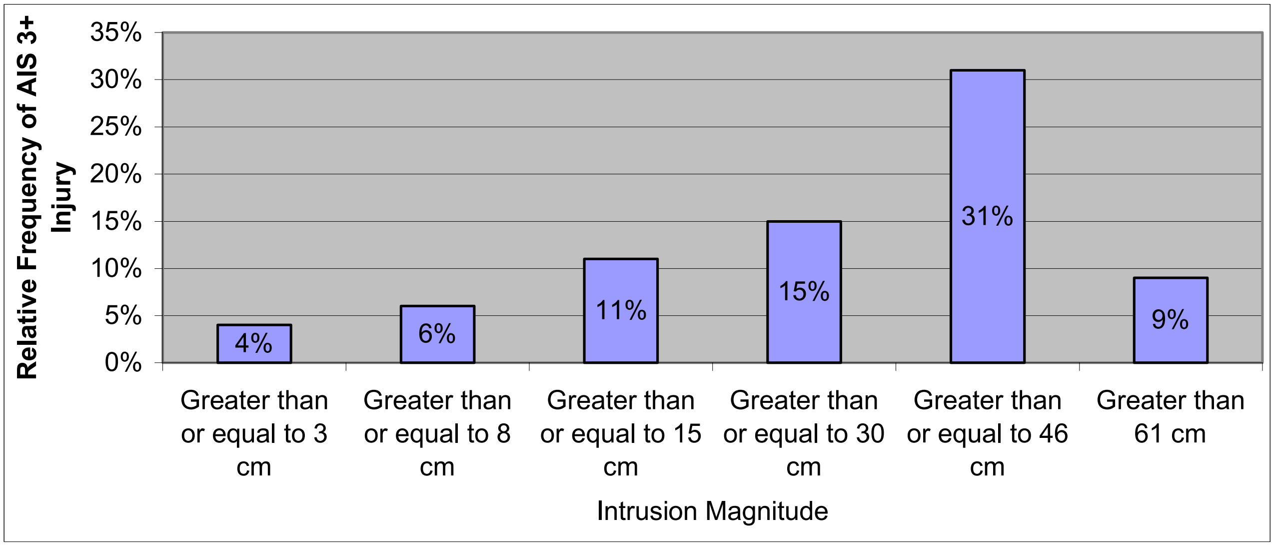
Figure 8: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 2 in Vehicles with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusion Striking Non-Vehicle



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

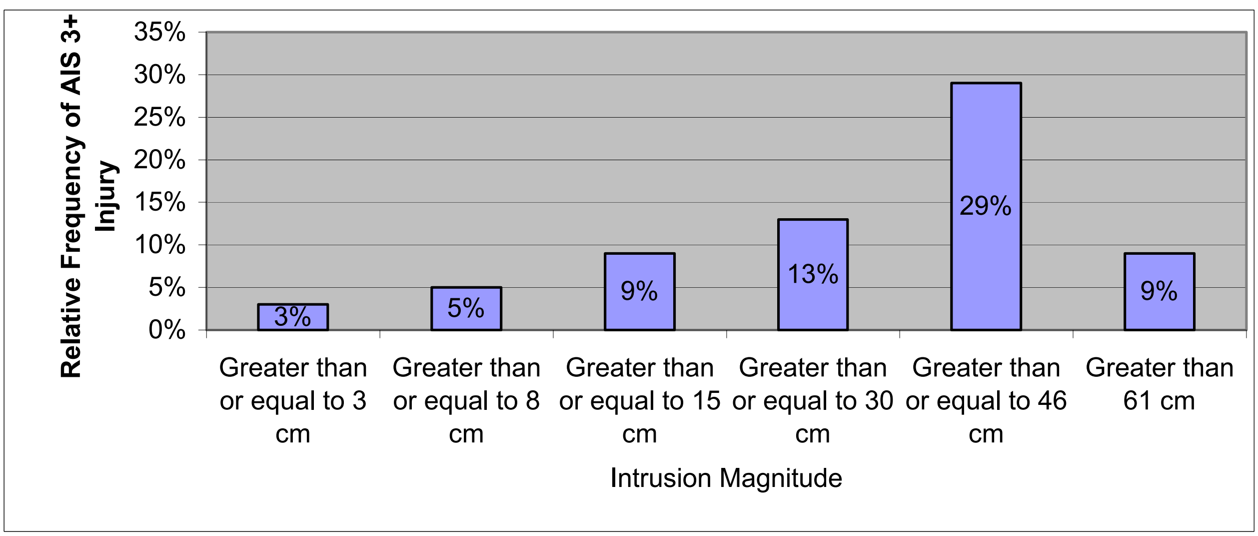
In comparison, note the percentages reported for AIS 3 and greater in Figures 9 and 10 are much smaller but increase, as would be expected, for increasing intrusion magnitudes. The standard errors for these calculations are exceedingly high unlike those for the AIS 2 and greater calculations. The relative frequencies are based on a very small sample size. Also, the y-axes of Figures 9 and 10 report a lower maximum value for the y-axis than do Figures 7 and 8. This was chosen to avoid obscuring the smaller relative frequencies. These findings are included to comply with a literal interpretation of injury severity based upon the guideline, as it corresponds to the AIS definition.

