DRAFT REPORT

IDENTIFICATION OF VEHICULAR IMPACT CONDITIONS ASSOCIATED WITH SERIOUS RAN-OFF-ROAD CRASHES

NCHRP Project 17-22

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1 INTRODUCTION

1.1 Background

Single-vehicle, ran-off-road crashes are a major cause of serious injuries and fatalities along our nation's highways. Approximately 12,000 motorists lose their lives each year as a result of these crashes. Most of the efforts to reduce this carnage have been focused on designing more forgiving roadsides by removing or relocating hazards and designing better safety features to mitigate the severity of those hazards that cannot be removed or relocated. The fact that the total number of single-vehicle, ran-off-road crashes has remained relatively stable and even declined in recent years while the number of vehicle miles traveled has increased steadily indicates that these efforts have been successful.

The safety performance of roadside features is evaluated primarily through full-scale crash testing. The purpose of this testing is to observe and evaluate the performance of safety features under impact conditions that are either similar or more severe than those associated with real-world crashes resulting in serious injuries and fatalities. Important crash test parameters, such as impact speed and angle, point of impact, and vehicle orientation have been selected based on findings from limited studies of ran-off-road accidents (1, 2, 3). Although full-scale crash test data provides a small window into the nature of ran-off-road crashes, it does not provide sufficient data to identify the impact conditions associated with serious injury and fatal crashes. The research program described herein is undertaken primarily to identify appropriate impact conditions for use in full-scale crash testing guidelines.

However, knowledge of the characteristics of ran-off-road crashes has many more applications than just selecting impact conditions for full-scale crash testing guidelines. Many of the decisions related to design guidelines and policies could benefit significantly by better information on the impact conditions of ran-off-road crashes. For example, while the concept of multiple performance levels is embraced by the roadside safety community, highway designers are having difficulty determining when and where to use various roadside safety devices. The multiple-performance-level concept involves selecting a roadside safety feature to match the range of expected impact conditions in the area where it is to be installed. Under this design philosophy, roadside safety features are developed to meet one of several different performance levels or impact capacities. Lower capacity - and presumably less costly - safety devices are installed at sites where the risks of high-energy impacts are lower. Although the multiple-performance-level concept has been largely embraced by the roadside safety community, a significant amount of uncertainty remains regarding how performance levels should be defined and where the various performance level designs should be installed. Detailed data on ran-off-road crashes could provide a sound basis for determining appropriate performance levels for different classes of highway included in the study.

Safety performance evaluation criteria, such as occupant impact velocity (OIV) and ridedown acceleration (RA), are used as surrogate measures of the risk of injury for vehicle occupants during full-scale crash tests. OIV is a theoretical estimate of the speed at which the head of an unbelted occupant would strike the dash board. RA is calculated as the maximum 10 ms average vehicle acceleration measured after occupant impact occurs. These measures are intended as indicators of the risk that an occupant will be seriously injured during an impact with a roadside safety device. Unfortunately, these measures of occupant risk have never been successfully linked to actual injuries. The difficulty associated with establishing this link is the lack of available data where both the actual injuries and occupant risk measures can be determined. Detailed accident investigations that provide calculations of the occupant risk parameters and include crash injury information should provide the basis for determining the merits of the current safety performance evaluation procedures.

Another measure of occupant risk includes occupant compartment deformation and intrusion. NCHRP Report 350 (4) requires that "Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted." This requirement is relatively subjective and has been interpreted differently by the various crash testing agencies. The requirements are quantified under MASH (5) based on limited NASS data and engineering judgment. Nevertheless, a database with detailed information on ran-off-road crashes would provide the needed data to develop a link between the location and magnitude of vehicle intrusion and the severity of occupant injury. Any such link would provide an objective basis for establishing limits on occupant compartment deformation and intrusion.

Vehicle stability is also used as a measure of occupant risk. Although crash data clearly shows that the risk of injury increases when a vehicle rolls over, some engineers believe that the risk of injury for occupants of vehicles that only roll 90 degrees is relatively low. Unfortunately, no data is available that can be used to explore this possibility. If data on sufficiently large numbers of ran-off-road crashes are collected, it may be possible to test this hypothesis.

Guidelines on the selection and placement of roadside safety features can also benefit from a detailed crash study such as the one described herein. Most current guidelines are based on benefit/cost (B/C) analysis techniques and rely heavily on crash severity estimates. These crash severity estimates are based on both the estimated impact conditions, including speed, angle, and vehicle orientation at impact, as well as the severity resulting from any given impact condition. Data collected in this study would be extremely valuable if collected in a sufficiently representative manner to allow an estimate of impact conditions associated with all ran-off-road crashes.

Furthermore, if data is collected in a representative manner, detailed crash reconstructions could also provide a wealth of crash severity data with which to validate procedures for relating impact conditions to occupant risk.

Placement guidelines provide procedures for selecting and designing safety features to accommodate the characteristics of specific sites. For example, guardrail installation guidelines recommend procedures for calculating length-of-need and flare configurations based on the characteristics of the specific site where the barrier is to be located. Many facets of safety hardware installation guidelines are based on the expected vehicle trajectories and impact conditions at the given site. For example, procedures for selecting guardrail runout lengths included in the Roadside Design Guide (RDG) (6) are based on vehicle trajectories measured in a study of encroachments into the medians of divided highways during the 1960's (7). Vehicle trajectory data collected in the current study should provide a significant source of additional data regarding such information as the trajectories and the distances vehicles travel along the roadside during a crash. Guardrail placement guidelines also make recommendations regarding maximum flare rates. Increasing the flare rate raises the vehicle impact angles and thereby increases crash severity. Detailed crash data, coupled with injury severity information, should shed some light on this relationship and thereby provide a better foundation for making recommendations on maximum flare rate.

Finally, guidelines on grading requirements are provided for guardrail terminals and crash cushions, including limits on slopes in front of and behind these systems. These guidelines are based mostly on data from limited full-scale crash tests without information from real-world crashes. Also, the RDG provides guidelines as to roadside slopes that merit guardrail protection. Again, these guidelines are based on limited testing and simulation. Detailed data on roadside topography for ran-off-road crashes would provide additional insight into the currently accepted guidelines.

1.2 Objective

The specific objectives for this study included:

1. Identify the vehicle types, impact conditions, and site characteristics associated with serious injury and fatal crashes involving roadside features and safety devices
2. Create a robust relational database for future research, and
3. Develop an implementation plan for a long-term data collection effort.

The first objective pertains to the collection of detailed information on serious injury and fatal crashes involving roadside features and safety devices. The data was then analyzed to identify the vehicle types, impact conditions, and site characteristics associated with these crashes.

The second objective was to create a relational database suitable for future research. The database consists of crash data from prior and current studies with in-depth crash data as well as future data collection efforts.

The third objective was to develop an implementation plan for a long-term data collection effort on detailed data for ran-off-road crashes. As discussed previously, there are many additional applications for such detailed crash data beyond the current study, from performance evaluation of selected roadside safety features and devices to the formulation of policies regarding roadside safety. Thus, a long-term continuing effort to collect detailed data on ran-off-road crashes would be highly desirable.

1.3 Scope

The scope of work for this study was specifically formulated to address the three objectives and consisted of the following major tasks:

1. Identify the data needs for addressing the specific objectives of this study. A literature review was conducted on previous studies involving: in-depth crash data

collection, impact conditions of ran-off-road crashes, data needs for study of ran-off-road crashes, and reconstruction of ran-off-road crashes.

2. Develop a work plan to collect the needed data. Various data collection alternatives were evaluated and a retrospective supplemental data collection approach was selected for use with the current study. An appropriate data collection protocol was developed, including the sampling plan, data collection forms and field procedures, as well as manual review and reconstruction procedures.
3. Conduct a retrospective supplemental data collection effort of approximately 400 crashes selected from the 2000 and 2001 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) data. Supplemental field data were collected to gather additional information about the crash sites and roadside features. In addition, these crashes were reconstructed to estimate the impact conditions, including speed, angle and vehicle orientation.
4. Develop a relational database suitable for future research. The database was first developed with data from the current study. Similar data from previous studies, including NCHRP Project 17-11 and the Federal Highway Administration (FHWA) rollover study were then manually reviewed and reconstructed prior to incorporation into the database.
5. Analyze the database to address the specific objectives of this study, including identification of the vehicle types, impact conditions, and site characteristics associated with serious and fatal crashes.
6. Develop a proposed implementation plan for a long-term data collection effort. The implementation plan outlined a long-term effort to continue collecting detailed data

on representative ran-off-road crashes and the flexibility to conduct special studies on specific roadside safety features and devices. Data collection protocols for the continuous data collection and a selected special study were developed. Also, a pilot program was conducted to demonstrate the feasibility of the long-term data collection effort and to iron out the details and identify any potential problems.

1.4 Report Organization

This report summarizes the results of the work conducted under the study. Chapter 2 presents a summary of the literature review and other ongoing and future research and data collection efforts. Chapter 3 outlines the study approach, including data collection alternatives, data collection plan, and development of database. Results of the analyses are presented in Chapter 4. The proposed plan for a long-term data collection effort was outlined in Chapter 5. Finally, a summary of the study findings and conclusions are presented in Chapter 6. Some of the details too voluminous for the main body of the report are included as appendices. Appendix A presents the critical review of individual references. Appendix B summarized the results of the analysis of the 1997-2001 NASS CDS data, including the list of 2000 and 2001 cases to be sampled for supplemental field data collection. Appendix C outlines the protocol for the supplemental field data collection and manual review used for the current study. The details of database elements are shown in Appendix D. Additional tables, plots, and analysis results too voluminous for the main report are shown in Appendix E. Finally, the field data collection forms and the corresponding coding instructions and field procedures for the proposed long-term data collection effort are presented in Appendix F. Descriptions of the reconstruction procedures used to estimate impact speeds of the crashes are presented in Volume II of this report.

2 LITERATURE REVIEW

A detailed literature review was conducted to identify studies relevant to the identification of impact conditions for ran-off-road crashes. The review identified numerous studies pertaining to ran-off-road crashes that could have some bearing on this project. However, upon review, most of these studies utilized only police level crash data, which do not have the required details or information to assess the impact conditions of ran-off-road crashes. An annotated bibliography is shown as Appendix A and a summary of related ongoing research studies are presented in Appendix B. Only a summary of results of the literature review is presented in this chapter. The literature review is presented under four general headings:

1. In-depth crash data collection
2. Impact conditions of ran-off-road crashes
3. Data needs for study of ran-off-road crashes
4. Reconstruction of ran-off-road crashes

2.1 In-Depth Crash Data Collection

Crash data collection can be grouped into three general categories:

1. Police reported level
2. Enhanced police reported level
3. In-depth level

More detailed discussions on these three categories of crash data collection are presented in this section with examples. It should be noted, however, that these examples are intended as illustrations only and are by no means all inclusive. There have been so many studies using crash data over the years that it would not be feasible to include even a fraction of the studies in this review.

Police reported level is the most common type of crash data available. State and local police officers are required by law to investigate all reportable crashes and complete police accident reports on these crashes. The data are then coded and entered into state crash data files. Police reported level crash data are generally very limited in detail. Occasionally, more detailed data are collected on selected crashes, such as those resulting in fatalities and severe injuries, but such detailed investigations constitute only a small fraction of crashes.

Most of the collected data elements are intended for identification and record-keeping purposes, such as date, time and location of crash, vehicle(s) and driver(s) involved, damage to the involved vehicle(s) and other property, injury sustained by driver(s) and occupant(s) of vehicle(s), and a brief description of what happened in the crash. The crash data may be merged with other data files for additional information. For example, the Highway Safety Information System (HSIS) combines crash data with other roadway and vehicle related data files, such as roadway inventory, traffic, alignment, bridge inventory, vehicle identification and registration, etc., to expand the information database for use in various analyses.

Even with the merged files, police reported level crash data still lack the detail needed for analysis beyond problem identification and are of little use from the standpoint of estimating impact conditions of single-vehicle, ran-off-road crashes or evaluation of the impact performance of roadside safety features. Thus, studies pertaining to police reported level crash data are not included in the literature review.

Enhanced police reported level of crash data is used in selected research studies in which additional data elements are collected to supplement the police reported data. The supplemental data collected vary from study to study depending on the objective(s) of the study. Most of the supplemental data pertain to items of specific interest to the studies, such as details of roadside conditions, inventory of a particular roadside object(s), etc. However, there have been a few studies in which the investigating officers were asked to provide information on departure and impact conditions.

In a study by Garrett and Tharp, the investigating officers were asked to provide estimates on impact speed and angle on 324 crashes that occurred on the Ohio Turnpike over a period of five months during the summer and fall of 1967 (8). Similarly, in a study by Perchonok, et al to assess the relationships between single-vehicle, ran-off-road crash frequency, severity, and roadway and roadside features, data on over 9,000 crashes were collected from six states (2). The investigating police officers were asked to complete supplemental field forms, including data pertaining to impact conditions, such as impact speed and angle.

While enhanced police level crash data provide more detailed information, its utility on estimating impact conditions is limited for a number of factors:

1. Expertise and experience of the investigating police officers. Most police officers receive some basic training in crash investigation, but only a small proportion of the officers receive the highly specialized training in crash reconstruction needed to accurately estimate impact conditions. The quality of data collected by police officers without the specialized training may be questionable.
2. Impact performance of roadside safety features. Even for trained officers, reconstruction of single-vehicle, ran-off-road crashes pose special problems unless the person is also knowledgeable of the impact performance of roadside features. Most reconstructions are based on energy dissipation and balance. For many ran-off-

road crashes, energy dissipated by the struck object constitutes a significant portion of the energy equation and must be properly accounted for. This in turn will require knowledge on the impact performance of roadside features, which is beyond the training received by police officers.

3. Time and effort required. In order to properly reconstruct a crash to estimate its impact conditions, it would require time and effort beyond those available to an investigating officer. Thus, it is reasonable to expect that estimates of impact conditions would be based mostly on the judgment of the officers and less so on step-by-step reconstruction of the crashes.

In summary, enhanced police level crash data using investigating officers to collect supplemental data could provide more detailed information on the impact conditions of single-vehicle, ran-off-road crashes. However, as discussed above, there are serious limitations to this approach that could not be easily overcome. Thus, the use of enhanced police investigation to estimate impact conditions is not recommended.

To properly estimate the impact conditions of single-vehicle, ran-off-road crashes, an in-depth level of crash investigation is required. The required data would include: detailed data on the roadway; vehicle trajectory; object(s) struck and damage sustained; vehicle and damage measurements; and driver and occupant injury levels. The costs associated with in-depth crash investigation is, as may be expected, very high and there have only been a few ad hoc studies that incorporated such in-depth crash data, i.e., the data collection was designed specifically for the study.

The most notable study involving in-depth crash data is perhaps the study on crashes involving pole support structures (9). A stratified random sample of over 1,000 crashes involving utility poles, breakaway and nonbreakaway luminaires and sign supports were investigated in-depth, and the crashes were reconstructed to estimate the impact conditions. The in-depth crash data was then analyzed in conjunction with police level data on all crashes and all pole crashes, enhanced police level data on unreported crashes, and pole inventory data to address the study objectives. The results of the study include: extent of pole crash problem; characteristics of pole crash sites, vehicle damage, and occupant injuries; assessment on the performance of various pole types; and a cost-effectiveness evaluation of the breakaway modification as a safety treatment.

Another study of crashes on highway narrow bridges involved in-depth investigation of 124 crashes that occurred on bridges (10). Again, the in-depth crash data was analyzed in conjunction with police level data on crashes that occurred on 11,880 bridges from five states and supplemental field data on a sample of 1,989 bridges to address the study objectives. The results of the study include: extent of the narrow bridge crash problem and the associated crash frequencies and rates; relationships between various bridge physical and operational characteristics to crash rates and severities; and the characteristics and relationships between crash and injury severity for crashes at bridges.

Other studies have utilized data from various in-depth crash investigation programs conducted by the National Highway Traffic Safety Administration (NHTSA). Since its inception in late 1960, NHTSA has sponsored numerous programs to collect in-depth crash data. The programs changed over the years, from the multidisciplinary accident investigation (MDAI) program in the late 1960's in which a small convenient sample of crashes were studied in great detail to the current National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) that investigates a nationally representative stratified random sample of crashes in lesser detail. However, these in-depth data collection programs are designed to meet the data needs of NHTSA and the emphasis is, therefore, on data pertaining to the vehicle, occupant, and injury severity. Unfortunately, data pertaining to roadway and roadside characteristics are mostly lacking, which limits the use of the data for highway related research, such as the current study.

In order to make use of the NASS CDS data, supplemental data collection is necessary to gather information required for the specific study. The supplemental data collection can be prospective or retrospective in nature. The NASS program has a special study subsystem that allows for prospective collection of supplemental data in addition to the standard data elements collected under CDS. For instance, three special studies were designed to collect in-depth crash data on longitudinal barriers, pole support structures, and crash cushions (11, 12, 13). These special studies were met with different degrees of success. Nearly 1,200 cases were collected under the Longitudinal Barrier Special Study (LBSS) while only a negligible number of cases were collected under the pole and crash cushion special studies. The LBSS cases were subsequently reconstructed using the conservation of energy approach and the data were analyzed to examine the severity of barrier length-of-need (LON) crashes versus barrier-end impacts. Cases involving failure of the barrier system were reviewed clinically (14).

Crashes involving concrete barriers were selected from the LBSS data file for use with an FHWA study on rollovers caused by concrete barriers (15). Of the 130 crashes involving concrete barriers, 31 resulted in rollovers. In addition to comparing the characteristics of crashes resulting in rollovers to those of non-rollovers, the rollover crashes were also clinically analyzed to identify potential causes for the rollovers.

These studies illustrated the potential application of the special studies as well as the problems associated with their conduct. This special study approach was not again utilized until the recent Large Truck Crash Causation Special Study, sponsored by the Federal Motor Carrier Safety

Administration (FMCSA). The purpose of this study was to determine specific causes of large truck (trucks with gross vehicle weight rating of over 10,000 lbs) crashes. These crash causation data will help to identify crash countermeasures the FMCSA can undertake with regard to interstate motor carriers, their drivers, and their vehicles; and in cooperation with other DOT agencies and State governments with regard to the non-commercial vehicles, pedestrians, and pedalcycles involved in the crashes.

Another approach is to supplement the NASS CDS data retrospectively with additional field data collection. Data elements of specific interest to the study, but not covered under NASS CDS, are identified and collected using supplemental field data collection. The key limitation of this approach is that the supplemental data elements should not change over time since the supplemental data are collected one to two years subsequent to the occurrence of the crashes. This is not a bad assumption for most data elements pertaining to highway and roadside characteristics since they typically do not change except during major construction or reconstruction.

This retrospective approach was utilized in the ongoing NCHRP Project 17-11, "Recovery-Area Distance Relationships for Highway Roadside" (16). The objective of the study is to develop relationships between recovery-area distance, roadway, and roadside features, vehicle factors, encroachment parameters, and traffic conditions for the full range of highway functional classes and design speeds. Part of the research involved clinical analysis of 338 NASS CDS cases from 1997 and 1998. Field data on roadway and roadside characteristics of crash sites were collected to supplement the standard NASS CDS data elements.

These sampled cases were then manually reviewed, e.g., police accident report, field forms, scaled diagram, and photographs, to glean additional information beyond the computerized data elements. The crashes were then reconstructed to estimate impact conditions and vehicle trajectories from the manual review such as impact sequence, pre- and post-impact vehicle trajectories, impact angle, etc.

The same retrospective approach and data collection protocol used in NCHRP Project 17-11 were used in the rollover study (17) sponsored by FHWA, except that the cases were sampled from the 1999 NASS CDS data file. The objectives of this study were to determine the specific causes of rollover events associated with the full range of passenger vehicle collisions in which such an event occurred. In fact, the data from NCHRP Project 17-11 were utilized in this study with additional in-depth clinical reconstruction on the 180 rollover crashes contained in the database. In addition, new data from 175 NASS CDS cases from 1999 were added to the database.

However, NHTSA recently changed its privacy policy to discard police accident reports after only one year. This policy change effectively eliminates this retrospective approach since the only means of identifying the crash sites was from the police accident reports. The prospective special study is the only viable approach for future studies using the NASS CDS program.

A new emerging technology may provide a totally new and better source of data on impact conditions. Automobile manufacturers have installed Event Data Recorders (EDRs) in selected vehicle lines in recent years. The EDR is designed as a controller for monitoring airbag deployment and seatbelt usage and recording data pertaining to the crash event in case of a crash. Data elements recorded include: crash pulse, seatbelt usage, and pre-crash information, such as speedometer reading and engine performance parameters. The EDR data would eliminate the need for reconstruction of the crashes to estimate impact conditions and an invaluable supplement to in-depth crash investigation.

NHTSA is currently collecting available EDR data under its NASS CDS and Special Investigations (SCI) programs and compiling the data into a national database. While the EDR technology is relatively new and little actual data is currently available, its potential in the future is very promising:

- The EDRs are now gaining widespread deployment in most vehicle lines, so more data could become available.
- The number of data elements and the length of recording period are somewhat limited now. However, with rapid advances in electronics, many more data elements could be incorporated into the EDRs and the recording period could increase significantly.
- In addition to the interest of NHTSA, the highway roadside safety community has also shown great interest in the EDR data. A study, NCHRP Project 17-24, "Use of Event Data Recorder (EDR) Technology for Roadside Crash Data Analysis," was conducted to review and recommend a minimum set of EDR data elements for roadside safety analysis as well as procedures to retrieve, store, and use the data (18).

While the EDR technology is very exciting and promising, there is still much development to be done and impediments to overcome before it can reach its potential, including:

- Engineering issues. There are no current standards governing the design and use of EDRs, such as data elements to be included, data format, data retrieval, etc. Such standards are needed if data are to be collected on a large scale. Also, current EDR data elements are, as expected, focused on vehicle parameters with no specific consideration for information pertaining to ran-off-road crashes.
- Institutional barriers. EDR data are intended for the data needs of vehicle manufacturers, which may be reluctant to share their proprietary designs for competitive and legal considerations. Inputs from governmental agencies and

research institutions are needed in the early planning and design stages if the EDR data are to be expanded into the roadside safety area.

- Legal consideration. There are still questions pertaining to ownership of the EDR data, privacy issues, use of EDR data in tort claims, etc. Until such concerns are addressed and resolved, large scale collection of EDR data appears unlikely.

2.2 Impact Conditions of Ran-Off-Road Crashes

Despite the large number of studies on ran-off-road crashes, there are relatively few studies that actually attempted to estimate the impact conditions. The main reason for the lack of such effort is that, in order to estimate the impact conditions, an in-depth level of crash investigation is required, including detailed data on the roadway, vehicle trajectory, object(s) struck and damage sustained, vehicle and damage measurements, and driver and occupant injury levels. The costs associated with in-depth crash investigation are, as may be expected, very high and there have only been a few studies that incorporated such in-depth crash data. Another limitation is that some of the studies, such as the LBSS data, were not based on a representative sample and the resulting distributions of impact conditions could be biased, probably toward the more severe crashes.

Some earlier work relied on reconstruction of impact speed and angle by the investigating officers, such as the studies by Garrett and Tharp (8), Perchonok, et al. (2), and Lampela and Yang (1). As discussed previously, the use of enhanced police level crash data to estimate impact conditions is limited for a number of factors, such as expertise and experience of the investigating police officers, availability of time for the officers, and lack of knowledge on the impact performance of roadside safety features. Thus, while the results from these studies provide some insights into impact conditions, their accuracy is somewhat questionable.

Under the Pole and Narrow Bridge studies (9, 10), impact conditions were estimated from in-depth investigations and presented in the reports. Mak, et al., took the data from these studies and developed statistical models for the distributions of impact speeds and angles (3). After screening, a total of 596 cases were available for analysis. The authors found that the gamma function provides the best fit for univariate impact speed and impact angle distributions. Statistical models for impact speed and angle distributions were then developed using the gamma function for the following five functional classes:

- Freeway
- Urban arterial
- Urban collector/local road
- Rural arterial
- Rural collector/local road

For some roadside features, such as longitudinal barriers, impact conditions are defined by both impact speed and angle. However, there is no known means of mathematically expressing a joint gamma distribution. The authors tested various known joint (bivariate) distributions, but with no success. They then proceeded by assuming that the impact speed and impact angle are independent of each other and estimated combined probability distributions for impact speed and angle stratified by functional class and based on the gamma distribution. These impact speed and angle distributions were used in some of the cost-effectiveness analysis procedures, including the Texas Transportation Institute (TTI) ABC model (19). The distributions were adjusted to reflect the current higher speed limits under NCHRP Project 22-14 (20). The revised impact condition distributions were used with the Roadside Safety Analysis Program (RSAP) (21).

Other sources of impact conditions include data from the ongoing NCHRP Project 17-11 and the FHWA rollover study (16, 17). A total of 559 NASS CDS cases from 1997 through 1999 were selected under these two studies. Supplemental field data were collected on these cases, which were then reconstructed to estimate the impact conditions. The impact speed and angle distributions developed under these two studies were significantly different from previous findings. However, it was later found that the scales on some of the diagrams used for the impact angle reconstructions might be distorted. In order to fit the scale diagrams onto a web page, the longitudinal and lateral scales were compressed differently, thus leading to incorrect impact angle estimates. Plans are underway to reconstruct these cases again to correct the errors and reanalyze the revised data.

It should be mentioned that in order to properly establish the distribution of impact conditions, the data source needs to be either the population (i.e., all ran-off-road crashes) or a representative sample. Some databases, such as the LBSS, are sampled on the basis of a comparative analysis and are not suitable for determining impact condition distributions.

2.3 Data Needs for Study of Ran-off-road Crashes

There have been a number of studies that looked into the data needs for studying ran-off-road crashes. A study by Mak and Sicking identified issues and gaps in the state-of-the-knowledge needed to improve the cost-effectiveness analysis procedure and to develop data collection plans for those issues and gaps that could be addressed with crash data. The research proposed five studies and developed data collection plans for those studies. These included:

- Validation of encroachment frequency/rate
- Determination of encroachment frequency/rate
- Effect of roadside conditions on impact probability and severity
- Distributions of impact conditions

- Relationships of impact conditions, performance limits, and injury probability and severity

These study plans were reviewed by a panel of experts and their comments taken into consideration. The recommended study on the distributions of impact conditions focuses on impact speed, angle, and vehicle orientation in addition to vehicle size, weight, and the nature of roadside object/feature. The plan for this study includes:

- Select sample roadway segments for each of the six highway types
- Set up data collection protocol, including sampling plan, accident notification scheme, data collection forms, etc. and familiarize and train investigators with the protocol through a small pilot study
- Investigate in-depth a representative sample of single-vehicle, ran-off-road type accidents on these selected roadway segments
- Reconstruct the sampled accidents to determine impact conditions
- Compile descriptive statistics on vehicle trajectory and impact conditions
- Develop mathematical models for the distributions of impact speeds and angles

These proposed studies and data collection plans are over 10 years old, but they still are applicable today and of great interest to the current study.

Miaou proposed a method to estimate vehicle roadside encroachment rates using accident-based models (22). Miaou concluded that the proposed method could be a viable approach to estimating roadside encroachment rates without actually collecting the encroachment data in the field, which can be expensive and technically difficult. A pilot study was conducted by Daily, et al. (23) to examine the feasibility of this approach. Data were collected on 56 km (35 mi) of tangent sections of rural two-lane highways in Idaho, including detailed roadside, crash, and traffic data.

Encroachment rates were estimated from the collected crash data and found to be in the same order of magnitude as previous research. It was concluded that this approach is feasible, although it is limited by the current state-of-the-knowledge with respect to data on the trajectories of vehicles involved in ran-off-road, fixed-object accidents. An experimental plan for future research that would produce improved estimates of encroachment rates was developed, but not recommended for immediate implementation.

While this study has no direct bearing on the current study, it could be of interest in future data collection efforts. Data on encroachment rates are over 25 years old and may be outdated in light of the significantly changed conditions in the intervening years, including improvements made to the safety design of highways (e.g., clear zone concept and improved barriers and terminals) and vehicles (e.g., front and side airbags, anti-lock brakes, and crush management), and other safety countermeasures (e.g., mandatory seatbelt law, tightened blood alcohol content law). If a major data collection effort is to be implemented in the future, encroachment data may be one of the objectives.

A list of suggested data elements for use with the current NASS CDS program was proposed by Eskandarian, et al. in a study to assess the compatibility between vehicle design characteristics and roadside safety hardware (24). These data elements pertain to struck feature design characteristics, pre-impact conditions, impact conditions, and assessment of impact performance of feature. While the suggested data needs pertain mostly to the issue of compatibility between vehicle design and roadside safety features, the information would be helpful to establishing the data needs for the data collection effort under the current study.

Under the recently completed NCHRP Project 17-24 on the potential use of EDR data for roadside safety evaluation, the authors examined the data needs for roadside safety analysis and made an assessment to determine if the data needs can be satisfied with EDR data. A list of new data elements for EDR is proposed. As mentioned previously, the EDR technology is very exciting and promising. However, until such time that these new EDR data elements become available, in-depth crash investigation will remain the primary means of obtaining such detailed crash data.

2.4 Reconstruction of Ran-Off-Road Crashes

There are a number of existing reconstruction procedures developed for reconstructing special types of ran-off-road, fixed-object crashes (14, 15, 25), including:

- Semi-rigid and flexible barrier
- Rigid barrier
- Pole support structure

These reconstruction procedures are based on the general principle of identifying the energy loss parameters during the collision and summing the total to determine the change in velocity from point of impact to point of final rest. The components of the energy loss in a typical crash include:

- Vehicle crush
- Deformation/damage of roadside feature
- Vehicle trajectory

Energy due to vehicle crush can be estimated manually using equations from Campbell (26) or using a computerized reconstruction procedure, such as CRASH3. Energy loss due to post-impact vehicle trajectory is estimated using equations of motion. Adjustments are made to account for skidding and sliding. For rotating vehicles, the distance traveled is based on the angle of rotation and the radius and the energy loss calculated accordingly. Energy loss due to vehicle trajectory can also be estimated using a computerized reconstruction procedure, such as CRASH3. These two energy loss items can be standardized and incorporated into a single reconstruction procedure. Unfortunately, energy loss due to deformation/damage of the roadside feature varies greatly among the roadside features and impact configurations, e.g., barrier length-of-need versus barrier end impact. Thus, there is not a single procedure that can be used to reconstruct all ran-off-road crashes.

Instead, different reconstruction procedures are needed to accommodate the wide variety of roadside features.

A reconstruction procedure for semi-rigid and flexible barriers was developed for the LBSS data (14). The procedure utilized similar techniques for estimating vehicle crush and trajectory energy losses. Energy loss associated with the deformation of semi-rigid barriers was estimated from a series of computer simulations that correlated Impact Severity (IS) to maximum barrier deflection. The Impact Severity (IS), calculated using the following equation, has been shown to be a good indicator of the degree of loading and maximum deflection of a barrier during an impact.

$$IS = \frac{1}{2} * M * (V * \sin \theta)$$

where:

IS = Impact Severity
M = Vehicle mass
V = Vehicle velocity
θ = Impact angle

The IS value, in conjunction with the impact angle, can then yield a direct estimate of impact speed. The impact speed calculated from barrier deflection should be verified by energy loss calculations to make sure that the estimates using both approaches are consistent.

Another procedure was developed for reconstructing rigid barrier impacts under the study to assess rollovers on concrete barriers (15). For impacts involving concrete barriers, there is typically no deformation/damage to the barrier. However, it was found that vehicle/barrier friction was a major source of energy dissipation during a crash. Thus, energy loss due to deformation/damage to the barrier is replaced by vehicle/barrier friction, which is estimated as a function of the length of barrier contact. Total energy loss is then calculated as the sum of energy losses due to: vehicle crush, vehicle/barrier friction, post-impact vehicle trajectory, and the impact speed calculated accordingly.

As a means of verification, the vehicle crush energy was matched to the energy associated with the lateral velocity of the impacting vehicle. If both energy estimates are comparable, the procedure was believed to be reasonably accurate. If not, the vehicle crush energy would be adjusted appropriately and a new estimate of the impact speed was generated. This iterative procedure was found to give reasonably good estimates of impact speed when used to evaluate finding from full-scale crash tests.

Another computerized reconstruction procedure was developed for ran-off-road crashes involving pole support structure, including breakaway and nonbreakaway utility poles, luminaire supports, and sign supports (25). Energy losses due to vehicle crush and post-impact vehicle trajectory were estimated using the CRASH3 program. Energy loss associated with breaking or fracture of the pole is estimated based on empirical test data. Impact speed is then calculated from the total energy loss.

3 STUDY APPROACH

3.1 General

To accomplish the study objectives, the following major tasks were undertaken in this study:

- Identify data needs
- Evaluate data collection alternatives
- Develop data collection protocol
- Conduct supplemental data collection, manual review, and reconstruction
- Create relational database
- Incorporate data from previous studies into database

Details of these tasks are presented in the following sections. The database was then analyzed to address the study objectives and the results are presented in Chapter 4. Finally, a proposed implementation plan for a long-term data collection effort was developed and outlined in Chapter 5.

3.2 Data Needs

The primary question to be addressed under the current study is to identify distribution of impact conditions associated with serious injury and fatal ran-off-road accidents, including speed, angle, and vehicle orientation at impact. It is hoped that this information can then be used to select impact conditions to be used in full-scale crash testing of roadside hardware. In order to address this question, the needed data elements are identified, as listed in Table 1. The data elements are categorized as available from:

1. Basic NASS CDS data. These data elements are already available as part of the basic CDS data.

2. Supplemental field data collection. These data elements will require field data collection.
3. Reconstruction. These data elements will require reconstruction of the crashes.

The data collection plan presented in this chapter covers the data elements requiring supplemental field data collection and reconstruction.

3.3 Data Collection Alternatives

Three basic alternatives were considered for the data collection effort in the current study:

1. New data collection system
2. Prospective special study under the National Automotive Sampling System (NASS) Crashworthiness Data Subsystem (CDS) program
3. Retrospective supplemental data collection for existing NASS CDS cases

More detailed discussions of these alternatives are presented below.

3.3.1 New Data Collection

The first alternative was to establish a totally new data collection system. The major activities required in the setup of a new data collection system at multiple sites include, but are not limited to:

- Establish data collection teams. This would require hiring of new personnel, establishing and furnishing the offices, purchasing the necessary equipment for conducting crash investigation, etc.
- Train investigators in the basics of in-depth level crash investigation. The newly hired investigators would need to be trained extensively to acquire the required level of expertise, including both classroom and on-the-job training.

- Establish cooperation with local agencies. This would include law enforcement agencies for the notification system, vehicle towing and repair facilities for access to the involved vehicles, hospitals and clinics for medical records/information on injury severity, and transportation agencies for highway related information.
- Establish quality control procedures. To assure proper data collection in terms of validity and accuracy, appropriate quality control procedures would need to be established, similar to the Zone Centers in the NASS program.

After the data collection system was established, additional activities would be required to establish the specific data collection effort, including:

- Develop data collection protocol. The field forms and accompanying coding and instruction manuals, data collection procedures, data submission processes, and quality control procedures would have to be developed for the specific data collection effort.
- Train investigators in specific data collection effort. The investigators would have to be trained in the details of the specific data collection effort. This would be in addition to the basic training mentioned above.
- Conduct pilot study. A pilot study would have to be conducted to work out any unforeseen problems in the data collection protocol.

It is evident from the above discussion that the alternative of establishing a new data collection system was not a viable option for this study due to funding constraints. The startup costs would be prohibitive for such a short term data collection effort. However, this remains a viable alternative for a long term data collection effort.

3.3.2 Prospective NASS CDS Special Study

The second alternative was to establish a special study under the NASS CDS program. The special study would be prospective in nature (i.e., data would be collected on new crashes) and could be within sample (i.e., only crashes that are already sampled under the NASS CDS program would be eligible) or outside of sample (i.e., all crashes are eligible). Again, this is not a viable alternative for this study due to time and funding constraints. First, it will take a minimum of 12 to 18 months to set up a special study under the NASS CDS program. Second, this assumes that the NASS CDS program can accommodate a new special study on short notice, which is rarely the case. Because the CDS system itself requires a certain number of crashes to be investigated and the researchers can handle only so many crashes (1-1/2 to 2 cases per week per researcher), the ability of the system to conduct special studies is limited. This can be overcome by hiring new investigators specifically to handle the special study, such as in the case of the Large Truck Crash Causation Special Study. The addition of new investigators is not as time consuming or costly as establishing new data collection teams, but would still require more time and funding than available for the current study. However, this remains a viable alternative for a long term data collection effort.

3.3.3 Retrospective Supplemental Data Collection

The third alternative was to conduct a retrospective study using previously investigated NASS CDS cases. This approach was similar to that successfully used in NCHRP Project 17-11 and the FHWA Rollover Study. In those studies, single-vehicle ran-off-road crashes were selected from 1997 through 1999 NASS CDS cases. Since NASS CDS cases are oriented toward vehicle crashworthiness and occupant injury and lack details pertaining to the highway and roadside characteristics, supplemental field data collection and manual review and reconstruction of the cases were used to fill in the data gaps. A total of 559 cases were sampled under these studies.

This approach can be implemented within a short period of time since it involves only existing NASS CDS cases. Supplemental field data collection protocol and manual review and reconstruction procedures had already been developed and field investigators at the Primary Sampling Units (PSUs) and the Zone Center personnel were already familiar with the protocol and procedures. Thus, this approach could be easily implemented for this study within the time and funding constraints. Also, this will allow cases from the previous studies to be incorporated into the database with the new cases collected under this study.

This third alternative of retrospective supplemental field data collection and manual review and reconstruction of existing NASS CDS cases was, therefore, selected for this study. However, it should be noted that NHTSA had changed its policy, starting with the 2003 data, to keep police accident reports in the file for only one year. This in effect eliminates the location information on existing NASS CDS cases. Thus, this alternative of retrospective supplemental field data collection and manual review and reconstruction of existing NASS CDS cases is no longer a viable option. For the long term data collection effort in the future, only the alternatives of a new data collection effort or a special study under the NASS CDS system could be considered.

3.4 Data Collection Protocol

As discussed previously, the plan for the current study was based on a retrospective supplemental data collection approach. This retrospective approach involved collecting supplemental field data and manual review and reconstruction of existing NASS CDS cases. The major components of the data collection protocol are summarized as follows:

- Sampling plan
- Supplemental field data collection,
- Manual review of sampled cases

- Reconstruction of crashes to estimate impact speed

Brief descriptions on activities pertaining to the supplemental field data collection are presented in this section.

3.4.1 Sampling Plan

As discussed previously, a similar retrospective supplemental field data collection approach was used in two previous studies: NCHRP Project 17-11 and the FHWA Rollover Study. Supplemental field data were collected on NASS CDS cases from 1997 through 1999 in these two studies, as follows:

- NCHRP Project 17-11
    - 1997 - 138 cases
    - 1998 - 200 cases
- FHWA Rollover Study
    - 1999 - 221 cases

The scope of the supplemental data collection effort for this study was, therefore, selected to include 2000 and 2001 NASS CDS cases. To maintain consistency among the three studies, the sampling criteria remained the same as the two previous studies. The sampling criteria included the following parameters:

- Area type - rural and suburban. Urban PSUs were excluded from the sample because urban roadways tend to have lower speed limits and the roadsides are typically cluttered with fixed objects. More importantly, inspections at urban crash sites are generally less detailed with a higher percentage of incomplete data due to hazardous working conditions and traffic congestion.

- Single-vehicle, ran-off-road crashes. Only single-vehicle, ran-off-road crashes were included in the sample. Single-vehicle crashes that occurred on the roadway, or involving parked vehicles, animals and pedestrians were excluded since the nature of the crashes is different from that of a ran-off-road crash. Similarly, multiple-vehicle crashes were excluded from the sample.
- Passenger type vehicles. Only passenger type vehicles, i.e., passenger cars and light trucks with a gross vehicle weight (GVW) of less than 4,536 kg (10,000 lbs), were included in the NASS CDS sample. Heavy trucks, i.e., single unit trucks with higher GVW and tractor-trailers, present very different problems than passenger vehicles. Also, reconstruction of crashes involving heavy trucks is much more difficult than those involving passenger type vehicles.
- Speed limit ≥ 72 km/h (45 mph). Only crashes that occurred on highways with speed limits of 72 km/h (45 mph) or higher were included. Low-speed roadways tend to have lower design standards and have crash characteristics that are significantly different from those of high-speed highways. Thus, it is not desirable to mix crashes from both low-speed and high-speed highways.
- Complete vehicle inspection, vehicle trajectory, and injury severity data. It would not be possible to reconstruct crashes without vehicle inspection and trajectory data, and those crashes would be of little interest to the proposed study. Thus, only crashes with complete vehicle inspection and trajectory data were included. Also, the emphasis of the study was on serious and fatal injury crashes, so the injury severity should, therefore, be known for the sampled cases.

Table 2 shows a breakdown of the 2000 and 2001 CDS cases by the first four sampling criteria. In year 2000, there were a total of 4,307 cases, 2,929 (68.0%) of which occurred in the 16 rural and suburban PSUs, and 1,518 (51.8%) of which occurred on highways with speed limits above 72 km/h (45 mph). Of these crashes, 603 (39.7%) were single-vehicle, ran-off-road crashes. In year 2001, there were a total of 4,090 cases, 2,833 (49.3%) of which occurred in the 16 rural and suburban PSUs, and 1,500 (52.9%) of which occurred on highways with speed limits above 72 km/h (45 mph). Of these crashes, 593 (39.5%) were single-vehicle, ran-off-road crashes. Combining data from the two years, there were a total of 1,196 eligible cases that occurred in rural and suburban PSUs on highways with speed limits above 72 km/h (45 mph), and involving single-vehicle, ran-off-road crashes.

As shown in Table 3, of the 1,083 eligible cases with known injury severity, 348 (32.13%) resulted in serious to fatal injuries (AIS >= 3), 229 (21.14%) resulted in moderate injury (AIS=2), 385 (35.55%) resulted in minor injury (AIS=1), and 121 (11.17%) incurred no injury (AIS=0). However, it should be noted that the sampling scheme for NASS CDS is biased toward the more serious crashes. When the cases are weighted accordingly to the sampling scheme, the distribution of injury severity is very different: 43.64 percent no injury, 40.15 percent minor, 8.32 percent moderate; and 7.90 percent serious to fatal injury. Thus, all analyses shown herein show both unweighted and weighted frequencies and percentages.

Table 4 shows the distribution of the eligible cases by the number of lanes. The vast majority of the cases, 998 (83.44%), occurred on highways with two or three lanes. Another 38 (3.18%) occurred on one-lane roadways (i.e., ramps). The remaining 160 cases (13.38%) occurred on highways with 4 or more lanes. The weighted distributions are similar, 3.45 percent for one lane, 82.02 percent for two or three lanes, and 14.53 percent for four or more lanes. The similarity between the unweighted and weighted percentages suggests that the severity of crashes is similar for different highway types, though slightly higher for highways with two or three lanes.

Table 5 shows the distribution of the eligible cases by vehicle type. Passenger cars accounted for the majority, 696 (58.19%), of the eligible cases, followed by pickup trucks, 247 (20.65%), and sport utility vehicles, 198 (16.56%). The weighted distributions show a higher percentage for passenger cars (64.60%) and lower percentages for the other vehicle types. This suggests that a higher proportion of crashes involving passenger cars had lower injury severity.

The final screening criteria include: documentation of vehicle trajectory, complete vehicle inspection, and known injury severity data. Of the 1,196 eligible cases, only 437 (36.54%), met all three criteria. Table 6 shows the distribution of these 437 cases by Primary Sampling Unit (PSU). Note that three of the PSUs (4, 73 and 83) do not have any complete cases. Two other PSUs (5 and 43) have only 2 and 4 complete cases, respectively. Also, three other PSUs (8, 9 and 75) have less than 20 complete cases.

Since the targeted sample size was only 400 cases, it was decided to eliminate these seven PSUs (4, 5, 8, 9, 43, 73 and 81) from the sampling due to overly small number of cases, which renders the data collection effort inefficient. The number of sample cases was thus reduced from 437 to 404 cases. Distribution of the 404 sampled cases by PSU is also shown in Table 6.

In order to make sure that the sampled cases are reasonably representative of the NASS CDS cases, and thus the overall crash population nationwide, a check was conducted on a few key variables, including highest injury severity, number of lanes, and vehicle type.

As shown in Table 7, of the 404 sampled cases, 139 (34.41%) resulted in serious to fatal injuries (AIS >= 3), 94 (23.27%) in moderate injury (AIS=2), 142 (35.15%) in minor injury (AIS=1), and 29 (7.18%) with no injury (AIS=0). The distribution of the sampled cases was quite similar to that of the eligible cases shown previously in Table 3 with a slight decrease in the percentage of crashes with no injury. The same is true for the weighted distributions.

Table 8 shows the distribution of the eligible cases by number of lanes. The dominance of highways with two or three lanes is even more pronounced for the sampled cases with the weighted percentages, increasing from the 82.02 percent for the eligible cases (see Table 4) to 90.36 percent for the sampled cases. The proportion of crashes on one-lane roadways also increased slightly. Correspondingly, the weighted percentages of crashes on highways with 4 or more lanes dropped from 14.5 percent to only 5.69 percent. This drop in the proportion of cases occurring on highways with 4 or more lanes is not surprising given that only three of the sampled PSUs are in suburban areas, where multi-lane facilities are more common.

As shown in Table 9, the distributions of the sampled cases by vehicle type are similar to those of the eligible cases, shown previously in Table 5. Passenger cars accounted for about 65 percent for both the eligible and sampled cases. The proportions of sport utility vehicles and vans/minivans decreased somewhat for the sampled cases while the percentage of pickup trucks increased.

Overall, the distributions of these key variables for the sampled cases were reasonably similar to those of the eligible cases, given that the sampled cases are not truly a representative sample of the eligible cases. Rather, it is a sample of convenience to make sure that the sampled cases have complete documentation of the vehicle trajectory, vehicle inspection, and information on injury severity.

3.4.2 Supplemental Field Data Collection

Data elements requiring supplemental field collection are shown in Table 10. The protocol for the supplemental field data collection effort was developed, including the field forms and the accompanying coding and instruction manuals. The field forms were used by the PSU investigators during the actual data collection while the manual provided definitions of the data elements, field data collection procedures, and coding instructions.

Note that given the retrospective nature of the data collection approach, there was an implicit assumption that the data elements would not change significantly with time. This is a reasonable assumption for most of the supplemental data elements, such as roadway, traffic and roadside characteristics. As for the struck object characteristics, there was an additional assumption that any damaged objects would be replaced in kind, i.e., the replaced object or feature would have the same characteristics as the original that was damaged. The investigators would compare the site and struck object characteristics at the time of supplemental data collection to those at the time of the crash, using photographs from the case files to make sure that these assumptions were accurate. Cases in which the site and/or struck object/feature characteristics had been changed significantly would be deleted from the sample.

There were two sets of field data collection forms:

- Supplemental Highway Data Collection Form
- Object Struck Data Collection Form

A complete copy of the field forms and the accompanying coding and instruction manuals are included as Appendix C and will not be repeated here.

The Supplemental Highway Data Collection Form was completed for each sampled case. The form contains 20 data elements under four general headings:

- Case Identification:
    1. Year
    2. Primary Sampling Unit

3. Case Number-Stratum

- General Highway Data:

4. Land Use
5. Class Trafficway
6. Access Control
7. Average Lane Width
8. Roadway Alignment at Point of Departure
9. Radius of Curve
10. Roadway Profile at Point of Departure
11. Vertical Grade

- Roadside Data:

12. Curb Presence
13. Curb Height
14. Shoulder Type
15. Shoulder Width

- Slope Data:

16. Roadside Cross Section at Point of Departure
17. Number of Slopes
18. Lateral Offset to Beginning of Slope
19. Rate of Slope
20. Width of Slope

An Object Struck Data Collection Form was completed for each object involved in the crash. The form contains seven data elements under four general headings:

- Case Identification:
    1. Year
    2. Primary Sampling Unit
    3. Case Number-Stratum
- General Struck Object Data:
    4. Impact Number
    5. Object Type
    6. Material
- Dimensions of Struck Object - annotation
- Photography:
    7. Photographs Taken?

Due to the large number of potential roadside objects and features, the variables are necessarily very general without specific details. Instead, investigators were asked to provide annotations or descriptions and photographs of the struck object.

Since the data collection protocol was similar to that of NCHRP Project 17-11 and the FHWA Rollover Study, the Zone Center staff and PSU investigators were already familiar with the data collection protocol. Thus, the data collection experienced little problem or difficulty. The actual field data collection was conducted by PSU investigators under the direction of the Zone Centers: Veridian Corporation for Zone Center 1 and KLD Associates for Zone Center 2. After a quality check was conducted by Zone Center personnel for accuracy, the completed data were forwarded to KLD Associates, which was a subcontractor for this study. The supplemental field data were then combined with the regular NASS data in the manual review of the cases.

3.4.3 Manual Review of Sampled Cases

Additional data elements not available from the computerized data file or supplemental field data collection were gleaned from manual review of hard copies (in electronic form) and reconstruction of the sampled cases. The data elements coded from this manual review are shown in Table 11. Part of the review included verification of data elements that were already coded under existing NASS CDS or supplemental data collection, such as:

- Highway data - highway type, number of lanes, divided/undivided, presence/absence of shoulder, and impact sequence
- Roadside feature impacted - guardrail, tree, ditch, etc.
- Driver input - steering and/or braking

The main function of the manual review was to conduct detailed reconstruction of the crashes to estimate parameters such as:

- Vehicle encroachment conditions - angle and orientation
- Vehicle trajectory after encroachment - vehicle path
- Impact conditions - angle and orientation
- Impact performance of struck roadside safety feature

With the exception of the reconstruction of impact speed, which was performed by the project staff, the manual review and reconstruction were conducted by Zone Center personnel from KLD Associates. Two reconstruction coding forms were designed specifically for coding of these manual review and reconstruction data elements, one for the first event or impact, and one for subsequent events or impacts. Copies of the reconstruction coding forms and the accompanying coding and instruction manual are shown in Appendix C and will not be repeated here. Zone Center personnel were trained on the manual review procedure and the coding of the data elements.

Under the reconstruction coding form for the first event, there are 20 data elements under six general categories:

- Case Identification:
    1. Year
    2. Primary Sampling Unit
    3. Case Number-Stratum
- Encroachment Data:
    4. Departure Angle
    5. Vehicle Heading Angle
- Vehicle Trajectory Data:
    6. Driver Action
    7. Longitudinal Distance of Travel
    8. Number of Trajectory Profile Points
    9. Lateral Offset of Trajectory Profile Points
    10. Maximum Lateral Offset
- Impact Conditions – First Event:
    11. Location of Impact
    12. NASS CDS Data
    13. Impact Angle
    14. Vehicle Heading Angle at Impact
- Separation Conditions – First Event:
    15. Location of Separation
    16. Separation Angle

17. Vehicle Heading Angle at Separation

- Subsequent Event/Final Rest

18. Subsequent Event

19. Location of Final Rest

20. Vehicle Heading Angle at Final Rest

Under the reconstruction coding form for subsequent events, there are also 20 data elements under six general categories:

- Case Identification:

1. Year

2. Primary Sampling Unit

3. Case Number-Stratum

- Current Event Identification:

4. Current Event Number

5. Current Event Location

- Vehicle Trajectory Data:

6. Driver Action

7. Longitudinal Distance of Travel

8. Number of Trajectory Profile Points

9. Lateral Offset of Trajectory Profile Points

10. Maximum Lateral Offset

- Impact Conditions – Current Event:

11. Location of Impact

12. NASS CDS Data

13. Impact Angle

14. Vehicle Heading Angle at Impact

- Separation Conditions – Current Event:

15. Location of Separation

16. Separation Angle

17. Vehicle Heading Angle at Separation

- Subsequent Event/Final Rest

18. Subsequent Event

19. Location of Final Rest

20. Vehicle Heading Angle at Final Rest

The completed case, including data from the regular NASS CDS data collection, the supplemental field data collection, and the manual review and reconstruction, was then sent to the project staff for final quality control and reconstruction to estimate the impact speeds.

3.4.4 Reconstruction of Impact Speed

As mentioned above, the completed cases from KLD Associates went through one final quality check by the project staff to assure completeness and accuracy. The cases were then reconstructed to estimate the impact speeds. Reconstruction of single-vehicle, ran-off-road crashes is greatly complicated by the wide variety of roadside objects. For example, Table 12 shows a list of first harmful events caused by objects struck from the 1999 Fatality Analysis Reporting System (FARS) data. It is obvious from the list that the object struck varies widely, from impacts with roadside hazards (e.g., trees and utility poles) to roadside safety devices (e.g., guardrails and crash cushions) to terrain features (e.g., embankments and ditches). In order to accurately identify impact conditions associated with these accidents, it is critical to implement crash reconstruction procedures appropriate for each of the hazards listed.

In general, reconstructions of single-vehicle, ran-off-road crashes primarily involve calculating energy losses and gains after leaving the roadway. Energy changes during ran-off-road crashes can generally be attributed to one or more of these seven categories:

- Vehicle crush
- Damage to roadside feature
- Tire braking
- Tire side slip
- Vehicle rollover
- Change in vehicle elevation
- Friction between vehicle and roadside feature

Key data elements needed to accurately estimate these energy changes include, but are not limited to:

- Impact sequence
- Vehicle crush profile
- Impact angle/principal direction of force during crash
- Vehicle trajectory, including tire mark measurement and description
- Driver action, i.e., steering/braking, Roll distance and number of quarter roll
- Changes in elevation along the vehicle path
- Extent of damage to roadside feature

It should be noted that these data elements pertain to perishable evidence that have to be collected at the time of the crash investigation. For a prospective study in which data are collected on crashes as they occur, the study can be designed to properly document the required data elements. However, in the case of a retrospective study like the current project, the data availability and quality is limited by what was actually collected and could be lacking for some of the data elements. The availability and quality of the data elements can be divided into the following general categories:

- Data elements that are well documented and coded in the NASS CDS cases, such as impact sequence, vehicle crush profile, principal direction of force, and number of quarter rolls. The quality of these data elements is typically high and no further work is needed.
- Data elements that are documented and coded in the CDS cases, but the quality of the data may be somewhat questionable, e.g., driver action. These data elements would need to be checked against other available evidence, such as the scaled diagram, annotated remarks, and photographic documentation, to verify the accuracy of the coded data.
- Data elements are documented, but not coded, and the quality of the data may vary greatly from case to case, e.g., vehicle trajectory, tire marks, impact angle, and roll distance. These data elements would have to be gleaned from the scaled diagram, annotated remarks, and photographic documentation.
- Data elements that are not documented. The two areas where existing NASS CDS cases may not contain sufficient information are elevation changes along the vehicle path and the characteristics and sustained damage of the impacted roadside feature(s). These data elements would have to be gleaned from the photographic documentation to the extent possible or the information collected in the supplemental data collection effort. It should be noted, however, that the implicit assumption was

that the data from the supplemental data collection were the same as at the time of the crash, which may or may not be true.

Although deformation of roadside features is an important source of energy dissipation for some crashes, many ran-off-road crashes would not involve deformable fixed objects. For the limited number of cases where this energy dissipation factor is important, it may be necessary to make estimates of deformation from case photographs and supplemental site investigations. Change in elevation during a crash is generally not an important source of energy change unless the vehicle has traversed a very deep roadside embankment. Elevation changes along the vehicle path can be estimated by recording the dimensions of the various side slopes.

While the general principle of identifying the energy loss parameters during the collision and summing the total to determine the change in velocity from the point of impact to the final resting position is rather straightforward, the actual reconstruction is greatly complicated by the wide variety of roadside features. There is not a single procedure that can be used to reconstruct all ran-off-road crashes. Instead, different reconstruction procedures are needed to accommodate the wide variety of roadside features and types of impact.

There are a number of existing reconstruction procedures developed for reconstructing special types of ran-off-road, fixed-object crashes, including:

- Pole support structure (25)
- Rigid barrier (15)
- Semi-rigid and flexible barrier (14)

These roadside features accounted for about 55 percent of all ran-off-road, fixed-object fatal crashes, as shown in Table 12. For the remaining 45 percent of crashes, the vast majority can be grouped into one of the following five categories:

- Roadside terrain
- Rigid hazards
- Drainage structures
- Buildings and walls
- Fences and shrubbery

New reconstruction procedures were developed for these five categories of roadside features. Brief discussions on reconstruction procedures for the various roadside features are presented in the following sections.

3.4.4.1 Pole Support Structures

A computerized reconstruction procedure was developed for ran-off-road crashes involving pole support structure, including breakaway and nonbreakaway utility poles, luminaire supports, and sign supports (25). Energy loss is grouped into three major categories:

- Vehicle crush. The CRASH3 (27) reconstruction program was utilized to estimate vehicle crush energy based on vehicle crush measurements.
- Fracture of pole. Energy associated with breaking or fracture of the pole was estimated based on empirical test data.
- Post-impact vehicle trajectory. The CRASH3 reconstruction program was also utilized, to the extent possible, for estimating the energy or speed loss associated with the post-impact vehicle trajectory. Otherwise, manual calculations were performed for the reconstruction.

This procedure was utilized whenever possible for reconstruction of crashes involving pole support structures, e.g., utility poles, luminaire, sign, and traffic signal supports, other post/supports, and fire hydrants.

3.4.4.2 Rigid Barrier

Another procedure was developed for reconstructing rigid barrier impacts during a study to assess rollovers on concrete barriers (15). This study found that vehicle/barrier friction was a major source of energy dissipation during a crash. Again, energy loss is grouped into three major categories:

- Vehicle crush. The CRASH3 (27) reconstruction program was utilized to estimate vehicle crush energy based on vehicle crush measurements.
- Friction. Energy loss associated with vehicle/barrier friction was estimated as a function of the length of barrier contact.
- Post-impact vehicle trajectory. The CRASH3 reconstruction program was also utilized, to the extent possible, for estimating the energy or speed loss associated with the post-impact vehicle trajectory. Otherwise, manual calculations were used for the reconstruction.

The vehicle crush energy was then matched to the energy associated with the lateral velocity of the impacting vehicle. If both energy estimates are comparable, the procedure was believed to be reasonably accurate. If not, the vehicle crush energy would be adjusted appropriately and a new estimate of the impact speed was generated. This iterative procedure has been found to give reasonably good estimates of impact speed when used to evaluate findings from full-scale crash tests.

3.4.4.3 Semi-Rigid and Flexible Barrier

A reconstruction procedure for semi-rigid and flexible barriers was developed in a study of ran-off-road crashes (14). This procedure utilized similar techniques for estimating vehicle crush and trajectory energy losses. Energy loss associated with the deformation of semi-rigid barriers was estimated from a series of computer simulations that correlated Impact Severity (IS) to maximum barrier deflection. The Impact Severity (IS) is calculated using the following equation:

$$IS = \frac{1}{2} * M(V * \sin\theta)^2$$

where:

IS = Impact Severity

M = Vehicle mass

V = Vehicle velocity

θ = Impact angle

The IS value has been shown to be a good indicator of the degree of loading and maximum deflection of a barrier during an impact. Unfortunately, the maximum barrier deflection after a crash is seldom measured during a NASS CDS investigation. Thus, the permanent barrier deflection was estimated from available photographic documentation. The measured or estimated permanent barrier deflection was then related to the maximum dynamic deflection, which in turn was used to estimate the IS value from the impact.

The impact speed could be estimated from IS value along with the impact angle or by traditional energy loss calculations, including vehicle crush, barrier deformation, and post impact trajectory. An iterative procedure similar to that used to reconstruct rigid barrier crashes was developed for this application.

The procedure from reference 14 was refined and updated for use in the current study. The revised procedure also included techniques for reconstructing impacts with guardrail terminals and crash cushions. These procedures are presented in Volume II of this report.

3.4.4.4 Roadside Terrain

Impacts involving embankments and ditches could be reconstructed if detailed information is available on the terrain and any associated gouges in the terrain along with the vehicle crush. Efforts to model vehicles traversing hazardous roadside terrains have established reasonable measures of the forces and energy associated with vehicle undercarriage components gouging into the terrain (28). Furthermore, for crashes involving vehicles plowing into steep embankments virtually head-on, vehicle crush measurements would produce a good estimate of the total force generated between the embankment and the vehicle. Finally, energy losses associated with rollover accidents have been investigated through computer simulation for a variety of passenger vehicles (29). Hence, impact speeds for crashes involving roadside terrain could be estimated by combining conventional trajectory analyses, such as that used in the CRASH3 reconstruction program, and incorporating procedures for estimating the effects of terrain gouging and vehicle rollover.

3.4.4.5 Rigid Hazards

For rigid obstacles, such as bridge piers and parapets, boulders, and heavy construction equipment, there is little energy dissipated by the rigid hazards themselves. Thus, reconstructions could be based almost entirely on vehicle crush energy and post impact trajectories. These procedures would be similar to those used by Mak (25) to reconstruct pole crashes in which the poles remained intact.

3.4.4.6 Drainage Structures

Drainage structures, such as culverts and curbs, are often traversed during a ran-off-road accident without a significant speed reduction. Full-scale crash testing and computer simulation have shown that speed losses during curb impacts are very low (30). These simulation and test findings were used to obtain gross estimates of the total speed loss associated with curb impacts. Thereafter, other reconstruction techniques could be used to estimate the total energy lost during the post impact trajectory of the vehicle.

Culverts offer significantly greater challenges. Cross-drainage culverts with high headwalls can act as a rigid hazard and could be reconstructed based largely on vehicle crush as described in the previous section. Crash tests of cross-drainage culverts that have been cut to match the slope and/or grated to reduce the severity of crashes have shown that these hazards provide very little energy dissipation (31). This low level of energy dissipation would allow crashes involving these hazards to be reconstructed based on the post-impact trajectory alone. Unfortunately, reconstruction of crashes involving parallel drainage structures were somewhat more difficult. Crash testing has indicated that vehicles striking culverts under driveways or intersecting streets are frequently subjected to violent rollovers. Where possible, procedures for estimating energy losses during vehicle rollover formed the basis for rollover crashes associated with culvert accidents. Conventional trajectory analyses will be used whenever the vehicles remain upright after striking the culvert.

3.4.4.7 Buildings and Walls

When buildings and walls are struck in a more or less head-on configuration conventional reconstruction techniques are applicable only if the building or wall is relatively rigid. No procedure has been developed that can effectively estimate the energy required to break through a building or wall. However, if the structures remain intact, the building or wall was treated as either a rigid hazard or a rigid longitudinal barrier, depending on the nature of the impact.

3.4.4.8 Fences and Shrubbery

Most fences, including chain link and wooden privacy fences, provide relatively little energy dissipation when struck by an automobile traveling at a high rate of speed. Similarly, small shrubs do not offer significant resistance to an impacting vehicle. Therefore, crashes involving these hazards were reconstructed using conventional procedures unless the fence had an unusual construction or the shrubs were large enough to pose a major obstacle to a vehicle.

In summary, by utilizing and refining available reconstruction techniques, it was possible to produce accurate estimates of the impact conditions for most ran-off-road crashes. The reconstruction procedures discussed above should account for almost 90 percent of the serious injury and fatal ran-off-road crashes.

3.4.5 Conduct of Data Collection

The work on supplemental field data collection, quality control, and manual review and reconstruction of the sampled cases was conducted over a period of approximately 12 months. Of the 404 sampled cases, 15 were found to have major construction/reconstruction at the crash sites and thus were eliminated from the sample. One additional case was eliminated because it involved two vehicles. Thus, the final sample size was reduced from 404 to 388.

3.5 Data from Previous Studies

NCHRP Project 17-11 and FHWA's Rollover Study incorporated the same data collection procedures as used in the current study and included at total of 485 cases from NASS-CDS for the years 1997 through 1999. These studies were both conducted by the Texas Transportation Institute, (TTI), and therefore the data from the two studies will be referred collectively as "TTI data." Because the TTI data was collected and processed using the same protocol as the data collected in this study, it was believed to be appropriate to combine the two data sets into a single file. Unfortunately, upon comparison of basic crash data, such as departure velocity and angle, it became apparent that the two data sets were not sufficiently similar to be combined. The biggest differences were found in departure and impact angles. For example, the average departure angle for the TTI data was found to be 19.9 degrees, compared to 17.2 degrees for the 17-22 data. This 15 percent difference in average departure angle was considered to be excessive. When a simple T-test was applied to compare the two data sets, differences in departure angle were found to be significant at the $p = 0.001$ level. These findings prompted a more careful examination of the differences between the TTI data set and the 17 – 22 data set. It was discovered that the TTI cases were reconstructed from scene diagrams downloaded from the NASS–CDS website. These scene diagrams had been converted to PDF format before being posted on the website. Unfortunately, the process of converting the scene diagrams to PDF changed the scaling of the drawings. The compression in the longitudinal direction was found to be greater than the compression in the lateral direction. As a result, all angle measurements were corrupted.

3.5.1 Manual Review and Crash Reconstruction of Prior Cases

In order to salvage the 485 cases included in the TTI data set, it was necessary to obtain the original scene diagrams and repeat the reconstruction process for all of the cases. Unfortunately, supplemental data forms for 35 of the TTI cases were lost in transit from College Station, Texas to Lincoln, Nebraska. Although reconstructions were possible for these 35 cases, much of the supplemental information such as roadside topography, land-use, highway classification, and highway alignment could not be determined.

3.5.2 Incorporation of Prior Data into Database

After the reconstructions and manual reviews were for repeated for the TTI cases, the TTI and 17-22 data sets were subjected to a comprehensive evaluation to determine the appropriateness of combining them into a single data set. Each important variable was tested to determine the significance of differences between the two data sets. Whenever a variable was found to be significantly different at the $p = 0.05$ level, all 877 cases were re-examined to identify the source of the error. In some cases, the errors were found to be related to the way a specific parameter was measured. For example, the heading angle at departure was measured from -180 to 180 degrees in the 17-22 data and from 0 to 360 degrees in the TTI data. These errors were easily corrected. Other data elements were found to have been poorly recorded on the supplemental data forms. For example, in some cases, the one of the roadside slopes was recorded as the highway grade. In this situation, the research team was forced to reexamine every case to compare photographs at the scene with the recorded highway grade. Whenever there was reasonable evidence of an error, the entire file was examined for evidence of the highway grade. In some cases, the highway grade was found in investigator notes on the supplemental data forms. In other situations, the elevation changes along the roadway were recorded between the point of departure and at a point where the vehicle reentered the roadway. These elevation changes were then used to estimate highway grade at the crash site. Unfortunately, there were many cases where the highway grade could not be identified and the variable had to be labeled as unknown. This type of examination was undertaken for a large number of data elements that were found to be significantly different in the two data sets.

As shown in Table 13, most variables with significant differences between the two data sets were corrected and the two data sets could be considered to be relatively similar. Unfortunately, significant differences remained for some variables, including speed limit, vehicle weight, height and width of object struck, rollover, and vehicle class. Differences in speed limit and vehicle weight are believed to be appropriate. The national speed limit law was repealed in late 1995 and was not implemented immediately in many states. In fact, 18 states had not implemented any change in speed limit before the end of 1997. Many of these states eventually raised speed limits. Recall that the TTI data included crashes from 1997 through 1999 while the 17-22 study included data from 2000-2001. Thus, it is not surprising that speed limits were found to increase between the time of data collection for the TTI and 17-22 data sets. Similarly, the average weight of the vehicle fleet increased dramatically during the 1990's. In the early 1990's, the 5th and 95th percentile passenger vehicle weights were 1800 and 4400 lb respectively. By 2002, the 5th and 95th percentile weights had increased to 2500 and 5200 lb respectively. This dramatic increase in vehicle weight would be expected to cause the average weight of crash vehicles to be higher in 2000 & 2001 than during the 1997 through 1999 period. Hence, the nearly 200 lb increase in average weight between the TTI and 17-22 data sets is not unexpected.

Careful examination of the two data sets revealed that the differences in the width and height of the object struck between the two data sets could be attributed to an over representation in the number of tall trees impacted in the 17-22 data and over representation of wide ditches in the TTI data. Note that the increase in the number of trees or the number of ditches was not sufficient to produce statistically significant differences in the object struck category. However, the number of very tall trees (15 meters or more) in the 17-22 data was sufficient to produce significant differences in the height of the object struck. Further, a relatively small number of wide ditches in the TTI data produced significant differences in the width of the object struck.

The number of rollovers in the 17-22 was found to be significantly greater than in the TTI data. As shown in Table 13, 59% of the cases from 17-22 involved vehicle rollover compared to only 50% for the TTI data. A careful evaluation of each case in both data sets could not provide any explanation for the magnitude of the difference in rollover frequency. The only possible explanations for the high rollover rate is that the 17-22 data also had 47% light truck involement compared to 38% for TTI data. Although light truck sales were growing during the 1997 through 2001 time frame, the 9% increase in light truck involvement is unexpectedly high. Further, even though light trucks are known to have a higher risk of rollover, the over representation of light trucks is insufficient to explain the full magnitude of the difference in rollover rate. The rollover rate for both cars and light trucks were found to be significantly higher in the 17-22 data than in the TTI data. The 17-22 data had 50% and 69% rollover rates for cars and light trucks, respectively, while the comparable numbers from the TTI data were 44% and 59%. Unfortunately, the fundamental differences in rollover rate could neither be eliminated nor explained.

In spite of the differences found in the 6 variables described above, differences between the two data sets were not statistically significant for the vast majority of data elements. Based upon this finding, combining the two data sets was deemed acceptable. Note finding differences not to be statistically significant does not necessarily imply that the data sets are similar. Users should use caution whenever using the combined database to examine highway or crash characteristics that are close to the threshold of statistical significance.

3.6 Relational Database

The design of a relational database for the purpose of storage and retrieval of crash data was developed and implemented. In addition to the data collected under this study, the crash database also stored data from NCHRP 17-11 and the FHWA Rollover Study.

The crash database design revolved around the Oracle server, which is an object-relational database management system providing an open, comprehensive, and integrated approach to data management. The crash database was composed of a data file containing different types of elements (e.g., CASE_NUM, CASE_ID, DEPARTURE ANGLE, etc.). A user process (or a client process) and a server process were used for successful communication between users and the crash database. Together these two processes enabled users to run various queries on the database.

Access to the crash database could be obtained by directly issuing SQL commands or through the use of an application that contains SQL statements. The Oracle crash database processes the commands and returns results to the users. It is physically located on a server residing at the Nebraska Transportation Center (UNL). Currently, logging in directly on the host computer is supported, i.e., the computer running the Oracle crash database server is used for database access. The communication pathway is established using the inter-process communication mechanisms available on the host computer. Logging in via a two-tiered (client-server) connection, where the machine on which the user is logged in is connected directly to the machine running the Oracle crash database serve,r and via a three-tiered connection, where users will connect to the Oracle crash database server via network server(s) by using a customized application, are possible but have not been implemented. However, remote access to the database is available using Windows® Remote Desktop Connection (password protected). Data element names and definitions are presented in Appendix D.

Table 1. Data Needs for Current Study

Variable	Availability
Case Screening Criteria	
• Area type - PSU	1
• Crash type - Single-vehicle, ran-off-road crashes	1
• Vehicle type - Passenger vehicles only	1
• Completeness of data on key variables	1
• Injury severity - Serious and fatal injury	1
Variables of Primary Interest:	
• Encroachment conditions at point of departure	
- Action prior to leaving travelway	1
- Speed	3
- Angle	3
• Pre-impact vehicle trajectory	
- Vehicle path	3
- Maximum lateral extent of encroachment	3
- Total longitudinal distance	3
• General impact data	
- Impact sequence	1
- Object struck	1
- Rollover occurrence	1
- Post-impact trajectory	3
• Impact conditions – first harmful event	
- Impact speed	3
- Impact angle	3
- Vehicle orientation	3
• Impact conditions – most harmful event	
- Impact speed	3
- Impact angle	3
- Vehicle orientation	3
• Driver action	
- Evasive action	1
- Steering – vehicle path	3
- Braking	3
Controlling Variables:	
• Highway type	
- Functional class	2
- Roadway type	1
- Speed limit	1

Table 1. Data Needs for Current Study (Cont'd)

Variable	Availability
Controlling Variables (Cont'd):	
• Travelway characteristics	
- Number of lanes	2
- Lane width	2
- Horizontal curvature - Point of departure and maximum	2
- Vertical grade - Point of departure and maximum	2
• Roadside characteristics	
- Shoulder type and width	2
- Roadside slopes – widths and rates of slopes	2
- Median type, width, and slope	2
• Traffic characteristics	
- ADT	2
- Percent truck	2
• Struck object characteristics	
- Object type	2
- Impact performance	3
• Vehicle characteristics	
- Type	1
- Make and Model	1
- Curb weight	1
- Vehicle damage	1
- Occupant compartment deformation and intrusion	1
• Highest occupant injury severity	
- Abbreviated Injury Scale (AIS)	1
- Police Injury Code (PIC)	1
• EDR data	1
Variables of Secondary Interest:	
• Time	
- Day of week	1
- Time of day	1
• Environmental conditions	
- Light	1
- Weather	1

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*Legends for Data Availability:

1. Existing NASS CDS data
2. Supplemental field data collection
3. Reconstruction

Table 2. Breakdown of 2000 and 2001 NASS CDS Cases by Screening Criteria

Year	Total No. Of Cases	16 Rural and Suburban PSUs	Speed Limit ≥ 45 mph	Passenger Vehicle/ Single-Vehicle Ran-Off-Road Crashes
2000	4307	2929	1518	603
2001	4090	2833	1500	593
Total	8397	5778	3063	1196

Table 3. Eligible Cases by Maximum AIS

Abbreviated Injury Scale (AIS)	Unweighted		Weighted	
	Number	Percent	Number	Percent
No Injury (0)	121	11.17	280,985	43.64
Minor Injury (1)	385	35.55	258,559	40.15
Moderate Injury (2)	229	21.14	53,554	8.32
Serious Injury (3)	175	16.16	23,074	3.58
Severe Injury (4)	80	7.39	20,846	3.24
Critical Injury (5)	68	6.28	5,190	0.81
Maximum Injury (6)	25	2.31	1,712	0.27
Total	1,083	100.00	672,745	100.00

* Missing Cases = 113 unweighted (45,970 weighted)

Table 4. Eligible Cases by Number of Lanes

Number of Lanes	Unweighted		Weighted	
	No.	Percent	No.	Percent
1	38	3.18	23,809	3.45
2 & 3	998	83.44	565,855	82.02
>= 4	160	13.38	100,227	14.53
Total	1,196	100.00	689,891	100.00

Table 5. Eligible Cases by Vehicle Type

Vehicle Type	Unweighted		Weighted	
	No.	Percent	No.	Percent
Passenger Car	696	58.19	445,651	64.60
Sport Utility Vehicle	198	16.56	103,434	14.99
Van/Minivan	55	4.60	26,138	3.79
Pickup Truck	247	20.65	114,668	16.62
Total	1,196	100.00	689,891	100.00

Table 6. Eligible, Complete, and Sampled Cases by Primary Sampling Unit (PSU)

Area Type	PSU	Eligible Cases		Complete Cases		Sampled Cases	
		No.	Percent	No.	Percent	No.	Percent
Rural	2	59	4.93	31	7.09	31	7.67
	4	35	2.93	0	0.00	0	0.00
	11	145	12.12	59	13.50	59	14.60
	13	130	10.87	86	19.68	86	21.29
	43	100	8.36	4	0.92	0	0.00
	48	114	9.53	40	9.15	40	9.90
	76	109	9.11	41	9.38	41	10.15
	78	85	7.11	43	9.84	43	10.64
	Subtotal	777	64.97	304	69.57	300	74.26
Suburban	5	16	1.34	2	0.46	0	0.00
	8	28	2.34	15	3.43	0	0.00
	9	64	5.35	12	2.75	0	0.00
	12	94	7.86	47	10.76	47	11.63
	45	60	5.02	38	8.70	38	9.41
	73	48	4.01	0	0.00	0	0.00
	75	57	4.77	19	4.35	19	4.70
	81	52	4.35	0	0.00	0	0.00
	Subtotal	419	35.03	133	30.43	104	25.74
Total		1,196	100.00	437	100.00	404	100.00

Table 7. Sampled Cases by Highest Injury Severity

Abbreviated Injury Scale (AIS)	Unweighted		Weighted	
	Number	Percent	Number	Percent
No Injury (0)	29	7.18	88,968	41.15
Minor Injury (1)	142	35.15	87,723	40.58
Moderate Injury (2)	94	23.27	16,063	7.43
Serious Injury (3)	69	17.08	11,387	5.27
Severe Injury (4)	30	7.43	9,966	3.68
Critical Injury (5)	32	7.92	3,056	1.41
Maximum Injury (6)	8	1.98	1,024	0.47
Total	404	100.00	216,187	100.00

Table 8. Sampled Cases by Number of Lanes

Number of Lanes	Unweighted		Weighted	
	No.	Percent	No.	Percent
1	14	3.47	8,531	3.95
2 & 3	356	88.12	195,360	90.36
>= 4	34	8.42	12,296	5.69
Total	404	100.00	216,187	100.00

Table 9. Sampled Cases by Vehicle Type

Vehicle Type	Unweighted		Weighted	
	No.	Percent	No.	Percent
Passenger Car	212	52.48	140,692	65.08
Sport Utility Vehicle	64	15.84	67,169	11.25
Van/Minivan	23	5.69	3,502	1.62
Pickup Truck	105	25.99	45,511	21.05
Total	404	100.00	216,187	100.00

Table 10. Data Elements Requiring Supplemental Field Data Collection

- Highway type
    - Functional class
- Highway characteristics
    - Number of lanes
    - Lane width
    - Horizontal curvature - Point of departure and maximum
    - Vertical grade - Point of departure and maximum
- Roadside characteristics
    - Shoulder type and width
    - Roadside slopes – widths and rates of slopes
    - Median type, width and slope
- Traffic characteristics
    - ADT
    - Percent truck
- Struck object characteristics
    - Object type
    - Impact performance

Table 11. Data Elements Requiring Reconstruction

- Encroachment conditions at point of departure
  - Speed
  - Angle
- Pre-impact vehicle trajectory
  - Vehicle path
  - Maximum lateral extent of encroachment
  - Total longitudinal distance
- General impact data
  - Post-impact trajectory
- Impact conditions – first harmful event
  - Impact speed
  - Impact angle
  - Vehicle orientation
- Impact conditions – most harmful event
  - Impact speed
  - Impact angle
  - Vehicle orientation
- Driver action
  - Steering – vehicle path
  - Braking

Table 12. Object Struck as First Harmful Event from 1999 FARS Data

Object	Frequency	Percent
Tree	2,997	26.09
Embankment	1,213	10.56
Guardrail	1,078	9.39
Utility Pole	1,018	8.86
Ditch	887	7.72
Curb	681	5.93
Culvert	592	5.15
Fence	490	4.27
Sign Support	368	3.20
Other Post/Support	308	2.68
Concrete Barrier	275	2.39
Bridge Rail	158	1.38
Bridge Pier/Abutment	155	1.35
Wall	119	1.04
Luminaire Support	103	0.90
Boulder	79	0.69
Building	79	0.69
Shrubbery	56	0.49
Bridge Parapet	36	0.31
Equipment	26	0.23
Fire Hydrant	25	0.22
Other Longitudinal Barrier	23	0.20
Snow Bank	23	0.20
Traffic Signal Support	22	0.19
Unknown	22	0.19
Impact Attenuator	11	0.10
Other Fixed Object	506	4.41
Other Object (not fixed)	135	1.18
Total	11,485	100.00

Table 13. Comparison of 17-22 and TTI Data

		17-22 Data			TTI Data			
Variable	Units	Mean	Std Dev.	SEM	Mean	Std Dev.	SEM	P Value
Dep. Velocity	km/hr	80.00	26.00	1.32	78.70	25.30	1.15	0.48
Dep. Angle	deg.	17.20	11.90	0.60	16.90	10.20	0.47	0.70
IS Value	kJ	41.70	59.60	3.02	36.90	74.90	3.41	0.31
Degree of curvature	deg.	2.27	7.50	2.65	2.65	6.72	0.32	0.45
Driver Action		3.92	3.03	0.15	4.16	3.09	0.15	0.27
Month		6.68	3.45	0.17	6.39	3.00	0.14	0.20
Access control		2.27	0.92	0.05	2.28	0.94	0.04	0.82
Accident time		0.48	0.30	0.02	0.52	0.40	0.02	0.10
Alignment		1.53	0.79	0.04	1.61	0.80	0.04	0.17
Curb height	mm	5.59	29.23	1.48	8.24	39.31	1.86	0.27
Curbs		0.09	0.40	0.02	0.08	0.36	0.02	0.64
Departure side		1.49	0.50	0.03	1.43	0.50	0.02	0.07
Divided/ Undivided		1.43	0.50	0.03	1.38	0.49	0.02	0.14
Grade	%	1.50	1.67	0.08	1.39	1.49	0.07	0.10
Highway speed limit	mph	57.45	9.24	0.47	55.68	9.44	0.43	0.006
Land use		1.76	0.43	0.02	1.70	0.47	0.02	0.06
Lane width	m	3.69	0.55	0.03	3.64	0.52	0.02	0.18
Lat distance from departure to rest	m	0.07	13.45	0.68	1.24	13.22	0.60	0.20
Lateral travel	m	0.37	12.22	0.62	1.02	12.93	0.59	0.45
Heading angle at Point of Rest	deg.	166.15	111.15	5.63	165.27	111.47	5.21	0.91
Long. distance from dep. to rest	m	46.40	37.83	1.91	44.84	40.05	1.82	0.56

Table 13. Comparison of 17-22 and TTI Data (Cont'd)

		17-22 Data			TTI Data			
Variable	Units	Mean	Std Dev.	SEM	Mean	Std Dev.	SEM	P Value
Long. travel, 1st encroachment	m	39.14	30.89	1.56	39.79	34.71	1.58	0.78
Material of Object struck		5.02	2.60	0.13	4.70	2.29	0.11	0.06
No. of slopes		4.11	1.81	0.09	3.94	1.59	0.08	0.15
Object Diameter	cm	33.54	26.55	2.81	29.44	38.90	2.66	0.36
Object Height	cm	475.84	699.70	62.33	215.86	240.01	17.60	0.0001
Object Length	cm	2937	6326	922.8	1145	2229.	388.1	0.12
Object Width	m	68.91	292.38	19.15	292.38	433.98	38.97	0.0003
Road Class		2.77	2.86	1.29	2.86	1.43	0.07	0.33
Road Condition		1.36	0.82	0.04	1.31	0.72	0.03	0.32
Road Profile		0.52	0.82	0.04	0.53	0.89	0.04	0.90
Road Surface		1.21	0.65	0.03	1.25	0.75	0.03	0.46
Rollover		0.59	0.49	0.02	0.50	0.50	0.02	0.008
Shoulder type		1.27	0.74	0.04	1.30	0.84	0.04	0.55
Shoulder Width	m	1.77	1.31	0.07	1.86	1.40	0.07	0.37
Sideslip angle	deg.	-1.02	38.61	1.38	0.63	38.59	1.76	0.46
Vehicle weight	lb	3348.32	861.96	43.59	3154.16	738.30	33.52	0.0003
Weather		1.24	0.69	0.03	1.20	0.57	0.03	0.32
X-section at departure		5.43	2.66	0.13	5.45	2.67	0.13	0.89

4 RESULTS

4.1 General

The following chapter presents an overview of the data set developed under the current study. A brief comparison of the content of the 17-22 and TTI data set are presented below. Descriptive statistics for the combined data set are then presented followed by a detailed evaluation of the impact conditions and comparison of the current data and historical studies. Encroachment lengths from the combined data set are then compared to historical studies and implications of the new data on the calculation of appropriate guardrail length is discussed. Additional tables and plots describing the basic characteristics of the combined data set are presented in Appendix E.