Figure 9: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 3 in Vehicles with Toe Pan Striking Vehicle



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

Figure 10: Relative Frequency of Nearside Occupant Injuries Greater than or Equal to AIS 3 in Vehicles with Toe Pan, Forward of A-Pillar, and/or Floor Pan Intrusion Striking Non-Vehicle



Source: NCSA, NHTSA, NASS – CDS, 1991 – 2000

9. *Summary of Results*

The data indicate that many moderate to maximum injuries occur at occupant compartment intrusions less than 15 centimeters, the current FHWA guideline. However, the analysis was performed without controlling for important variables, such as safety belt usage and age of injured occupant. In addition, the result was based on crashes into fixed objects and other vehicles, and so might not apply to roadside hardware, per se. This was based on ***relevant crashes*** that resulted in approximately 58,000 non-vehicle nearside occupant injuries and 62,000 vehicle nearside occupant injuries.

In addition, it was found that a predominance of injuries to the lower limb was evident. The data set was reflecting a succession of unlike events. Finally, a non-uniform vehicle fleet may alter the results, slightly.

The non-vehicle contacts represented contact with a disparate collection of objects. Hence, distinct behavior can be expected from the various contacting objects. The intrusion induced will also vary based upon the object.

Statistically significant relationships were found for non-minor injuries with occupant compartment intrusions of 8 to 15 centimeters. This suggested that there was an association between intrusions lower than the NCHRP testing protocol, as interpreted by FHWA, and injury. It was found that 26 percent of ***relevant crashes*** into roadside hardware had intrusion greater than or equal to 15 centimeters, 61 percent had intrusion greater than or equal to 8 centimeters, and 35 percent had intrusion 8 through 14 centimeters.

Vehicle Striking Vehicle

About half of the injuries are attributable to a vehicle striking another vehicle, a multi-vehicle crash (contact with non-parked vehicles.) Owing to the complexity of this crash configuration, many factors occur simultaneously thereby weakening the relationship of injury severity and intrusion magnitude. However, several unique events generally occur in this scenario. Finally, the many variations within the current fleet mix cause incompatibilities in the intrusion patterns.

Fixed Object Struck

As a result of the many different attributes described by the object contacted variable and the overwhelming representation of vehicle impacts, an analysis of similarly performing groups of objects was undertaken for all non-vehicle objects struck. This aggregation tends to yield a disparate collection of objects that behave in different fashions when struck and impart distinct intrusion and injury patterns.

The guideline (Powers, 2003) prevents many injuries, however, reducing the allowable intrusion in the guideline could prevent many more injuries. The injuries of severity (AIS) 2 and greater appear to be most related to intrusions. Injuries of AIS 3 and greater could potentially be more attributable to increasing delta-v. As expected the intrusion magnitude increased as the injury severity rose. (Please reference Section 11, Subsection C.)

10. Recommendations for Future Study

Based on the results, there may be several paths to improve the data set supporting any proposed guideline change. Possible solutions could include: examining more years in CDS, expanding search by generalizing scope to include GES, working with anecdotal data, controlling for vehicle body types, and/or examining all cases involving intrusion into the toe pan, floor pan, or forward of the A-Pillar.

Examine Several More Years of NASS - CDS

This approach would yield more data. It may also be more responsive to the current vehicle fleet mix. Additionally, more cases were reported in earlier years of CDS. Finally, more experience in user needs would be present.

These advantages are tempered by the fewer variables available to qualify a crash in earlier years. Technological advances allow for much better data quality and accuracy in later years of CDS owing to greater and more precise instrumentation.

Expand Search by Generalizing Scope to Include GES

The immediate benefit exists in the greater number of cases. The GES is a nationally representative sample of crashes occurring in the United States.

GES, although the repository for more cases, are less specific. Owing to the broader nature, vehicle inspections are absent thereby forfeiting any intrusion data. The non-medically assessed injury severity scale is based on the police officer's assessment of the occupant.