4.1.1 Comparison of 17-22 and TTI Data

A summary of the efforts to compare the 17-22 and TTI data sets was presented previously in Section 3.5. As shown in Table 13, differences between the two data sets were found to be statistically insignificant for the vast majority of the important variables. Vehicle weight, highway speed limit, rollover frequency, and vehicle class were exceptions to this finding. The modest changes observed in vehicle weight and roadway speed limits could be explained by changes in the vehicle fleet and elimination of the national speed limit law. Unfortunately, the magnitude of the change in vehicle class and the rollover rates between the 17-22 and TTI data could not be adequately explained.

Most other important variables correlated very well between the two data sets. As shown in Table 14, injury and fatality rates for the two studies are virtually identical. Departure speeds and angles are also very similar as shown in Figures 1 and 2. Vehicle heading angle distributions were also found to be very similar, as shown in Figure 3. Although the Impact Severity (IS) distributions, shown in Figure 4, were not as similar as the other comparisons, the differences were not statistically significant. Recall that IS was defined in Chapter 2 as:

$$IS = \frac{1}{2} * M * (V * \sin \theta)$$

where:

IS = Impact Severity

M = Vehicle mass

V = Vehicle velocity

θ = Impact angle

Table 14 and Figures 1 through 4 clearly illustrate that injury rates and departure conditions from the TTI and 17-22 data are sufficiently similar to allow the data to be combined into a single data base. As discussed in the prior chapter, the similarity between the two data sets for the vast majority of important data elements is sufficient to justify combining them into a single database. Never-the-less, database users should be cognizant of the differences in rollover rates and vehicle classes when developing data queries. Additional comparisons between the 17-22 and TTI data sets are presented in Appendix E.

4.2 Descriptive Statistics

When combined into a single data set, the 17-22 and TTI data included a total of 877 cases. The following sections provide a basic description of the combined data set.

4.2.1 Characteristics of Sampled Cases

As shown in Table 15, rural highways comprise approximately 72 percent of the accident cases with the remaining 28 percent of cases located in urban areas. Table 16 shows that the data set includes a significant representation of cases on Interstate, US Highways, State Routes, and County roads. The largest number of cases, 275 (32.7%), occurred on County Roads and 195

(23.2%) cases were on Interstate highways. The number of cases on US and State highways are approximately the same at 160 (19.0%) and 161 (19.1%) cases respectively. As would be expected for crashes collected from these highway types, the data set includes a wide distribution of speed limits ranging from 45 to 75 mph, as shown in Table 17. Table 18 presents this distribution of speed limit by highway class. As expected, most of the data collected from high-speed facilities involved interstate highways and the majority of cases involving low-speed minutes were collected on county roads. Tables 19 and 20 shows the number of lanes at the accident site for divided and undivided highways, respectively.

Surprisingly, even though a large proportion of crashes involved interstate and US highways, very few cases involved vehicles departing from a portland cement pavement surface. As shown in Table 21, the vast majority of the cases, 773 (88.1%), occurred on asphalt with only 45 (5.1%) involving portland cement concrete.

As shown in Table 22, winter months were significantly underrepresented in the data. Only 132 (15.1%) crashes occurred during the winter months from December through February. The low proportion of crashes during the winter provided an explanation for the low numbers of crashes with ice, 28 (3.1%), or snow, 25 (2.9%), on the roadway surface, as shown in Table 23. This table also shows that almost 80 percent of all of the crashes in the data set occurred on dry roadways. These findings correlated with the weather conditions at the time of the crash, shown in Table 24. More than 85 percent of the crashes occurred in clear weather and less than 10 percent occurred in the rain.

A total of 529 of the 877 cases were recorded as having struck an object on the roadside. As shown in Table 25, more than 37 percent of these "fixed object" crashes involved trees and another 7 percent involved utility pole impacts. More than 18 percent of the fixed object crashes involved longitudinal barrier impacts. Thus, approximately 62 percent of fixed object crashes involved impacts that would be expected to significantly reduce vehicle speed or redirect it back toward the roadway. The remaining 38 percent of crashes involved fixed objects that would be less likely to significantly reduce the speed of the impacting vehicle (e.g. embankments, ditches, curbs, breakaway sign in luminaire supports, fences, mailboxes and culverts).

Table 26 presents the distribution of vehicle classes included in the data set. Almost 58 percent of vehicles included in the data set were classified as "car". Further, another 28 percent of vehicles fell into the compact light truck class including compact pickups, compact utility vehicles, and minivans. Only 13 percent of vehicles included in the database were full-size pickups, utility vehicles, or vans.

4.2.2 Crash Severity

As expected the data set is biased toward higher severity crashes. As shown in Table 27, roughly 15 percent of the cases involved a fatality and approximately 73 percent of all cases involved either an A-injury or a fatality (A+K). A recent study of single vehicle crashes on controlled access freeways in Kansas found a fatality rate of only 0.73 percent and an A+K rate of only 3.8 percent (32). From the data in Table 27, the fatality rate for Interstate highways in the data set was 18 percent and the A+K rate was 74 percent. These fatality and A+K rates were 25 and 19 times higher, respectively, than the values for controlled access freeways in Kansas. This degree of bias is associated with the original case selection criteria used to identify the NASS-CDS cases and therefore cannot be avoided. This inherent bias toward increased severity may be masking the relationship between highway functional class and crash severity for this database. As shown in Table 27, the A+ K rates for all highway functional classes is approximately the same with a minimum of 69 percent for County roads and a high of 75 percent for US highways.

This same bias toward higher severity crashes is also evident in Tables 28 through 31. Table 28 presents the relationship between specific vehicle class and crash severity. There appears to be no consistent trend between vehicle size and crash severity. Table 29 condenses this information to produce crash severity by overall vehicle type. Again there is appears to be only modest differences in crash severity as a function of overall vehicle type. Tables 30 and 31 also illustrate that the severity bias masks the effects of rollover and object struck on crash severity, respectively. For example, fatality rates for tree and guardrail impacts are found to be very similar at 13.2% and 12.7% respectively. Thus, Tables 27 through 31 clearly illustrate that the database described herein cannot be used to evaluate the severity of different types of crashes whether it involves crash outcome such as rollover, vehicle class, or object struck.

However, the purpose of this database is not to provide relative comparisons of crash severities available from conventional databases, but rather to provide the basis for developing a relationship between crash conditions and severity for various types of hazards. Table 32 illustrates the strong relationship between departure velocity and crash severity. Both fatality rate and A+ K rate increased with each increment in departure velocity. Tables 33 and 34 show injury severity and rollover risk, respectively, by vehicle type for departure velocities from 60-75 mph.

Table 35 shows the relationship between impact velocity and crash severity for W-beam guardrails. Again, there appears to be a strong correlation between impact speed and probability of fatal and serious injury. Table 36 provides a comparison between impact angle and crash severity for W-beam guardrails. Although at first glance, there appears to be a general trend for lower impact angles to produce higher crash severities, when A+K severities are considered, the apparent relationship disappears and impact angle appears to have little correlation with severity. Even in light of the very limited amount of data, this finding was quite surprising. The relationship between

IS value and severity, shown in Table 37, was also quite surprising. After further investigation, it was discovered that the guardrail impact was not the most harmful event for most of the serious injuries associated with low angle and low IS crashes. Tables 38 and 39 present crash severity versus impact angle and IS value for crashes where the guardrail impact was the most severe event. These tables display the expected correlation between impact angle and IS versus crash severity.

4.3 Departure Conditions

One of the primary objectives of developing the database described herein was to identify the departure conditions associated with serious ran-off-road crashes. The encroachment conditions described below are associated with a database that has an A+K injury rate of more than 70%. Clearly, this database is heavily biased and it can be considered to be representative serious ran off-road crashes.

4.3.1 Departure Speed and Angle Distributions

As shown in Table 40, the mean departure speed was found to be 49.26 mph. This value was higher than the mean value found by Mak (3) in the late 1970's. Table 41 presents a comparison of velocity data from the current study and Mak's pole study. In order to compare the two studies, it was necessary to adjust the roadway classifications in this study to match the functional classes in reference 3. All fully controlled access roadways were classified as freeways and US and State routes were classified as arterials. County roads and city streets were then placed into the collector/local category. Although this classification scheme is not perfect, it did place all roadways with high volume and most medium volume roadways in the arterial category. Note the velocity distributions from this study are significantly higher than those found by Mak (3). This finding is believed to arise from the elimination of the national speed limit law and the bias in the current study toward severe crashes. Figure 5 graphically illustrates the differences between the velocity distributions on freeways in the two studies.

The mean impact angle shown in Table 40 is also higher than the corresponding angle from the Pole Study. A simple cornering analysis would indicate that higher departure speeds should produce lower departure angles. Thus, the increase in both departure speed and departure angle is unexpected. The most plausible explanation for this finding would be the wide implementation of antilock brakes. In the late 1970s, very few passenger cars had antilock brakes and by the late 1990s, the majority of the vehicle fleet was so equipped. In theory, antilock brakes are intended to allow drivers to continue to steer through emergency braking procedures. Unfortunately, research has not been able to identify significant reduction crash risk or crash severity associated with the use of antilock brakes. This finding may indicate that allowing drivers to continue to steer through emergency situations does not necessarily reduce the angle of departure from the roadway. Figure 6 shows a graphical comparison of freeway departure angles for the MwRSF database, the Pole Study, and encroachment data from Cooper and Hutchinson and Kennedy. Note that the angle distributions from the current study are very near those found by Cooper. Table 42 presents a comparison between departure angles from the MwRSF and Pole studies for all roadway classes. Notice that with the exception of urban local/collector, all measures of departure angle for the current study were higher than those from the Pole Study. However, the magnitude of the differences was found to be relatively modest.

4.3.2 Theoretical Modeling of Impact Speed and Angle Distributions

Tables 43 and 44 show descriptive statistics for departure velocity and angle respectively, segregated by road class. Note that with the exception of the Interstate classification, the mean velocities were quite similar. Further departure angle did not vary significantly from one road classification to the next. These findings lead to the conclusion that roadway classification may not be the best discriminator for departure conditions.

Tables 45 and 46 show descriptive statistics for departure velocity and angle respectively, segregated by speed limit. Note that the mean velocities now show more significant variation and the trend is correlated with speed limit. There is also more discrimination in the mean angle when the data are segregated by speed limit. Although prior studies showed that functional class was the best discriminator for departure speed, functional class was not identifiable in the current database. Findings from Tables 43 through 46 indicate that the surrogate measures used to indicate functional class may not be appropriate. However, speed limit does appear to provide a significant degree of discrimination for both departure speed and angle.

Tables 43 through 46 also present skewness values for velocity and angle data. Note that mean skewness for velocity data is near zero while mean skewness for angle data is above 1.0. These skewness measures indicate that the velocity data may best be modeled with a normal distribution while angle data would be more likely to fit a gamma model.

Angle and velocity data from the Pole Study were found to fit a gamma distribution while other studies (1) found that the speed data fit a normal distribution. As a first step to modeling departure conditions, normal and gamma distributions were fit to departure speed and angle data for the total database and for each speed limit range as shown in Tables 47 and 48. Table 47 shows that the velocity distributions for the total database and all categories of speed limit were found to fit a normal distribution quite well. Although the gamma distribution was found to fit most speed limit categories acceptably well, p-values for both the total data set and the 50 mph speed limit category were below 0.05, indicating a poor fit to the data. Figure 7 shows the quality of fit for normal and gamma distribution to velocity data for the total database. Notice that the gamma distribution does not match the data very well.

Table 48 shows that neither normal nor gamma distributions provided an acceptable fit to departure angle data for all speed limit categories. Figure 8 shows the poor quality of fit for these distributions to the departure angle data from the total data set. In light of the poor quality of the normal and gamma distribution fits to the departure angle data, 53 other distributions were then fit to the departure angle data from all speed limit categories. Unfortunately, it was found that no single distribution adequately fit all speed limit categories. In fact, the gamma distribution was found to come as close to fitting all data categories as any of the distributions. In order to produce an acceptable fit to departure angle data, it was decided to utilize the square root of the departure angle as the independent variable. Using the square root of the departure angle shifts the distribution to the left and reduces the accuracy of predictions at the high end of the curve. However, adjusting the independent variable in this manner is an acceptable method for improving statistical fits to measured data. As shown in Table 49, the gamma distribution was found to fit the square root of the departure angle for all speed limit categories. The p-value of 0.0754 found for the gamma distribution fit to the total data set indicates that this fit is relatively marginal. Note however that the p-values for all individual speed limit categories were found to be 0.27 or higher which indicates a reasonably good fit to the data. Figure 9 illustrates the use of a gamma distribution fit to the square root of the departure angle to model departure angle data.

Tables 47 and 49 provide parameters for fitting normal and gamma distributions to departure speed and square root of departure angle respectively. The next step in modeling departure conditions involved exploring the dependence of speed and angle. A Chi-square test for independence was employed for this evaluation. Table 50 shows a contingency table for all departure speed and angle combinations and Table 51 resents expected frequencies if speed and angle are independent. A Chi-square goodness-of-fit test was then used to measure the appropriateness of the independence assumption using the following equation to calculate the Chi-square statistic.

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

Where:

χ = Chi-square measure of error between the two contingency tables.

Oi = Observed frequency in cell i.

Ei = Expected frequency in cell i.

k = number of cells in table.

The Chi-square statistic calculated from Tables 48 and 49 was found to be 30.54. The number of degrees of freedom for this test is one less than the number of rows times one less than the number of columns. In the example of the entire data base, the 6x6 contingency table shown in Table 48 has 25 degrees of freedom. The Chi-square statistic of 30.54 and 25 degrees of freedom produce a p-value of 0.205. This magnitude of the p-value indicates that angle and speed data can be considered to be independent. The relationship between speed and angle of departure can be graphically illustrated by plotting the distribution of departure angle for three different speed ranges as shown in Figure 10. Note that the angle distribution for the low speed range was found to be higher than the middle or high speed range while differences in departure angle distribution for high and middle speed ranges were found not to be statistically significant. The fact that the differences between departure angle distributions for the middle and high speed ranges were not statistically significant further reinforces the finding that the correlation between speed and angle is sufficiently weak to treat them as independent.

In view of the finding of limited dependence between departure speed and angle for the total database, the Chi-square test for independence was applied to the speed and angle of departure data for each speed limit category. The resulting p-values from these analyses were found to be much higher as shown in Table 52. With all of the p-values greater than 0.05, it is impossible to reject the assumption that the velocity and angle data are independent whenever cases are segregated by speed limit. Based upon the finding of, at most, a very limited degree of dependence between departure speed and angle, the normal distribution fit to velocity data and the gamma distribution fit to square root angle data can be applied independently to produce speed and angle probability distributions for each speed limit category as shown in Tables 53 through 59.

Chi-square tests were then conducted to compare predicted and observed frequencies for each speed limit category. As shown in Table 60, the predicted frequencies compared reasonably well with the observed values for most speed limit categories. These findings indicate that it is acceptable to model departure speed and angle as independent variables. Further, departure speed can be modeled using the normal distribution parameters shown in Table 47 and departure angle can be modeled using the gamma distribution fits to square root of departure angle presented in Table 49. These models produce the departure conditions shown in Tables 53 through 59.

4.4 Encroachment Length

The distance that a vehicle travels along the roadside is an important input to the design of guardrail installations. For the last 30 years or more, guardrail designs were based upon findings from a study of roadside encroachments by Hutchinson and Kennedy (H&K) (7). More recently, data from an encroachment study by Cooper (33) have shown longitudinal travel distances to be much shorter than those measured by H&K. This discrepancy has been attributed to two fundamental differences between the two studies (34, 35). The Cooper study involved highways with speed limits of 59-62 mph (95-100 km/hr) while the H&K study involved speed limits of 70 mph. The other explanation for differences in longitudinal travel distances is the over representation of low angle encroachments in the H&K data. Recall that as shown in Figure 6 above, the angle of departure data from the current study was found to be quite similar to that from Cooper and the pole study while departure angles from H&K were found to be much lower. When H&K data are adjusted to eliminate the bias toward low angle encroachments, the differences between the Cooper and H&K longitudinal travel distances were reduced to the a level that could easily be explained by differences in speed limit.

The database described herein should provide some clarification of which of the two encroachment studies is most appropriate for use in determining guardrail length. Note that the MwRSF database has been constructed from reported accidents, many of which involved impacts with roadside objects. It is reasonable to conclude that many of these vehicles would have traveled farther if the obstacle had not been impacted. However, as described above, the crashes included in this study are strongly biased toward serious injury and fatal crashes. In effect, the data included herein was taken from the very types of roadside crashes guardrail is intended to prevent. Thus, designing guardrail configurations to against these crashes is more appropriate than relying on roadside encroachment data that includes very few reported crashes and undoubtedly includes many controlled encroachments that would never produce a crash.

4.4.1 Raw Data

The first step in the process of evaluating longitudinal travel distances from the current study was to compare encroachment length data from Cooper and H&K to longitudinal travel distances from the current study as shown in Figure 11. For this figure, the data from the current study was limited to access controlled freeways with speed limits of 70-75 mph. The Cooper data was restricted to divided highways with 59-62 mph (95-100 km/hr) speed limits and the H&K data was collected on rural interstate highways with a 70 mph speed limit. Notice that the MwRSF travel distances are close to those from Cooper and that the differences can be explained by the higher speed limits associated with the current study. Figure 12 illustrates the effects of speed limit by comparing data from the current study collected on access controlled highways with 55-65 mph speed limits to the Cooper data taken from divided highways with 59-62 mph (95-100 km/hr) speed limits. These two distributions are not only visually similar, a two tailed T-test analysis indicated that the differences are not statistically significant with a p-value of 0.966. The excellent comparison between Cooper's data and the MwRSF data supports the hypothesis that the long encroachments observed in the H&K study are associated with the over representation of low angle encroachments in the study.

Procedures contained in AASHTO's 2006 Roadside Design Guide identify the required length of a guardrail in terms of a runout length parameter which is based upon the distribution of encroachment lengths from the H&K study. As shown in Table 61, the runout length associated with high volume, high speed roadways was based upon the 85th percentile encroachment length while lower volume roadways were assigned runout lengths based upon a lower percentile encroachment length. Note that 92% of the encroachments collected by H&K were from highways with a 70 mph design speed and traffic volumes less than 6000 vehicles per day. Hence the traffic volume categories shown in Table 61 were based upon the source of the H&K data. The data from Table 61 was then extrapolated to lower design speeds. A more recent study of guardrail length-of-need utilized this same approach to apply Cooper's data to this problem (36). Table 62 presents the comparable results from the Cooper Data. Thus, encroachment length distributions, presented in tabular form as shown in Tables 61 and 62 have been used to develop the recommended values for the guardrail runout length parameter. The MwRSF longitudinal encroachment lengths will therefore be presented in this same format.

Longitudinal departure length data from the MwRSF data set were first examined when categorized by speed limit, access control, and traffic volume. Table 63 presents departure length data segregated by speed limit. Note that there were too few cases with 65 and 50 mph to reliably establish the tail of the distributions. These cases were lumped with the next lower speed limit categories to illustrate the general trend between speed limit and departure length. Table 63 shows that there is a relatively strong trend for departure length to increase with higher speed limits.

The effects of traffic volume and access control on departure lengths were then explored as shown in Tables 64 and 65. Notice that there is no clear trend between traffic volume category and departure length and that there appears to be a strong relationship between access control and departure length. However, there is also correlation between speed limit and access control. In order to isolate the importance of access control on departure length, it is necessary to isolate the evaluation to a constant speed limit. This type of evaluation could not be conducted on the tail of the departure length distribution as shown in Tables 63 through 65 due to the small sample sizes at any one speed limit. Therefore, the effect of access control was evaluated at the median for a 55 mph speed limit. The median departure lengths for a 55 mph roadway were found to be 45.2 m and 32.0 m for full and no access control respectively. The nearly 50 percent increase in median departure length demonstrates that full access control has a significant effect beyond its correlation with speed limit.

In light of the finding that traffic volume had no consistent effect on departure length, this parameter was eliminated from further consideration. Departure length data was then segregated by access control and speed limit as shown in Table 66. Note that the for the 55-65 mph category, there was sufficient data to provide departure lengths for both full and no access control.

4.4.2 Screened Data

The data shown in Table 66 provides measures of the length of vehicle departures for several speed limit and access control categories. Although this table represents the actual travel distances associated with serious injury and fatal crashes, the data may be distorted by the placement of longitudinal barriers. Barriers placed adjacent to the travelway are designed to redirect vehicles away from roadside obstacles and toward the travelway. Thus, longitudinal barriers are likely to reduce the length of travel along the roadside and the departure length data shown in Table 66 may be artificially shortened. The effects of longitudinal barriers on the length of roadside travel were investigated by removing all crashes involving barrier impacts. The data shown in Table 66 was then adjusted by excluding all crashes involving barrier impacts and is presented in Table 67. Note that the number of cases in the 55-65 mph, full access-control category was reduced to the point that there the tail of the distribution could not be reliably determined. Further, eliminating barrier impacts increased longitudinal travel distance values for access control freeway by an average of 2% and decreased lengths for roadways without access control by approximately 1%. The minor differences between Tables 66 and 67 appear to indicate that longitudinal barriers do not produce a significant reduction in the distances that vehicles travel along the roadway during ran-off-road events. This finding may indicate that, for most impacts, longitudinal barriers do not redirect cars back onto the roadway, but rather allow impacting vehicles to rub along the face of the barrier.

There was also a concern that rigid objects may have an effect on longitudinal travel distances. This concern is based on the assumption that, for most crashes involving a rigid obstacle, impacting vehicles are brought to a premature stop. In this situation, the length the vehicle travels along the roadside would be artificially reduced. This effect was again explored by removing crashes involving rigid obstacles from the data set and re-tabulating the data as shown in Table 68. Again, the effects of removing rigid obstacle crashes from the database were extremely minor. The average change in departure length between Tables 67 and 68 was found to be less than 0.5%. Based upon the minor differences in Tables 66, 67, and 68, it can be concluded that the upper tails of the roadside departure length distributions from the MwRSF database are not significantly affected by the presence of roadside barriers or rigid obstacles. Thus it is recommended that Table 66 be used in the evaluation of guardrail runout length calculation procedures.

4.5 Significance for Guardrail Runout Length

As mentioned previously, guardrail length-of-need is determined based upon the design runout length. This length is used to identify locations along the roadway in advance of a roadside object where barriers must begin to be effective. Table 69 shows the recommended runout lengths contained in the 2006 AASHTO Roadside Design Guide. As mentioned above these values are based on the Hutchison and Kennedy encroachment data (7). Table 70 presents runout length recommendations from a 1996 study that applied Cooper's data (33) to the design of guardrail layouts. Note that the runout length recommendations were based upon the upper tail of encroachment length distributions from H&K and Cooper. For Table 69, the top row of runout lengths were obtained from the 85th, 80th, 75th, and 70th percentile runout lengths from the H&K. study. Because the Cooper study contained no highways with 70 mph speed limits, the top row of

Table 70 was obtained by extrapolating the 90th, 85th, 80th, and 75th percentile encroachment lengths from the divided highways with 59 to 62 mph speed limits included in the Cooper study.

When the data from the MwRSF study shown in Table 66 is compared with RDG runout length guidelines, it is clear that existing guardrail design procedures greatly over estimate guardrail lengths. Note the 90th percentile departure length shown in Table 66. Note that the recommended runout length for high traffic volumes with a 70 mph design speed is approximately 1/3 greater than the 90th percentile departure length found along access controlled freeways with speed limits from 70 to 75 miles mph. The difference between the MwRSF departure lengths and the H&K based runout lengths increases further until it reaches 46% for traffic volumes less than 800 ADT which were intended to correlate with the 70th percentile encroachment length. Thus, MwRSF data indicates length that the guardrail length recommendations contained in the Roadside Design Guide grossly overstate guardrail length. It is important to note that guardrail is a roadside hazard that produces approximately 1200 fatalities per year. Therefore, there is a penalty for placing too much guardrail adjacent to the roadway and excessive guardrail length is likely to produce greater numbers of serious injury and fatalities than would be associated with shorter installations.

Note that findings from the MwRSF data compare much better to guardrail length guidelines developed from Cooper. Notice that the 90th percentile departure length for 70-75 mph speed limits with full access control is virtually identical to be recommended guardrail runout length for a 70 mph design speed and high traffic volume. However, the recommended runout lengths for lower traffic volumes appear to drop faster than would be indicated from the MwRSF accident data shown in Table 66. However, the recommended lengths do match up well with the 80th, 75th, and 70th percentile departure length from Table 66. Recall that the original guardrail length guidelines were developed based on the 85th through 70th encroachment lengths from the H&K data. The approach was shifted slightly to utilize the 90th through 75th percentile encroachment length when Cooper data was utilized in place of the H&K study. This adjustment was implemented in recognition of the fact that Cooper's data did not included any highways with speed limits greater than 62 mph. When the entire history of guardrail length determination is considered, the guardrail runout length recommendations for a 70 mph design speed shown in Table 70 are found to compare very well with the MwRSF departure length distribution for access controlled freeways with 70 to 75 mph speed limits.

Note that for design speeds of 60 mph, guardrail runout lengths shown in Table 70 appear to be midway between the full access control and no access control data for 55 to 65 mph speed limits. If it is assumed that full access controlled freeways are designed to a 70 mph or higher design speed, guardrail runout length recommendations shown in Table 70 can be considered to be conservative. However, if full access control roadways utilized a 60 mph design speed, the recommended guardrail lengths should probably be extended. Recommended guardrail runout lengths for a 50 mph design speed also compare well with departure lengths from roadways with speed limits of 45 to 50 mph and no access control. Note that the recommended runout lengths are consistently 3 m longer than the measured departure lengths shown in Table 66.

In summary, with the exception of highway with a design speed of 60 mph and full access control, guardrail length recommendations based on Cooper's data compare surprisingly well with departure length data described herein. Therefore, it is recommended that AASHTO consider adding a recommendation that guardrails placed along full access control freeways should be designed for 70 mph, regardless of the actual design speed.

Table 14. Injury Severity by Study

	17-22 Data		TTI Data		Total Data	
Injury Type	No.	Percent	No.	Percent	No.	Percent
Fatal	55	14.0%	74	15.3%	129	14.7%
A-injury	228	58.2%	279	57.5%	507	57.8%
B-injury	40	10.2%	49	10.1%	89	10.2%
C-injury	33	8.4%	42	8.7%	75	8.6%
PDO	36	9.2%	41	8.5%	77	8.8%
Total	392	100.0%	485	100.0%	877	100.0%

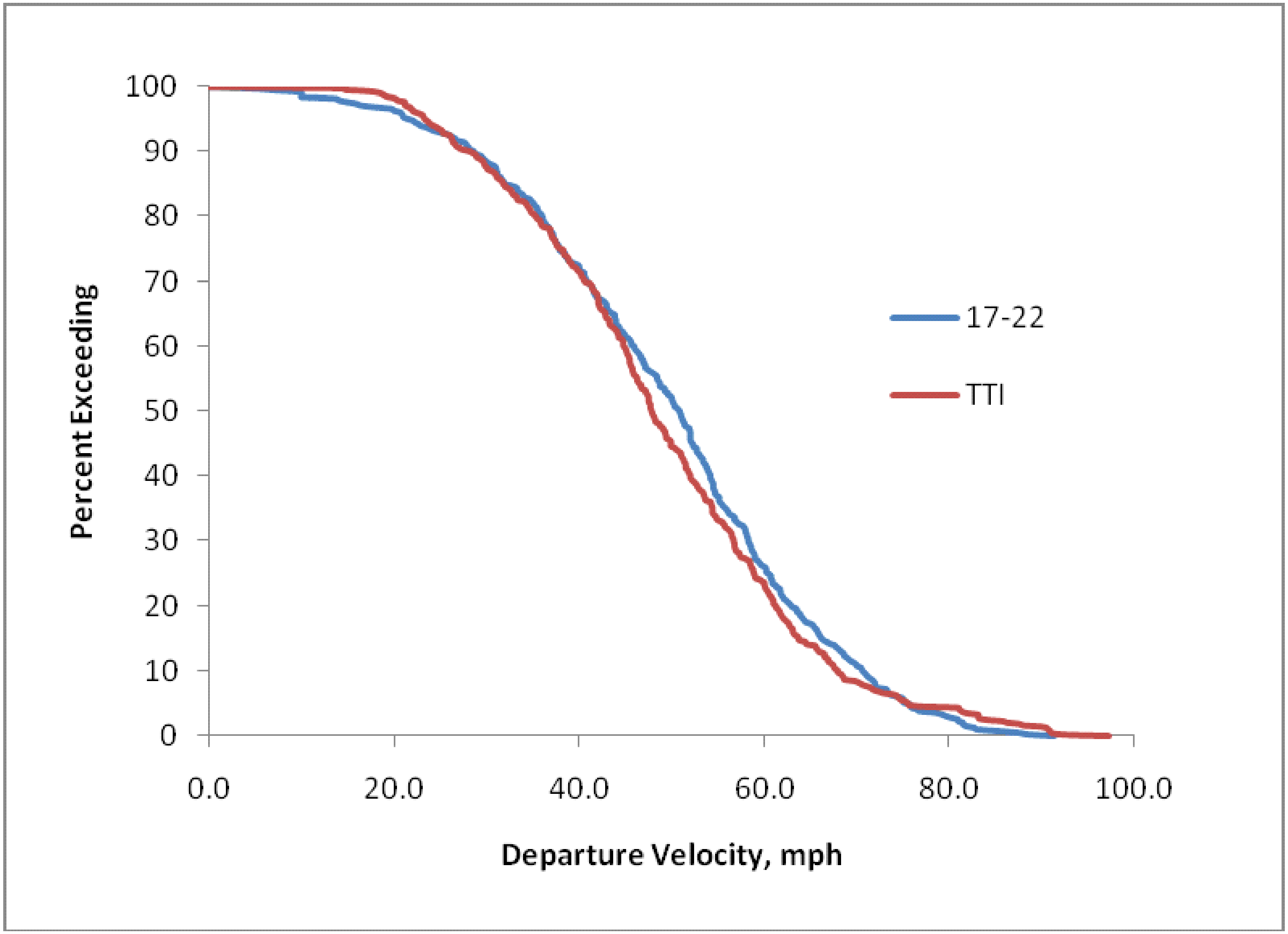

Figure 1. 17-22 and TTI departure velocity distributions

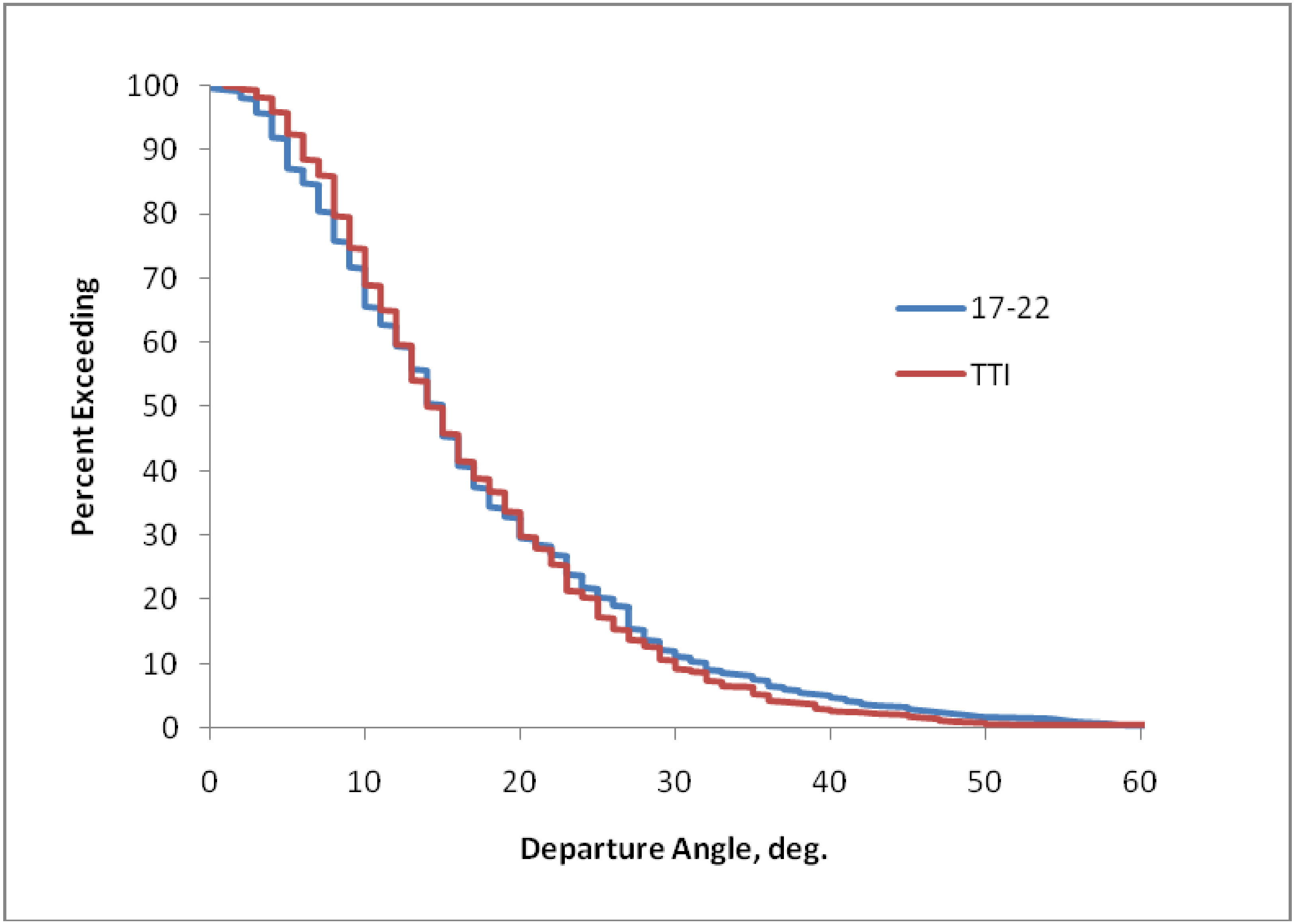

Figure 2. 17-22 and TTI departure angle distributions

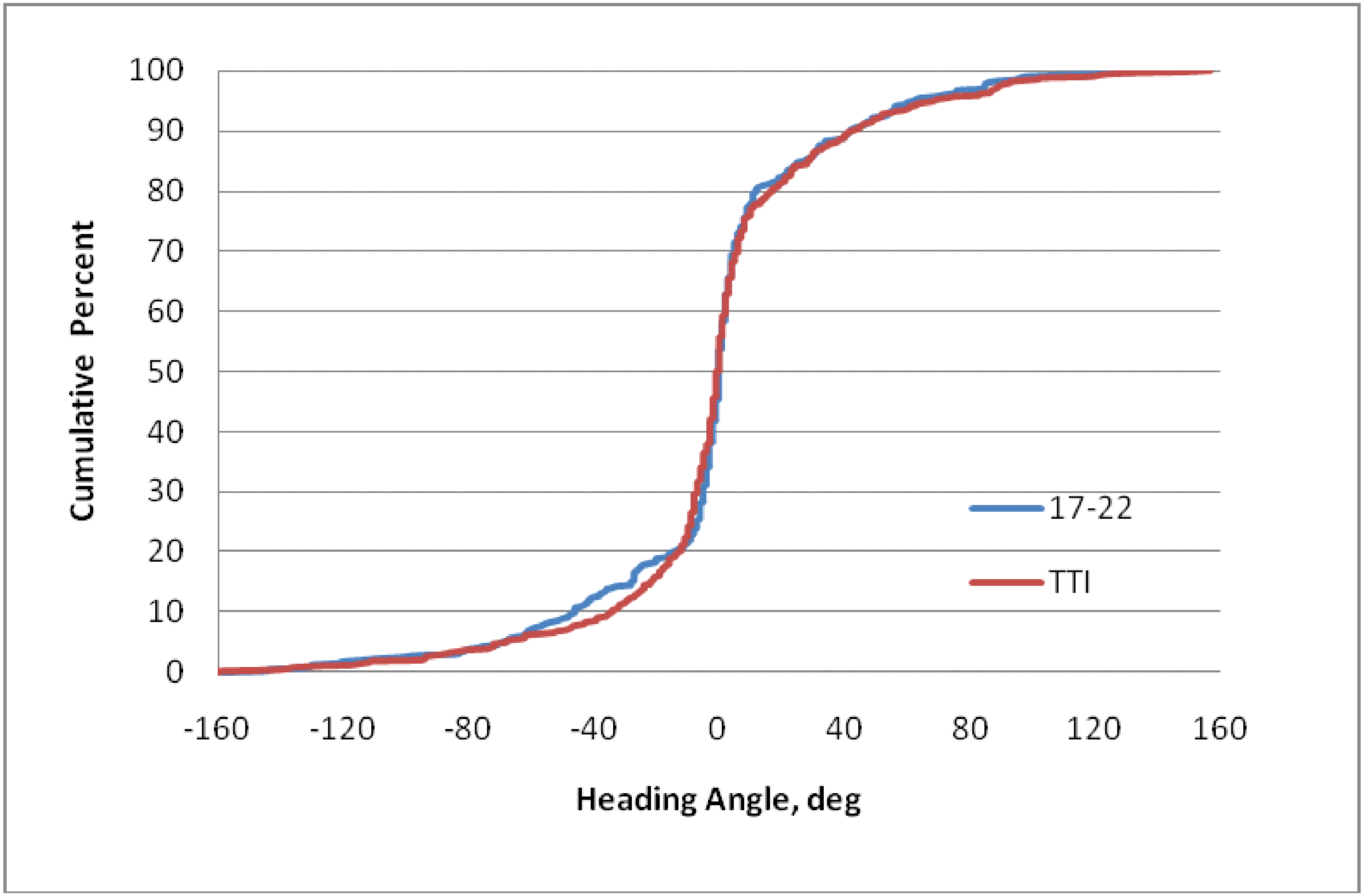

Figure 3. 17-22 and TTI heading angle distributions

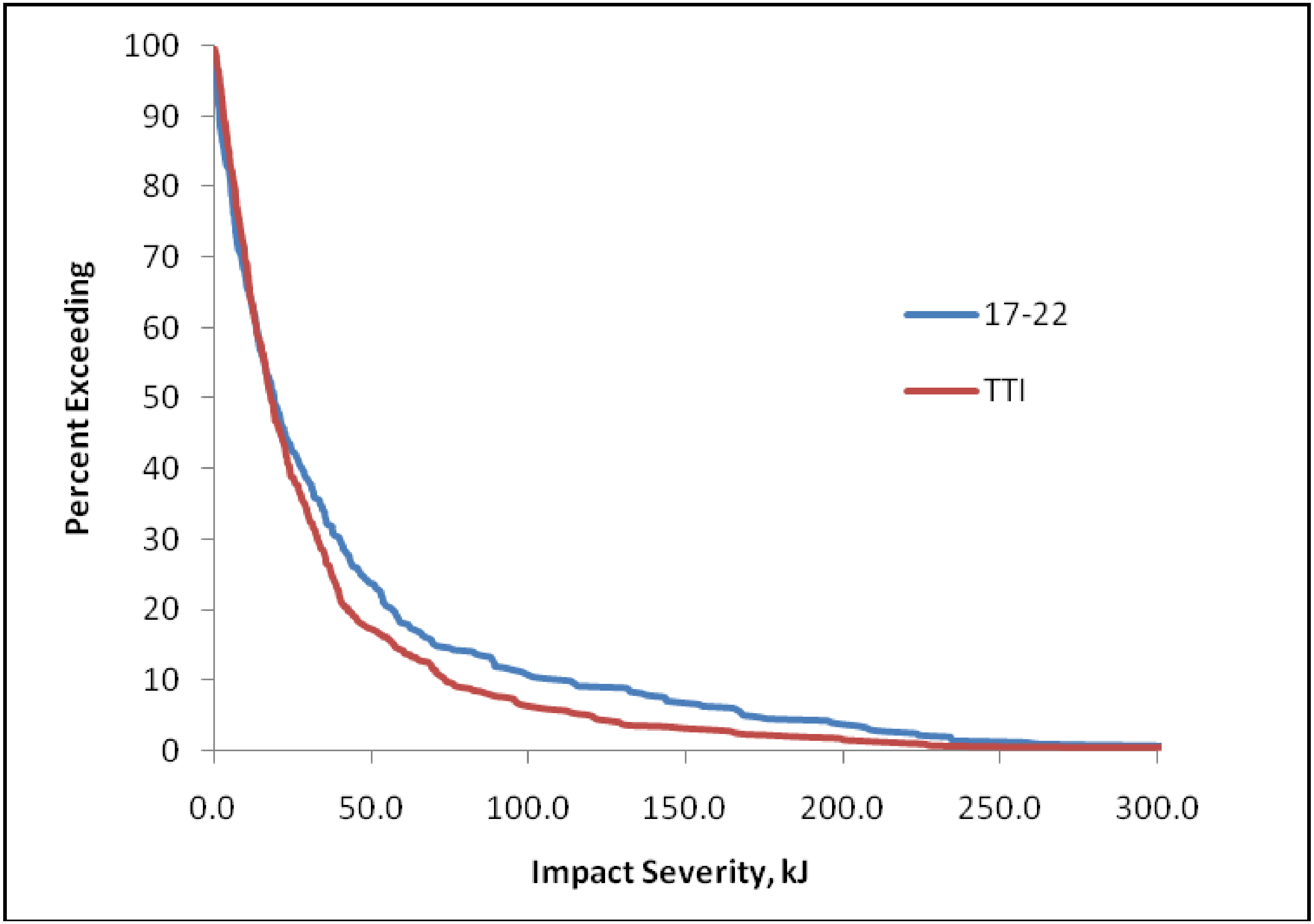

Figure 4. 17-22 and TTI IS distribution

Table 15. Case Distribution by Land Use

	No. of Cases	Percent
Urban	235	27.94%
Rural	606	72.06%
Total	841	100.00%

Table 16. Highway Classification

Hwy Class	No. of Cases	Percent
Interstate	195	23.16%
US Route	160	19.00%
State Route	161	19.12%
County Road	275	32.66%
City Street	43	5.11%
Other	8	0.95%
Total	842	100.00%

Table 17. Speed Limit

Speed Limit	Cases	
	No.	Percent
75	58	6.7%
70	114	13.1%
65	75	8.6%
55	361	41.4%
50	68	7.8%
45	195	22.4%
Total	871	100.0%