Work with Anecdotal Data

Although few cases exist in individual non-vehicular objects contacted, these could be viewed anecdotally to ascertain injury patterns and their related intrusions. These cases could stimulate research and study into related areas or establish surrogates that exhibit statistical significance.

Data of this sort would not merit statistical analysis. Additionally, there may be limited applicability for the anecdotal data.

Control for Vehicle Body Types

Controlling for vehicle body types would allow accurate conclusions and extrapolations to be made regarding the impacted vehicle based on the striking vehicle's geometry. The current form of the study aggregates all vehicles without regard for the body type of the striking or struck vehicles. It is proposed to aggregate corporate cousins (vehicle classified as geometrically similar although produced by different manufacturers) rather than by vehicle body type.

With the advent of smaller vehicles, the incompatibility is not only seen amongst the vehicle classes but with the protective roadside hardware. It is theorized that guardrails standards were designed to protect an older vehicle fleet that was different to the one active today. Further, some smaller vehicles may be exposed to damage, if softer structures, unintended structures are making contact with the guardrail. As a corollary, larger vehicles may not be afforded the intended protection and could even damage the roadside appurtenance, if an inappropriate vehicle structure makes contact with it. SUVs, for instance, may not be adequately protected. Further, the guardrail pursuant to an SUV impact may sustain damage. Via real-world crash outcomes and subsequently testing to generate simulations, it would be prudent to establish that the guardrail will not induce vehicle damage owing to possibly outdated design standards/parameters.

An overpowering disadvantage is the small data sets associated with each vehicle body type. Analysis may become inappropriate.

Examine All Toe Pan, Floor Pan, or Forward of the A-Pillar Cases

The intrusion to nearside occupant injury relationship can be further studied by controlling for key factors, such as age and safety belt use. Similar patterns have been established in the vehicle and fixed objects data subsets. It is, therefore, proposed that the vehicle and fixed objects subsets should be combined to obtain a sufficient sample for a controlled analysis.

A minor disadvantage exists in the loss of struck object definition, however, this is counteracted by the sample size benefits to be obtained.

11. *Appendix*

A. Data Sets

The following data sets were consulted in the preparation of this report. Although data found in the Fatality Analysis Reporting System and National Automotive Sampling System - General Estimates System were excluded from the analysis, the content was considered during the preparation of the preliminary phase and in subsequent recommendations.

National Automotive Sampling System

National Automotive Sampling System (NASS) case collection began in 1979. NASS is composed of two systems - the Crashworthiness Data System (CDS) and the General Estimates System (GES). Both systems are based on cases selected from a sample of police crash reports. CDS data focus on passenger vehicle crashes, and are used to investigate injury mechanisms to identify potential improvements in vehicle design. GES data focus on the bigger overall crash picture, and are used for problem size assessments and tracking trends. The system was established as part of an effort to reduce motor vehicle crashes, injuries, and deaths on our nation's highways. NASS enjoys a wide audience: government scientists, engineers, public health professionals, and university researchers.

NASS – GES

GES provides basic injury data based on a nationally representative probability sample of police-reported crashes. For a case to become eligible for GES, it must have a completed PAR, the crash must involve at least one motor vehicle traveling on a traffic way, and result in property damage, injury, or death. GES started sampling cases in 1988.

Data are reported in three files. These files are the Accident, Vehicle, and Person Files. The injury data are based on the injury severity scale with the categories including K (killed), A (incapacitating injury), B (non-incapacitating injury), C (possible injury), and O (no injury).

NASS - CDS

CDS yields a comprehensive description of the crash events based on the PAR. These cases are then investigated to obtain a complete file on the vehicles involved in the crash, the geometry of the crash location, the interaction of the vehicles with the geometry/location attributes, the demography of the passenger vehicle occupants, and the injury mechanisms/patterns, if any exist, for each of the occupants. With regard to this report, the strength of CDS lies in the injury severity ratings and the associated injury sources. The abbreviated injury scale (AIS) is used to assess risk of fatality. The AIS injury categories are defined as follows:

AIS 1 – Minor
AIS 2 – Moderate
AIS 3 – Serious
AIS 4 – Severe
AIS 5 – Critical
AIS 6 – Maximum (untreatable)

Currently, CDS integrates 11 files: Accident Description, Accident, Event, General Vehicle, Occupant Assessment, Occupant Injury, Person Profile, Accident Type, Vehicle Exterior, Vehicle Profile, Vehicle Interior. The Accident Description, Person Profile, Accident Type, and Vehicle Profile are text descriptions of the people, crash, and vehicles as summarized by the investigator. The Accident and Event files convey the most general crash elements such as roadway geometry, crash type, numbers of vehicles and occupants, offending roadside elements, and general vehicle classifications. The General Vehicle, Vehicle Exterior, and Vehicle Interior files convey vehicle related attributes of the crash. The Occupant Assessment and Occupant Injury files compile the crash demography placing the occupant in the vehicle and associating him with crash attributes and injury mechanisms.

The elements used for the study were taken from the Occupant Assessment and Occupant Injury files. These files indicated the age, seating position, injury level and injury type for each occupant within the struck vehicle. These elements were then merged with the Vehicle Interior file to retain only nearside occupant injuries associated with **relevant intrusion**.

B. Selected CDS Definitions

The following variables were used in part or unrestricted for the intrusion analysis. The entire description is retained to elucidate the finer points of the query. Object contacted, vehicle body type, injury severity, and injured body region variables were each compacted to capture a greater number of cases and to ease statistical analysis. The following definitions are taken from the CDS format files.

Object Contacted

```
VALUE  OBJCONT

      . = 'NO EVENT/CDC'
     01 = 'VEHICLE NO.  1'          02 = 'VEHICLE NO.  2'
     03 = 'VEHICLE NO.  3'          04 = 'VEHICLE NO.  4'
     05 = 'VEHICLE NO.  5'          06 = 'VEHICLE NO.  6'
     07 = 'VEHICLE NO.  7'          08 = 'VEHICLE NO.  8'
     09 = 'VEHICLE NO.  9'          10 = 'VEHICLE NO. 10'
     11 = 'VEHICLE NO. 11'
     31 = 'ROLLOVER-OVERTRN'        56 = 'OTHER BARRIER'
     32 = 'ROLLOVER-ENDOVER'
     33 = 'FIRE/EXPLOSION'          57 = 'FENCE'
     34 = 'JACKKNIFE'               58 = 'WALL'
     35 = 'INTRAUNIT DAMAGE'        59 = 'BUILDING'
     36 = 'NONCOLLISION INJ'        60 = 'DITCH/CULVERT'
     38 = 'OTH NONCOLLISION'        61 = 'GROUND'
     39 = 'UNK NONCOLLISION'        62 = 'FIRE HYDRANT'
                                    63 = 'CURB'
                                    64 = 'BRIDGE'
                                    68 = 'OTH FIXED OBJECT'
     41 = 'SMALL TREE'
                                    69 = 'UNK FIXED OBJECT'
     42 = 'LARGE TREE'              70 = 'NOT IN TRAN LGTVEH'
     43 = 'BUSH'                    71 = 'NOT IN TRAN HVYVEH'
     44 = 'EMBANKMENT'
                                    72 = 'PEDESTRIAN'
     45 = 'BREAKAWAY POLE'          73 = 'CYCLIST'
                                    74 = 'OTH NONMOTORIST'
                                    75 = 'VEHICLE OCCUPANT'
     50 = 'SMALL POLE'              76 = 'ANIMAL'
                                    77 = 'TRAIN'
     51 = 'MEDIUM POLE'             78 = 'TRAILER, DISCONN'
                                    79 = 'OBJ FELL FRM VEH'
     52 = 'LARGE POLE'              88 = 'OTH NONFIXED OBJ'
                                    89 = 'UNK NONFIXED OBJ'
     53 = 'UNK SIZE POLE'
                                    98 = 'OTHER EVENT'
     54 = 'CONCRETE BARRIER'        55 = 'IMPACT ATENUATOR'
     .U = 'UNK EVENT/OBJECT';
```