Table 18. Highway Class vs. Speed Limit

	Speed Limit (mph)											
	75		70		65		55		50		45	
Hwy Class	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Interstate	57	98.3	63	56.3	25	34.2	41	11.9	2	3.2	5	2.7
US Route	0	0.0	46	41.1	34	46.6	50	14.5	11	17.5	18	9.7
State Route	1	1.7	2	1.8	13	17.8	95	27.5	20	31.7	29	15.6
County Road	0	0.0	0	0.0	0	0.0	153	44.3	27	42.9	94	50.5
City Street	0	0.0	0	0.0	0	0.0	2	0.6	3	4.8	38	20.4
Other	0	0.0	1	0.9	1	1.4	4	1.2	0	0.0	2	1.1
Total	58	100.0	112	100.0	73	100.0	345	100.0	63	100.0	186	100.0

Table 19. Number of Lanes – Divided Highways

		Number of Lanes		
		1 - 2	3 - 4	More than 4
Highway Class	Interstate	67 (38.3%)	86 (49.1%)	22 (12.6%)
	US Route	29 (30.9%)	56 (59.6%)	9 (9.6%)
	State Route	17 (37.8%)	25 (55.6%)	3 (6.7%)
	County Road	1 (33.3%)	2 (66.7%)	0 (0.0%)
	City Street	7 (58.3%)	5 (41.7%)	0 (0.0%)
	Other	0 (0.0%)	1 (100.0%)	0 (0.0%)

Table 20. Number of Lanes – Undivided Highways

		Number of Lanes		
		1 - 2	3 - 4	More than 4
Highway Class	Interstate	18 (94.7%)	1 (5.3%)	0 (0.0%)
	US Route	54 (81.8%)	7 (10.6%)	5 (7.6%)
	State Route	101 (87.8%)	11 (9.6%)	3 (2.6%)
	County Road	237 (98.8%)	3 (1.3%)	0 (0.0%)
	City Street	20 (64.5%)	7 (22.6%)	4 (12.9%)
	Other	6 (100.0%)	0 (0.0%)	0 (0.0%)

Table 21. Distribution by Roadway Material

Roadway Surface	No. of Cases	Percent of Total
Asphalt	773	88.1%
Portland Cement	45	5.1%
Dirt	31	3.5%
Gravel	28	3.2%
Total	877	100.0%

Table 22. Case Distribution by Month

Month	Number of Occurrences	Percent
January	37	4.2%
February	50	5.7%
March	102	11.6%
April	87	9.9%
May	82	9.4%
June	101	11.5%
July	83	9.5%
August	86	9.8%
September	76	8.7%
October	71	8.1%
November	57	6.5%
December	45	5.1%
Total	877	100.0%

Table 23. Distribution by Surface Condition

Surface Condition	No. of Cases	Percent of Total
Dry	695	79.2%
Wet	121	13.8%
Ice	28	3.2%
Snow	25	2.9%
Other	8	0.9%
Total	877	100.0%

Table 24. Weather Condition

Weather Condition	No. of Cases	Percent
Clear	750	85.81%
Rain	82	9.38%
Snow	30	3.43%
Fog	6	0.69%
Hail	3	0.34%
Sleet	2	0.23%
Sandstorm	1	0.11%
Total	874	100.00%

Table 25. First Impact

Object/Feature Struck	No.	%
Tree	197	37.2%
Guardrail	71	13.4%
Embankment	65	12.3%
Sign and Luminaire Support	39	7.4%
Utility Pole	37	7.0%
Culvert	30	5.7%
Concrete Barrier	25	4.7%
Ditch	24	4.5%
Mailbox	18	3.4%
Fence	13	2.5%
Curb	10	1.9%
Total	529	100.0%

Table 26. Vehicle Class

	Vehicle Class	No. of Cases	Percent by Veh. Subclass	Percent of Total
Car	Subcompact Car	145	28.7%	16.6%
	Compact	167	33.0%	19.1%
	Intermediate	117	23.1%	7.7%
	Full-Size Sedan	55	10.9%	6.3%
	Large Size	22	4.3%	2.5%
	Subtotal	506	100.0%	57.9%
Pickup Truck	Compact Pickup	99	52.7%	11.3%
	Large Pickup	87	46.3%	10.0%
	Other Pickup Type	2	1.1%	0.2%
	Subtotal	188	100.0%	21.5%
Utility Vehicle	Compact Utility	120	83.9%	13.7%
	Large Utility	15	10.5%	1.7%
	Stationwagon Utility	8	5.6%	0.9%
	Subtotal	143	100.0%	16.4%
Van	Minivan	27	73.0%	3.1%
	Large Van	10	27.0%	1.1%
	Full-Size Van	2	5.4%	0.2%
	Subtotal	37	100.0%	4.2%
	Total	874		100.0%

Table 27. Highway Class vs. Crash Severity

Hwy Class	Maximum Severity									
	Fatality		Injury Type A		Injury Type B		Injury Type C		PDO	
	No.	%	No.	%	No.	%	No.	%	No.	%
Interstate	35	17.9%	109	55.9%	15	7.7%	20	10.3%	16	8.2%
US Route	19	11.9%	102	63.8%	11	6.9%	15	9.4%	13	8.1%
State Route	26	16.1%	93	57.8%	18	11.2%	11	6.8%	13	8.1%
County Road	40	14.5%	150	54.5%	36	13.1%	23	8.4%	26	9.5%
City Street	7	16.3%	30	69.8%	3	7.0%	1	2.3%	2	4.7%
Other	0	0.0%	4	50.0%	1	12.5%	3	37.5%	0	0.0%
All	127	15.1%	488	58.0%	84	10.0%	73	8.7%	70	8.3%

Table 28. Crash Severity by Vehicle Class

Vehicle Class		No. of Cases	Maximum Injury (%)				
			Fatal	A-injury	B-Injury	C-Injury	PDO
Car	Subcompact	167	16.2	52.1	10.8	10.2	10.8
	Compact Car	145	13.1	53.8	11.0	12.4	9.7
	Intermediate	117	13.7	63.2	9.4	6.0	7.7
	Full-Size Sedan	55	14.5	54.5	12.7	10.9	7.3
	Large Size	22	4.5	68.2	13.6	0.0	13.6
Pickup Truck	Compact Pickup	99	19.2	57.6	7.1	8.1	8.1
	Large Pickup	87	10.3	64.4	5.7	10.3	9.2
	Other Pickup Type	2	50.0	0.0	0.0	0.0	50.0
	Other Pickup Type	1	0.0	100.0	0.0	0.0	0.0
Utility Vehicle	Compact Utility	120	14.2	59.2	14.2	5.0	7.5
	Large Utility	8	0.0	75.0	12.5	0.0	12.5
	Stationwagon Utility	15	13.3	60.0	6.7	13.3	6.7
Van	Minivan	27	22.2	63.0	7.4	3.7	3.7
	Large Van	2	50.0	50.0	0.0	0.0	0.0
	Full-Size Van	10	30.0	50.0	10.0	10.0	0.0

Table 29. Crash Severity by Vehicle Type

Vehicle Type	No. of Cases	Maximum Injury (%)				
		Fatal	A-injury	B-Injury	C-Injury	PDO
Automobile	506	14.0%	56.1%	10.9%	9.5%	9.5%
Pickup	189	15.3%	60.3%	6.3%	9.0%	9.0%
Utility	143	13.3%	60.1%	13.3%	5.6%	7.7%
Van	39	25.6%	59.0%	7.7%	5.1%	2.6%

Table 30. Rollover and Crash Severity

	Maximum Injury	No. of Cases	Percent by Roll Result	Percent of Total
Rollover	Fatality	79	16.7%	9.0%
	A-injury	274	57.9%	31.2%
	B-injury	48	10.1%	5.5%
	C-injury	40	8.5%	4.6%
	PDO	32	6.8%	3.6%
	Subtotal	473	100.0%	53.9%
No Rollover	Fatality	50	12.4%	5.7%
	A-injury	233	57.7%	26.6%
	B-injury	41	10.1%	4.7%
	C-injury	35	8.7%	4.0%
	PDO	45	11.1%	5.1%
	Subtotal	404	100.0%	46.1%
	Total	877		100.0%

Table 31. First Impact vs. Crash Severity

Object/Feature Struck	No. of Cases	Fatal		A-Injury		B-Injury		C-Injury		PDO	
		No.	%	No.	%	No.	%	No.	%	No.	%
Tree	197	26	13.2%	127	64.5%	16	8.1%	14	7.1%	14	7.1%
Guardrail	71	9	12.7%	36	50.7%	7	9.9%	6	8.5%	13	18.3%
Embankment	58	6	10.3%	34	58.6%	9	15.5%	4	6.9%	14	24.1%
Vertical Support	37	6	16.2%	19	51.4%	6	16.2%	1	2.7%	5	13.5%
Utility Pole	37	9	24.3%	17	45.9%	7	18.9%	3	8.1%	1	2.7%
Concrete Barrier	27	5	18.5%	13	48.1%	2	7.4%	4	14.8%	3	11.1%
Culvert	27	3	11.1%	20	74.1%	1	3.7%	2	7.4%	1	3.7%
Ditch	25	2	8.0%	15	60.0%	2	8.0%	5	20.0%	1	4.0%
Mailbox	18	2	11.1%	10	55.6%	2	11.1%	2	11.1%	2	11.1%
Fence	13	2	15.4%	8	61.5%	0	0.0%	3	23.1%	0	0.0%
Curb	10	0	0.0%	7	70.0%	1	10.0%	1	10.0%	1	10.0%
Total	520	70	13.5%	306	58.8%	53	10.2%	45	8.7%	55	10.6%

Table 32. Crash Severity by Departure Velocity

Departure Velocity (mph)	No. of Cases	Injury Severity Levels									
		Fatal		Injury A		Injury B		Injury C		PDO	
		No.	%	No.	%	No.	%	No.	%	No.	%
< 30	103	3	2.9%	50	48.5%	10	9.7%	17	16.5%	23	22.3%
30 – 45	240	18	7.5%	135	56.3%	35	14.6%	23	9.6%	29	12.1%
45.1 - 60	313	52	16.6%	192	61.3%	30	9.6%	26	8.3%	13	4.2%
60.1 - 75	166	40	24.1%	98	59.0%	9	5.4%	8	4.8%	11	6.6%
> 75	48	15	31.3%	26	54.2%	5	10.4%	1	2.1%	1	2.1%

Table 33. Crash Severity by Vehicle Size for Departure Velocities of 60-75 mph

Vehicle Class	Injury Severity Levels									
	Fatal		Injury A		Injury B		Injury C		PDO	
	No.	%	No.	%	No.	%	No.	%	No.	%
Car	15	19.5%	47	58.4%	5	6.5%	3	3.9%	7	9.1%
Pickup	10	22.7%	26	59.1%	3	6.8%	2	4.5%	3	6.8%
Utility	13	33.3%	21	53.9%	1	2.6%	3	7.7%	1	2.6%
Van	2	33.3%	4	66.7%	0	0.0%	0	0.0%	0	0.0%

Table 34. Rollover Risk by Vehicle Size for Departure Velocities of 60-75 mph

Vehicle Class	Rollover			
	Yes		No	
	No.	%	No.	%
Car	51	66.2%	26	33.8%
Pickup	35	79.6%	9	20.5%
Utility	35	89.7%	4	10.3%
Van	5	83.3%	1	16.7%

Table 35. Crash Severity vs. Impact Speed For W-beam Guardrail

		Maximum Injury									
		Fatalities		"A" Injuries		"B" Injuries		"C" Injuries		PDO Crashes	
Impact Speed	Cases	No.	%	No.	%	No.	%	No.	%	No.	%
< 25 mph	1	0	0	0	0	0	0	0	0	1	100
25-40 mph	2	1	50	1	50	0	0	0	0	0	0
40-55 mph	12	0	0	8	67	2	17	0	0	2	17
55-70 mph	9	1	11	5	56	0	0	1	11	2	22
70-85 mph	5	3	60	1	20	1	20	0	0	0	0
≥ 85 mph	3	2	67	1	33	0	0	0	0	0	0
Unknown	4	0	0	3	75	0	0	0	0	1	25

Table 36. Guardrail Severity by Impact Angle

		Maximum Injury									
		Fatal		A-Injury		B-Injury		C-Injury		PDO	
Impact Angle	Cases	No.	%	No.	%	No.	%	No.	%	No.	%
0-6 deg	4	2	50%	2	50%	0	0%	0	0%	0	0%
6-12 deg	11	3	27%	5	45%	0	0%	0	0%	3	27%
12-18 deg	7	2	29%	2	29%	1	14%	1	14%	1	14%
18-24 deg	2	0	0%	2	100%	0	0%	0	0%	0	0%
≥ 24 deg	12	0	0%	8	67%	2	17%	0	0%	2	17%

Table 37. Guardrail Severity by IS Value

		Maximum Injury									
		Fatal		A-Injury		B-Injury		C Injury		PDO	
Impact Severity	Cases	No.	%	No.	%	No.	%	No.	%	No.	%
0-5 kJ	4	0	0%	4	100%	0	0%	0	0%	0	0%
5-13 kJ	4	2	50%	1	25%	0	0%	0	0%	1	25%
13-30 kJ	5	1	20%	2	40%	0	0%	0	0%	2	40%
30-90 kJ	10	4	40%	3	30%	1	10%	1	10%	1	10%
≥ 90 kJ	9	0	0%	6	67%	2	22%	0	0%	1	11%

Table 38. Guardrail Severity by Impact Angle when Guardrail Impact was Most Harmful Event

		Maximum Injury			
		Fatalities		"A" Injuries	
Impact Angle	Cases	No.	%	No.	%
0-6 deg	0	0	N/A	0	N/A
6-12 deg	0	0	N/A	0	N/A
12-18 deg	3	2	67	1	33
18-24 deg	3	0	0	3	100
≥ 24 deg	9	1	11	8	89

Table 39. Guardrail Severity vs. IS when Guardrail Impact was Most Harmful Event

		Maximum Injury			
		Fatalities		"A" Injuries	
Impact Severity	Cases	No.	%	No.	%
0-5 kip-ft	0	0	N/A	0	N/A
5-13 kip-ft	0	0	N/A	0	N/A
13-30 kip-ft	1	0	0	1	100
30-90 kip-ft	7	3	43	4	57
≥ 90 kip-ft	4	0	0	4	100
Unknown	3	0	0	3	100

Table 40. Velocity and Angle Descriptive Statistics

Variable	Mean	Median	Standard Deviation	Minimum	Maximum	10th percentile	90th percentile
Velocity	49.3	49.2	15.91	5.00	97.2	28.5	69.3
Angle	16.9	15.0	10.49	0.00	84.0	5	30

Table 41. Velocity Comparison with Mak (3)

	Velocity (mph)					
	Mean		70th Percentile		90th Percentile	
Highway Class	MwRSF	Pole Study	MwRSF	Pole Study	MwRSF	Pole Study
All	49.3	31.3	57.4	39.1	69.3	59.4
Freeway	56.3	43.9	63.2	51.2	75.5	65.9
Urban Arterial	44	25.3	52	30.4	62.6	44
Rural Arterial	49.1	37.4	56	45.5	65.8	64.1
Urban Loc/Col	44.2	20.8	49.2	25	61.4	37
Rural Loc/Col	44.6	29.1	51.1	35.6	62.4	48.2

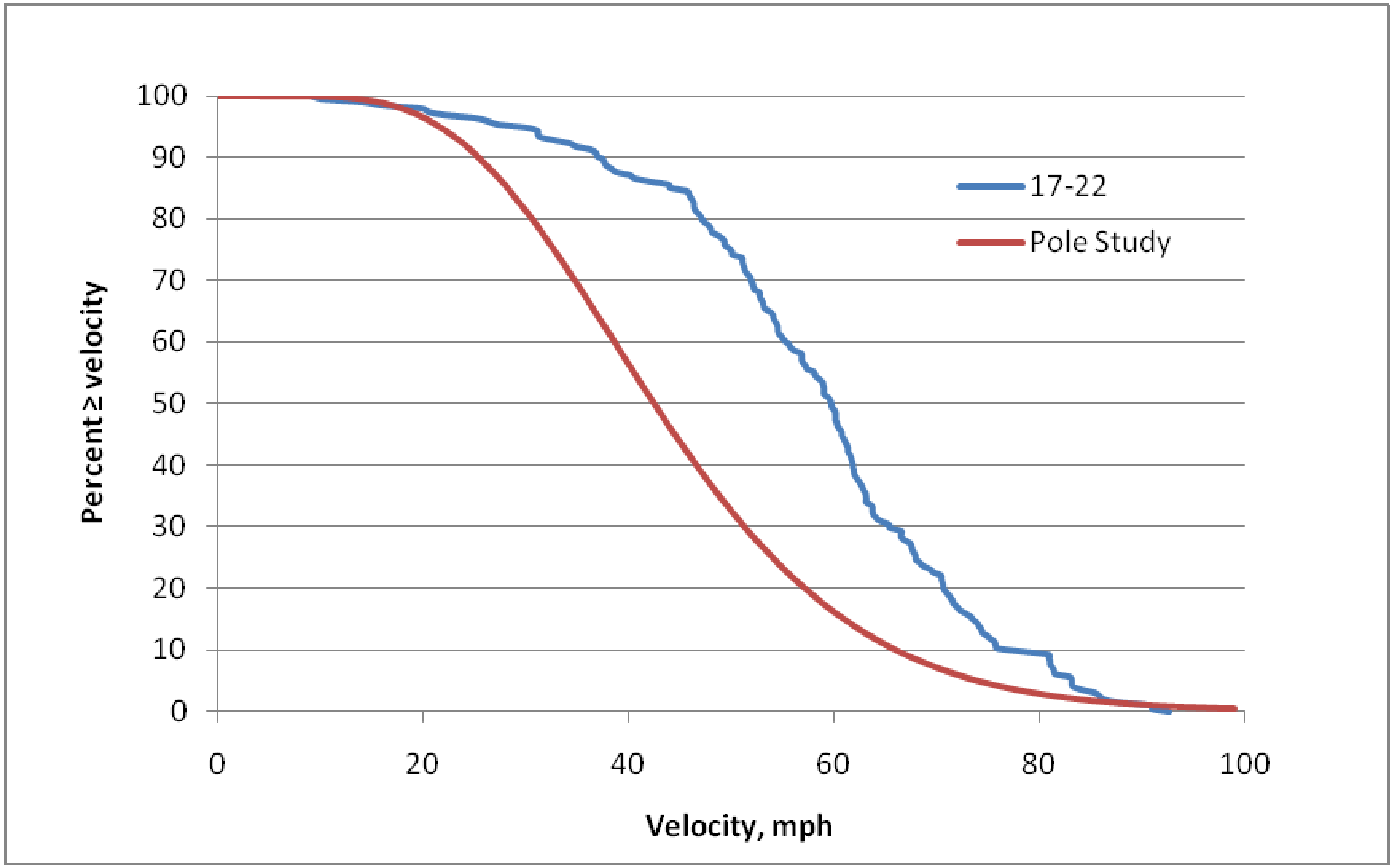

Figure 5. Freeway Velocity Distributions from Pole Study and MwRSF

Table 42. Angle Comparison with Mak (3)

	Departure Angle (deg)					
	Mean		70th Percentile		90th Percentile	
Highway Class	MwRSF	Pole Study	MwRSF	Pole Study	MwRSF	Pole Study
All	16.9	15.9	20	19.2	30	29.4
Freeway	16.8	15.5	20	18.7	29	28.4
Urban Arterial	16.6	15.5	17	18.9	29.3	29.5
Rural Arterial	16.3	15.0	20	18.4	30	30.3
Urban Loc/Col	15.4	16.5	18.0	19.8	28.4	28.7
Rural Loc/Col	16.6	15.4	19.5	18.8	29.5	30.4

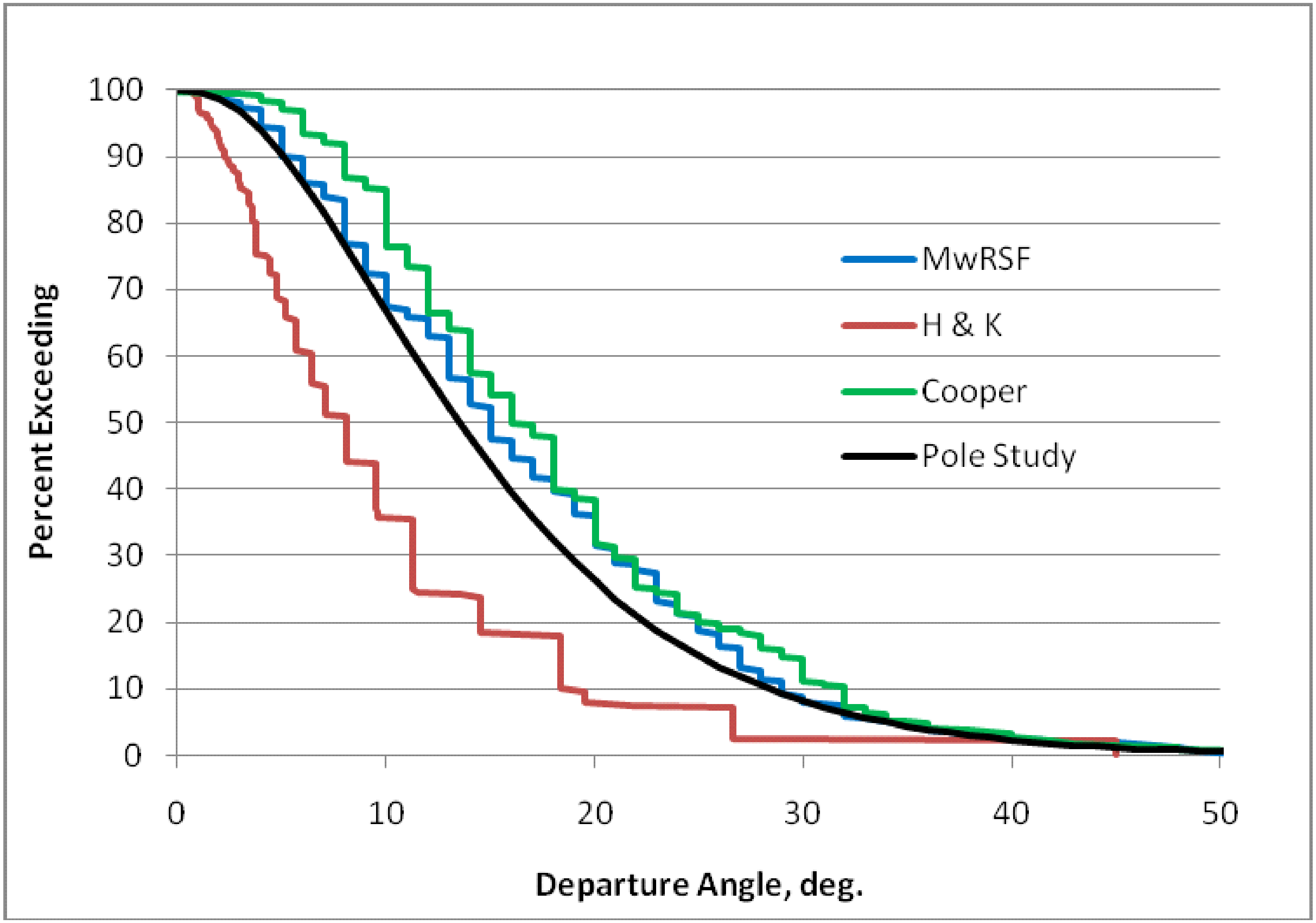

Figure 6. Comparison of Freeway Departure Angle Distributions

Table 43. Departure Velocity Statistics by Highway Class

Road Class	Speed Limit (mph)	No. of Cases	Min. Vel (mph)	Mean Vel. (mph)	Max. Vel (mph)	Standard Deviation	Skewness
All	45-75	870	5	49.3	97.2	15.913	-0.09537
Interstate	45-75	194	10	58.24	92.6	15.587	-0.44254
U.S. Highway	45-75	155	5	48.679	97.2	16.775	-0.09055
State Highway	45-65	159	10	49.494	89.9	15.39	0.08016
County Road	45-55	274	14.5	44.668	90.6	13.666	0.82561

Table 44. Departure Angle Statistics by Highway Class

Road Class	Speed Limit (mph)	No. of Cases	Min. Ang. (deg)	Mean Ang. (deg)	Max. Ang. (deg)	Standard Deviation	Skewness
All	45-75	877	0	16.9	84	10.949	1.5728
Interstate	45-75	194	0	16.5	56	9.7802	1.0612
U.S. Highway	45-75	157	2	16.5	55	10.159	1.2036
State Highway	45-65	161	3	16.7	59	10.828	1.422
County Road	45-55	274	0	16.6	84	11.05	1.7913

Table 45. Departure Velocity Statistics by Speed Limit

Speed Limit (mph)	No. of Cases	Min. Vel. (mph)	Mean Vel. (mph)	Max. Vel (mph)	Standard Deviation	Skewness
75	58	42	66.045	92.6	11.081	0.37389
70	112	7.5	54.951	90.8	16.206	-0.13195
65	75	10	53.939	88.5	16.539	-0.90328
55	357	13.8	47.331	97.2	14.894	0.24393
50	68	18.7	46.231	81.9	13.632	0.06293
45	194	5	43.999	91.1	14.741	0.5794

Table 46. Departure Angle Statistics by Speed Limit

Speed Limit (mph)	No. of Cases	Min. Ang. (deg)	Mean Ang. (deg)	Max Ang. (deg)	Standard Deviation	Skewness
75	58	2	14.2	32	8.3183	0.43907
70	114	2	18	56	11.128	1.2138
65	75	3	14.9	49	9.0404	1.4983
55	361	0	17.3	76	11.389	1.4225
50	68	4	17.0	84	13.94	2.4057
45	195	0	17.2	76	10.011	1.5565

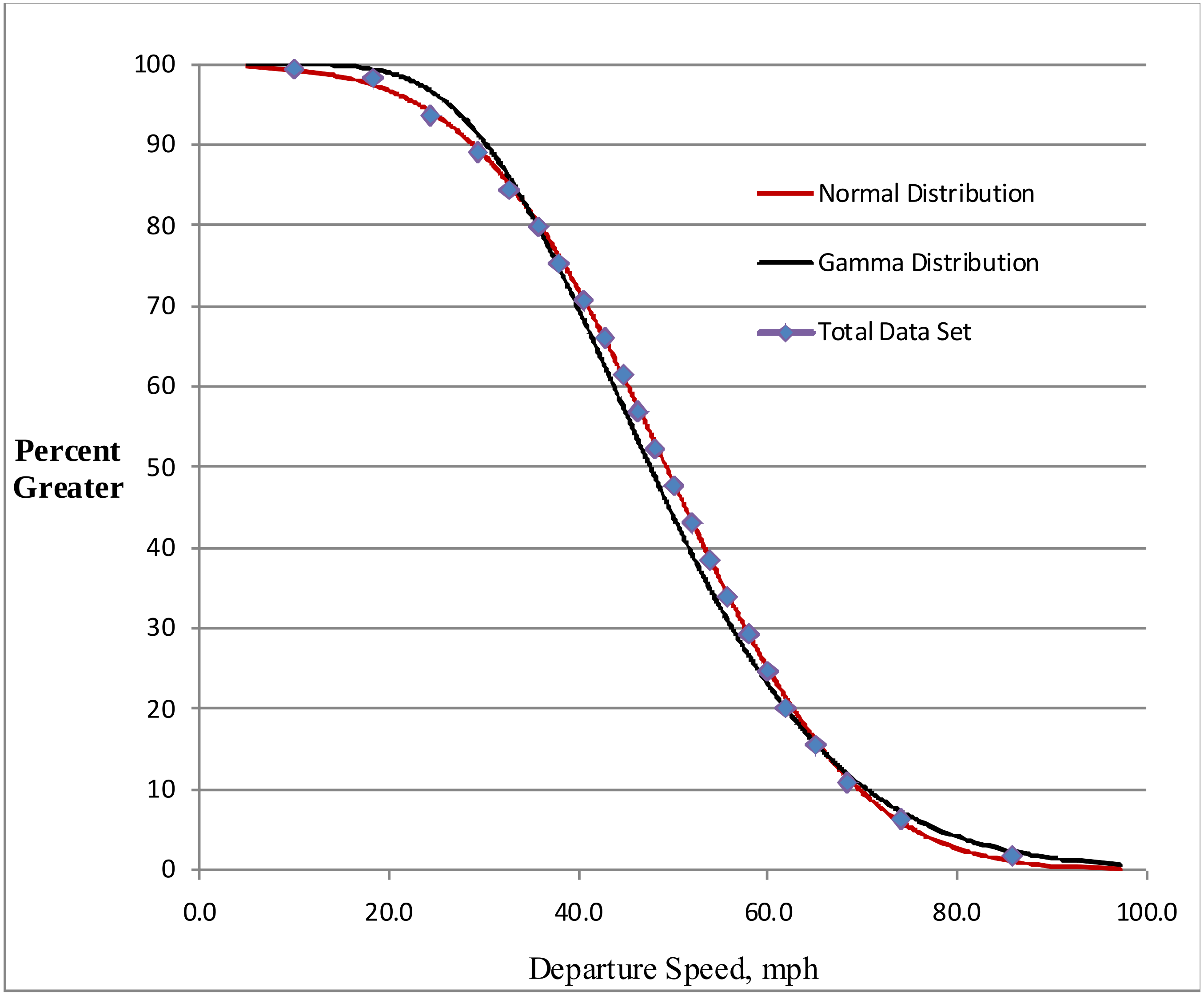

Figure 7. Normal and Gamma Distribution Fits to Departure Speed

Table 47. Normal and Gamma Distribution Fits to Speed Data

Speed Limit (mph)	No. of Cases	Mean Vel. (mph)	Standard Deviation	Chi Squared – Normal			Gamma Dist.		Chi Squared – Gamma		
				DOF	Chi Stat.	P-Value	Alpha	Beta	DOF	Chi Stat.	P-Value
All	870	49.3	15.913	9	2.3071	0.9856	9.5964	5.137	9	23.917	0.0044
75	58	66.045	11.081	5	0.96147	0.9615	35.526	1.859	5	1.4802	0.9153
70	112	54.951	16.206	6	6.9659	0.3240	11.498	4.7792	6	7.7562	0.2565
65	75	53.939	16.539	5	7.7495	0.2570	10.637	5.071	5	7.7209	0.1723
55	357	47.331	14.894	8	6.8966	0.5478	10.099	4.6867	8	19.862	0.0109
50	68	46.231	13.632	6	4.7869	0.5714	11.501	4.0198	5	6.5352	0.2576
45	194	43.999	14.741	7	5.61	0.5860	8.908	4.9388	7	1.6949	0.9748

Table 48. Normal and Gamma Distribution Fits to Angle Data

Speed Limit (mph)	No. of Cases	Mean Angle (deg)	Standard Deviation	Chi Squared – Normal			Gamma Dist.		Chi Squared - Gamma		
				DOF	Chi Stat.	P-Value	Alpha	Beta	DOF	Chi Stat.	P-Value
All	877	16.936	10.949	9	133.04	0.0001	2.6183	6.483	9	17.895	0.0364
75	58	14.224	8.3183	7	12.754	0.0783	13.961	4.1716	7	12.962	0.0731
70	114	18	11.128	6	9.2486	0.1601	2.6166	6.8791	6	3.4874	0.7456
65	75	14.88	9.0404	5	5.4896	0.3591	2.7091	5.4925	6	8.1237	0.2292
55	361	17.263	11.389	8	47.362	$1\text{x}10^{-7}$	2.4615	7.0327	8	13.894	0.0846
50	68	17.044	13.94	4	19.612	$6\text{x}10^{-4}$	1.495	11.400	6	21.943	0.0012
45	195	17.195	10.011	7	13.412	0.0627	2.9502	5.8285	7	7.70539	0.4233

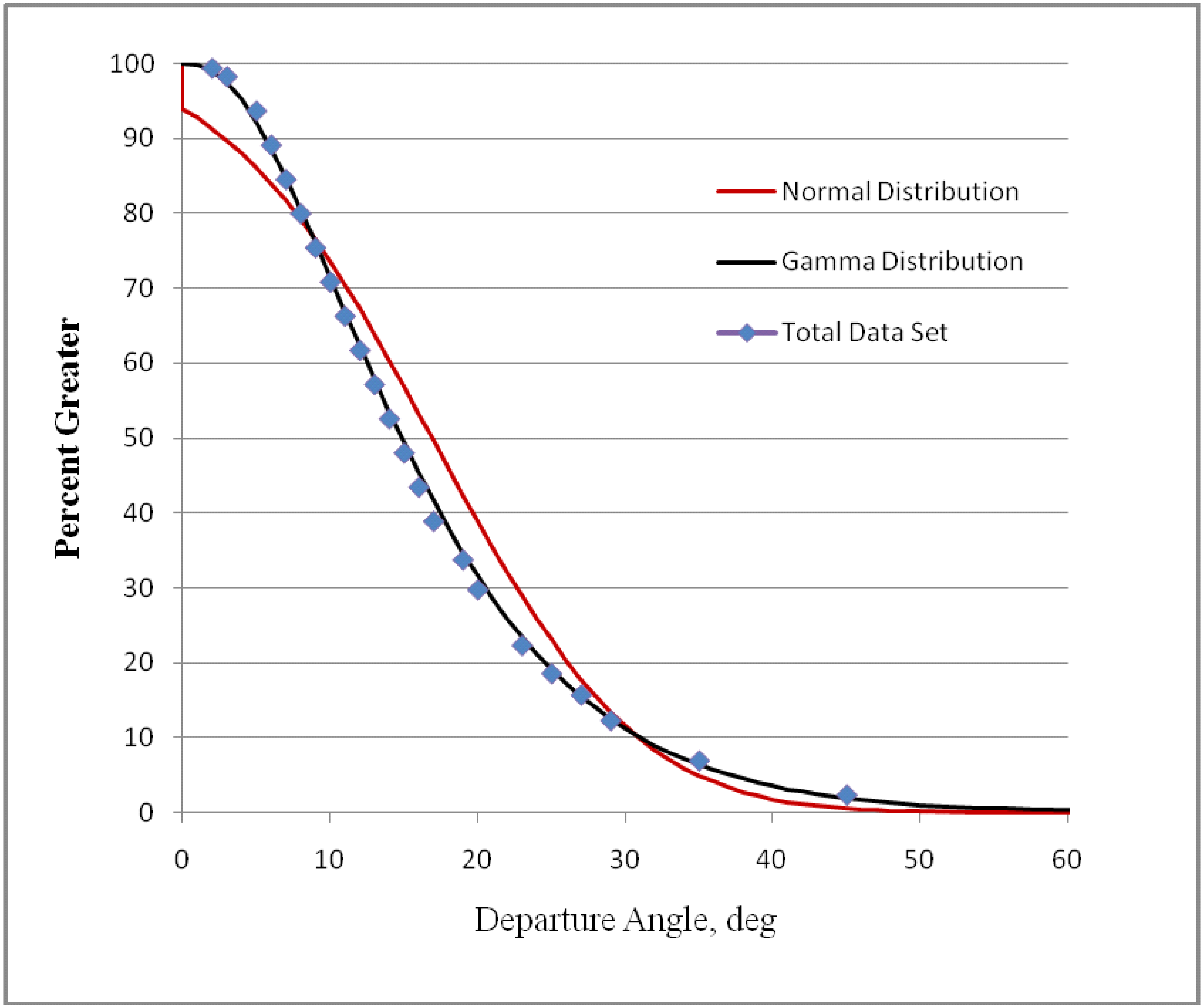

Figure 8. Normal and Gamma Distribution Fits to Departure Angle (all data)

Table 49. Gamma Distribution Fit to Square Root of Dep. Angle

Speed Limit (mph)	No. of Cases	Square Root Angle		Gamma Distribution		Chi Squared - Gamma		
		Mean	Std. Dev.	Alpha	Beta	DOF	Chi Stat.	P-Value
All	877	3.916	1.266	9.6039	0.40868	9	15.613	0.0754
75	58	3.5992	1.1366	10.028	0.35892	5	4.2553	0.51327
70	114	4.0482	1.2754	10.074	0.40183	6	6.066	0.41583
65	75	3.6995	1.0998	11.316	0.32693	6	6.5419	0.3653
55	361	3.9405	1.3184	8.9338	0.44108	8	9.837	0.27665
50	68	3.8812	1.4177	7.4944	0.51788	5	6.3047	0.2777
45	195	3.9755	1.1822	11.309	0.35132	7	6.3246	0.5024

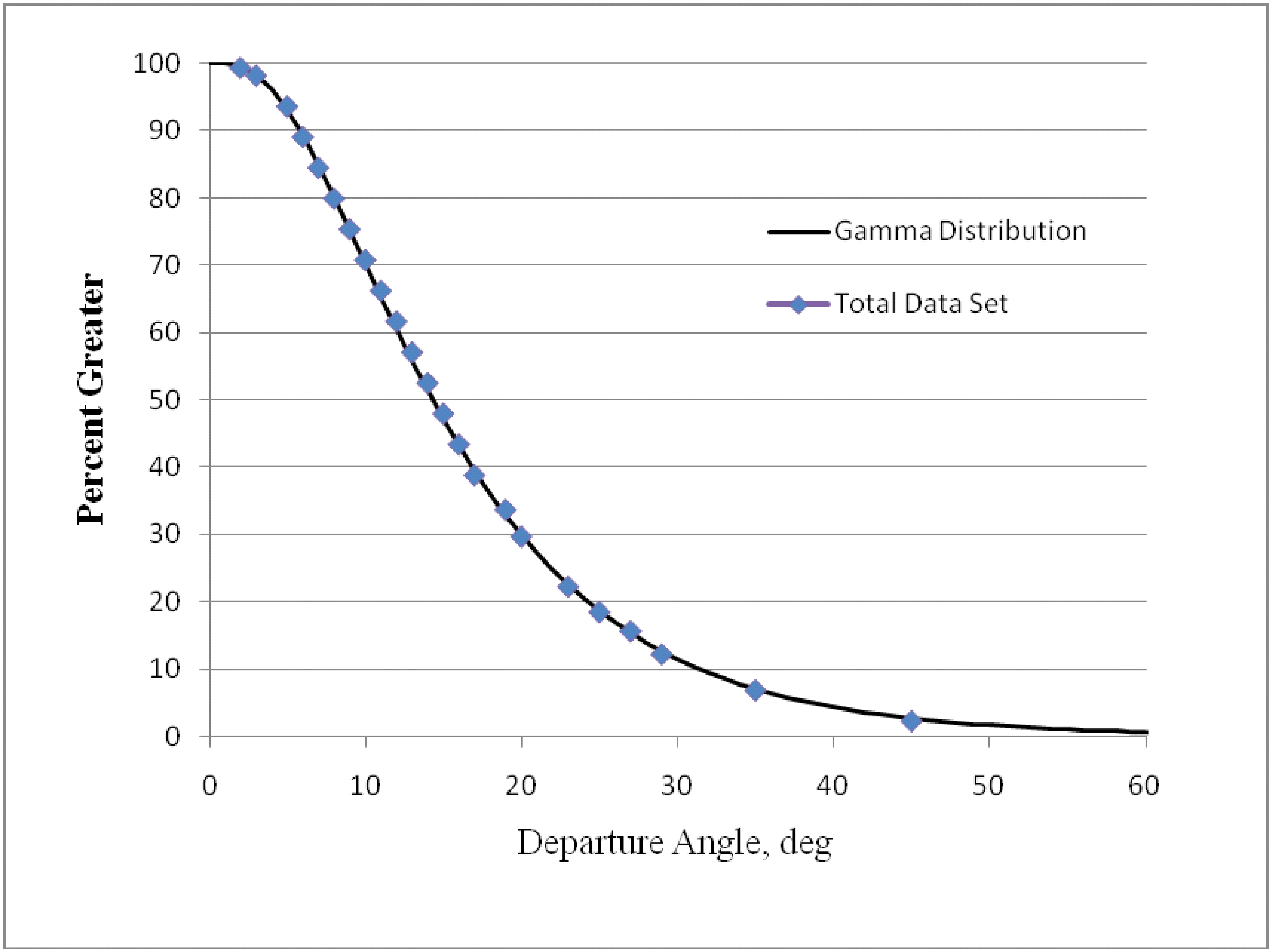

Figure 9. Square Root of Dep. Angle Used to Model Dep. Angle (all data)

Table 50. Observed Departure Conditions

Departure Velocity, mph	Departure Angle, deg.					
	<6	6 - 12	12 - 18	18 - 24	24-30	>30
<25	4	15	16	10	7	13
25 - 35	9	24	29	15	12	16
35 - 45	15	40	43	31	30	20
45 - 55	25	65	62	31	21	19
55 - 65	13	45	46	32	15	18
>65	22	41	30	19	12	12

Table 51. Expected Departure Velocity and Angle Frequencies

Departure Velocity, mph	Departure Angles, deg.					
	<6	6 - 12	12 - 18	18 – 24	24-30	>30
<25	6.52	17.05	16.75	10.23	7.19	7.26
25 - 35	10.54	27.54	27.06	16.52	11.61	11.73
35 - 45	17.96	46.94	46.13	28.17	19.80	20.00
45 - 55	22.38	58.48	57.47	35.09	24.66	24.92
55 - 65	16.96	44.32	43.55	26.59	18.69	18.88
>65	13.65	35.67	35.05	21.40	15.04	15.20