Vehicle Body Type

```
BODYTYPE

    01 = 'CONVERTIBLE'
    02 = '2DR SEDAN/HT/CPE'
    03 = '3DR/2DR HATCHBAK'
    04 = '4-DR SEDAN/HDTOP'
    05 = '5DR/4DR HATCHBAK'
    06 = 'STATION WAGON'
    07 = 'HATCHBACK DR UNK'
    08 = 'OTHER AUTOMOBILE'
    09 = 'UNK AUTO TYPE'
    10 = 'AUTO BASE PICKUP'
    11 = 'AUTO BASED PANEL'
    12 = 'LARGE LIMOUSINE'
    13 = 'THREE-WHEEL AUTO'
    14 = 'COMPACT UTILITY'
    15 = 'LARGE UTILITY'
    16 = 'UTILITY STAWAGON'
    19 = 'UTILITY UNK BODY'
    20 = 'MINIVAN'
    21 = 'LARGE VAN'
    22 = 'STEP VAN <10K LB'
    23 = 'VAN BASE MTRHOME'
    24 = 'VAN BASED SCHBUS'
    25 = 'VAN BASED OTHBUS'
    28 = 'OTHER VAN TYPE'
    29 = 'UNKNOWN VAN TYPE'
    30 = 'COMPACT PICKUP'
    31 = 'LARGE PICKUP'
    32 = 'PICKUP/CAMPER'
    33 = 'CONVERT PICKUP'
    39 = 'UNK PICKUP TRUCK'
    40 = 'CAB CHASSIS'
    41 = 'TRUCK BASE PANEL'
    42 = 'LT TRK MOTORHOME'
    45 = 'OTH LIGHT TRUCK'
    48 = 'UNK LIGHT TRUCK'
    49 = 'UNK LIGHT VEH'
    50 = 'SCHOOL BUS'
    58 = 'OTHER BUS'
    59 = 'UNKNOWN BUS'
    60 = 'STEP VAN >10K LB'
    61 = 'SU TRUCK 10-19.5'
    62 = 'SU TRUCK 19.5-26'
    63 = 'SU TRUCK >26K LB'
    64 = 'SU TRUCK GVW UNK'
    65 = 'MH TRK MOTORHOME'
    67 = 'BOBTAIL TRACTOR'
    68 = 'TRK-TRAC 1 TRAIL'
    69 = 'TRK-TRAC 2 TRAIL'
    70 = 'TRK-TR UNK TRAIL'
    78 = 'UNK MED/HVY TRK'
    79 = 'UNKNOWN TRUCK'
    80 = 'MOTORCYCLE'
    81 = 'MOPED'
    82 = '3 WHEEL MC/MOPED'
    88 = 'OTH MOTORED CYCL'
    89 = 'UNK MOTORED CYCL'
    90 = 'ATV AND ATC'
    91 = 'SNOWMOBILE'
    92 = 'FARM EQUIPMENT'
    93 = 'CONSTRUCT EQUIP'
    97 = 'OTHER VEHICLE TYPE'
```

```
    98 = 'NOT APPLICABLE'
    .N = 'NOT COLLECTED'
    .U = 'UNKNOWN BODY TYPE';
```

Seating Position

```
VALUE  SEATPOS

     11 = 'FRONT LEFT SIDE'
     12 = 'FRONT MIDDLE'
     13 = 'FRONT RIGHT SIDE'
     14 = 'FRONT OTHER'
     15 = 'FRONT ON/IN LAP'

     21 = 'SECOND LEFT'
     22 = 'SECOND MIDDLE'
     23 = 'SECOND RIGHT'
     24 = 'SECOND OTHER'
     25 = 'SECOND ON/IN LAP'

     31 = 'THIRD LEFT'
     32 = 'THIRD MIDDLE'
     33 = 'THIRD RIGHT'
     34 = 'THIRD OTHER'
     35 = 'THIRD ON/IN LAP'

     41 = 'FOURTH LEFT'
     42 = 'FOURTH MIDDLE'
     43 = 'FOURTH RIGHT'
     44 = 'FOURTH OTHER'
     45 = 'FOURTH ON/IN LAP'

     97 = 'UNENCLOSED AREA'
     98 = 'OTHER SEAT'
     .U = 'UNKNOWN';
```

Intrusion Location

```
VALUE  INLOC

     11 = 'FRONT LEFT'
     12 = 'FRONT MIDDLE'
     13 = 'FRONT RIGHT'
     21 = 'SECOND LEFT'
     22 = 'SECOND MIDDLE'
     23 = 'SECOND RIGHT'
     31 = 'THIRD LEFT'
     32 = 'THIRD MIDDLE'
     33 = 'THIRD RIGHT'
     41 = 'FOURTH LEFT'
     42 = 'FOURTH MIDDLE'
     43 = 'FOURTH RIGHT'
     97 = 'CATASTROPHIC'
     98 = 'OTH ENCLOSE AREA'
     .U = 'UNKNOWN';
```

Intruding Component

```
VALUE  INCOMP

     01 = 'STEER ASSEMBLY'
     02 = 'INSTR PANEL LEFT'
     03 = 'INSTR PANEL CTR'
     04 = 'INSTR PANEL RT'
     05 = 'TOE PAN'
     06 = 'A-PILLAR'
     07 = 'B-PILLAR'
     08 = 'C-PILLAR'
     09 = 'D-PILLAR'
     10 = 'FRONT SIDE PANEL'
     11 = 'DOOR PANEL'
     12 = 'REAR SIDE PANEL'
     13 = 'ROOF/CONVERT TOP'
     14 = 'ROOF SIDE RAIL'
     15 = 'WINDSHIELD'
     16 = 'WINDSHIELD HDR'
     17 = 'WINDOW FRAME'
     18 = 'FLOOR PAN'
     19 = 'BACKLIGHT HEADER'
     20 = 'FRONT SEAT BACK'
     21 = 'SECOND SEAT BACK'
     22 = 'THIRD SEAT BACK'
     23 = 'FOURTH SEAT BACK'
     24 = 'FIFTH SEAT BACK'
     25 = 'SEAT CUSHION'
     26 = 'BACK DOOR/PANEL'
     27 = 'OTHER COMPONENT'
     30 = 'HOOD'
     31 = 'OUTSIDE SURFACE'
     32 = 'OTH EXTERIOR OBJ'
     33 = 'UNK EXTERIOR OBJ'
     97 = 'CATASTROPHIC'
     98 = 'UNLIST COMPONENT'
     .U = 'UNKNOWN';
```