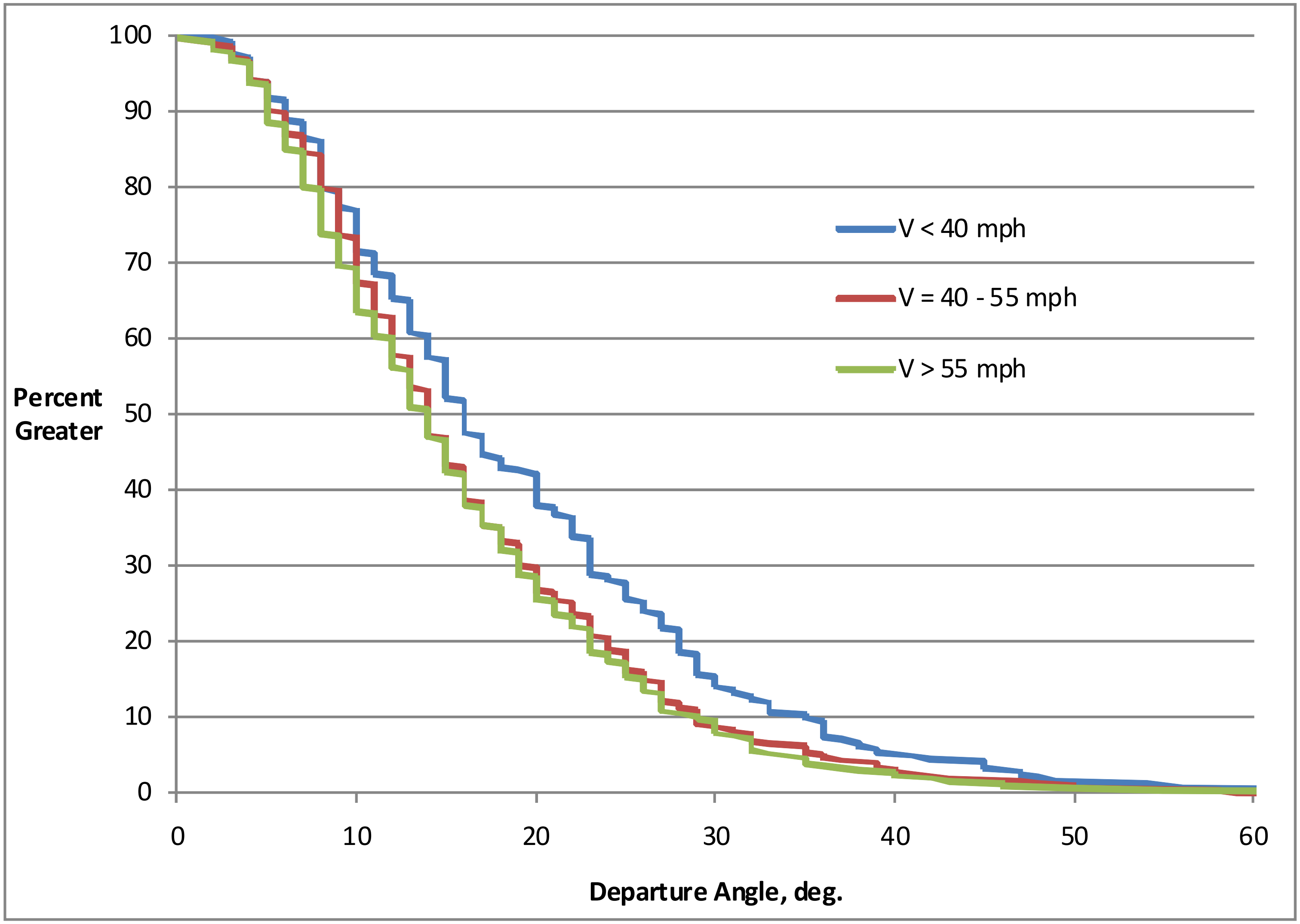

Figure 10. Departure Angle Distribution for 3 Departure Speed Categories

Table 52. Results of Independence Tests

Speed Limit (mph)	No. of Cases	Deg. of Freedom	Chi-square Statistic	P-value
75	58	4	2.69	0.611
70	114	4	3.57	0.467
65	75	1	3.37	0.066
55	361	9	10.55	0.308
50	68	4	3.56	0.469
45	195	9	11.98	0.214

Table 53. Departure Condition Distribution For All Speed Limits

Velocity (mph)	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<20	0.00227	0.00516	0.00984	0.00564	0.00374	0.00236	0.00379
20 - 30	0.00552	0.01256	0.02394	0.01372	0.00910	0.00575	0.00921
30 - 40	0.01154	0.02627	0.05006	0.02869	0.01903	0.01202	0.01926
40 - 50	0.01647	0.03748	0.07142	0.04093	0.02715	0.01714	0.02748
50 - 60	0.01603	0.03649	0.06954	0.03985	0.02644	0.01669	0.02676
60 - 70	0.01065	0.02425	0.04620	0.02647	0.01756	0.01109	0.01778
>70	0.00668	0.01522	0.02900	0.01662	0.01102	0.00696	0.01116

Table 54. Departure Condition Distribution For 75 mph Speed Limits

Velocity (mph)	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<30	0.00004	0.00009	0.00017	0.00010	0.00007	0.00004	0.00007
30 - 40	0.00061	0.00139	0.00264	0.00151	0.00100	0.00063	0.00102
40 - 50	0.00446	0.01014	0.01933	0.01108	0.00735	0.00464	0.00744
50 - 60	0.01514	0.03446	0.06567	0.03763	0.02496	0.01576	0.02527
60 - 70	0.02398	0.05459	0.10402	0.05960	0.03954	0.02497	0.04002
70 - 80	0.01775	0.04040	0.07699	0.04411	0.02927	0.01848	0.02962
>70	0.00719	0.01637	0.03119	0.01787	0.01186	0.00749	0.01200

Table 55. Departure Condition Distribution For 70 mph Speed Limits

Velocity (mph)	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<30	0.00428	0.00973	0.01855	0.01063	0.00705	0.00445	0.00714
30 - 40	0.00804	0.01831	0.03489	0.01999	0.01326	0.00837	0.01342
40 - 50	0.01396	0.03178	0.06056	0.03470	0.02302	0.01454	0.02330
50 - 60	0.01676	0.03815	0.07270	0.04165	0.02764	0.01745	0.02797
60 - 70	0.01391	0.03167	0.06034	0.03458	0.02294	0.01448	0.02322
70 - 80	0.00798	0.01818	0.03464	0.01985	0.01317	0.00831	0.01333
>70	0.00423	0.00962	0.01833	0.01050	0.00697	0.00440	0.00705

Table 56. Departure Condition Distribution For 65 mph Speed Limits

Velocity (mph)	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<30	0.00511	0.01163	0.02217	0.01270	0.00843	0.00532	0.00853
30 - 40	0.00870	0.01980	0.03774	0.02162	0.01435	0.00906	0.01452
40 - 50	0.01426	0.03247	0.06186	0.03545	0.02352	0.01485	0.02380
50 - 60	0.01640	0.03733	0.07114	0.04076	0.02704	0.01707	0.02737
60 - 70	0.01323	0.03011	0.05738	0.03288	0.02181	0.01377	0.02208
70 - 80	0.00748	0.01704	0.03246	0.01860	0.01234	0.00779	0.01249
>70	0.00398	0.00906	0.01726	0.00989	0.00656	0.00414	0.00664

Table 57. Departure Condition Distribution For 55 mph Speed Limits

Velocity (mph)	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<20	0.00230	0.00523	0.00998	0.00572	0.00379	0.00239	0.00384
20 - 30	0.00616	0.01402	0.02671	0.01531	0.01015	0.00641	0.01028
30 - 40	0.01307	0.02976	0.05670	0.03249	0.02155	0.01361	0.02182
40 - 50	0.01797	0.04091	0.07795	0.04466	0.02963	0.01871	0.02999
50 - 60	0.01600	0.03643	0.06942	0.03978	0.02639	0.01666	0.02671
60 - 70	0.00923	0.02102	0.04005	0.02295	0.01522	0.00961	0.01541
>70	0.00443	0.01008	0.01920	0.01100	0.00730	0.00461	0.00739

Table 58. Departure Condition Distribution For 50 mph Speed Limits

Velocity mph	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<20	0.00188	0.00428	0.00815	0.00467	0.00310	0.00196	0.00314
20 - 30	0.00621	0.01413	0.02692	0.01542	0.01023	0.00646	0.01036
30 - 40	0.01431	0.03258	0.06207	0.03557	0.02360	0.01490	0.02388
40 - 50	0.01972	0.04489	0.08553	0.04901	0.03252	0.02053	0.03291
50 - 60	0.01624	0.03698	0.07046	0.04037	0.02678	0.01691	0.02711
60 - 70	0.00800	0.01820	0.03469	0.01988	0.01319	0.00833	0.01335
>70	0.00281	0.00639	0.01218	0.00698	0.00463	0.00292	0.00469

Table 59. Departure Condition Distribution For 45 mph Speed Limits

Velocity mph	Departure Angle Range						
	0° - 5°	5° - 10°	10° - 15°	15° - 20°	20° - 25°	25° - 30°	>30°
<20	0.00188	0.00428	0.00815	0.00467	0.00310	0.00196	0.00314
20 - 30	0.00621	0.01413	0.02692	0.01542	0.01023	0.00646	0.01036
30 - 40	0.01431	0.03258	0.06207	0.03557	0.02360	0.01490	0.02388
40 - 50	0.01972	0.04489	0.08553	0.04901	0.03252	0.02053	0.03291
50 - 60	0.01624	0.03698	0.07046	0.04037	0.02678	0.01691	0.02711
60 - 70	0.00800	0.01820	0.03469	0.01988	0.01319	0.00833	0.01335
>70	0.00281	0.00639	0.01218	0.00698	0.00463	0.00292	0.00469

Table 60. Goodness-of-fit Test Results

Speed Limit (mph)	No. of Cases	Deg. of Freedom	Chi-square Statistic	P-value
All	870	31	40.61	0.116
75	58	4	4.47	0.346
70	114	11	11.82	0.377
65	75	4	8.01	0.091
55	361	20	19.73	0.475
50	68	4	3.18	0.528
45	195	9	10.37	0.324

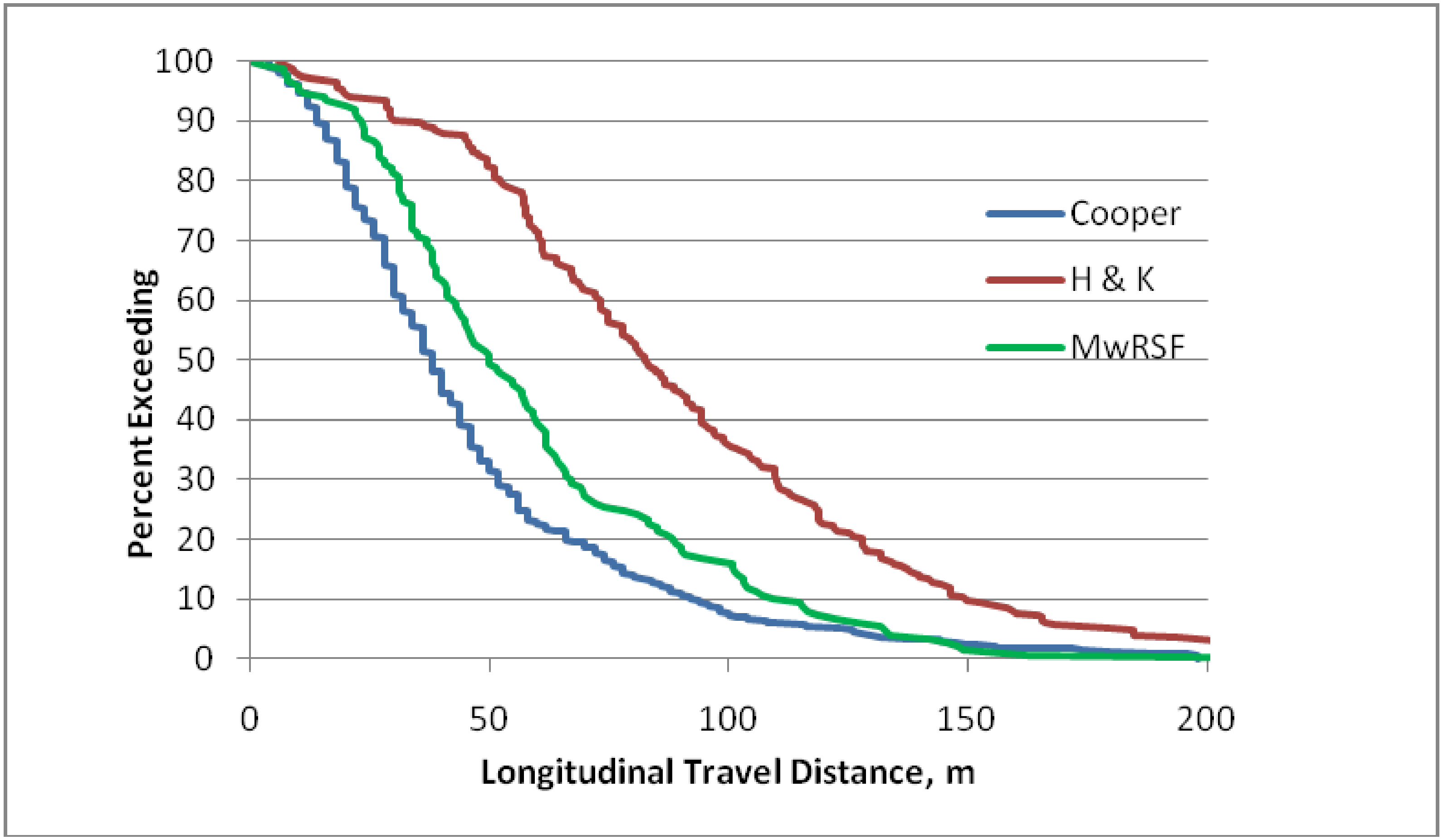

Figure 11. Encroachment Lengths for Different Studies

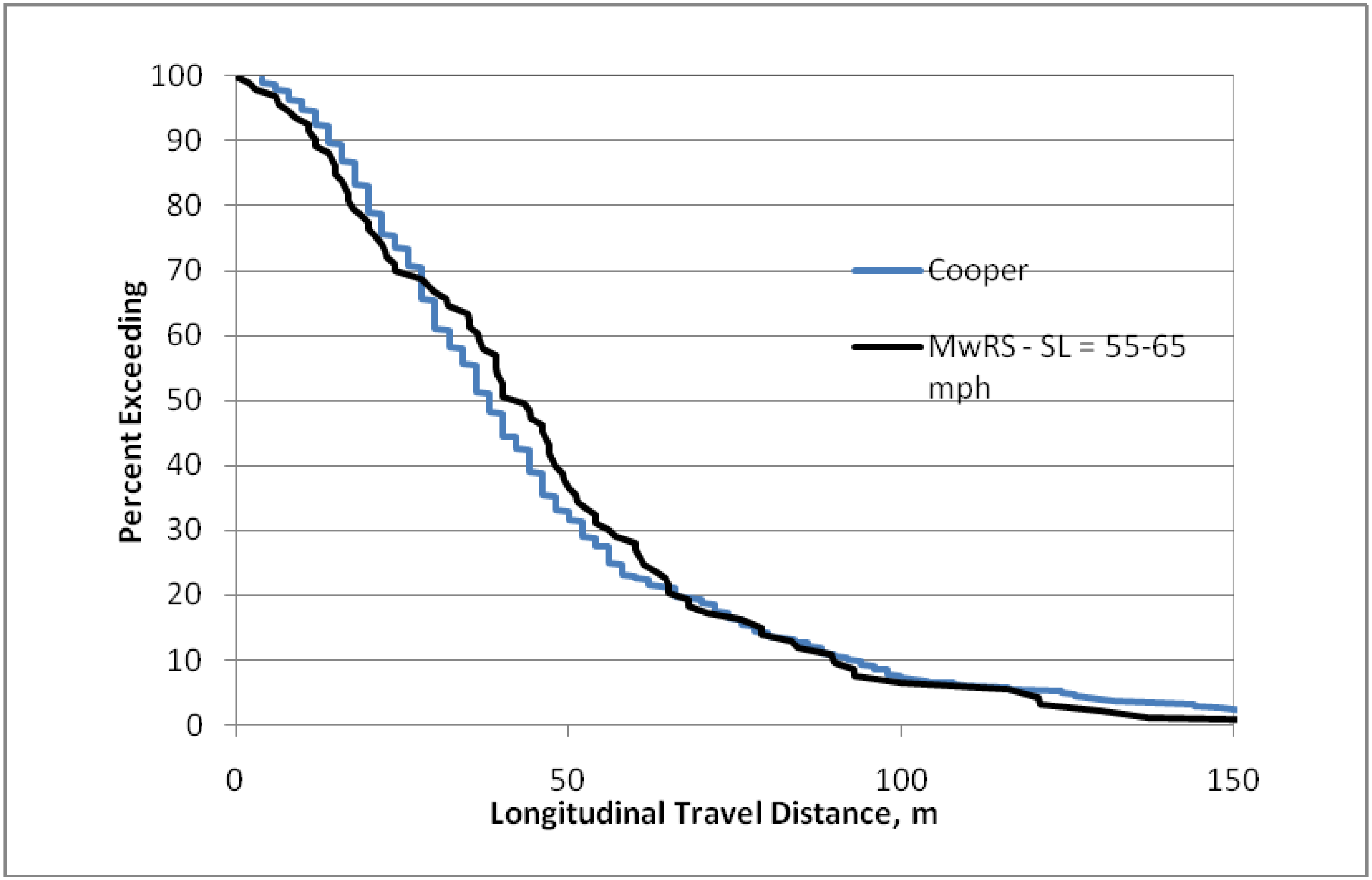

Figure 12. Cooper and MwRSF (55-65 mph) Encroachment Data Comparison

Table 61. RDG Runout Lengths for 70 mph Design Speed

Traffic Volume (ADT)	>6000	2000-6000	800-2000	<800
Design Runout Length, m	146.3	134.1	121.9	109.7
Enc. Length Percentile	85%	80%	75%	70%

Table 62. Encroachment Length Distributions

Source	Average Speed Limit	Encroachment Length Percentile				
		90%	85%	80%	75%	70%
Cooper	60.5 mph	96.3	78.6	69.2	57.3	52.4
	50.3 mph	54.9	46.9	42.4	38.4	34.7

Table 63. Departure Length Segregated by Speed Limit

		Departure Length Percentile					
Speed Limit	No. of Cases	90%	85%	80%	75%	70%	50%
70-75	169	109.9	101.0	85.4	73.8	66.3	49.5
65-55	424	77.0	65.4	57.0	50.0	46.5	33.8
55	353	74.4	62.0	52.0	47.0	44.7	32
45-50	253	63.1	50.0	43.2	38.8	34.8	24
45	186	60.8	47.1	41.8	37.0	33.0	24

Table 64. Departure Length Segregated by Traffic Volume

		Departure Length Percentile					
Volume Class	No. of Cases	90%	85%	80%	75%	70%	50%
High	189	92.1	80.9	70.2	61.2	57	38
Medium	207	95.3	84	71.2	64.6	61.8	42.6
Low	388	65.2	53	47	43.6	40	26.6

Table 65. Departure Length Segregated by Access Control

		Departure Length Percentile					
Access Control	No. of Cases	90%	85%	80%	75%	70%	50%
Full	263	102.7	89.3	76.5	68	62.8	45.4
None	493	66.7	54	47	43.5	40	28

Table 66. Departure Length Segregated by Speed Limit and Access Control

Speed Limit	Access Control	No. of Cases	Departure Length Percentile					
			90%	85%	80%	75%	70%	50%
70-75	Full	151	109.1	101.1	88	75.1	66.7	50
55-65	Full	98	89.6	76.9	65	60.5	54	40
55-65	None	284	68.7	57.8	49.2	46	43	32
45-50	None	205	61	49	42.9	37	33	24.8

Table 67. Departure Lengths Excluding Barrier Impacts

Speed Limit	Access Control	No. of Cases	Departure Length Percentile					
			90%	85%	80%	75%	70%	50%
70-75	Full	137	111	101.6	88.7	77.2	67	52.5
65-55	None	263	67.9	55.6	49	46	43	31.8
45-50	None	201	61.8	48.4	41.8	36.8	32.6	24.7

Table 68. Departure Lengths Excluding Barrier and Rigid Obstacle Impacts

Speed Limit	Access Control	No. of Cases	Departure Length Percentile					
			90%	85%	80%	75%	70%	50%
70-75	Full	136	111.5	101.7	88.9	78.2	67.4	53
65-55	None	262	67.9	55.7	49	46	43	31.6
45-50	None	196	62.3	48	41.7	36	32.2	24.6

Table 69. Runout Length Recommendations from the RDG

	Traffic Volume ADT			
	>6000	2000-6000	800-2000	<800
Design Speed, mph	Runout Length, m	Runout Length, m	Runout Length, m	Runout Length, m
70	146	134	122	110
60	122	112	101	91
50	98	89	81	73
40	73	67	61	55
30	49	45	41	37

Table 70. Runout Length Recommendations from Wolford & Sicking

	Traffic Volume ADT			
	>10,000	5,000-10,000	1,000-5000	<1,000
Design Speed (mph)	Runout Length (m)	Runout Length (m)	Runout Length (m)	Runout Length (m)
70	110	91	79	67
60	79	64	55	49
50	64	52	46	40
40	49	40	34	30
30	34	27	24	21

5 LONG-TERM DATA COLLECTION PLAN

5.1 General

The primary goal of the current study is to identify the distribution of impact conditions, including speed, angle, and vehicle orientation, of serious injury and fatal ran-off-road crashes. However, there remain many other questions and issues that need to be addressed, some of which are listed as follows:

1. Identify distributions of impact conditions, including speed, angle, and vehicle orientation, as a function of highway functional class. This data would provide inputs for benefit-cost (B/C) analysis codes and development of hardware performance level selection guidelines.
2. Develop a link between occupant compartment deformation and occupant risk in ran-off-road crashes. This data would be helpful in establishing intrusion limits for crash testing guidelines. The magnitude and location of intrusion would need to be identified in order to establish reasonable limits.
3. Quantify the occupant risk associated with partial rollovers by vehicle class. Large trucks are allowed to roll 90 degrees during a crash test, but the test is deemed a failure if a small car or a light truck rolls 90 degrees. Data correlating degree of rollover with occupant injury would be helpful.
4. Establish a link between impact conditions and probability of injury for common safety features and roadside hazards. This data would provide a link between crash conditions and accident severity that would be invaluable in refining B/C analysis techniques.

5. Identify distribution of all vehicle trajectories. This data could be used to incorporate curvilinear paths into the Roadside Safety Analysis Program (RSAP) and developing guardrail length of need calculation procedures.
6. Identify the effects of roadside slopes on vehicle trajectories. This information would contribute to the refinement of B/C analysis tools and the development of length-of-need calculations.
7. Identify the relationship between impact angle and crash severity for longitudinal barriers. This data would contribute to the refinement of B/C analysis tools that in turn would be useful in identifying optimum flare rates for longitudinal barriers.
8. Identify the effects of curbs, ditches, and other terrain irregularities placed in front of safety hardware on the probability of injury during a crash.

This list of questions and issues is by no means exhaustive, but it serves to illustrate the many unanswered questions that can be addressed with in-depth crash data. The database created from the current study may provide answers to some of these questions, but the sample size and the level of detail would limit its applications. There remains a need for a long-term effort to collect in-depth data on single-vehicle, ran-off-road crashes in a continuous and systematic manner.

This long-term data collection effort will require a sponsoring agency with continuing funding sources. The sponsoring agency would ideally be national in scope and have sufficient resources to provide the needed funding on a long-term basis. One possible sponsoring agency is the Federal Highway Administration (FHWA). However, given the situation with the research budget in recent years, it is unlikely that FHWA will sponsor such a long-term data collection effort. Another alternative is to establish a multi-state pooled fund study, similar to the Mid-

States Pooled Fund Program administered by the Nebraska Department of Roads. While this is a viable approach, the required funding per year and the commitment for a long-term effort may be too much for individual states to handle.

The most logical choice is for the American Association of State Highway and Transportation Officials (AASHTO) to sponsor the effort and the program administered through the NCHRP program. There is no question that AASHTO and NCHRP have the required organization and resources to carry out this long-term data collection effort. For example, this current study is sponsored by the AASHTO Technical Committee on Roadside Safety (TCRS) and administered through the NCHRP program. In this setup, the TCRS could serve as the panel overseeing and directing the study.

This chapter outlines a proposed plan for such a long-term data collection effort. Unlike the work plan for the current study, this proposed long-term data collection plan is more at the conceptual level. If and when this proposed plan is adopted for implementation, it will then be necessary to develop a more detailed data collection plan.

5.2 Data Collection Alternatives

As discussed previously, there were three basic alternatives for the data collection effort in the current study:

1. New data collection system
2. Prospective special study under the National Automotive Sampling System (NASS) Crashworthiness Data Subsystem (CDS) program
3. Retrospective supplemental data collection for existing NASS CDS cases

The retrospective approach is too limited in terms of data items that can be collected and in flexibility. Some of the desired data elements are perishable, i.e., lost after a period of time.

For example, data on the struck object would be lost after repair of the object. This could be important to assess the pre-impact characteristics and conditions of the object as well as to determine its impact performance. The sampling scheme is dictated by the CDS system since only within sample cases are available. For certain types of crashes, it would require a very long time before the sample size becomes sufficiently large for proper analysis. Furthermore, NHTSA has changed its policy in 2003 so that police accident reports are no longer a part of the final NASS case. Police reports are maintained at the Zone Centers for only one year to allow for quality control procedures. This change in policy will, in essence, eliminate the use of the retrospective approach.

The establishment of a new data collection system is a viable, but expensive approach. As discussed previously, there will be an initial setup cost for the data collection teams, such as hiring of new personnel, establishing and furnishing the offices, purchasing the necessary equipment for conduct of crash investigation, etc. The investigators will then have to be trained extensively in the basics of in-depth level crash investigation, including both classroom and on-the-job training. Then, there is the need to establish cooperation with the local agencies, such as law enforcement agencies for the notification system, vehicle towing and repair facilities for access to the involved vehicles, hospitals and clinics for medical records/information on injury severity, and transportation agencies for highway related information. It is also necessary to establish quality control procedures to assure that the data collection effort is conducted properly in terms of validity and accuracy.

The most efficient and economical approach is to make use of the existing NASS data collection system. First, the initial setup cost will be greatly reduced since the NASS data teams are already in place. Depending on the nature of the data collection, new investigators may have to be hired and trained and there may be requirements for additional office space and equipment. However, the setup costs should be only a fraction of the cost required to establish a new data collection system. Second, with supplemental field data collection, the portion of the CDS cases involving single-vehicle, ran-off-road crashes will be available for use at a relatively low cost. Third, under the NASS special study subsystem, cases may be selected outside of the CDS sample to address specific types of crashes under study.

The proposed long-term data collection plan is, therefore, built around the NASS CDS data collection system, including both within sample supplemental data collection and outside sample special studies. Note that while NHTSA has maintained the philosophy of allowing the NASS infrastructure to be used for other data collection needs, there are requirements that the special study:

- Should not have an adverse affect on normal NASS operations
- Should not reduce the current NASS CDS caseload for researchers
- Should not have any impact on current CDS data collection procedures and data elements being collected
- Should not have any impact on NASS operational costs
- Must cover all costs associated with the development and operation of the study
- Should be within the interests and expertise of the National Center for Statistics and Analysis (NCSA)
- Must conform with NHTSA privacy guidelines regarding collected data
- Must use existing NASS contractors for all data collection and quality control operations
- Should use a feasibility study to appraise the likely impact and success of the

study

- Should use a pilot study in the development of formalized procedures
- Should present to NHTSA an analysis plan, i.e., what research questions are to be answered

These considerations are addressed in the development of the proposed data collection plan presented in the following section.

5.3 Proposed Data Collection Plan

The proposed data collection plan would have two major subsystems, both of which would be prospective in nature, i.e., the cases would be sampled from new crashes.

1. Continuous sampling subsystem within the CDS sample, and
2. Special study subsystem outside the CDS sample.

The continuous sampling subsystem is intended for a general database to address items of interest pertaining to single-vehicle, ran-off-road crashes. This general database would be similar to the database developed under this study. This continuous sampling subsystem would consist of selecting eligible cases from within the CDS sample and supplementing the basic CDS data with additional field data on roadway, roadside, and struck object characteristics. In addition, the cases would be reconstructed to the extent possible to estimate impact conditions and vehicle trajectories.

The special study subsystem would be ad hoc in nature, intended to address specific questions or roadside safety features. For example, a special study may be designed to assess the impact performance of guardrail terminals. In order to assure a sufficient sample size to properly assess the field impact performance, the special study may have to select cases from outside as well as within the CDS sample. In addition to the basic CDS data and the supplemental field data on roadway and roadside characteristics, detailed information would be collected on the safety device of interest. Again, the cases would be reconstructed to the extent possible to estimate impact conditions and vehicle trajectories.

More detailed descriptions of these two subsystems are presented in the following sections.

5.3.1 Continuous Sampling Subsystem

As mentioned above, the continuous sampling subsystem is intended for a general database on single-vehicle, ran-off-road crashes. The cases would be selected from within the NASS CDS sample using sampling criteria similar to those used with the retrospective approach in the current study, i.e.,

- Area type - rural and suburban
- Single-vehicle, ran-off-road crashes
- Passenger type vehicles only – passenger cars and light trucks
- Speed limit >= 75 km/h (45 mph)

The sampling criteria may be modified periodically to change the range of eligible cases. For example, the area type may be expanded to include urban areas with speed limits of 65 km/h (40 mph) and slower, or the vehicle type may be expanded to include single unit trucks and tractor-trailers, depending on the questions to be addressed with the data. Also, since the cases would be selected within the CDS sample, the notification system would be the same as the CDS.

The basic data elements collected under NASS CDS are very extensive in areas pertaining to the vehicle and occupants, but are lacking in detail in the areas of:

1. Roadway and traffic characteristics
2. Roadside characteristics
3. Struck object characteristics

For the type of questions that are of interest to the roadside safety community, information on the roadway, traffic, roadside, and struck object characteristics would be needed for the analyses. Thus, it would be necessary to collect supplemental field data on these data elements. Some of the supplemental data, such as highway type, functional class, and traffic characteristics, would be obtained from the local or state transportation agencies, and cooperation would need to be established with these agencies.

Note that even with the supplemental data collection, the level of detail on struck object characteristics would still be limited. First, there are simply too many roadside features to include in the data collection protocol for any details to be collected on a particular roadside feature. Second, given the intent of a general database on single-vehicle, ran-off-road crashes, overly detailed information on struck objects would be overkill. Furthermore, it would be very difficult and costly to train the investigators on the details of all these roadside features. The special study subsystem is the more appropriate vehicle for collecting detailed information on selected roadside features.

It is anticipated that the supplemental field data elements for the continuous sampling subsystem would be similar to those used in the current study, with perhaps a few more data elements and additional photographs. It is also anticipated that there would be additional coding on information pertaining to impact conditions and vehicle trajectories based on the basic CDS data, scaled diagram, and supplemental field data. Finally, the cases would be reconstructed to estimate the impact speeds.

One key consideration is how the supplemental field data would be collected. There are basically two approaches for the data collection:

- Existing NASS investigators
- Newly hired and specially trained investigators

For the continuous sampling subsystem, the use of existing NASS investigators would be the more logical and cost-effective means of collecting supplemental field data. Based on previous experience with the retrospective studies, the additional time required to collect and code the supplemental field data is estimated to be no more than two hours per case. For a given PSU, the number of eligible cases is likely to be less than 50 per year. Thus, the additional time devoted to the supplemental data collection would not be more than 100 hours per year per PSU, or less than two hours per week per PSU. It is evident from the estimated workload that it would not be cost-effective to hire an additional investigator per participating PSU for this supplemental field data collection.

On the other hand, if the special study subsystem is implemented with the continuous sampling subsystem, then one new investigator per participating PSU would make imminent sense. This additional investigator would be responsible for collecting both the supplemental data on the continuous sampling cases as well as the special study cases, although the majority of the investigator's time would be devoted to special study cases.

5.3.2 Special Study Subsystem

The general database developed under the continuous sampling subsystem will be invaluable to addressing general trends and questions on single vehicle, ran-off-road crashes. However, it lacks the detail and sample size to address specific questions, such as the impact performance of guardrail terminals. As discussed previously, the level of detail on struck object characteristics will be limited for the supplemental data collected under the continuous sampling subsystem. Also, the number of cases involving a specific roadside feature will be relatively small since the cases are sampled within the CDS sample and it will likely take a very long time before a sufficient sample size becomes available.

The special study subsystem is designed to handle these ad hoc studies. In contrast to the continuous sampling subsystem, a special study is tailored to a specific roadside feature. Thus, the data elements, particularly those pertaining to the roadside feature, can be designed to the desired level of detail. Also, the sampling of the cases would be outside of the CDS sample, thus assuring a sufficient sample size within a reasonable period of time.

As mentioned previously, a new investigator would be hired specifically for the data collection effort at each participating PSU. The investigator would first receive training similar to that of a NASS investigator so that the investigator can collect the basic data elements for a CDS case. In addition, the investigator would receive special training to collect and code the new data elements for the continuous sampling subsystem and the special study being conducted.

5.3.3 Quality Control

Two Zone Centers currently provide the quality control and oversight of the PSUs in the CDS data collection effort. It is envisioned that the Zone Centers would serve the same role in the continuous sampling subsystem and the special study subsystem.

One question is whether the additional coding on information pertaining to impact conditions and vehicle trajectories should be handled at the PSU level by the designated investigators or by Zone Center personnel. Either approach is workable, but it may be more appropriate for the Zone Center personnel to handle this task. First, the task requires considerable expertise and experience, which may be beyond the capability of the PSU investigators, particularly the new hires with little or no experience. Second, the work would likely be more accurate and consistent if handled by Zone Center personnel. Third, one or more new persons can be hired at each of the two Zone Centers specifically for this task of quality control and coding of the additional information. This would minimize the concern of adversely impacting the CDS operation.

5.3.4 Project Management

It is envisioned that an outside contractor would be hired by the sponsoring agency to coordinate with NASS on the data collection effort. The key responsibilities for this contractor would include, but not be limited to:

- Design of the data collection protocol for both the continuous sampling subsystem and the special study subsystem
- Reconstruction of the cases to estimate the impact speeds and conditions
- A second level of quality control of the supplemental data collected
- Maintenance of the general database and special study database
- Analysis of the data to address specific questions

A project panel or a technical advisory committee, comprised of management level personnel from the sponsoring agency and NASS, would oversee the overall conduct of the study. The panel would provide guidance and direction to the contractor and review the study progress and results.

5.4 Pilot Study

A pilot study was conducted to demonstrate the feasibility of such a long-term data collection effort to both the potential sponsor and to NHTSA. Specifically, the objectives of this pilot study were to:

- Demonstrate the feasibility of integrating this long-term data collection effort on ran-off-road crashes into the regular NASS CDS program.
- Identify and resolve any potential problems associated with this long-term data collection effort.

- Estimate time and manpower requirements associated with this long-term data collection effort.

5.4.1 Scope

The pilot study covered only the continuous sampling subsystem within the CDS sample. The feasibility and costs of the special study subsystem outside of the CDS sample would vary greatly depending upon the specific nature of the study to be under taken. Therefore, evaluation of the special study subsystem is beyond the scope of the current study. The scope of the pilot study involved the conduct of a supplemental data collection effort at a small number of Primary Sampling Units (PSUs) for a limited period of time. The same data collection protocol used for the current retrospective study was employed for this pilot study for the sake of simplicity. This eliminated the need to develop a new data collection protocol and to retrain the PSU researchers and Zone Center (ZC) personnel.

It should be pointed out that the integrated supplemental field data collection and reconstruction effort are actually easier and more efficient than the current retrospective study:

- No wasted effort to re-familiarize the researchers and ZC personnel with details of the old cases.
- No additional time to travel and locate the crash site.
- Scene evidence (e.g., damage to roadside hardware) available for documentation.
- ZC staff can perform the reconstruction in conjunction with their regular quality control effort in less time and with greater accuracy.

More detailed descriptions of the pilot study are presented in the next section, followed by results of the study and conclusions and recommendations.

5.4.2 Data Collection Protocol

As mentioned previously, the same data collection protocol used for the current retrospective study was employed for the pilot study with minor modifications. Highlights of the data collection protocol are summarized as follows.

Two PSUs were selected for participation in the pilot study based on the frequency of single-vehicle, ran-off-road crashes and availability of trained researchers, including: PSU 48 and PSU 78. The time period for the pilot study was the nine weeks from October 4, 2004 to December 4, 2004.

The cases were selected from within CDS sample, i.e., from cases that were already included in the CDS sample. The sampling criteria were the same as the current supplemental data collection effort except for the completion requirement, i.e., single-vehicle, ran-off-road crashes on roadways with speed limit greater than or equal to 45 mph. In order to avoid disruptions to the regular CDS data collection effort, each researcher was limited to no more than one case per week. However, all eligible cases were documented for the report. Thus, the maximum expected number of eligible cases was limited to four per week, two cases per week from each PSU.

The same data collection forms and procedures as the current effort were used for the pilot study, including:

- Supplemental Data Collection Form
- Object Struck Data Collection Form
- Reconstruction Coding Form
- Scene photographs

A log form was developed to identify each case and its status (i.e., active or not active); track the additional time spent on the supplemental field data collection at the PSU level and quality control and reconstruction at the ZC level; and document any problems and provide comments. No training for the PSU researchers or ZC personnel was deemed necessary since they were already familiar with the data collection protocol.

The supplemental data collection forms and reconstruction coding forms were completed and submitted in hard copies. The CDS data elements of the selected cases were obtained from preliminary approved cases posted on the NHTSA website with a time lag of approximately 6 to 8 weeks.

5.4.3 Pilot Study Results

As shown in Table 71, there were a total of 22 eligible cases during the nine-week study period, 16 cases for PSU 48 and 6 cases for PSU 78. Of these 22 eligible cases, 16 cases (72.7%) were actually sampled, 11 cases (68.8%) for PSU 48 and 5 cases (83.3%) for PSU 78.

For each sampled case, the PSU and Zone Center personnel were asked to complete a log form, documenting the time required to collect, process, and quality control the additional field data and to reconstruct the cases except for impact speed, including:

- PSU
    - Field time to collect the additional data
    - Office time to process the additional data
- Zone Center
    - Time to quality control the additional data
    - Time to reconstruct the impact conditions other than impact speed

Note that these times pertain to only the additional data elements and not the time required for the NASS CDS data collection effort. In addition, the researchers were asked to note any problems or unusual events encountered in the field or office on the log form.

Table 72 summarizes the additional time required for each of these 16 sampled cases and their averages. As may be expected, the additional time varies greatly on a case-by-case basis, depending on the complexity of the crash and, to some extent, the efficacy and expertise of the individual investigators. Overall, the time required for the additional work on the supplemental data collection ranges from 60 to 255 minutes per case with an average of 135.3 minutes per case.

At the PSU level, the additional field time for collection of the supplemental data ranges from 20 to 120 minutes with an average of 52.8 minutes. The processing time in the office ranges from 0 to 120 minutes with an average of 41.9 minutes. The combined field and office time at the PSU level ranges from 30 to 180 minutes with an average of 94.7 minutes.

At the Zone Center level, the additional time for quality control of the supplemental data ranges from 5 to 10 minutes with an average of 8.1 minutes. The time needed to reconstruct the impact conditions (except for impact speeds) ranges from 15 to 65 minutes with an average of 32.5 minutes. The combined time at the Zone Center level ranges from 15 to 75 minutes with an average of 40.6 minutes.

The researchers were asked to report any problems or unusual events encountered during different phases of this supplemental data collection effort for this pilot study. To ensure completeness, the researchers were asked to enter "None" if there are no problems or comments. The comments are tabulated in Table 73. Overall, there are no major comments of concern. Some of the comments pertain to common operational issues, such as scene evidence, photography, and interference from traffic and Visio printer setup, which are not specifically related to the supplemental data collection. Other comments pertained to definitions and procedural issues that can be easily remedied with some training, including:

- Multiple impacts
- Impacts with more than one object in close proximity
- Reference framework for lateral distance measurements of trajectory

5.4.4 Summary of Findings and Recommendations

The following is a summary of findings and recommendations gleaned from the pilot study:

- The study clearly demonstrated the feasibility of incorporating a long-term data collection effort on ran-off-road crashes into the existing NASS CDS program. However, note that the study included only the continuous data collection subsystem. Thus, the study results would not apply to the special study subsystem.
- It took an average of 135 minutes per case for the supplemental data collection effort, consisting of 95 minutes at the PSU level and 40 minutes at the Zone Center level. Furthermore, it is reasonable to expect that the time would decrease slightly once the researchers are trained and become familiar with the data elements and procedures.
- There were no major issues of concern regarding the data collection or reconstruction of the cases.

5.5 Data Collection Protocol – Continuous Sampling Subsystem

The data collection protocol for the proposed continuous sampling subsystem is essentially unchanged from that of the current retrospective study or the pilot study. Detailed descriptions of the data collection protocol are provided previously in Chapter 1 and Section 5.4 and will not be repeated herein. Only the highlights of the data collection protocol are summarized in this section.

5.5.1 Sampling Plan

The cases for the continuous sampling subsystem would be selected from within the NASS CDS sample, using the same notification system. The sampling criteria may include, but are not limited to, the following:

- Area type - rural and suburban
- Single-vehicle, ran-off-road crashes
- Passenger type vehicles only – passenger cars and light trucks
- Speed limit >= 75 km/h (45 mph)

The actual sampling criteria used may vary, depending on the specific questions to be addressed with the data. For example, the area type may be expanded to include urban areas with speed limits of 65 km/h (40 mph) and slower, or the vehicle type may be expanded to include single unit trucks and tractor-trailers, depending on the questions to be addressed in the study. On the other hand, the actual sample size and the PSUs to be included in the data collection effort is merely a question of available funding.

5.5.2 Data Collection Forms

The proposed data collection forms and procedures for the Continuous Sampling Subsystem are similar to those used in the current effort and the pilot study, but with some enhancements based on experience gained in this study, including:

- Supplemental Highway Data Collection Form
- Object Struck Data Collection Form:
  - Barrier
  - Crash Cushion
  - Embankment
  - Pole Support

    - Tree
    - Other Struck Object
- Reconstruction Coding Form:
    - First Harmful Event
    - Subsequent Harmful Event
- Performance Assessment Form
- Scene Photographs

Copies of these proposed data collection forms and the corresponding coding and field procedures manuals are included in Appendix F.

5.5.3 Organization

The data collection effort is best sponsored by AASHTO and administered through the NCHRP program. An outside contractor would be hired to conduct the study and to coordinate the data collection effort with NASS. A project panel, or a technical advisory committee comprised of management level personnel from the sponsoring agency and NASS, would oversee the overall conduct of the study, provide guidance and direction to the contractor, and review the study progress and results.