Intruding Magnitude

```
VALUE  INMAG

     1 = '3-7 CENTIMETERS'
     2 = '8-14 CENTIMETERS'
     3 = '15-29 CENTIMETER'
     4 = '30-45 CENTIMETER'
     5 = '46-60 CENTIMETER'
     6 = '61 OR MORE CM'
     7 = 'CATASTROPHIC'
    .U = 'UNKNOWN';
```

Dominant Crush Direction

```
VALUE  CDRIR

     1 = 'VERTICAL'
     2 = 'LONGITUDINAL'
     3 = 'LATERAL'
     7 = 'CATASTROPHIC'
    .U = 'UNKNOWN';
```

Injury Severity Scales

```
VALUE  INJSEV

    0 = 'O  NO INJURY'
    1 = 'C  POSSIBLE INJ'
    2 = 'B  NONINCAPAC'
    3 = 'A  INCAPACITATING'
    4 = 'K  KILLED'
    5 = 'U  SEVERITY UNK'
    6 = 'DIED PRIOR'
   .U = 'UNKNOWN';

VALUE  AIS

     0 = 'NOT INJURED'
     1 = 'MINOR INJURY'
     2 = 'MODERATE INJURY'
     3 = 'SERIOUS INJURY'
     4 = 'SEVERE INJURY'
     5 = 'CRITICAL INJURY'
     6 = 'MAXIMUM INJURY'
     7 = 'INJURED, UNK SEV'
    .N = 'NOT COLLECTED'
    .U = 'UNK IF INJURED';
```

Injured Body Region

```
VALUE $BDYREGN

    'A' = 'ARM'
    'B' = 'BACK'
    'C' = 'CHEST'
    'E' = 'ELBOW'
    'F' = 'FACE'
    'H' = 'HEAD'
    'K' = 'KNEE'
    'L' = 'LEG/LOWER'
    'M' = 'ABDOMEN'
    'N' = 'NECK'
    'P' = 'PELVIC/HIP'
    'Q' = 'ANKLE/FOOT'
    'R' = 'FOREARM'
    'S' = 'SHOULDER'
    'T' = 'THIGH'
    'U' = 'INJURED/UNK REG'
    'W' = 'WRIST/HAND'
    'X' = 'UPPER LIMBS'
    'Y' = 'LOWER LIMBS';
```

C. Number of Nearside Occupant, Age 13 Years and Older, Injuries that were Associated with a Relevant Intrusion

Table 9: Intrusion into Occupant Compartment by Intruding Component, AIS 1
Controlling for AIS=1

Intrusion into Occupant Compartment	Intruding Component			Total
	TOE PAN	FRONT SIDE PANEL	FLOOR PAN	
3-7 CENTIMETERS	23,469	3,004	1,390	27,863
8-14 CENTIMETERS	28,438	5,907	2,258	36,603
15-29 CENTIMETER	25,085	5,197	5,552	35,834
30-45 CENTIMETER	6,796	3,453	2,509	12,758
46-60 CENTIMETER	3,902	534	644	5,079
61 OR MORE CM	2,413	0	405	2,818
Total	90,102	18,094	12,758	120,954

Table 10: Intrusion into Occupant Compartment by Intruding Component, AIS 2				
Controlling for AIS=2				
Intrusion into Occupant Compartment	Intruding Component			Total
	TOE PAN	FRONT SIDE PANEL	FLOOR PAN	
3-7 CENTIMETERS	16,782	415	1,290	18,487
8-14 CENTIMETERS	18,792	214	7,575	26,581
15-29 CENTIMETER	29,251	4,072	3,975	37,298
30-45 CENTIMETER	10,548	781	509	11,837
46-60 CENTIMETER	6,541	282	1,158	7,981
61 OR MORE CM	4,741	10	1,005	5,756
Total	86,655	5,773	15,512	107,940