If only the continuous sampling subsystem is to be implemented, then the most logical and cost-effective arrangement is for the field data to be collected by existing NASS investigators and quality controlled by Zone Center personnel, assuming the additional work load would not adversely affect the regular CDS operation. Based on previous experience with the retrospective studies, the additional time required to collect and code the supplemental field data is estimated to be no more than two hours per case. For a given PSU, the number of eligible cases is likely to be less than 50 per year. Thus, the additional time devoted to the supplemental data collection would not be more than 100 hours per year per PSU, or less than two hours per week per PSU. It is evident from the estimated workload that it would not be cost-effective to hire an additional investigator per participating PSU for this supplemental field data collection.

Coding of additional information and reconstruction of the cases as well as the performance assessment would be handled by the outside contractor so as to minimize the time required of the PSU and Zone Center personnel.

5.6 Data Collection Protocol – Special Studies Subsystem

Under the special study subsystem, single-vehicle, ran-off-road crashes involving specific roadside safety features or devices would be selected from both within and outside the CDS sample. The data to be collected under this special study subsystem would include:

1. Selected CDS data
2. Supplemental highway data for the continuous sampling subsystem
3. Detailed information on the roadside feature or device under study

The special study cases would then be reconstructed to estimate impact conditions and vehicle trajectories, and the impact performance of the specific roadside feature/device under study will be assessed.

The specific data collection protocol will differ from special study to special study. Thus, the discussions will be more general in nature to cover the key considerations.

5.6.1 Sampling Plan

As mentioned previously, it is impossible to devise a specific sampling plan that works for all special studies. Thus, the discussions will be more general in nature to cover the key considerations in developing the sampling plan.

Sample Size. The number of cases to be investigated would first have to be determined. This is usually determined by study/analysis requirements and the available funding.

Study Location. PSUs with the most eligible cases would first be identified. The most appropriate PSUs would be selected for participation in the special study, based on the required sample size and factors such as: number of eligible crashes, the number and experience of the investigators, geographical location, work load, etc. It is critical that the PSUs are selected in conjunction with NHTSA and the two Zone Centers. Every effort should be made to avoid interference with the regular NASS CDS work of the selected PSUs.

Study Period. Again, this is a function of the required sample size and the number of eligible cases from the participating PSUs.

Sampling Plan. The special study subsystem would typically select cases from both within and outside the NASS CDS sample. The sampling plan should take into account key considerations as those for the selection of PSUs including number of eligible crashes, the number and experience of the investigators, geographical location, work load, etc. Again, it is critical to develop the sampling plan in conjunction with NHTSA and the two Zone Centers. Every effort should be made to avoid interference with the regular NASS CDS work of the selected PSUs.

Notification System. A special notification system is needed for cases to be selected from outside the NASS CDS sample. Care should be taken to make sure that the notification system for the special study would not interfere with the CDS or add too much work to the cooperating agencies. Depending on the nature of the special study, another consideration is the time lag from the time the crash occurred to the time the PSU is notified of the crash. For certain types of crashes, the time lag may need to be relatively short in order to gather the needed scene evidence. In such cases, the notification system would have to be devised to reduce the time lag to an acceptable level.

5.6.2 Data Collection Forms

The general structure of the data collection forms and procedures for the special study subsystem would be similar to those used with the continuous sampling subsystem, including but not be limited to:

- Supplemental Highway Data Collection Form
- Object Struck Data Collection Form
- Reconstruction Coding Form
- Performance Assessment Form
- Scene Photographs

However, the forms would be tailored to the specific roadside feature/object under study. The supplemental highway data collection form would likely remain mostly unchanged. The other data collection forms would have to be modified to address the specific roadside feature/object with more specific and greater details.

5.6.3 Organization

The sponsorship and organization of a special study data collection effort would be similar to those of the continuous sampling subsystem. The program is best sponsored by AASHTO and administered through the NCHRP program. The conduct of the study would be handled by an outside contractor and coordinated with NASS while a project panel or a technical advisory committee would provide guidance and direction to the contractor and review the study progress and results.

If both the continuous sampling subsystem and the special study subsystem are implemented, then the most logical arrangement is to hire a new investigator for each participating PSU since the special study cases are mostly sampled outside of CDS cases. Similarly, new personnel would have to be hired at the two Zone Centers to handle the quality control of the collected data and coding of additional information for the special study. The additional staff at the PSUs and Zone Centers would ensure that the regular CDS operation will not be adversely affected. The outside contractor would continue to handle the coding of additional information, reconstruction of the cases, and the performance assessment.

In addition to the training required for the regular CDS data collection and the continuous sampling subsystem, both PSU investigators and Zone Center personnel assigned to the special study data collection effort would require special training in order to collect and quality control the specific and detailed data for the special study. The training would be conducted by the outside contractor on data elements, coding instructions, and field procedures specific to the special study data collection effort. The training should include both classroom lectures and field training as well as on-the-job training.

5.7 Summary

A long-term data collection plan on single-vehicle, ran-off-road crashes is proposed. The proposed plan is built around the NASS CDS data collection system, including both within sample supplemental data collection and outside sample special studies. The efforts would be prospective in nature, i.e., the cases would be sampled from new crashes and consist of two major subsystems or components:

1. A continuous sampling subsystem intended for a general database to address items of interest pertaining to single-vehicle, ran-off-road crashes. The cases

would be selected from within the CDS sample and supplementing the basic CDS data with additional data on roadway, roadside, and struck object characteristics. In addition, the cases would be reconstructed to estimate impact conditions and vehicle trajectories.

2. An ad hoc special study subsystem intended to address specific questions or roadside safety features. The cases would be selected from both within and outside the CDS sample to assure sufficient sample size within a reasonable period of time. In addition to the basic CDS data and the supplemental field data on roadway and roadside characteristics, detailed information would be collected on the safety device of interest. Again, the cases would be reconstructed to the extent possible to estimate impact conditions and vehicle trajectories.

The data collection effort is best sponsored by AASHTO and administered through the NCHRP program. An outside contractor would be hired to conduct the study and to coordinate the data collection effort with NASS. A project panel or a technical advisory committee comprised of management level personnel from the sponsoring agency and NASS would oversee the overall conduct of the study, provide guidance and direction to the contractor, and review the study progress and results.

If only the continuous sampling subsystem is to be implemented, then the most logical arrangement is for existing NASS investigators to collect the data since the additional time for the supplemental data would not be sufficient to require new staff. Quality control would be conducted by Zone Center personnel. It may be necessary to hire new Zone Center staff to handle the additional work. Coding of additional information, reconstruction of the cases, and assessment of the impact performance would be handled by the outside contractor. It is important to make sure that the additional work would not adversely affect the regular CDS operation.

If both the continuous sampling subsystem and the special study subsystem are to be implemented, then the most logical arrangement is to hire a new investigator for each participating PSU. This new investigator would be trained not only in the collection of CDS data, but also supplemental data pertaining to the continuous sampling subsystem and the special study subsystem. Similarly, new personnel would be hired at the two Zone Centers to handle the quality control of the collected data and coding of additional information. The completed cases would then be forwarded to the outside contractor for additional quality control and reconstruction.

Table 71. Number of Eligible and Sampled Cases

Week Beginning	No. of Eligible Cases			No. of Sampled Cases		
	PSU 48	PSU 78	Total	PSU 48	PSU 78	Total
October 4	0	2	2	0	1	1
October 11	4	0	4	2	0	2
October 18	2	1	3	1	1	2
October 25	1	0	1	1	0	1
November 1	4	1	5	2	1	3
November 8	2	1	3	2	1	3
November 15	1	0	1	1	0	1
November 22	1	0	1	1	0	1
November 29	1	1	2	1	1	2
Total	16	6	22	11	5	16

Table 72. Additional Time Required

Case Number	Additional Time Required (Minutes)				
	PSU		Zone Center		Total
	Field	Office	Quality Control	Recon-struction	
04-48-235J	60	20	10	40	130
04-48-238K	30	45	5	25	105
04-48-246D	20	30	5	35	90
04-48-253H	60	120	5	35	220
04-48-254B	50	50	5	10	115
04-48-259K	30	20	5	15	70
04-48-262C	20	20	10	30	80
04-48-265K	40	40	10	20	110
04-48-267J	60	20	10	50	140
04-48-274J	25	5	5	25	60
04-48-280K	60	120	10	65	255
PSU 48 Average	41.4	44.6	7.3	31.8	125.0
04-78-134D	60	60	10	35	165
04-78-140K	120	0	10	35	165
04-78-143K	90	60	10	20	180
04-78-144J	60	60	10	30	160
04-78-148K	60	0	10	50	120
PSU 78 Average	78.0	36.0	10.0	34.0	158.0
Combined Average	52.8	41.9	8.1	32.5	135.3

Table 73. Summary of Comments

Case No.	PSU Comments	Zone Center Comments
04-48-235J	I had to go back to the scene and redo my lateral measurements because I forgot to separate the rollover initiation, but that was the researcher’s fault. Other than that, no problems.	Visio printer setup. Had to “grab” missing images from case.
04-48-238K	None.	Visio printer setup.
04-48-246D	None.	Had to create an object form for 2nd object struck. Visio printer setup.
04-48-253H	Two utility poles situated close beside each other were struck and coded as one event.	Visio printer setup. 2 extra object forms added for Events 2 and 3.
04-48-254B	Another crash occurred in same area / deciphering evidence.	In-house Visio issue.
04-48-259K	None.	In-house Visio issue.
04-48-262C	Difficult to place ID card in images on scene due to Interstate traffic.	Reconstruction – changed angle of departure off barrier, so re-calculated FRP. (No scene evidence at FRP.)
04-48-265K	Vehicle departed right road edge and returned to road to rollover. Slope measurements taken at road departure.	None.
04-48-267J	None.	Visio did not migrate properly. Had to create from printout copy.
04-48-274J	None.	Visio printer software issues.
04-48-280K	Multiple events and scene evidence being contaminated made it difficult to determine impacts and locations.	Same Visio printer setup problem. Listed 3 events (that affected CG) only (not 6). Laterals on a curve were changed to be perpendicular to the curved road edge.
04-78-134D	None.	Had to annotate POD,, etc. on Visio. Advised researcher how to do that “next time”.
04-78-140K	Had a hard time placing the cones in a straight line from road edge to final rest.	12 laterals taken from POD to FRP, not POD to POI. Had to re-calculate these from Visio.
04-78-143K	Heavy rain and it caused delays in getting out to take images.	None.
04-78-144J	None.	Researcher took 12 laterals from POD to FRP. Re-computed 6 laterals from POD to POI.
04-78-148K	Researcher unsure how to fill in the reconstruction form for events 2 and 3.	Filled in subsequent reconstruction form for researcher.

6 SUMMARY OF FINDINGS

6.1 Study Approach

Data was collected under three different studies, the FHWA rollover study, NCHRP 17-11, and NCHRP 17-22. Each of these studies involved a retrospective data collection and analysis of historical NASS CDS cases. Supplemental site information was collected to identify characteristics of the roadway, roadside, and objects struck during the crash. This supplemental information was then utilized to reconstruct each crash in order to determine vehicle departure and impact conditions. The data was then compiled into a relational database that can be used to analyze the data.

6.2 Findings

A relational database of ran-off-road crashes has been developed. The database includes detailed characteristics of the vehicle, trajectory, roadway, roadside, objects struck, and crash result for 877 crashes. The data is strongly biased toward serious crashes with 15% fatal and 72% A+K crashes. The database can be used for many different purposes, including identification of roadway departure and roadside impact conditions, and ran-off-road trajectories. The database can also be used to develop a relationship between impact conditions and crash severity for some common obstacles, such as trees and poles.

Although prior studies showed departure velocity to be most closely associated with highway functional class, this roadway classification was not available in the current database. In the absence of highway functional class, speed limit was found to provide the best discriminator for departure velocity and angle. Departure velocities were found to be accurately modeled with a normal distribution while no single common distribution provided a good fit to departure angles for all speed limit classes. However, the gamma distribution was found to fit the square root of the departure angle for all speed limit classes. The dependency between departure angle and velocity was found to be relatively insignificant for all individual speed limit classes. Chi-square tests for independence showed that departure velocity and angle could be considered independent for all speed limit classes. Further, combined velocity and angle distributions developed based on the assumption of independence were subjected to chi-square tests for goodness-of-fit. These tests showed that the differences between predicted and measured distributions of departure velocities and angles were not statistically significant at the p=0.05 level for any speed limit class. Thus, the models of departure velocity and square root of departure angle can be reliably used to develop distributions for a variety of speed limit classes included in the study.

Further, the database provides definitive support for reducing the length of guardrail used in advance of roadside obstacles. The distributions of longitudinal departure lengths included in the data set correlated surprisingly well with recommended guardrail runout lengths generated from Cooper's encroachment data. The only significant difference between the longitudinal departure length distributions and the modified runout length guidelines was associated with the use of a 60 mph design speed for a full access control freeway. In this situation, modified runout length guidelines were found to be shorter than longitudinal travel distances found in the data set. Therefore, it is recommended that states either use a design speed of 70 mph for all controlled access roadways, or an additional category should be added to the guardrail runout length table to accommodate 60 mph design speeds with full access control.

6.3 Long-Term Data Collection

A detailed work plan for a long-term data collection system was developed and pilot tested. The plan involves implementing a continuous sampling subsystem and possibly a special study subsystem within the NASS-CDS. The continuous sampling subsystem would provide a steady stream of new cases that would be very similar to the existing database while a special study would focus on one particular type of crash such as W-beam guardrail impacts.

If implemented the long-term data collection plan could provide information that would allow development of the relationships between impact severity and crash conditions for a wide variety of roadside features. Further, such a study would provide greater information regarding the causation of injuries and fatalities during crashes involving roadside safety hardware. This information will provide the foundation for the next generation roadside safety features designed to dramatically reduce injuries and fatalities associated with ran-off-road crashes.

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APPENDIX A
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This research circular is focused on issues that may warrant consideration in future updates of the guidelines contained in NCHRP Report 350 on evaluation of impact performance of roadside safety features. The areas pertaining to impact conditions discussed by the author include: impact speed, impact angle, impact energy considerations, accident data, and lateral offset relationship. The areas pertaining to the test matrices in NCHRP Report 350 discussed include: terminals/crash cushions, terminal/crash cushion transitions, truck mounted attenuators, optional tests, and side impact testing.

Impact speeds in NCHRP Report 350 test matrices do not exceed 100 km/h (62.2 mph) but the national speed limit of 89 km/h (55 mph) has since been revoked and many transportation agencies have raised speed limits. This change has raised questions regarding the appropriateness of the current test speeds. The author cautions that when contemplating a change in the test speeds, the consequences should be carefully examined. For redirection devices such as longitudinal barriers, the increased impact speed may be accompanied by a decrease in impact angle, such that the overall impact severity may remain the same.

Regarding impact angle, the author indicates that tests have identified problems with stability and severity criteria rather than with the 25-degree angle, which is currently specified in NCHRP Report 350. As for energy considerations, it is pointed out that for end-on impacts with terminals and crash cushions, the impact severity is simply defined as the kinetic energy of the impacting vehicle and the energy that must be managed by absorbing devices increases with the square of the impact speed. Regarding accident data, the author points out that most of the available information on impact speed and distribution is based on accident data which were collected under 89 km/h (55 mph) conditions. There are no data available to determine if and how much the distributions of impact conditions have changed as a result of higher speed limits.

The author reviews the test matrices in NCHRP Report 350 and identifies some issues that require clarification or additional research. These include additional information required on specification of critical impact point (CIP) in Test 34 (small car redirection test), the requirements of conducting Test 39 (reverse direction impact for guardrail), and the appropriateness of the 2000P as the design test vehicle (e.g., the 820C may be more critical for guardrail terminals using a cable anchor assembly due to its increased propensity for under riding the rail). Since Test 32 (15 degree angle impacts on the nose of a terminal or crash cushion) is generally considered to be more critical than Test 33 (utilizing 2000P), it may be appropriate to eliminate Test 33. An additional test may be needed because NCHRP Report 350 is unclear on the transition of a terminal or crash cushion to a standard barrier section. The author also raises issues regarding tests on truck-mounted attenuators.

Limitations and Use for NCHRP 17-22

This article provides useful information on issues related to impact conditions and test matrices for consideration in future updates of the crash test and evaluation procedures presently recommended in NCHRP Report 350. Guidance can be obtained from this article for research to be conducted under NCHRP 17-22 on improving state-of-the-knowledge on accident impact conditions.

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The author provides useful insights into limitations and capabilities of the NASS system from a highway safety researcher's viewpoint. Five major limitations listed by the author include: 1) non-availability of statewide estimates of the accident problem, 2) inability to link accident data to exposure measures, 3) disparity among FHWA and NHTSA interests, 4) problems with accident reconstruction processes used with barrier crashes and multiple-hit situations, and 5) problematic definitions for some of the collected data elements.

Regarding the first limitation, according to the author, the NASS sampling scheme is designed to produce national estimates and is not setup to provide estimates within states. Regarding the second, the author cites that there is no way to link the accident data collected with any exposure data. Therefore, rates involving million vehicle miles or other highway-related measures cannot be calculated. On the third limitation, the author states that rates which are of interest to the NHTSA are not necessarily the same as those of interest to the FHWA. Since NASS has only information on accidents, a bias exists for the researcher interested in studying countermeasures that prevent accidents. On the fourth limitation, the author cites problems with accident reconstruction computer programs and that the emphasis has been on vehicle and driver. It is for this reason that highway barrier programs are not as adequate as they might be. Lastly, definitions of some of the data elements are not clear and the example of intersections with raised channelization being recorded as Adivided highway@ is given.

Next, information is provided on the capabilities of the NASS data. The main accomplishments possible are provision of national estimates and help with performance evaluations of highway hardware under certain conditions. Adequate national estimates may be obtained for type of accidents, accident severity, etc. However, in carrying out performance evaluations, the researcher must be aware of the basic issue of sample size and numerous factors (e.g., speed of impact, vehicle size, shoulder width, etc.) that must be controlled. Sample size will increase greatly with increasing factors that the research must control. The solution is to initiate special studies, such as the Longitudinal Barrier Special Study (LBSS), but these studies are expensive and time consuming. The researcher must also define data items very carefully, train field data collectors, and ensure high data quality during collection.

In view of the limitations, the author concludes that the NASS system may be of limited use to the highway accident researcher. Suggested changes to make it more useful include incorporation of exposure data, monitoring of highways rather than accidents, and periodic review for removal of unneeded data elements.

Limitations and Use for NCHRP 17-22

This article provides useful insights into the limitations and capabilities of the NASS data. NCHRP 17-22 data collection efforts must be planned to avoid some of the pitfalls discussed in this article. These include: careful planning of data collection, considerations of sample size and factors to be controlled in the analysis, precise definitions of data elements and data collector training, and data quality control during collection.

3. Cooper, P. J., “Analysis of Roadside Encroachment Data from Five Provinces and Its Application to an Off-Road Vehicle Trajectory Model,” March 1981.

Cooper performed an analysis of data acquired by Transport Canada over a five-month period from June to October 1978. Data was acquired from visual identification of encroachments on the roadside.

Encroachment data was collected from various types of roadways, including two-lane undivided and four-lane divided highways with ADTs from 700 to 29,300 vpd and totaling 4560 km (2833 mi). Statistical analysis was performed to determine the encroachment rates, distances, and angles.

Cooper attempted to address many of the problems found with the Hutchison and Kennedy data. Primarily, Cooper addressed intentional encroachments by recording encroachments where the vehicle track formed a continuous arc from the point of departure to the point of re-crossing the shoulder with no apparent discontinuities in the path.

Limitations and Use for NCHRP Project 17-22

Analysis of the Cooper study by McGinnis showed the importance of documentation of every minute detail of data collection and analysis. The importance of well-trained personnel performing both data collection and reconstruction was also identified.

The results of the Cooper study were statistically similar to the Hutchison and Kennedy’s results once adjustments are made for study conditions.

4. Council F., and J. Stewart, "Development of Severity Indices for Roadside Objects," FHWA Publication No. FHWA-RD-95-165, Federal Highway Administration, McLean, VA, 1995.

This study was an attempt to develop severity indices (SI) for various fixed objects impacted by vehicles in run-off-the-road accidents. SI is the average, or typical, severity of the impact of a vehicle with a given object or the injury sustained by a vehicle occupant. The authors first reviewed pertinent literature indicating the gaps in knowledge. Briefly, the gaps included the need for multi-state accident databases, identification of crashes in which the occupant injury could be directly attributed to the fixed object struck, the need for a methodology that provided not only an average measure of the SI, but a measure of the possible variability of the measure, and a need for SIs that are specific to a large array of crash locations and circumstances. Finally, the issue of change in vehicle fleet (e.g., airbag equipped vehicles) on SI values was afforded some attention.

The authors' first attempted to utilize crash test data with police reported accident data for SI development. However, this was not successful because of limited variability in the crash test conditions, the lack of information on impact angle and speed in the police data, and the need to define a better composite measure of occupant risk in the crash test measurements. Thus, the final SI development was based on the police reported data only.

Using accident data from North Carolina and Illinois, two SIs were developed for a wide range of crash situations: the first was a severe injury SI while the second was a cost-based SI. For consistency, driver injury as opposed to most severe injury, which could be experienced by any occupant in a vehicle, was chosen in the SI development. The Classification and Regression Trees (CART) procedure was used to define the control variables that produced significant differences in the SIs for a given object. Overall, the SIs were moderately consistent between the two states, and findings from the two databases were consistent to a significant degree with SIs developed by Mak, et al., using data from Texas. Also, the analysis indicated that airbags appeared to significantly reduce the value of SI, and that the reduction could range from 30-70 percent. The cost-based SI figures provided a wider range of values for indices, and they appeared to provide a more accurate index of relative hazardousness for impact attenuators. However, when small samples were compared, it appeared that the severe injury index was superior in that it was less sensitive to random fluctuations of fatalities.

Limitations and Use for NCHRP 17-22

This study provides useful information on development of severity indices for roadside objects. It has some limitations including non-reporting of accidents and the use of data from only two states. Even the data utilized in the study were not consistent across the two states. The potential use of this information in NCHRP 17-22 is somewhat limited.

5. **Daily, K., W. E. Hughes, and H. W. McGee, "Experimental Plans for Accident Studies of Highway Design Elements: Encroachment Accident Study," Report No. FHWA-RD-96-081, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., January 1997.**

This study examines the feasibility of using accident data to derive estimates of: (1) encroachment rates on level, tangent sections of rural two-lane highways, and (2) percentage of unreported accidents.

A pilot study involving 56 km (35 mi) of tangent sections of rural two-lane highways in Idaho were conducted. Data collected included detailed roadside, accident, and traffic data. Encroachment rates were estimated from the collected accident data and found to be in the same order of magnitude as previous research. It was concluded that the methodology is feasible, although it is limited by the current state-of-the-knowledge with respect to data on the trajectories of vehicles involved in ran-off-the-road, fixed-object accidents.

An experimental plan for future research that would produce improved estimates of encroachment rates was developed, but not recommended for immediate implementation.

Limitations and Use for NCHRP Project 17-22

This study has no direct bearing on the current study, but could be of interest in future data collection efforts. Data on encroachment rates are almost 25 years old and may be outdated in light of the significantly changed conditions in the intervening years, including improvements made to the safety design of highways (e.g., clear zone concept and improved barriers and terminals) and vehicles (e.g., front and side airbags, anti-lock brakes, and crush management) and other safety countermeasures (e.g., mandatory seatbelt law, tightened blood alcohol content law). If a major data collection effort is to be implemented in future, encroachment data may be one of the objectives.

6. O. Erinle, W. Hunter, M. Bronstad, F. Council, R. Stewart, and K. Hancock, "An Analysis of Guardrail and Median Barrier Accidents Using the Longitudinal Barrier Special Studies (LBSS) File," Final Report, Volumes 1 and 2, FHWA Publication No. FHWA-RD-92-098, Federal Highway Administration, McLean, VA, February 1994.

The Longitudinal Barrier Special Study (LBSS) was one of three studies initiated within the National Accident Sampling System (NASS) to provide in-depth knowledge of specific types of crashes. Under this special study, additional data was collected on accidents involving longitudinal barriers. In order to be eligible for inclusion, the accident must involve a vehicle striking a guardrail or median barrier, be reported by the police, and the following data had to be available: (1) barrier damage, (2) vehicle trajectory, and (3) vehicle damage. The data collection was conducted in a prospective mode such that the additional elements could be identified during the initial accident investigation. In addition to data collected under NASS, supplemental data elements were collected, including detailed information about the barrier that was struck and terrain traversed during the accident. Barrier information included type of system and measurements of the damaged section of barrier.

Data was collected from 1982 to 1986. Onward from mid-1983, accidents involving vehicle-to-vehicle impacts prior to the guardrail or median barrier impact were not included. A total of 1,146 accidents met the acceptance criteria and were included in the study.

Under this study by Erinle, et. al., the NASS LBSS data file was cleansed and reviewed. This involved recoding portions of the data for consistency and correcting erroneous data. Also, barrier impacts were separated by length-of-need and impact severity as well as barrier type. The accidents were then reconstructed to determine vehicle speed, angle, and vehicle orientation at impact. The reconstruction procedure involved determining energy losses during each stage of the accident, ranging from pre-impact skidding to secondary impacts with vehicles or other objects. Energy dissipated during an impact was estimated based on vehicle and barrier damage. Vehicle crush energy was estimated from measured damage profiles using vehicle stiffness parameters derived from the New Car Assessment Program (NCAP) crash tests. Barrier damage energy was estimated using computer simulations that correlated barrier deformation to energy dissipation. Damage associated with other types of impacts, including secondary vehicular impacts and other fixed object crashes, were estimated based largely on vehicle crush measurements.

Length-of-need (LON) impacts were reconstructed using conservation of energy and summing the energy losses from vehicle crush, barrier deformation, and vehicle trajectory. A relationship between maximum dynamic barrier deflection and impact severity was used to estimate energy losses from barrier deformation. Barrier end impacts were reconstructed for W-beam turndowns, W-beam blunt ends, and Breakaway Cable Terminals (BCTs). The authors used vehicle drag, crush, trajectory, vehicle/barrier damage, occupant injuries, and yaw marks, as well as crash test experience to reconstruct the accident.

The main conclusions from the study were:

- Weak-post barriers were less associated with driver injury than other barrier types.

- Driver injury rates were higher for vehicles redirected to the roadway than vehicles remaining on the roadside, penetrating the barrier, or remaining in contact with the barrier.
- Blunt and turndown ends were more dangerous than LON impacts.
- Reconstructed values of longitudinal barrier impact speed typically had an error margin of 10 mph.
- Unusual circumstances were commonly present when a barrier reportedly failed.

Limitations and Use for NCHRP 17-22

This study provides useful information on a study that generated impact conditions for longitudinal barriers. The same general approach is proposed for Project 17-22 with the exception that it will not be limited to longitudinal barriers. Procedures utilized to reconstruct the longitudinal barrier accidents will be very similar to what will be needed in Project 17-22. Further, problems associated with representativeness of the accident data should be avoided if possible.

The study also highlighted the importance of discerning between types of guardrail "failure." In many cases, "failure" was not an accurate description of the guardrail behavior and was recoded in the LBSS file. Systematic investigations of every data variable are critical and verification that photographic evidence matches database coding is essential. The study also noted that the end terminal type must be verified from photographic evidence, since miscoding and misidentification in the file had occurred.

Although this study developed a great deal of information on accidents involving roadside and median barriers, it does have some representativeness problems. The authors were not able to utilize the data to obtain distributions of impact conditions for ran-off-road accidents. Further, because the study was limited to longitudinal barriers, it was not possible to generalize any of the information to accidents involving other roadside objects.

7. Eskandarian, A., G. Bahouth, K. Digges, D. Godrick, and M. Bronstad, "Improving the Compatibility of Vehicles and Roadside Safety Hardware," Final Report, NCHRP Project 22-15, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., October 2002.

The objectives of this study were to: (1) identify current and future vehicle characteristics that are incompatible with existing roadside hardware; (2) evaluate the possibility of improving compatibility; and (3) provide the automotive industry and roadside hardware developers with an increased awareness of these compatibility issues.

Preliminary findings suggest that pickup trucks may not be a good surrogate for SUVs, impacts with concrete barriers tend to be more serious, and there is a good correlation between certain vehicle characteristics and injury outcome. Of particular interest to Project 17-22 is a list of suggested data elements for use with the current NASS CDS program. These data elements pertain to struck feature design characteristics, pre-impact conditions, impact conditions, and assessment of impact performance of feature.

<u>Limitations and Use for NCHRP Project 17-22</u>

While the suggested data needs pertain mostly to the issue of compatibility between vehicle design and roadside safety features, the information would be helpful to establishing the data needs for the data collection effort under Project 17-22.

8. Fitzpatrick, M. S., K. L. Hancock, and M. H. Ray, "Videolog Assessment of Vehicle Collision Frequency with Concrete Median Barriers on an Urban Highway in Connecticut," Transportation Research Record 1690, Transportation Research Board, Washington, D.C., 1999, pp 59-67.

In-service performance evaluation of concrete median barriers (CMB) in Connecticut is the focus of this paper. The authors concentrate on determining how often CMBs are struck and how often such collisions are reported to police. They used repeated videologs of a selected highway to collect information on CMB collisions and then compared those to police reported crashes. A ratio of 23% between the total number of collisions and those reported to the police was found. Collision rate on curved segments was approximately three times greater than that on tangent segments. Neither the Roadside model nor the RSAP model provided accurate predictions of the collision frequency observed on the study section. Roadside under predicted while RSAP over predicted the number of collisions. The authors concluded that the differences could be due to the variation in characteristics of their study segment and those of the data sets used in the development of the two encroachment models. Finally, the authors indicated that the character and nature of vehicle encroachments and collision rates on high-volume, high-speed highways in urban areas are not well understood.

Limitations and Use for NCHRP 17-22

It appears that the study has limitations, some of which have not been taken into account. For example, 40 blocks of CMBs were excluded from the study because of lighting problems with the videolog equipment when passing under bridges. This could potentially introduce bias in the collected data especially since underpasses were systematically excluded. The study failed to collect information on collisions that did not mark CMBs and encroachments that did not result in a collision. Further, the study was limited to median barriers and differences in vehicle fleet mix across different lanes could potentially bias the data. Despite these limitations, the study provides useful information for calibrating impact frequency models.

9. Hunter, W., “Data Collection and In-Service Evaluation Issues,” Transportation Research Circular 416, Transportation Research Board, Washington, D.C., 1993.

This paper presents an overview of relevant data issues for in-service evaluation of roadside safety management systems. The author stresses the need for in-service evaluations on a continual basis since the vehicle fleet is changing with time. The paper starts with inherent problems with crash evaluations. Some of the problems include variations in accident reporting thresholds, erroneous reporting on accident data collection forms, inaccurate location of accidents, and considerable delays in data processing in some areas. Some of the suggested sources for building an appropriate database include existing accident data files, manual surveys by maintenance personnel, photolog and videolog, and other automated or semi-automated methods of data collection. After this, the author focuses on in-service evaluation issues such as, “what is being measured?” and threats to validity. The suggestion is that investigators should clearly decide, “What is the treatment supposed to accomplish?” before embarking with the evaluation. Some treatments (e.g., warning signs, median barriers, etc.) attempt to reduce accident frequency while others (e.g., crash cushions) attempt to reduce collision severity. Regarding threats to validity, some of the issues highlighted are other things taking place at the same time (history), trends over time (maturation), regression to the mean, and data instability.

The next topic discussed is evaluation design. Probably the most common design in highway safety has been the simple before-after design, where data are compared before and after a treatment to evaluate safety impacts. Unfortunately, this simplistic approach is subject to several validity threats. A better design is the before and after study with randomized control groups. In the absence of randomized groups, a before and after study with a selected control site might be acceptable. Finally, the author presents suggestions on data elements and studies that may be utilized to fill gaps in existing knowledge. These include the use of LBSS data, data on real world barrier crashes (vehicle impact speed and angle, vehicle yawing angle or vehicle tracking, barrier impact point, subsequent vehicle trajectory, etc.)

Limitations and Use for NCHRP 17-22

The paper provides useful information on issues with in-service evaluations. As suggested in the paper, vehicle impact speed and angle data will be collected in NCHRP 17-22.

10. Hunter, W. W., and F. M. Council, "Future of Real World Roadside Safety Data," Transportation Research Circular Issue 453, Transportation Research Board, Washington, D.C., 1996, pp 38-54.

The issue of data adequacy to meet various evaluations of roadside safety hardware is the focus of this paper. It points to a number of goals related to roadside safety hardware including:

- Determine whether a new design can pass a "practical worst case" scenario
- Determine which roadside features to treat
- Determine whether what has been designed using crash tests and simulation works in the real world

The authors then attempt to examine the questions of whether adequate data exist to meet the above goals, and if not, what can be done to produce relevant data. They discuss the encroachment and accident-based models for roadside safety and indicate existing gaps in the available data for both models. Lack of current data availability on encroachments, lack of roadside inventory, and unreported accidents are some of the limitations mentioned by the authors. The authors also discuss limited data availability for development of injury indices.

The authors discuss some databases that could potentially be utilized. These include: the HSIS database and the Longitudinal Barrier Special Study (LBSS). However, both have limitations; HSIS does not contain information on impact conditions (speed and angle) and not enough detail on specific hardware, while the LBSS data suffers from bias toward more severe accidents. Other sources mentioned are maintenance data and videolog data. The authors conclude that there are clear gaps in existing knowledge of roadside safety measures and gaps in the databases used to build this knowledge. They recommend proper targeting of funds and creative thought about new and existing data to overcome the gaps.

Limitations and Use for NCHRP 17-22

The paper is a good review of the existing gaps in knowledge of roadside safety and what might be done to fill those gaps. The existing databases mentioned in the paper (HSIS, LBSS, etc.) have limitations and their applicability to NCHRP 17-22 research is doubtful. Videolog data and in-service evaluations of hardware, although good sources for data, do not provide impact speed and angle data needed in NCHRP 17-22.

11. Hutchison, J. W., and T. W. Kennedy, “Medians of Divided Highways By Frequency and Nature of Vehicle Encroachments,” Engineering Experiment Station Bulletin 487, University of Illinois, 1966.

Hutchinson and Kennedy encroachment data was used as the basis for AASHTO’s Roadside Design Guide, providing the basis of analysis of off-road excursions. The frequency, nature, and causes of vehicle encroachments on medians of divided highways were investigated to obtain information needed to establish traffic safety criteria for median width and cross-section design. Many aspects of roadway design were examined, including median width, traffic volume, roadway alignment, weather, roadway signs, grade separation structures, and other departures. Relationships between traffic volume and the frequency and nature of vehicle encroachments on medians were examined.

Researchers analyzed the distances and angles of errant vehicles through visual inspection of the roadside. Encroachments with less than a 0.9-m (3-ft) lateral movement were ignored due to the difficulty detecting encroachments on stabilized shoulders.

The medians were frequently covered with snow during the data collection phase. However, encroachments during winter months were less than those for non-winter months.

Limitations and Use for NCHRP Project 17-22

Several issues exist with the data set, including the lack of adjustment for intentional encroachments and the differences due to changes in the deregulation of speed limits, the introduction of anti-lock brakes, and the other technological or sociological changes that have occurred in the past four decades. Encroachment data was biased towards low angle impacts, given that four-lane roadways were new to the public and medians provided an attractive area for picnics or pulling off of the road to rest. These changes must be taken into consideration when determining future data needs.

12. Kent, R. W., and C. E. Strother, "Wooden Pole Fracture Energy in Vehicle Impacts," Advances in Safety Technology, Society of Automotive Engineers, February 1998.

Fixed-object collisions, which account for less than 8% of all crashes, represent nearly 30% of all fatal crashes. Almost half (43%) of all fixed-object impacts are into a tree, pole, or post. This study performed a literature review, a series of one-eighth scale-model pole/pendulum impacts, and an analytical study using static analysis and dynamic finite element modeling of vehicle/pole impacts.

A methodology was developed correlating the scale-model testing of several species of wood to full-scale impacts. It was assumed that the pole or tree in question acts as a cantilevered beam when impacted with no significant base translation and/or rotation in addition to fracture.

The implementation of this methodology requires the following additional data be known during the reconstruction:

1. The geometry of the struck pole/tree (diameter and height).
2. Species of wood making up the pole or tree in question (however conservatively, the accident reconstructionist can assume the pole or tree was constructed of a material which will absorb a minimum amount of energy).
3. The likely moisture content of the pole or tree in question (poles can generally be assumed to be of low moisture content (i.e. less than six percent), trees generally have moisture contents greater than 20 percent).
4. The nature of damage to the pole or tree. This includes whether the fracture was complete and the height of the fracture.

Limitations and Use for NCHRP Project 17-22

This paper offers another methodology for reconstructing pole impacts. The specificity required to reconstruct the accidents, specifically wood species and moisture content, may be necessary should experience with crash reconstructions deem it necessary. However, the acquisition of this data would require expertise generally beyond that of the average technician unless specially trained to do so.

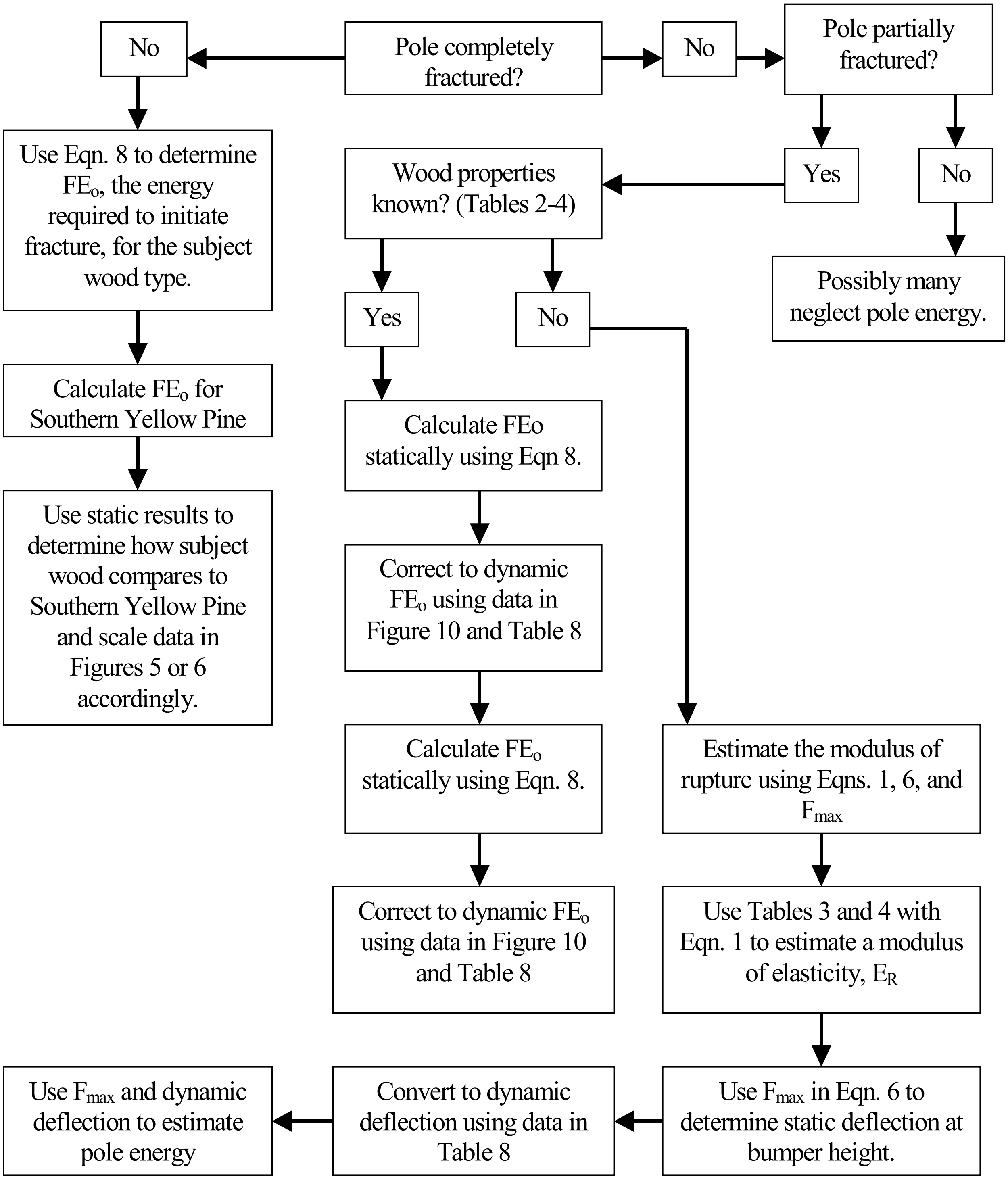


Figure A-1. Kent and Strother Methodology for Post Fractures

13. Labra, J. J., and K. K. Mak, "Development of Reconstruction Procedure for Pole Accidents," Final Report, Contract No. DTNH22-80-C-07014, National Highway Traffic Safety Administration, Washington, D.C., November 1980.

An examination of existing simulation and analytical models was performed. Software programs designed for reconstructing pole accidents, including DASF, LUMINAIRE, MODASF, and UTILITY POLE, were deemed unusable due to the significant amounts of information required to reconstruct the accident, e.g. the structural properties of individual poles and the physical properties of a luminaire transformer base. Therefore, a procedure to create a new subroutine for the well-validated CRASH was developed.

The examined analytical models made assumptions and simplifications in order to keep the mathematics and calculations at a manageable level. The key assumption was that the post failed in a shear mode and that shearing is instantaneous once the shear strength or base fracture energy is reached. While this assumption is valid for metal bases, timber poles cannot adequately be modeled this way, since wooden posts fail mostly in a bending mode with fiber striping.

Pole impacts were divided into three categories: (1) no noticeable pole damage, (2) partial fracture of the pole, and (3) complete separation of the post. In cases where there was no noticeable pole damage, the pole was treated as a rigid object. The pole was assumed to not absorb energy and that all energy dissipation occurred due to vehicle crush.

Equations were derived for the fracture of wooden utility poles. These are shown below in tabular and graphical format.