Table 11: Intrusion into Occupant Compartment by Intruding Component, AIS 3				
Controlling for AIS=3				
Intrusion into Occupant Compartment	Intruding Component			Total
	TOE PAN	FRONT SIDE PANEL	FLOOR PAN	
3-7 CENTIMETERS	1,025	162	106	1,293
8-14 CENTIMETERS	1,338	32	85	1,454
15-29 CENTIMETER	4,153	921	550	5,624
30-45 CENTIMETER	1,712	309	70	2,092
46-60 CENTIMETER	2,876	141	232	3,249
61 OR MORE CM	594	10	58	662
Total	11,699	1,573	1,101	14,373

Table 12: Intrusion into Occupant Compartment by Intruding Component, AIS 4				
Controlling for AIS=4				
Intrusion into Occupant Compartment	Intruding Component			Total
	TOE PAN	FRONT SIDE PANEL	FLOOR PAN	
3-7 CENTIMETERS	0	127	0	127
8-14 CENTIMETERS	0	20	0	20
15-29 CENTIMETER	0	0	0	0
30-45 CENTIMETER	0	60	0	60
46-60 CENTIMETER	0	0	0	0
61 OR MORE CM	0	0	0	0
Total	0	206	0	206

D. Relevant Intrusions Resulting from Impact with Other Vehicle

Table 13: Relative Frequency of Bifurcated Nearside Occupant Injury Levels Occurring at Bifurcated Intrusion Levels in Crashes with Impacts with Other Vehicles Inducing Toe Pan, Floor Pan, and/or Forward of the A-Pillar Damage

Intrusions in Toe Pan, Floor Pan, or A-Pillar by Contact with Another Vehicle			Intrusions in Toe Pan by Contact with Another Vehicle		
Intrusion	Injury	Relative Frequency of Injury Level at Intrusion Level	Intrusion	Injury	Relative Frequency of Injury Level at Intrusion Level
≥ 3 cm	AIS ≥ 1	33.65 %	≥ 3 cm	AIS ≥ 1	52.46 %
≥ 3 cm	AIS ≥ 2	16.74 %	≥ 3 cm	AIS ≥ 2	28.37 %
≥ 3 cm	AIS ≥ 3	3.11 %	≥ 3 cm	AIS ≥ 4	0.00 %
≥ 3 cm	AIS ≥ 4	0.07 %	≥ 8 cm	AIS ≥ 1	64.49 %
≥ 8 cm	AIS ≥ 1	43.65 %	≥ 8 cm	AIS ≥ 2	33.72 %
≥ 8 cm	AIS ≥ 2	21.29 %	≥ 8 cm	AIS ≥ 3	6.96 %
≥ 8 cm	AIS ≥ 3	4.42 %	≥ 8 cm	AIS ≥ 4	0.00 %
≥ 8 cm	AIS ≥ 4	0.05 %	≥ 15 cm	AIS ≥ 1	93.07 %
≥ 15 cm	AIS ≥ 1	66.00 %	≥ 15 cm	AIS ≥ 2	61.50 %
≥ 15 cm	AIS ≥ 2	42.03 %	≥ 15 cm	AIS ≥ 3	14.67 %
≥ 15 cm	AIS ≥ 3	10.41 %	≥ 15 cm	AIS ≥ 4	0.00 %
≥ 15 cm	AIS ≥ 4	0.12 %	≥ 30 cm	AIS ≥ 1	100.00 %
≥ 30 cm	AIS ≥ 1	82.44 %	≥ 30 cm	AIS ≥ 2	89.12 %
≥ 30 cm	AIS ≥ 2	65.44 %	≥ 30 cm	AIS ≥ 3	19.90 %
≥ 30 cm	AIS ≥ 3	15.91 %	≥ 30 cm	AIS ≥ 4	0.00 %
≥ 30 cm	AIS ≥ 4	0.43 %	≥ 46 cm	AIS ≥ 1	100.00 %
≥ 46 cm	AIS ≥ 1	99.33 %	≥ 46 cm	AIS ≥ 2	88.14 %
≥ 46 cm	AIS ≥ 2	77.98 %	≥ 46 cm	AIS ≥ 3	19.76 %
≥ 46 cm	AIS ≥ 3	19.57 %	≥ 46 cm	AIS ≥ 4	0.00 %
≥ 46 cm	AIS ≥ 4	0.00 %	≥ 61 cm	AIS ≥ 1	100.00 %
≥ 61 cm	AIS ≥ 1	100.00 %	≥ 61 cm	AIS ≥ 2	98.18 %
≥ 61 cm	AIS ≥ 2	98.32 %	≥ 61 cm	AIS ≥ 3	18.71 %
≥ 61 cm	AIS ≥ 3	17.29 %	≥ 61 cm	AIS ≥ 4	0.00 %
≥ 61 cm	AIS ≥ 4	0.00 %			