Table A-1. Pole Fracture Energy

Pole Circumference, C (in.)	Extent of Fracture	BFE (ft-lb)
≤26	Complete	20000
	Partial	½ (20,000 - $(1.4 \times 10^{-5}) C^{4.38}$)
>26	Complete	$(1.4 \times 10^{-5}) C^{4.38}$
	Partial	½ ($(1.4 \times 10^{-5}) C^{4.38}$ -20,000)

Table A-2. Pole Curve Segments

Pole Circumference, C (in.)	Damage	Curve Segment
≤26	None	1
	Partial	3
	Complete	4
>26	None	5
	Partial	3
	Complete	2

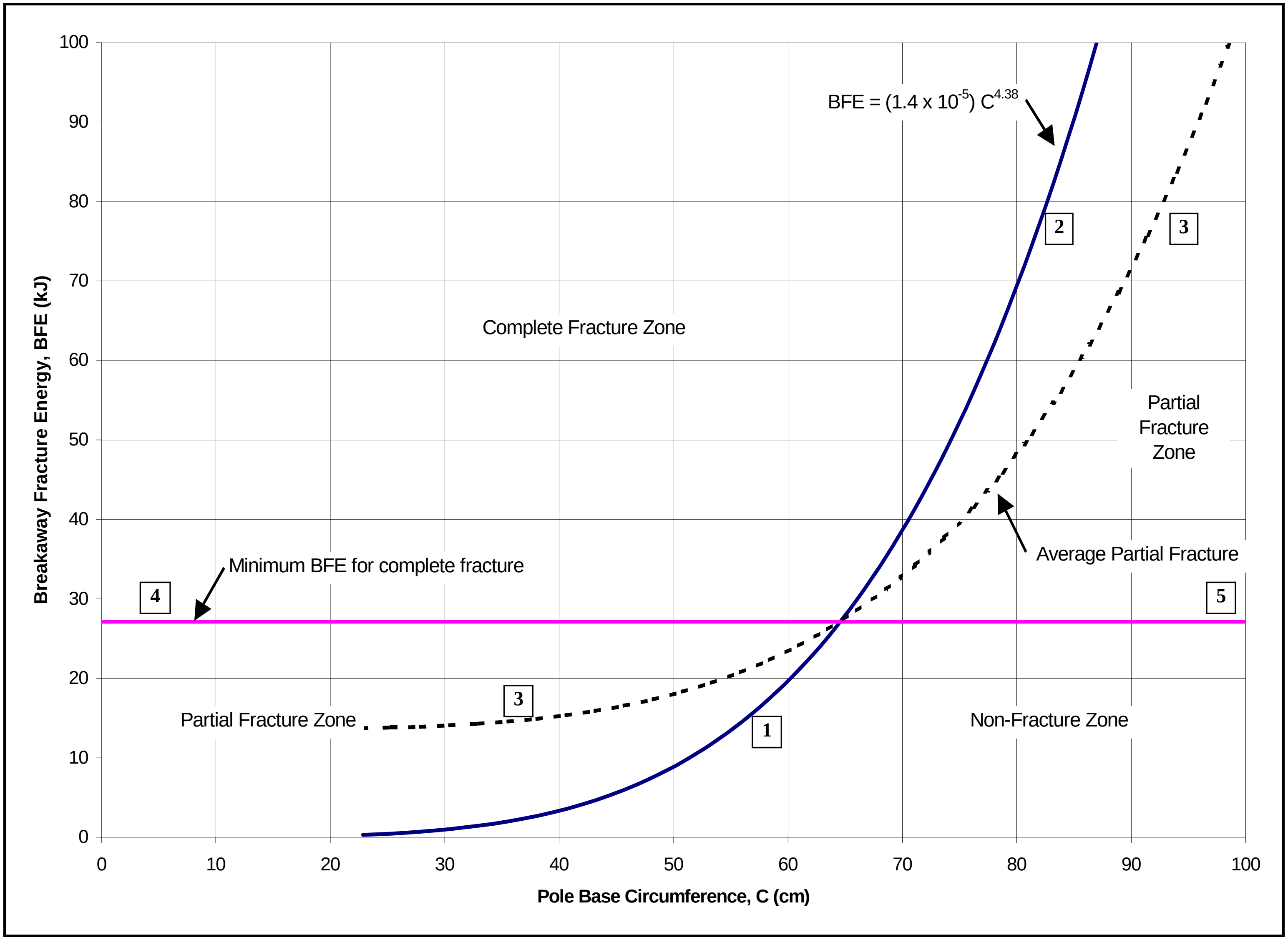


Figure A-2. Graphical Representation of Fracture of Wooden Utility poles

Averages found for breakaway luminaries were ~10 kip-ft.

The study determined that the minimum elements required for a complete reconstruction of a pole impact are: (1) type of pole, (2) material of pole or base, (3) length of pole, (4) cross-sectional dimensions at base of pole, (5) type of base / anchoring mechanism, (6) type of breakaway design, and (7) damage extent of the pole. It was found to be desirable to have the following information: (1) height of break / length of broken segment, (2) cross-sectional dimensions at the top and bottom of the broken segment, (3) final resting position of the pole, and (4) manufacturer of the breakaway device.

The analytical procedure for the five full-scale impacts varied between -5.5% and 45.9%. However, the procedure was never coded into subroutines for CRASH and is numerically intensive beyond the levels of accuracy obtained from the manual procedure.

Limitations and Use for NCHRP Project 17-22

The report gives good advisement on the energy absorption of fully- and partially-fractured posts during impact. The report also gives good suggestions on the data necessary to accurately reconstruct the crash and data that were considered desirable. While the procedure was never coded into subroutines for CRASH, this methodology provides a usable way to reconstruct pole impacts.

14. Mak, K. K. and R. L. Mason, "Accident Analysis - Breakaway and Nonbreakaway Poles Including Sign and Light Standards along Highway," Technical Report, Southwest Research Institute, San Antonio, Texas, August 1980.

The objectives of the study are to: (1) identify the extent of the pole accident problem; (2) determine the accident and injury severity rates associated with pole accidents; (3) assess the characteristics of pole accidents; and (4) evaluate the performance and cost-effectiveness of breakaway designs.

A probabilistic sample of 1,014 pole accidents and a non-random stratified sample of 533 metal pole accidents were investigated, in-dept,h in the study together with a census of all pole accidents and a sample inventory of poles. The data were collected in seven geographical locations over a period from January 1976 to October 1979.

The study results include:

- Extent of pole accident problem
- Characteristics of pole accident sites, vehicle damage, and occupant injuries
- Assessment of performance of various pole types
- Cost-effectiveness evaluation of breakaway modification as a safety countermeasure

The authors also established distributions of impact speeds and angles for pole accidents using the in-depth crash data as well as the relationships of impact conditions to injury severity.

<u>Limitations and Use for NCHRP Project 17-22</u>

This is one of the first major efforts to collect and analyze in-depth crash data on an ad hoc basis, i.e., not on a continuing basis like the NASS program. This effort was later continued with the NASS Longitudinal Barrier Special Study (LBSS). Also, the data from this study and the Narrow Bridge study (Mak 1983) were used to estimate impact speed and angle distributions (Mak 1986), similar to the objectives of NCHRP Project 17-22. This study provides a road map on the collection and analysis of in-depth crash data and the estimation of impact conditions.

15. **Mak, K. K., and A. Magaro, "National Accident Sampling System (NASS) Longitudinal Barrier Special Study Coding/Editing and Field Procedures Manual," National Highway Traffic Safety Administration and Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1984.**

16. **Mak, K. K., and A. Magaro, "National Accident Sampling System (NASS) Luminaire and Sign Support Special Study Coding/Editing and Field Procedures Manual," National Highway Traffic Safety Administration and Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1982.**

17. **Mak, K. K., and A. Magaro, "National Accident Sampling System (NASS) Crash Cushion Special Study Coding/Editing and Field Procedures Manual," National Highway Traffic Safety Administration and the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1982.**

These reports deal with the coding and field procedures used to document the NASS special studies of Longitudinal Barriers, Luminaires and Sign Supports, and Crash Cushions. These manuals outline methods for collecting, recording, and verifying data for use in in-service evaluations. The manuals were intended for use by Primary Sampling Unit (PSU) investigators for data collection and Zone Center (ZC) personnel in their review process. The manual includes information identifying the name of each category, the references used in formulating the definitions, and the coding instructions for each of the variables. For each variable or group of variables, the variable number, name, format, beginning column, element value, source, remarks, field procedures, and related variables were included. The manual contains a section that identifies editing and consistency checks to aid PSU investigators and ZC personnel when reviewing the special study forms.

The NASS Longitudinal Barrier Special Study was designed to collect detailed information about accidents involving longitudinal barriers. The data was collected along with cases included in the NASS CDS program. Supplemental data collected during this study included the type of barrier struck, other objects or vehicles impacted, the type and slopes associated with the terrain traversed during the accident, and detailed information regarding vehicle trajectory throughout the accident. Due to the limited number of accidents included in the NASS CDS, all of these accidents involving longitudinal barriers were included in the LBSS study. Supplemental data collection included sufficient detail to reconstruct the barrier accidents in order to estimate impact speeds.

The other two special studies on luminaire and sign support and on crash cushion resulted in too few crashes to be of any significance.

Limitations and Use for NCHRP 17-22

This study provides a benchmark for data collection efforts sufficient to conduct accident reconstructions. Further, the data collection effort included much of the same information required for the current project. This study will help provide templates for supplemental data collection under both the retrospective and prospective data collection efforts.

18. Mak, K. K., and L. R. Calcote, "Accident Analysis of Highway Narrow Bridge Sites," Final Report, FHWA Contract No. DOT-FH-11-9285, Federal Highway Administration, Washington, D.C., April 1983.

Data was compiled from the computerized bridge and roadway inventory data files from the States of Arizona, Michigan, Montana, Texas, and Washington. Accident data was assembled from State accident files for all the reported accidents occurring within 152.4 m (500 ft) of these bridges for a three-year period using a mile-point matching process. A total of 24,809 accidents occurred on these bridges or within their approach areas.

In order to be included in the study, bridges had to be on the state highway system, have no traffic control signals, and have all key physical data about the bridge known. For this study, a "narrow bridge" was a bridge with: (1) a total width of 5.5 m (18 ft) or less for one-lane bridges, (2) a combined width of 7.3 m (24 ft) or less for two-lane bridges, or (3) the total approach roadway width is greater than the total bridge width and the bridge shoulder width is less than or equal to 50 percent of the approach roadway shoulder width.

It was found that significant shoulder reductions (greater than or equal to 50%) tended to increase the accident rate for a bridge. However, widening bridges more than the minimum widths required for bridges to remain in place given in the AASHTO "Green Book" and realigning approach roadways may not be cost-effective on the sole bases of safety benefits, given the lack of strong relationships found in this study.

Limitations and Use for NCHRP Project 17-22

The statistical analyses performed by Mak *et al* to determine the relationships of accident frequency, rate, and severity at bridge sites to bridge and approach characteristics used variance analysis, correlation analysis, factor analysis, simple and multiple linear regressions, and discriminant analysis. The experiences with these, particularly the identification of the applicability of discriminant analysis, could show correlation, if not causality, with specific roadway or roadside features.

Mak noted that a surprisingly high percentage of impacts resulted in improper barrier performance, which must be examined carefully. Additionally, subsequent impacts were prevalent for barrier collisions at bridge sites and the trajectory of vehicles should be studied closely.

19. Mak, K. K., D. L. Sicking, and H. E. Ross, Jr., "Real-World Impact Conditions for Run-off-the-Road Accidents," Transportation Research Record 1065, Transportation Research Board, Washington, D.C., 1986, pp 45-55.

This paper provides information on real-world impact conditions for run-off-the-road accidents and develops distributions for impact speed and angle for various functional classes of highways. Data are from two sources: a representative sample of pole accidents collected over a 20-month period in Texas and Kentucky and a census of accidents involving bridge rails collected over a 21-month period in Texas. After screening, a total of 596 cases were available for analysis. The gamma function provided best fits for univariate impact speed and impact angle distributions. Since there is no known means of mathematically expressing a joint gamma distribution, the authors tested various known joint (bivariate) distributions, with little success. They then assumed that the impact speed and impact angle are independent of each other and estimated combined probability distributions for impact speed and angle stratified by functional class and based on the gamma distribution. The authors provide two examples of potential use.

The paper is accompanied by a discussion from J. D. Michie, who argues that the representation of the data set (i.e., police-reported pole and bridge related accidents) significantly effects the resulting distributions. He suggests a more representative data set would have yielded an exponential distribution. Michie also indicates that the data suffer from: a) lack of exposure information such as traffic volume, operating speed distribution, vehicle types, and distribution and density of roadside features, and b) measurement or estimate of unreported accidents. Michie suggests that the approach suggested by Cirillo "*Limitations of the Current NASS System as Related to FHWA Accident Research*" (TRR Circular 256, 1983) may be appropriate as it appears to address these limitations.

Limitations and Use for NCHRP 17-22

The authors were cognizant of the limitations of the study and acknowledge them in the paper and their closure statement. The paper is an important milestone in providing distribution of impact conditions. The paper is closely related to NCHRP 17-22 research. Some of the limitations (e.g., reliance on police reported accidents, consideration of only two types of accidents, and limited geographic representation) must be taken into account during NCHRP 17-22. Some of the assumptions in the study must also be verified, e.g., the gamma distribution is appropriate for both individual functional classes and combining data. Also, NCHRP 17-22 research must check for the correlation between impact speed and angle. The paper found weak correlation between these two parameters (-0.153 between impact speed and angle, i.e., higher speeds result in smaller impact angles). If there is evidence that the two variables are more closely related, then NCHRP 17-22 must explore various joint (bivariate) distributions. The research effort reported in the paper did not have enough data on rural freeways and assumed that urban freeways and expressways would approximate rural freeways. Efforts should be made to collect more data on rural freeways to avoid the same problems.

Cirillo's suggested approach on data collection must be reviewed. Efforts should be made, to the extent possible, to incorporate the two databases investigated in the research reported in this paper. Information must also be collected on post-impact vehicle trajectory in NCHRP 17-22, since it is important for accidents with longitudinal barriers (multiple impacts may be involved and injury severity increases with the number of impacts). Finally, care must be exercised to minimize the representation problems cited by Michie.

20. Mak, K. K., and D. L. Sicking, "Rollover Caused by Concrete Safety Shaped Barrier," FHWA Report No. DTFH61-85-C-00129, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., January 1989.

An extensive and comprehensive effort was performed to determine: (1) the extent of the rollover problem with concrete safety-shaped barriers, (2) the causative or contributory factors associated with these rollovers, and (3) the potential counter-measures available to reduce rollover in these cases. These goals were achieved through analysis of the NASS Longitudinal Barrier Special Study (LBSS) data file and computer simulation.

The LBSS data was examined to identify cases involving impacts with concrete safety-shaped barriers. A total of 130 NASS LBSS cases were identified and the hard copies provided by FHWA to the project staff for analysis. If possible reconstructions were performed to estimate the vehicle impact speed with the barrier. All cases resulting in vehicle rollovers (a total of 31) were clinically analyzed in depth in an effort to identify factors that may have contributed to rollover.

It was determined that a constant-slope surface barrier may provide the best compromise between the F-shape barrier, which offers little improvement over the safety-shaped barrier, and a vertical wall, which offers the greatest reduction in rollover potential but also has the greatest increase in lateral accelerations.

Limitations and Use for NCHRP Project 17-22

The implementation of HVOSM to determine roll distances from initial velocities and vehicle shapes will prove extremely useful in reconstructing run-off-road crashes where rollover occurred. Also of considerable use are the subroutines adapted for impacts with concrete barriers for CRASH3. These original programs have been obtained and recompiled for operating on Windows 2000 based machines.

Extensive examination of the quality of NASS LBSS accident cases was performed. This examination is extremely beneficial since the PSU investigators are responsible for the data used in NCHRP 17-22. The anticipation of problems with data and how to address these problems is also identified in this research.

21. Mak, K. K. and D. L. Sicking, "Rollover Caused by Concrete Safety Shaped Barrier," Transportation Research Record 1258, Transportation Research Board, Washington, D.C., 1992.

The Longitudinal Barrier Special Study (NASS-LBSS) was a special study incorporated into the NASS CDS program. Under this special study, additional data was collected on approximately 125 accidents involving concrete safety shaped barriers. The data collection was conducted in a prospective mode such that additional elements could be identified during the initial accident investigation. These data elements included detailed information about the barrier that was struck and terrain traversed during the accident. Barrier information included type of system and measurements of the contact region between the vehicle and the barrier.

The concrete safety shaped barrier accidents contained in the NASS LBSS data file were reconstructed to determine the speed, angle, and vehicle orientation at impact. The reconstruction procedure involved identifying energy losses during each stage of the accident, ranging from pre-impact skidding to secondary impacts with vehicles or other objects. Energy dissipated during an impact was estimated based on vehicle damage and length of contact with the barrier. Vehicle crush energy was estimated from measured damage profiles using vehicle stiffness parameters derived from the New Car Assessment Program (NCAP) crash tests. A computer program was developed that balanced the vehicle energy with the energy from the skidding and barrier friction. Damage associated with other types of impacts, including secondary vehicular impacts and other fixed object crashes were estimated based largely on vehicle crush measurements.

Although this study developed a great deal of information on accidents involving concrete safety shaped barriers, it does have some representativeness problems. The authors were not able to utilize the data to obtain distributions of impact conditions for ran-off-road accidents. Further, because the study was limited to longitudinal barriers, it was not possible to generalize any of the information to accidents involving other roadside objects.

Limitations and Use for NCHRP 17-22

This paper provides useful information on a study that generated impact conditions for longitudinal barriers. The same general approach is proposed for Project 17-22 with the exception that it will not be limited to longitudinal barriers. Procedures utilized to reconstruct the longitudinal barrier accidents will be very similar to what will be needed in Project 17-22. Further, problems associated with representativeness of the accident data should be avoided if possible.

22. Mak, K. K. and D. L. Sicking, "Development of Roadside Safety Data Collection Plan," Report No. FHWA-RD-92-113, Federal Highway Administration, McLean, VA, 1994

The primary objective of this research was to identify issues and gaps in the state-of-the-knowledge needed to improve the cost-effectiveness analysis procedure and to develop data collection plans for those issues and gaps that could be addressed with accident data. The research proposed five studies and developed data collection plans for those studies. These included:

- Validation of encroachment frequency/rate
- Determination of encroachment frequency/rate
- Effect of roadside conditions on impact probability and severity
- Distributions of impact conditions, and
- Relationships of impact conditions, performance limits, and injury probability and severity

The study plans were reviewed by a panel of experts and their comments taken into consideration. The recommended study on the distributions of impact conditions focuses on impact speed, angle, and vehicle orientation besides vehicle size, weight, and the nature of roadside object/feature. The plan for this study includes:

- Select sample roadway segments for each of the six highway types
- Setup data collection protocol (including sampling plan, accident notification scheme, data collection forms, etc.) and familiarize and train investigators with the protocol through a small pilot study
- Investigate in-depth a representative sample of single-vehicle, ran-off-road type accidents on these selected roadway segments
- Reconstruct the sampled accidents to determine impact conditions
- Compile descriptive statistics on vehicle trajectory and impact conditions
- Develop mathematical models for the distributions of impact speeds and angles

Limitations and Use for NCHRP 17-22

The report is most useful to NCHRP 17-22 and perhaps to some other on-going research projects (e.g., NCHRP 17-11). The data collection plan for identifying impact conditions should be closely reviewed under Tasks 3 and 4 of Project 17-22. Note that the study recommends interviewing the driver involved in the accident via telephone. The telephone interview could be used to collect driver socioeconomic data, which according to Mak are often causal in run-off-the-road accidents but unavailable. Although not practical for the retrospective data collection effort, contacting drivers may be helpful in the prospective data collection procedures and should be carefully considered. The study also recommends collecting information on drinking establishment locations and economic vitality of the local economy. Such information could be used to improve benefit/cost analysis procedures.

23. Mak, K. K., “Methods for Analyzing the Cost-Effectiveness of Roadside Safety Features,” Transportation Research Circular Issue 435, Transportation Research Board, Washington, D.C., 1995, pp 42-62.

The author has discussed methods of cost-effectiveness evaluation of roadside safety features and appurtenances and provides information of the different cost-effectiveness analysis procedures. Most of the information in this document is based on "Development of Roadside Safety Data Collection Plan" by Mak and Sicking (1994).

The author provides an overview of the cost-effectiveness analysis methodology. Future research needs for the encroachment probability based cost-effectiveness analysis procedure are enumerated. According to the author, the most important area requiring improvement is the accident severity estimation procedures, which have the most effect on the outcomes of the cost-effectiveness analysis.

Several data sources are summarized (e.g., NASS Longitudinal Barrier Special Study (LBSS), NASS Continuous Sampling System (CSS), etc.) and their limitations discussed. Various previous research efforts are also presented. The data gaps suggested for improvement to the probability based cost-effectiveness procedure include (in order of relative importance to the procedure):

- Performance limits of roadside safety features and associated severity
- Relationships of injury probability and severity to impact conditions
- Distributions of impact conditions
- Effects of sideslopes on extent of lateral encroachment
- Severity associated with sideslopes
- Validation of encroachment frequency/rate and adjustment factors
- Evaluation of the extent of unreported accidents
- Trajectory of vehicles after encroaching into the roadside
- Relationships of surrogate severity measures to injury probability and severity

Limitations and Use for NCHRP 17-22

The paper provides a good review of efforts directed at cost-effectiveness analyses and lists the shortcomings of several cost-effectiveness tools such as, *AASHTO Guide for Designing, Selecting, and Locating Traffic Barriers*, the TTI’s ABC, FHWA’s BCAP, ROADSIDE, etc. The paper raises several important issues for future research including the ones under investigation in NCHRP 17-22 (identification of real-world impact conditions). It is useful in exposing the shortcomings of several databases for use in cost-effectiveness analysis. The use for NCHRP 17-22 is to avoid utilizing databases that have been identified in this paper as having limitations. These are NASS LBSS (non-representative) and NASS CSS (small sample of fixed object impacts).

24. Mak, K. K., R. P. Bligh, and L. I. Griffin, III, "Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features," Final Report, NCHRP Project 22-14, Transportation Research Board, Washington, D.C., November 2000.

The objectives of this study are to: (1) evaluate the relevance and efficacy of procedures for the safety performance evaluation of highway features, and (2) assess the needs for updates to NCHRP Report 350.

The study identified a list of updating needs for crash testing and evaluation guidelines set forth in NCHRP Report 350 and the NCHRP project panel selected seven specific updating issues for further study:

- Test vehicles and specifications
- Impact conditions
- Critical impact point
- Efficacy of flail space model
- Soil type/condition
- Test documentation
- Working width measurement

White papers were prepared for each of these seven topics. In addition, a prototype methodology to assess the relevance issue was developed. However, there was little consensus among the roadside safety community on how relevance is even to be defined, not to mention an evaluation procedure.

Limitations and Use for NCHRP Project 17-22

One of the impetuses for Project 17-22 is to provide better data on the impact conditions of severe single-vehicle, ran-off-road crashes so that the impact conditions for the crash testing guidelines can be properly established. The discussions on impact conditions from this report provide an indication on one of the potential applications of data on impact condition and would be helpful in determining the data needs for Project 17-22.

25. Mak, K. K., and D. L. Sicking, "Continuous Evaluation of In-Service Highway Safety Feature Performance," Final Report 482, Arizona Department of Transportation, Phoenix, Arizona, September 2002.

This paper is the result of research sponsored by the Arizona DOT and it is focused on the conceptual framework for a national center on in-service performance evaluation of roadside safety appurtenances. The authors first make the case for in-service evaluation by indicating that real-world conditions significantly vary from crash test conditions (i.e., frozen or saturated soil, unforeseen problems with installation and maintenance of devices, etc.). As such, in-service performance evaluation is needed to assure that safety appurtenances are indeed performing as intended.

Because in-service performance evaluations tend to be labor-intensive and not within easy reach of any one or two DOTs, a national center that promotes better data compilation and dissemination of available information is needed. The paper provides information on the center's mission and objectives, scope, organization and funding sources, and potential benefits.

Limitations and Use for NCHRP 17-22

The need for a national center on in-service performance evaluation of roadside features appears justified and the proposed conceptual framework is sound. There is little direct application of the material to NCHRP 17-22 research.

26. McGinnis, R. G., "Reexamination of Roadside Encroachment Data," Transportation Research Record 1690, Transportation Research Board, Washington, D.C., 1999, pp 42-58.

This somewhat controversial paper is broadly focused on the issue of revision to guardrail runout lengths in the AASHTO Roadside Design Guide (RDG) and particularly on two encroachment data sets and their properties. The RDG procedures for guardrail runout lengths are based on encroachment data collected by Hutchinson and Kennedy (H&K) during the early 1960's. Revisions to the guardrail runout lengths were recommended by Wolford and Sicking based on more recent encroachment data collected in Canada in 1978 (the so called Cooper's data). McGinnis compares the two datasets (H&K and Cooper's) and reports several inconsistencies in the Cooper's dataset. Based on his analysis and findings, McGinnis suggests that reducing guardrail runout lengths from current RDG guidelines for highways with high speed limits may not be prudent. This suggestion is based on:

- Highways surveyed in the Canadian study were not similar to US high-speed freeways
- Highways surveyed by H&K were similar to many US high-speed freeways
- Statistically significant differences in encroachment lengths and encroachment departure angles existed between the Canadian survey teams for highways with similar speed limits

The paper is accompanied by discussions from three discussers: Peter Cooper and R. Sanderson, both involved with the Canadian study, and Dean Sicking, one of the two authors of a study that recommended changes to the RDG guidelines based on the Canadian data. While Cooper and Sanderson defend the Canadian study and indicate shortcomings in McGinnis's research, Sicking's effort is based on provision of a more complete and balanced picture. Sicking points to two earlier versions of this paper where McGinnis' finding was the opposite of what has been reported in this paper. In the earlier versions, McGinnis made the case that the two data sets were essentially the same and recommended that the two data sets be combined for use in developing guardrail length guidelines.

Limitations and Use for NCHRP 17-22

It appears that there are several limitations to this paper as pointed out in detail by the discussers. Primarily, the paper is useful in raising awareness of the differences over a subject of considerable significance to the highway safety community. The usefulness for NCHRP 17-22 lies in that the research effort should not fall prey to such controversy. To avoid criticism such as that received by Cooper's research, NCHRP 17-22 must document each and every detail of data collection, utilize expert data collectors, and run quality checks during and after data collection. The fact that Cooper's research has received such heavy scrutiny after two decades points to the need to document even minute research details and maintain excellent documentation after completion of the project.

27. Mendoza, A., A. Uribe, C. Z. Gil, and E. Mayoral, "Development of a Relational Accident Database Management System for Mexican Federal Roads," Transportation Research Record 1717, Transportation Research Board, Washington, D.C., 2000, pp 84-93.

The paper describes the Mexican Transportation Institute's development of a computerized accident data management system that combines data collected by various organizations in Mexico. The organizations whose data are combined include: the Federal Highway Patrol, toll road operators, insurance companies, medical services (hospitals and emergency medical services), other emergency services (fire departments, towing services, etc.), and the public prosecutor departments. Other organizations considered for data were research institutions, weather agencies, state traffic departments, the National Institute for Geography, Statistics, and Data Management, and the General Directorate of Protection and Preventive Medicine in Transportation.

The management system primarily utilizes accident data collected by the Federal Highway Patrol (called PFC in Spanish) since it is deemed the most complete. An overall linking scheme has been developed that links the PFC data to data from other agencies. Various variables (e.g., time & date of accident, location, vehicle and driver data, and judicial information) available in the different databases are utilized for the linking process.

The system can present the data at the national, state, and local levels and in various formats (e.g., GIS). An application to 1997 data is described in the paper.

Limitations and Use for NCHRP 17-22

The paper provides useful information on accident data integration from a variety of sources in Mexico. However, direct application of the methodologies and the system developed in this research to NCRHP 17-22 research effort is minimal. This is because of procedural, organizational, and jurisdictional differences between USA and Mexico

28. Miaou, Shaw-Pin, "Estimating Roadside Encroachment Rates With The Combined Strengths Of Accident-And Encroachment-Based Approaches," Publication No. FHWA-RD-01-124, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., September 2001.

Miaou proposed a method to estimate vehicle roadside encroachment rates using accident-based models. Miaou concluded that the results of his study indicated that the proposed method could be a viable approach to estimating roadside encroachment rates without actually collecting the encroachment data in the field, which can be expensive and technically difficult.

Miaou tested the consistency of his approach using two data sets from FHWA's Highway Safety Information System (HSIS). The model allows the rates to be estimated by average annual daily traffic volume, lane width, horizontal curvature, and vertical grade for rural two-lane undivided roads.

Limitations and Use for NCHRP Project 17-22

While the encroachment data was statistically examined and the effects of multiple variables were examined, there was no collection of information regarding the actual characteristics of individual accidents. This study will be most helpful in the processing and analysis of data after reconstructions have been performed. Miaou examined the functional forms to best match the data and these may be applicable to the finalized database evolving from NCHRP Project 17-22. Particularly, Miaou used the Poisson assumption for the randomness of accident frequency together with the assumption that the exponential function of the unobserved variables is gamma distributed.

29. Michie, J. D., "Evaluation of Severity of Collisions with Roadside Features: Data Needs. Summary, Part 2," Transportation Research Circular 256, Transportation Research Board, Washington, D.C., 1983, p 13.

This write up appears in the Transportation Research Circular 256, which contains the proceedings of a 1981 workshop sponsored by the TRB Committee on Safety Appurtenances. It summarizes the information presented in support of B-C analysis procedures for roadside safety programs. The work of seven presenters is summarized as follows.

There is need to have baseline data of the untreated roadside for reference in safety improvement comparisons and development of warrants for appurtenances. Full-scale crash tests are not practical for investigation of all possible collision conditions and the importance of evaluating appurtenances under field conditions was emphasized. However, as a complement to vehicle crash testing methods during appurtenance development, computer simulations have been shown to be cost effective under certain conditions. Investigators are cautioned about the importance in assessing the compatibility of specific hardware with the traffic and site characteristics in field evaluations. There is also a need to acquire detailed clinical data from selected accident cases. With regard to establishing a link between vehicle crash test severity and potential injury of vehicle occupants, the use of anthropometric dummies has certain limitations in that dummy responses are insufficient for use in the B-C analysis procedures. Further, extensive in-service evaluation, including numerous collision cases, is necessary to develop sufficient input to the B-C equation.

Limitations and Use for NCHRP 17-22

This write up summarizes points raised by several presenters at the TRB sponsored workshop. Almost all of these are still pertinent and useful for NCHRP 17-22 research.

30. Michie, J. D., and M. E. Bronstad, “Highway Guardrails: Safety Feature or Roadside Hazard?” Transportation Research Record 1468, Transportation Research Board, Washington, D.C., 1994, pp 1-9.

The objective of the study was to examine and assess the conventional wisdom of guardrail performance on highways. The authors review past literature on highway guardrail usage and mention several documents published from 1964 to 1989 that focus on the hazardous nature of guardrails. From the statements quoted by the authors, a reader might conclude that guardrails are not only a roadside hazard but that the perceived safety benefit, if any, is decreasing with time. The authors argue that perceptions on the hazardous nature of guardrail are based on incomplete and misleading accident data and that the conclusions reached on the analyses of those data are invalid. The following reasoning is presented:

- Only severe impacts that include injuries or a disabled vehicle are generally reported; relatively little is known about the number and extent of drive-away accidents.
- The police officer investigating the accident rarely indicated the type of guardrail because most officers are not trained in this technology; moreover, information on guardrail condition prior to the accident is almost always unavailable.
- Accidents involving guardrails are generally grouped according to the first harmful event even though hitting the guardrail may not have been the most harmful event; as such, injuries and damage may be incorrectly attributed to guardrails.
- Guardrails may be attributed the blame for events that are beyond guardrail design envelope; combinations of vehicle mass, speed, and impact angle may exceed crash test values resulting in barrier failure. However, it is arguable whether the occurrence of such accidents should, in any way, suggest that the installation is a hazard.

The authors examined previous research in four key areas: unreported accidents, the effects of recording first harmful event (instead of most harmful event), length of need and terminals, and condition and design of barriers. Based on their examination, they concluded that the success rate of longitudinal barriers is 94%, the severity indexes for barrier impacts used in the benefit-cost models may be excessively severe (resulting in understating benefits of installing guardrails), and severity indexes for barrier ends should distinguish whether the end is one of the newer crashworthy ends meeting the criteria outlined in NCHRP Report 230 or one of the older designs that does not meet these criteria.

Limitations and Use for NCHRP 17-22

The paper presents a good review of pertinent studies regarding highway guardrails and the case for re-assessment of guardrail performance, in light of the shortcomings of previous research, is convincing. Two issues are pertinent to NCHRP 17-22 research: unreported accidents and the standard and condition of roadside objects before accident. Since NCHRP 17-22 effort is focused on serious accidents, subsequent use of the results in any cost-effectiveness model may underestimate benefits. Further, efforts should be made to collect information on standard and condition of roadside installations prior to the accident since some may not be properly installed or may not conform to newer standards.

31. Morgan, J. R., and D. L. Ivey, "Analysis of Utility Pole Impacts," Paper No. 870307, Society of Automotive Engineers, 1987.

A parametric study was conducted using a computer program that incorporated a fourth-order Runge-Kutta numerical integration scheme to create a two-dimensional model of the utility pole and vehicle. The model assumed that the energy required for pole facture is not velocity dependent over the range of interest. A linear relationship between load and crush distance was assumed for the vehicle, with the spring constant dependent only upon the vehicle mass.

Correlations between residual frontal deformation and the impact velocity were developed for various vehicle masses. Further testing was suggested on a wider range and combination of pole sizes, vehicle masses, and impact velocities to strengthen the database and the applicability of the reconstruction.

Limitations and Use for NCHRP Project 17-22

Focus of the study was on probabilities for injury levels as much as reconstruction of the crash itself. The simulation performed by Morgan *et al* can be used to verify velocity changes when compared with other methods for verification of results. However, stiffnesses for this study varied only upon weight, which is significantly less sophisticated than modern simulation methods.

32. Ray, M. H., and J. A. Hopp, "Performance of Breakaway Cable and Modified Eccentric Loader Terminals in Iowa and North Carolina: In-Service Evaluation," Transportation Research Record 1720, Transportation Research Board, Washington, D.C., 2000, pp 44-51.

This research, sponsored by the NCHRP (project 22-13), examined the in-service performance of the breakaway cable terminal (BCT) and the modified eccentric loader terminal (MELT) in Iowa and North Carolina. Data were collected in a two-year period (1997-1999) on 600 BCTs and 50 MELTs each in the two states. Data collection teams were notified about collisions from police and highway maintenance agencies, which then visited the collision site to collect guardrail terminal damage information. Data collected by the police and maintenance agency was also utilized in this study. Overall, data from 102 BCT and 42 MELT collisions were collected during the two years. Impact scenarios were determined on the basis of physical evidence at the scene (e.g., skid marks, ruts in the soil, scraps on the guardrail, etc.)

The authors compared their data to the NCHRP Report 350 crash tests and concluded that the tests in the report apparently relate to the way vehicles strike guardrail terminals in the field. However, some tested scenarios, such as the reverse-direction collisions, were rarely observed in the field, while important real-world scenarios such as side impacts are not included in NCHRP Report 350.

Characteristics of the collected data included: 60% of impacts striking the end of a 1.22 m offset guardrail terminal and the remaining 40% striking at or downstream of Post 2. Passenger cars dominated the in-service collision data. Over 60% of the police-reported MELT and BCT collisions resulting in property damage only. About 90% of collisions with guardrail terminals in Iowa were not reported to the police or the DOT. These collisions represent guardrail and guardrail terminal successes. Some potential problems with steel-tube foundations and the 12-gauge guardrail splice were observed. Only one of the concrete foundations used in a BCT in Iowa moved during an end-on collision while 12 end-on collisions involving the steel foundation tube moved.

No statistically significant differences were found between the performance of BCTs and MELTs or between the performances of the two devices across the two states.

Limitations and Use for NCHRP 17-22

The study appears sound and if BCTs and MELTs are focused during 17-22, then one could use the data collected during this study and investigate how it compares with newly collected 17-22 data. Since the authors of this study followed data collection methodology somewhat similar to what has initially been proposed in 17-22 (i.e., investigation of police reported accidents and collection of additional data during site visits), it would be useful to contact the authors for discussion on some of the pitfalls they faced during their data collection effort.

33. Ross, H. E., Jr., "Baseline Data Needs," Transportation Research Circular 256, Transportation Research Board, Washington, D.C., 1983, pp 6-7.

This write up appears in the Transportation Research Circular 256, which contains the proceedings of a 1981 workshop sponsored by the TRB Committee on Safety Appurtenances. It is focused on data needs for formulation of probabilistic models based on vehicle encroachment data that are used in benefit-cost (B-C) analysis. According to the author, the nature and frequency of inadvertent encroachments by a motorist are functions of numerous factors, including the motorist and the roadway. Data are needed to determine the relationship between encroachments and these various factors. With regard to roadway variables, encroachments are believed to be a function of roadway type, roadway and roadside geometry, traffic control devices, traffic conditions, and vehicle size. The author recommends collection of data that will enable predictions of: 1) the number of times an object will be struck in a given time period, 2) the type of vehicles expected to strike an object in a given time, 3) speeds and angles at which vehicles will strike objects, and 4) attitude at which vehicles will strike objects.

Once the number and type of vehicle involvements with a given roadside object have been estimated, the probability and level of injuries associated with each involvement must also be estimated. Impact severity may be estimated from physical test data, accident data, computer simulation, accident reconstruction, or engineering judgment.

Limitations and Use for NCHRP 17-22

This write up presents a critical view of the various data needed for conducting B-C analysis. There are no limitations to the write up and the data indicated in it are still sparsely available. NCHRP 17-22 is focused on collecting some of the data that has been alluded to in this write up. It is useful in providing background information.

34. Sicking, D. L., and H. E. Ross, Jr., "Benefit-Cost Analysis of Roadside Safety Alternatives," Transportation Research Record 1065, Transportation Research Board, Washington, D.C., 1986, pp 98-105.

This paper is focused on the improvement of benefit-cost (B-C) analysis of roadside safety alternatives. Although existing B-C analysis procedures do a good job of accounting for the different costs involved with a safety improvement, they generally overstate the severity of most accidents that are predicted to occur and are difficult to use. The procedure reported in this paper improves the versatility of the B-C analysis, the determination of severity associated with predicted accidents, and has been coded for use with microcomputers for easy implementation.

Development of the new procedure is based on an encroachment probability model that predicts accident occurrence and severity. The goal is to relate roadway and traffic characteristics to the expected accident frequency at a site. The model is based on the assumption that the number of run-off-the-road accidents that occur at a given site can be related to the number of vehicles that inadvertently leave the roadway at that site. Further, it is assumed that the frequency and nature of uncontrolled encroachments can be related to roadway and traffic characteristics. The general approach in calculating accident frequency is to determine the region along the roadway or hazard envelope, within which a vehicle leaving the travel way at a prescribed angle will strike the hazard. When two or more hazards are present, the hazard envelopes can overlap creating a complex geometric problem. Hazard envelopes in such cases can be described if the relative locations and the geometry of all hazards are known.

The encroachment probability model developed in this research uses hazard locations and geometry to determine the limits of all encroachment ranges and the lateral distances to each hazard within the range. The model then calculates the probability of a collision within each encroachment range. It utilizes encroachment characteristics from a database collected on Canadian four-lane divided highways and two-lane, two-way highways by Cooper in 1979. These data were adjusted to account for controlled encroachments and lateral extent of movement to eliminate the effect of paved shoulders. The model utilized combined impact speed and angle distributions developed from accident studies by Mak and Calcote and Mak, et al. Further, the model utilized accident costs based on societal costs of accidents linked to the severity index scale developed by Bronstad and Michie. Although crash tests provide a link between impact severities in terms of vehicle accelerations and damage, the fact that most crash tests are conducted at speeds near 60 mph creates a gap in severity indices data for roadside features at speeds of less than 60 mph. The authors assume a linear relationship between the severity index and impact speed in this model. Also, since most crash tests involve angles of 15-25 degrees, severity indices from other impact angles must be interpolated and extrapolated.

Overall, the B-C model described in the paper incorporates most of the improvements found in all previous models and has improved accuracy besides analysis of multiple hazards. The paper describes an application of the model to develop general barrier use guidelines.

Limitations and Use for NCHRP 17-22

Some of the limitations, acknowledged by the authors, include non-application to accidents other than run-off-the-road, the weak link between impact conditions and accident severity, and the difficulty in quantifying accident severities of some hazards such as drop-offs and roadside slopes. The data collected in NCHRP 17-22 can enhance some aspects of the model developed in this study; this paper can be used as a base for those improvements.

35. Troxel, L. A., "Severity Models for Roadside Objects," Transportation Research Circular Issue 416, Transportation Research Board, Washington, D.C., 1993, pp 58-68.

This paper provides useful information on historical development of methods used for determining which roadway designs are most likely to have accidents that result in serious or fatal injuries. After reviewing existing severity models, it then goes on to suggest some new models and likely data sources.

Within existing models, the paper discusses cost-based severity models, accident data probability severity models, relative severity index, and crash test severity models. These models have been based on expert opinion, accident data, crash test results, and computer simulations. Models based on engineering judgment are subjective and generally designed to relate to injury costs that are also subjective. The accident data models established that vehicle and accident characteristics can be used to predict injury severity, but problems of unreported accidents and low level of detail make most of these models unreliable. Crash test results used alone or with computer simulation show promise but a weak link is between vehicle or impact measurements with probability of occupant injury.

The paper suggests a model based on probability of injury rather than benefit/cost ratio:

$$P(I|C) = P(I|S)P(S|C) + P(I|F)\ P(F|C)$$

Where $P(I|C)$ = probability of injury given a crash
$P(I|S)$ = probability of injury given side impact
$P(S|C)$ = probability of side impact given a crash
$P(I|F)$ = probability of injury given frontal impact
$P(F|C)$ = probability of frontal impact given a crash

To determine $P(S|C)$ and $P(F|C)$, the use of crash test results and accident data are suggested. Crash test results on most roadside appurtenances can be obtained from the FHWA while the NASS accident databases including special studies (LBSS, Pole Special Studies, and the Crash Cushion Special Study) can be used for accident data.