E. *Relevant crashes*

Table 14: Relative Frequency of Bifurcated Nearside Occupant Injury Levels Occurring at Bifurcated Intrusion Levels in Crashes with Impacts with Non-Vehicles (Fixed Objects) Inducing Toe Pan, Floor Pan, and/or Forward of the A-Pillar Damage					
Intrusions in Toe Pan, Floor Pan, or A-Pillar by Contact with a Non-Vehicle (Fixed Object)			Intrusions in Toe Pan by Contact with a Non-Vehicle (Fixed Object)		
Intrusion	Injury	Relative Frequency of Injury Level at Intrusion Level	Intrusion	Injury	Relative Frequency of Injury Level at Intrusion Level
≥ 3 cm	AIS ≥ 1	52.73	≥ 3 cm	AIS ≥ 1	61.67
≥ 3 cm	AIS ≥ 2	25.69	≥ 3 cm	AIS ≥ 2	30.51
≥ 3 cm	AIS ≥ 3	3.46	≥ 3 cm	AIS ≥ 3	4.01
≥ 3 cm	AIS ≥ 4	0.00	≥ 3 cm	AIS ≥ 4	0.00
≥ 8 cm	AIS ≥ 1	62.19	≥ 8 cm	AIS ≥ 1	67.20
≥ 8 cm	AIS ≥ 2	35.68	≥ 8 cm	AIS ≥ 2	41.14
≥ 8 cm	AIS ≥ 3	5.41	≥ 8 cm	AIS ≥ 3	6.22
≥ 8 cm	AIS ≥ 4	0.00	≥ 8 cm	AIS ≥ 4	0.00
≥ 15 cm	AIS ≥ 1	83.07	≥ 15 cm	AIS ≥ 1	97.46
≥ 15 cm	AIS ≥ 2	48.96	≥ 15 cm	AIS ≥ 2	66.50
≥ 15 cm	AIS ≥ 3	8.54	≥ 15 cm	AIS ≥ 3	10.97
≥ 15 cm	AIS ≥ 4	0.00	≥ 15 cm	AIS ≥ 4	0.00
≥ 30 cm	AIS ≥ 1	90.86	≥ 30 cm	AIS ≥ 1	94.44
≥ 30 cm	AIS ≥ 2	53.82	≥ 30 cm	AIS ≥ 2	62.96
≥ 30 cm	AIS ≥ 3	13.18	≥ 30 cm	AIS ≥ 3	15.47
≥ 30 cm	AIS ≥ 4	0.00	≥ 30 cm	AIS ≥ 4	0.00
≥ 46 cm	AIS ≥ 1	100.00	≥ 46 cm	AIS ≥ 1	100.00
≥ 46 cm	AIS ≥ 2	78.61	≥ 46 cm	AIS ≥ 2	77.78
≥ 46 cm	AIS ≥ 3	28.79	≥ 46 cm	AIS ≥ 3	31.12
≥ 46 cm	AIS ≥ 4	0.00	≥ 46 cm	AIS ≥ 4	0.00
≥ 61 cm	AIS ≥ 1	100.00	≥ 61 cm	AIS ≥ 1	100.00
≥ 61 cm	AIS ≥ 2	77.09	≥ 61 cm	AIS ≥ 2	77.12
≥ 61 cm	AIS ≥ 3	9.17	≥ 61 cm	AIS ≥ 3	8.84
≥ 61 cm	AIS ≥ 4	0.00	≥ 61 cm	AIS ≥ 4	0.00

12. References

Eskandarian, A., Bahouth, G., Digges, K., Eigen, A., Bronstad, M., "NCHRP Project 22-15: Summary of Phase I Research and Revised Work Plan, Improving the Compatibility of Vehicles and Roadside Safety Hardware," National Cooperative Highway Research Program, Transportation Research Board, January, 2001.

Powers, Richard, "Draft Guidelines For Analysis of Passenger Compartment Intrusion," Federal Highway Administration, Washington, D.C., 2003.

Ross Jr., H. E., Sicking, D. L., Zimmer, R. A., and Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features", NCHRP Report 350," Transportation Research Board, Washington, D.C., 1993.

United States Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, "Crashworthiness Data System 2000 Coding and Editing Manual," Washington, D.C., February, 2000.

United States Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, National Automotive Sampling System – Crashworthiness Data System, Washington, D.C., 1979 – 2000.

United States Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, "1995 – 1997 National Automotive Sampling System Crashworthiness Data System," Washington, D.C., 2001.