Four models are suggested to determine $P(I|F)$ and $P(I|S)$. These are: Accident Data Regression Model, Modified Accident Data Regression Model, Crash Tests and Special Studies Model, and Crash Test Regression Model. The first two models use accident data alone (NASS, appropriate special studies, and state accident databases). The third proposed model is based on crash test data combined with LBSS data while the last model is based purely on crash test data. According to the author, whether the models suggested in this paper can be developed successfully or not, the process of developing them will be valuable in itself.

Limitations and Use for NCHRP 17-22

This paper provides a useful review of existing injury models and their limitations and suggests a new probability based model. Several data sources are suggested. Unfortunately, the suggested data sources have known limitations and it is doubtful if they can provide all of the information needed to develop the suggested probability model. The utility of this paper to NCHRP 17-22 is that data collected in NCHRP 17-22 can probably be used in conjunction with the databases cited in this paper to develop some of the regression-based models.

36. Viner, J. G., F. M. Council, and J. R. Stewart, "Frequency and Severity of Crashes Involving Roadside Safety Hardware by Vehicle Type," Transportation Research Record 1468, Transportation Research Board, Washington, D.C., 1994, pp 10-18.

In 1993, FHWA published a ruling that listed NCHRP Report 350 for guidance in determining the acceptability of roadside barriers and other safety appurtenances for use on National Highway System projects. Previously, most roadside hardware acceptance test programs had used the minimum crash test matrix of NCHRP Report 230, published in 1981. One of the differences between the two reports was the use of a 4,400-lb truck in NCHRP Report 350 compared to the 4,500 lb passenger car used in NCHRP Report 230.

This paper examines the relative safety experiences in crashes with roadside safety hardware by different vehicle body types. Data from North Carolina and Michigan were used to compare the relative severities of roadside safety hardware crashes involving two vehicle body types: the 4,400-lb pickup truck and the 4,500 lb passenger car. Additionally, FARS data were used both to define the size of the problem by vehicle type and to identify the vehicle types that appear to be over represented in hardware-related fatal crashes when compared with the estimated numbers of nationwide crashes into hardware from the GES files and with national numbers of registered vehicles from the R. L. Polk vehicle registration files.

Analysis indicated that the practical worst-case test philosophy of current roadside safety device evaluation procedures has provided about the same level of protection to drivers of vans, utility vehicles, and pickups as to passenger car drivers, provided the measure of safety is the likelihood of serious (fatal + incapacitating) injuries. However, if the measure of safety is the likelihood of fatalities, this does not appear to be the case. That is, drivers of pickups were found to be at greater risk. The likely reason for this greater risk of fatalities found for pickup drivers was ejection in rollover crashes. The authors recommend programs to increase seatbelt usage and other measures that may prevent ejection in a crash.

Limitations and Use for NCHRP 17-22

There are several limitations of the study that have been acknowledged by the authors. These include problems with the data such as: crash under-reporting in the two state databases and GES data and the inability of the Polk data to differentiate between urban and rural driving patterns. The study utilized data that are usually available for analyses and, as such, does not represent a unique source. Therefore, use for NCHRP 17-22 is limited, if any.

37. Zegeer, C. V., and M. R. Parker, "Effect of Traffic and Roadway Features on Utility Pole Accidents," Transportation Research Record 970, Transportation Research Board, Washington, D.C., 1984, pp 65-76.

The authors collected utility pole related data on 2,520 miles of highways utilizing different sources, e.g., highway and police files and photologs. Specifically, photologs were utilized to collect data on utility poles (diameter, material type, spacing, etc.), their lateral offsets, and obstructions in the encroachment envelope. About 65% of the data collected were in rural areas, 13% in urban areas, while the remaining were in urban fringe areas. The authors addressed the following questions:

- What are the dimensions of the utility pole accident problem (how many reported and how severe)?
- What factors affect the frequency of these accidents and can the relationships of accidents with these factors be utilized to estimate the effectiveness of utility pole countermeasures?
- What factors affect the severity of these accidents and what are the relationships between accident severity and utility pole accident countermeasures?

Using a variety of statistical analyses (correlation analysis, analysis of variance and covariance, and regression analysis) the authors reached the following conclusions:

- The overall accident rate was 16.61 utility pole accidents per hundred million vehicle miles and was 4.11 per hundred billion vehicle-pole interactions.
- Traffic volume, pole offset, and pole density are important in explaining accident frequency. Others include roadway class, shoulder width, horizontal curvature, lighting, and speed limit.
- Wooden poles and those with offsets of 1-10 ft resulted in greater injury severity. Severity also increased with roadway curvature for some speed limit categories. Speed limit was not found to be important.

A predictive regression model employing ADT, pole offset, and pole density as independent variables was formulated to explain accidents per mile per year.

Limitations and Use for NCHRP 17-22

Although the severity of utility pole accidents was identified and the effects of various highway variables on impact severity were examined, there was no attempt to collect any information regarding the nature of the impacts. No detailed information was collected that could help identify vehicular impact conditions. Other limitations of the study include the fact that all the independent variables used in the regression model, pole density, traffic volume, and pole offset, are all exposure related parameters. Other variables that may be important (e.g. driver characteristics, accident location, etc.) could not be included in the study.

APPENDIX B

1997-2001 NASS-CDS Cases

Table B-1. Eligible Cases by Primary Sampling Unit (PSU)

Area Type	PSU	Unweighted		Weighted	
		No.	Percent	No.	Percent
Rural	2	59	4.93%	22953	3.33%
	4	35	2.93%	4930	0.71%
	11	145	12.12%	51212	7.42%
	13	130	10.87%	57320	8.31%
	43	100	8.36%	97323	14.11%
	48	114	9.53%	139620	20.24%
	76	109	9.11%	49884	7.23%
	78	85	7.11%	33025	4.79%
	Subtotal	777	64.97%	456267	66.14%
Suburban	5	16	1.34%	22955	3.33%
	8	28	2.34%	10016	1.45%
	9	64	5.35%	19683	2.85%
	12	94	7.86%	40154	5.82%
	45	60	5.02%	42112	6.10%
	73	48	4.01%	11084	1.61%
	75	57	4.77%	40993	5.94%
	81	52	4.35%	46627	6.76%
	Subtotal	419	35.03%	233624	33.86%
Total		1196	100.00%	689891	100.00%

Table B-2. List of Sampled Cases

Sampled Cases for 2000											
PSU 02	**PSU 11**		**PSU 12**	**PSU 13**		**PSU 45**		**PSU 48**	**PSU 75**	**PSU 76**	**PSU 78**
25	3	79	40	2	122	5	164	16	29	19	20
26	5	90	45	7	123	14	166	20	30	72	21
31	10	103	46	15	129	43	170	27	38	81	22
42	19	104	47	28	130	52	172	30	39	83	30
44	28	105	53	32	131	57	173	35	40	95	31
46	32	109	64	44	132	82	182	36	43	99	40
53	36	110	65	50	140	83	199	62	44	105	43
61	39	147	89	55	142	85	211	70		129	57
63	44	150	109	60	147	104		73		132	67
74	45	160	119	64	160	109		97		137	71
86	47	162	145	78	161	112		120		142	77
89	48		158	82	165	123		143		145	78
130	52		167	86	170	124		161		151	85
140	53		172	88	173	131		162			87
142	63		202	91	178	139		167			88
148	65			92		141		170			97
	71			99		145		181			98
	73			104		147		182			111
	74			112		159					
	76			116		160					
Number of Cases by PSU											
16	31		15	35		28		18	7	13	18
Total Cases in Zone 1 = 125								Total Cases in Zone 2 = 56			
Number of Cases for 2000					181						

Table B-3. List of Sampled Cases (Cont'd)

Sampled Cases for 2001														
PSU 02	**PSU 11**		**PSU 12**		**PSU 13**			**PSU 45**	**PSU 48**	**PSU 75**	**PSU 76**		**PSU 78**	
5	13	166	6	99	5	79	180	11	6	5	6	106	8	130
9	15	169	7	104	6	80	185	23	14	12	11	112	14	136
17	32	191	11	105	7	81	188	75	21	13	17	117	17	138
23	42	194	16	125	13	86	190	82	27	17	21	121	23	
42	45	212	19	128	26	89	206	93	34	47	22	142	24	
45	48	217	24	133	30	90	207	99	36	54	41	144	35	
68	52		25	137	31	92	208	136	52	85	43		45	
77	57		26	157	32	93		158	59	111	48		46	
79	61		29	160	33	94		171	75	118	50		48	
83	66		30	168	34	105		217	87	119	54		49	
84	84		35		40	126			90	139	55		50	
92	88		45		44	130			100	160	60		59	
97	100		54		47	134			140		65		65	
110	110		56		49	142			151		77		69	
112	119		57		52	148			152		82		71	
	120		58		54	149			160		84		81	
	121		62		59	150			171		89		84	
	126		67		64	151			174		95		85	
	130		82		68	153			183		101		92	
	133		90		69	161			186		103		93	
	138		91		72	169			196		104		124	
	149		94		76	175			200		105		125	
Number of Cases by PSU														
15	28		32		51			10	22	12	28		25	
Total Cases in Zone 1 = 136									Total Cases in Zone 2 = 87					
Number of Cases for 2001								223						

Table B-4. Breakdown of 1997 and 1998 NASS CDS Cases by Screening Criteria

Year	All Crashes for the 16 Rural and Suburban PSUs	Single-vehicle, Ran-Off-Road Crashes		Speed Limit ≥ 45 Mph		Complete Vehicle Inspections		Trajectory Data Available	
		No.	%	No.	%	No.	%	No.	%
1997	2979	979	32.9%	548	56.0%	343	62.6%	163	47.5%
1998	2951	932	31.6%	558	59.9%	397	71.1%	220	55.4%
Total	5930	1911	32.2%	1106	57.9%	740	66.9%	383	51.8%

Table B-5. Breakdown of Eligible 1997-1998 NASS CDS Cases by PSU

PSU	Area Type	Single Vehicle Ran-Off-Road Crashes			Eligible Crashes	
		1997	1998	Total	No.	%
2	Rural	62	65	127	29	22.8%
4	Rural	46	41	87	2	2.3%
11	Rural	64	88	152	68	44.7%
13	Rural	50	79	129	40	31.0%
43	Rural	72	70	142	20	14.1%
48	Rural	83	56	139	38	27.3%
76	Rural	30	52	82	6	7.3%
78	Rural	62	58	120	52	43.3%
Rural Subtotal		469	509	978	255	26.1%
5	Suburban	60	38	98	7	7.1%
8	Suburban	70	56	126	9	7.1%
12	Suburban	64	65	129	21	23.3%
73	Suburban	50	38	88	10	11.4%
9	Suburban	41	53	94	21	22.3%
45	Suburban	93	71	164	30	12.8%
75	Suburban	67	61	128	27	21.1%
81	Suburban	65	41	106	3	2.8%
Suburban Subtotal		510	423	933	128	13.7%
TOTAL		979	932	1911	383	20.0

Table B-6. Breakdown of Eligible 1997-1998 NASS CDS Cases by PSU and Vehicle Type

PSU	Area Type	Passenger Car		Light Truck		Total
		No.	%	No.	%	
2	Rural	20	69.0%	9	31.0%	29
4	Rural	2	100.0%	0	0.0%	2
11	Rural	39	57.4%	29	42.6%	68
13	Rural	24	60.0%	16	40.0%	40
43	Rural	16	80.0%	4	20.0%	20
48	Rural	29	76.3%	9	23.7%	38
76	Rural	2	33.3%	4	66.7%	6
78	Rural	27	51.9%	25	48.1%	52
Rural Subtotal		159	62.4%	96	37.6%	255
5	Suburban	6	85.7%	1	14.3%	7
8	Suburban	5	55.6%	4	44.4%	9
12	Suburban	14	66.7%	7	33.3%	21
73	Suburban	7	70.0%	3	30.0%	10
9	Suburban	15	71.4%	6	28.6%	21
45	Suburban	19	63.3%	11	36.7%	30
75	Suburban	12	44.4%	15	55.6%	27
81	Suburban	2	66.7%	1	33.3%	3
Suburban Subtotal		80	62.5%	48	37.5%	128
Total		239	62.4%	144	37.6%	383

Table B-7. Breakdown of Eligible 1997-1998 NASS CDS Cases by Speed Limit and Vehicle Type

Speed Limit (mph)	Passenger Car		Light Truck		Total
	No.	%	No.	%	
45	71	70.3%	30	29.7%	101
50	28	73.7%	10	26.3%	38
55	96	61.9%	59	38.1%	155
65	14	45.2%	17	54.8%	31
70	17	58.6%	12	41.4%	29
75	13	44.8%	16	55.2%	29
Total	239	62.4%	144	37.6%	383

Table B-8. List of Sampled 1997 NASS CDS Cases

Sampled Cases for 1997

PSU 02	**PSU 09**	**PSU 11**		**PSU 12**	**PSU 13**	**PSU 43**	**PSU 48**	**PSU 73**	**PSU 75**	**PSU 78**
1	16	6	135	14	10	132	23	15	16	5
21	27	7	136	45	32		39	37	32	23
29	28	11	146	107	39		46	94	52	24
41	39	20	148	125	62		63	99	56	28
51	51	24	150	150	92		64	166	68	31
54	53	25	152	173	135		88		70	37
55	57	27	161	203	155		111		71	54
59	59	28	167	232	165		124		72	58
64	62	31	168	248	173		132		74	62
65	63	40	171		206		135		90	74
66	76	44	178		207		137		111	76
130	79	47	179		209		147		121	83
132		69	184				160		126	87
133		70	193				161		175	108
		71	194				163			120
		75					171			122
		85					198			124
		86					200			133
		128								137
Number of Cases by PSU										
14	12	34		9	12	1	18	5	14	19
Total Cases in Zone 1							Total Cases in Zone 2			
82							56			
Number of Cases for 1997					138					

Table B-9. List of Sampled 1998 NASS CDS Cases

Sampled Cases for 1998														
PSU 02	**PSU 09**	**PSU 11**		**PSU 12**		**PSU 13**		**PSU 43**	**PSU 48**		**PSU 73**	**PSU 75**	**PSU 78**	
2	12	6	134	18	214	7	145	25	4	145	7	2	20	94
22	28	11	135	28	224	14	155	50	10		12	23	24	95
37	52	15	136	33		15	156	99	13		85	46	27	107
70	59	30	142	36		17	159	101	22		143	54	29	108
74	63	39	143	46		18	165	105	25		149	56	31	110
79	80	55	144	52		38	167	111	26			62	36	113
80	87	56	153	65		46	182	129	30			100	47	114
84	89	88	155	76		52		138	31			115	48	115
88	91	92	170	87		54		170	44			140	53	119
91	123	94	178	88		55		177	45			184	60	124
102		95	185	115		76		185	47			218	63	131
112		102	189	133		102		188	61			229	68	138
122		104	199	143		103		204	62			234	70	142
148		106	207	147		105		217	95				71	
155		109	209	161		106		225	97				72	
		118		179		113		226	116				78	
		121		181		120		257	123				82	
		125		188		130		275	127				85	
		130		195		133		291	137				86	
		131		203		143			143				92	
Number of Cases by PSU														
15	10	35		22		27		19	21		5	13	33	
Total Cases in Zone 1									Total Cases in Zone 2					
128									72					

Number of Cases for 1998	128

APPENDIX C

Supplemental Data Collection Protocol

SUPPLEMENTAL DATA COLLECTION PROTOCOL

The field data collection forms and the accompanying coding and instruction manuals for the supplemental field data collection effort undertaken in this study are presented in this Appendix.

Field Data Collection Form

There are two sets of field data collection forms:

- Supplemental highway data collection form, and
- Object struck data collection form.

In addition, there are two sets of coding forms for reconstruction of the crashes:

- First impact coding form, and
- Subsequent impact coding form.

Each of these forms are presented on the following pages. Pages C-3 through C-7 contain the supplemental highway data collection form while the object struck data collection form is shown on page C-8. The first and subsequent impact coding forms are shown on pages C-9 though C-12.

Coding and Field Procedures Manual

There are two coding and field procedures manuals, one for the supplemental data collection field forms and the other for the reconstruction coding forms. The coding and field procedures manual for supplemental data collection is presented on pages C-13 through C-34. The manual for reconstruction coding forms is shown on pages C-35 through C-60.

SUPPLEMENTAL DATA COLLECTION FORM Page 1

CASE IDENTIFICATION

1. Year ___ ___
2. PSU No. ___ ___
3. Case No. - Stratum ___ ___ ___ ___

GENERAL HIGHWAY DATA

4. Land Use ___

___(1) Urban
___(2) Rural
___(9) Unknown

5. Class Trafficway ___

___(1) Interstate
___(2) U. S. route
___(3) State route
___(4) County road
___(5) City street
___(8) Other: ____________________

6. Access Control ___

___(1) Full
___(2) Partial
___(3) Uncontrolled

7. Average Lane Width ___ . ___ m

___(3.0) 3 m or narrower
___(3.1-4.9) Code actual lane width to nearest 0.1 m
___(5.0) 5 m or wider

8. Roadway Alignment at Point of Departure___

___(1) Straight
___(2) Curve right
___(3) Curve left

9. Radius of Curve

Measure the radius of curve using the middle ordinate method. See Coding Manual for field procedures.

At point of departure: R = ___ ___ ___ ___ m

Length of chord, C = _____________ m

Middle ordinate, M = _____________ mm

At point of maximum curvature within 100 m upstream of point of departure: R = ___ ___ ___ ___ m

Length of chord, C = _____________ m

Middle ordinate, M = _____________ mm

10. Roadway Profile at Point of Departure ___

___(0) Level (< 2%)
___(1) Upgrade
___(2) Downgrade
___(3) Crest
___(4) Sag

11. Vertical Grade

Measure the vertical grade using a digital inclinometer. See Coding Manual for field procedures.

At point of departure: +/- ___ ___ . ___ %

At point of maximum vertical grade within 100 m upstream of point of departure: +/- ___ ___ . ___ %

SUPPLEMENTAL DATA COLLECTION FORM

ROADSIDE DATA

12. Curb Presence ___

___(0) No curb
___(1) Barrier curb
___(2) Mountable curb

13. Curb Height ___ ___ ___ mm

___(000) No curb
___(001-998) Code actual curb height to nearest mm.

14. Shoulder Type ___

___(0) No shoulder
___(1) Paved shoulder
___(2) Gravel/Dirt shoulder
___(3) Grassy shoulder

15. Shoulder Width ___ . ___ m

___(0.0) No shoulder
___(0.1-9.8) Code actual shoulder width to nearest 0.1 m.

SLOPE DATA

16. Roadside Cross Section at Point of Departure ___

___ Choose the diagram that best describes the roadside cross section.
___(8) Other (Sketch)

17. Number of Slopes ___

___ (1-6) Code actual number of slopes
___ (7) 7 or more slopes.

Code for each slope the following data:

18. Lateral Offset to Beginning of Slope

Code actual lateral offset from edge of travelway to beginning of slope to nearest 0.1 m.

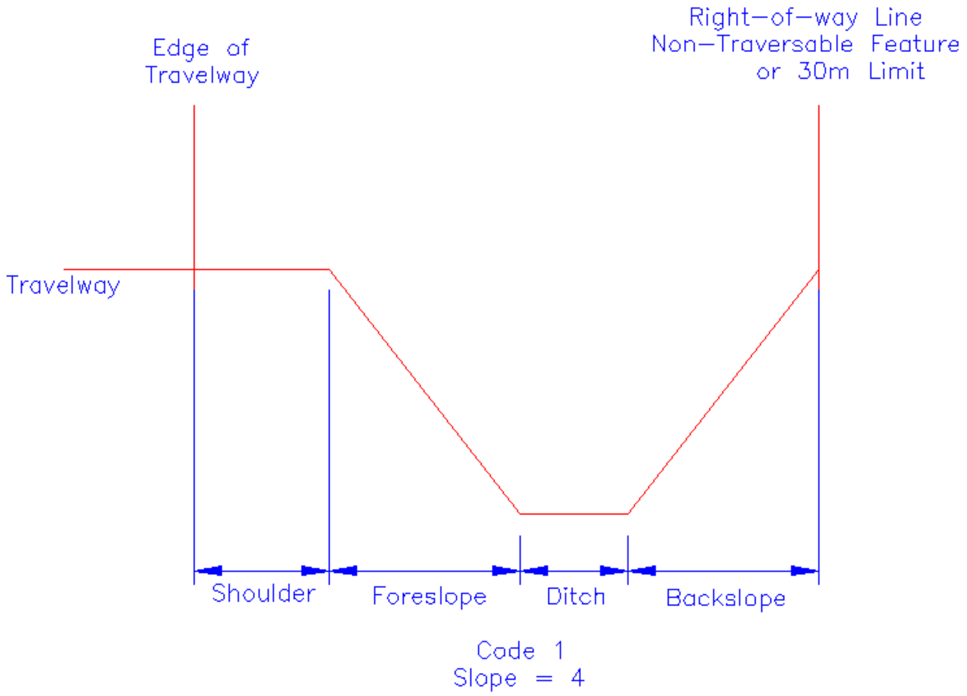
19. Rate of Slope

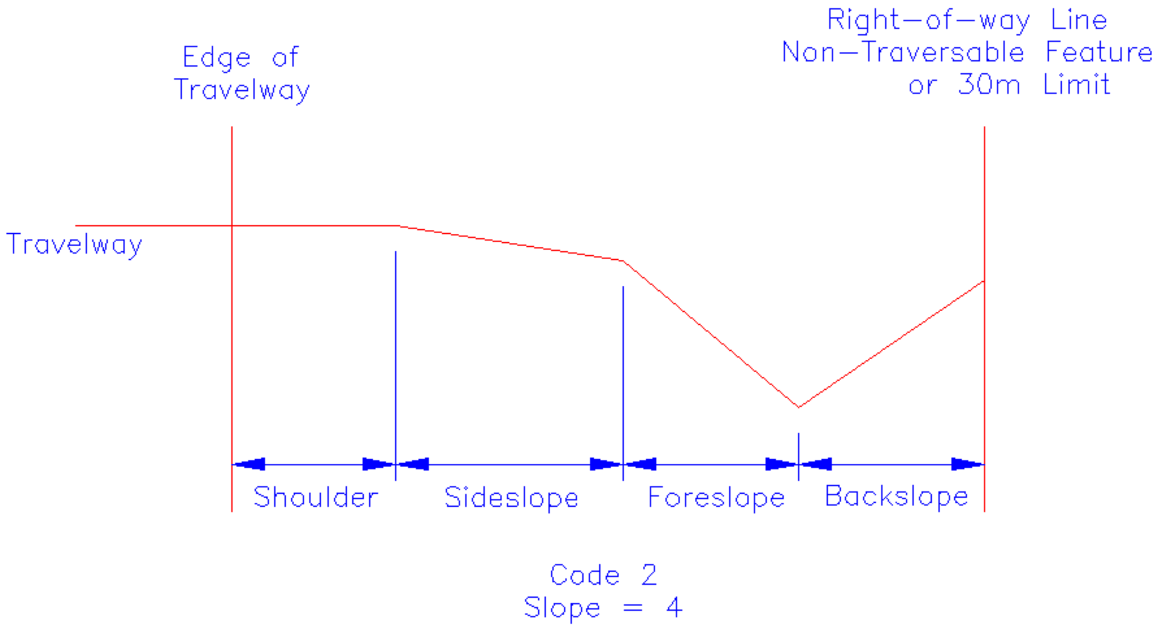
Measure the rate of slope using a smart level. See Coding Manual for field procedures.

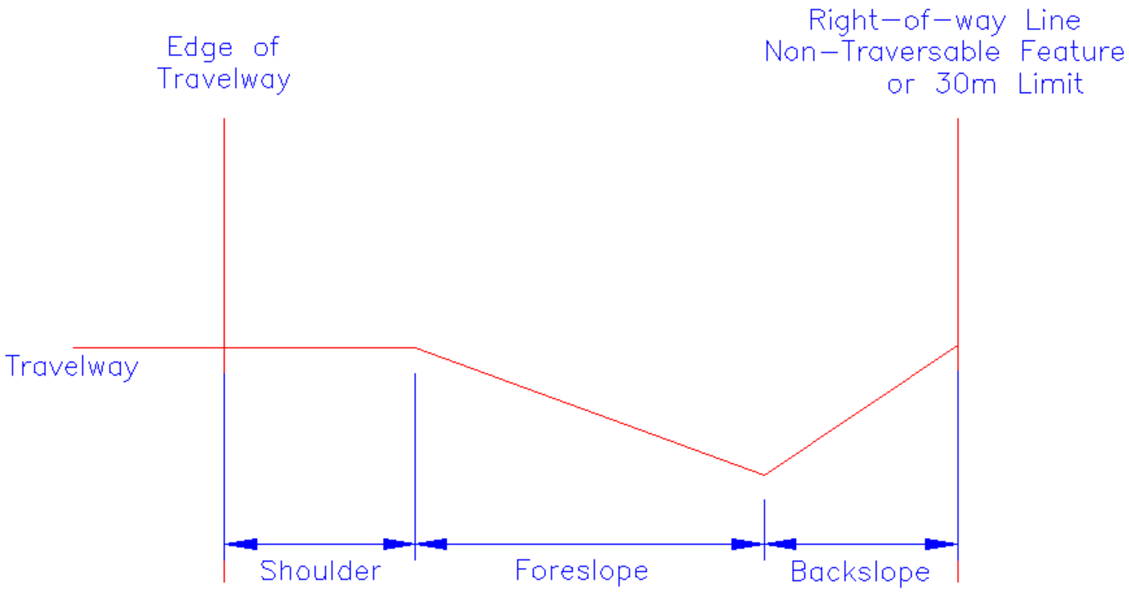
20. Width of Slope

Code actual width of slope to nearest 0.1 m.

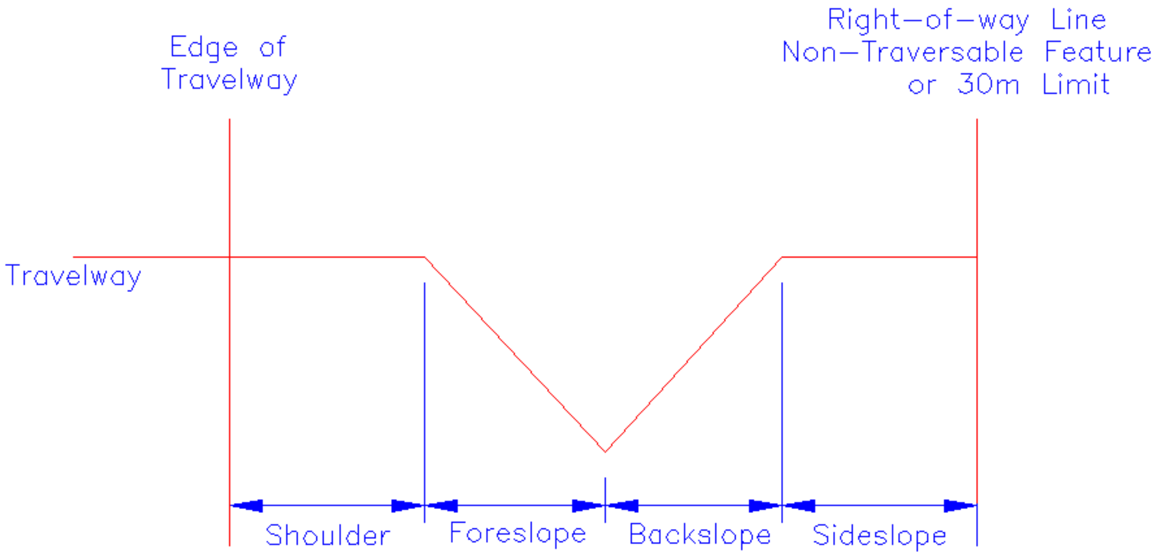
Slope	(18) Lateral Offset to Beginning of Slope	(19) Rate of Slope	(20) Width of Slope
1	0 0 . 0 m	+/- ___ ___ . ___ %	___ ___ . ___ m
2	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m
3	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m
4	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m
5	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m
6	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m


Edge of Travelway
Right-of-way Line
Non-Traversable Feature
or 30m Limit
Travelway
Shoulder
Foreslope
Ditch
Backslope
Code 1
Slope = 4

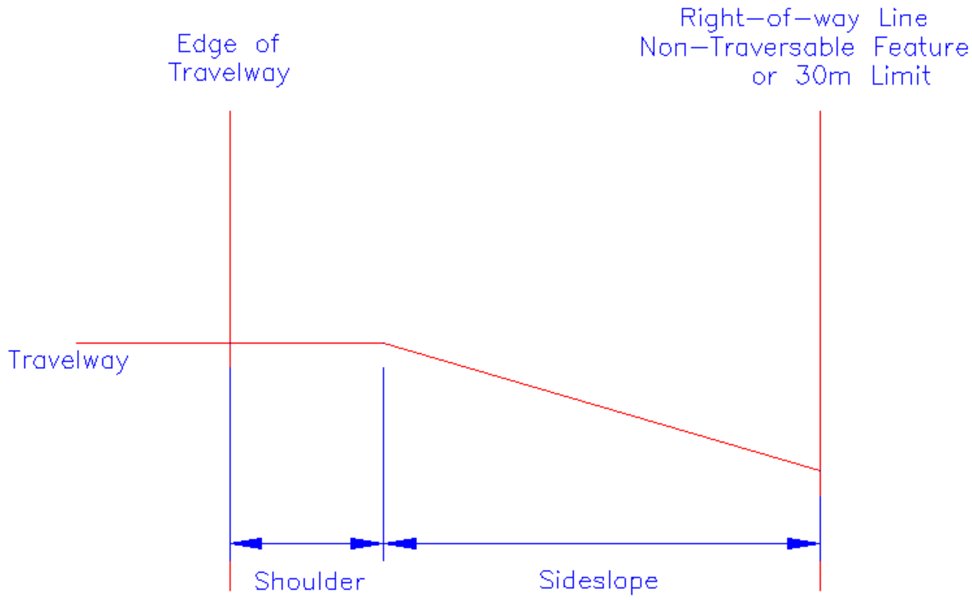

Edge of Travelway
Right-of-way Line
Non-Traversable Feature
or 30m Limit
Travelway
Shoulder
Sideslope
Foreslope
Backslope
Code 2
Slope = 4



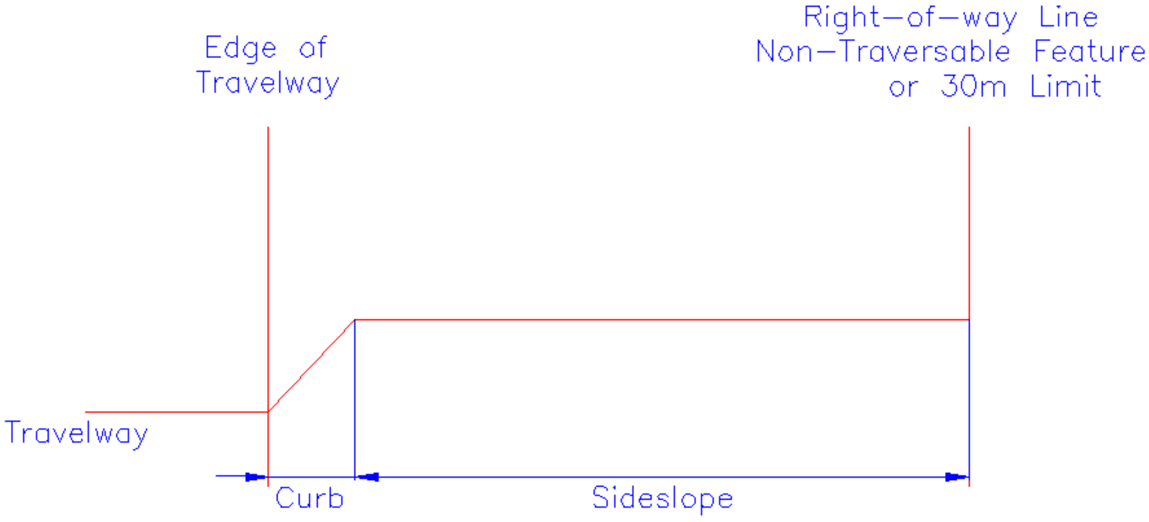
Code 3
Slope = 3



Code 4
Slope = 4



Code 5
Slope = 2



Code 6
Slope = 2

OBJECT STRUCK DATA COLLECTION FORM

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

GENERAL STRUCK OBJECT DATA

4. Impact No. ___

5. Object Type ___

___(1) Rigid Object
___(2) Barrier
___(3) Utility Pole
___(4) Light Support
___(5) Sign Support
___(6) Crash Cushion
___(7) Other
___(9) Unknown or N/A

Description:

____

____

____

____

6. Material ___

___(1) Concrete
___(2) Steel
___(3) Wood
___(4) Combination
___(7) Other
___(9) Unknown or N/A

Description:

____

____

____

DIMENSIONS OF STRUCK OBJECT

Enter dimensions of struck object. Note that required data vary depending on object type

Rigid Object: Length
Width
Height

Barrier: Mounting Height
Post Size
Post Spacing

Utility Pole: Height
Dimension at Base

Light Support: Height
Dimension at Base

Sign Support: Height
Dimension at Base

Crash Cushion: Length of Cushion

Dimensions:

____

____

____

PHOTOGRAPHY

Please take photographs of the struck object from at least two different angles. For light and sign supports, take an additional photograph of the base. When appropriate, include a measuring tape in the photograph for reference purposes.

7. Photographs taken? ___

___(1) Yes
___(2) No

Photograph Identification Numbers:

____

____

____

RECONSTRUCTION CODING FORM – FIRST EVENT

Page 1

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

ENCROACHMENT DATA

4. Departure Angle ___ ___ ___^{o}

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of departure.

5. Vehicle Heading Angle ___ ___ ___^{o}

Enter vehicle heading angle in relation to edge of travelway at point of departure.

VEHICLE TRAJECTORY DATA

6. Driver Action ___

___(1) None
___(2) Braking Only
___(3) Steering Only
___(4) Braking and Steering
___(9) Unknown

Supporting Data: ______________________________

____

____

7. Longitudinal Distance of Travel ___ ___ ___ m

Measure longitudinal distance of travel from point of departure to point of impact for first event and sketch the vehicle path in the space below:

8. No. of Trajectory Profile Points ___ ___

Enter number of points used for the trajectory profile. General guidelines:

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

9. Lateral Offset of Trajectory Profile Points

Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m).

D1 = ___ ___ . ___ m D2 = ___ ___ . ___ m
D3 = ___ ___ . ___ m D4 = ___ ___ . ___ m
D5 = ___ ___ . ___ m D6 = ___ ___ . ___ m
D7 = ___ ___ . ___ m D8 = ___ ___ . ___ m
D9 = ___ ___ . ___ m D10 = ___ ___ . ___ m
D11 = ___ ___ . ___ m D12 = ___ ___ . ___ m
D13 = ___ ___ . ___ m D14 = ___ ___ . ___ m
D15 = ___ ___ . ___ m D16 = ___ ___ . ___ m
D17 = ___ ___ . ___ m D18 = ___ ___ . ___ m

Comments: ________________________________

____

____

10. Maximum Lateral Offset

Enter longitudinal distance, L(max), from point of departure to point of maximum lateral offset and extent of lateral offset , D(max).

L(max) ___ ___ ___ m

D(max) ___ ___ . ___ m

RECONSTRUCTION CODING FORM – FIRST EVENT

IMPACT CONDITIONS – FIRST EVENT

11. Location of Impact

Enter location of point of impact for first event in relation to point of departure for longitudinal location and to edge of travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

12. NASS CDS Data

Copy the following data items from the NASS CDS forms for first event:

Object Struck ___ ___

Collision Deformation Classification (CDC):

___ ___ ___ ___ ___ ___ ___

Point of Impact on Vehicle: ___________________

____

____

Vehicle Damage Profile:

Length of Damage (L): ___ ___ ___ ___ cm

Damage Profile (D1-D6):

D1 = ___ ___ . ___ cm D2 = ___ ___ . ___ cm

D3 = ___ ___ . ___ cm D4 = ___ ___ . ___ cm

D5 = ___ ___ . ___ cm D6 = ___ ___ . ___ cm

13. Impact Angle ___ ___ ___ º

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of impact for first event.

14. Vehicle Heading Angle at Impact ___ ___ ___ º

Enter vehicle heading angle in relation to edge of travelway at point of impact for first event.

SEPARATION CONDITIONS - FIRST EVENT

15. Location of Separation

Enter location of point of separation for first event in relation to point of departure for longitudinal location and edge of the travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

16. Separation angle ___ ___ ___ º

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of separation for first event.

17. Vehicle Heading Angle at Separation ___ ___ ___ º

Enter vehicle heading angle in relation to edge of travelway at point of separation for first event.

SUBSEQUENT EVENT/FINAL REST

18. Subsequent Event ___

___(1) Yes
___(2) No - Final Rest

If yes, code variables 19 and 20 as “Not Applicable” and proceed with coding of the subsequent event form for the second event. If no, continue with variables 19 and 20.

19. Location of Final Rest

Enter location of point of final rest.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

20. Vehicle Heading Angle at Final Rest ___ ___ ___ º

Enter vehicle heading angle in relation to edge of travelway at point of final rest.

RECONSTRUCTION CODING FORM – SUBSEQUENT EVENT

Page 1

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

CURRENT EVENT IDENTIFICATION

4. Current Event No. ___ ___

5. Current Event Location

Enter location of point of impact for current event in relation to point of departure for longitudinal location and edge of travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

VEHICLE TRAJECTORY DATA

6. Driver Action ___

___(1) None
___(2) Braking Only
___(3) Steering Only
___(4) Braking and Steering
___(9) Unknown

Supporting Data: ____________________________

____

____

7. Longitudinal Distance of Travel ___ ___ ___ m

Measure longitudinal distance of travel from point of separation for prior event to point of impact for current event and sketch the vehicle path in the space provided below:

8. No. of Trajectory Profile Points ___ ___

Enter number of points used for the trajectory profile. General guidelines:

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

9. Lateral Offset of Trajectory Profile Points

Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m).

D1 = ___ ___ . ___ m
D2 = ___ ___ . ___ m
D3 = ___ ___ . ___ m
D4 = ___ ___ . ___ m
D5 = ___ ___ . ___ m
D6 = ___ ___ . ___ m
D7 = ___ ___ . ___ m
D8 = ___ ___ . ___ m
D9 = ___ ___ . ___ m
D10 = ___ ___ . ___ m
D11 = ___ ___ . ___ m
D12 = ___ ___ . ___ m
D13 = ___ ___ . ___ m
D14 = ___ ___ . ___ m
D15 = ___ ___ . ___ m
D16 = ___ ___ . ___ m
D17 = ___ ___ . ___ m
D18 = ___ ___ . ___ m

Comments: _________________________________

____

____

10. Maximum Lateral Offset

Enter longitudinal distance, L(max), from point of departure to point of maximum lateral offset and extent of lateral offset , D(max).

L(max) ___ ___ ___ m

D(max) ___ ___ . ___ m

RECONSTRUCTION CODING FORM – SUBSEQUENT EVENT

IMPACT CONDITIONS – CURRENT EVENT

11. Location of Impact

Enter location of point of impact for current event in relation to point of departure for longitudinal location and edge of travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

12. NASS CDS Data

Copy the following data items from the NASS CDS form for current event:

Object Struck ___ ___

Collision Deformation Classification (CDC):

___ ___ ___ ___ ___ ___ ___

Point of Impact on Vehicle: ____________________

____

____

Vehicle Damage Profile:

Length of Damage (L): ___ ___ ___ ___ cm

Damage Profile (D1-D6):

D1 = ___ ___ . ___ cm D2 = ___ ___ . ___ cm

D3 = ___ ___ . ___ cm D4 = ___ ___ . ___ cm

D5 = ___ ___ . ___ cm D6 = ___ ___ . ___ cm

13. Impact Angle ___ ___

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of impact for current event.

14. Vehicle Heading Angle at impact ___ ___ ___

Enter vehicle heading angle in relation to edge of travelway at point of impact for current event.

SEPARATION CONDITIONS - CURRENT EVENT

15. Location of Separation

Enter location of point of separation for current event in relation to point of departure for longitudinal location and edge of travelway for lateral offset

Longitudinal ___ ___ ___ . ___ m

Lateral ___ ___ . ___ m

16. Separation angle ___ ___ ___ º

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of separation.

17. Vehicle Heading Angle ___ ___ ___ º

Enter vehicle heading angle in relation to edge of travelway at point of separation.

SUBSEQUENT EVENT/FINAL REST

18. Subsequent Event ___

___(1) Yes
___(2) No - Final Rest

If yes, skip variables 19 and 20 and proceed with coding of the subsequent event form for the next event. If no, continue with variables 19 and 20.

19. Location of Final Rest

Enter location of point of final rest.

Longitudinal ___ ___ ___ . ___ m

Lateral ___ ___ . ___ m

20. Vehicle Heading Angle at Final Rest ___ ___ ___ º

Enter vehicle heading angle in relation to edge of travelway at point of final rest.

NATIONAL ACCIDENT SAMPLING SYSTEM (NASS)

SUPPLEMENTAL FIELD DATA COLLECTION

CODING INSTRUCTIONS AND FIELD PROCEDURES MANUAL

NCHRP Project 17-22
“Identification of Vehicular Impact Conditions
Associated with Serious Ran-Off-Road Crashes”

Prepared for

National Cooperative Highway Research Program
Transportation Research Board
Washington, D. C.

INTRODUCTION

Sample cases from the National Accident Sampling System (NASS) Crashworthiness Data System (CDS) are selected for use in clinical analysis under National Cooperative Highway Research Program (NCHRP) Project 17-22, "Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes." The objectives of the study are: (1) to identify the vehicle types, impact conditions, and site characteristics associated with serious injury and fatal crashes involving roadside features and safety devices, and (2) to create a robust relational database for future research.

The NASS CDS data are very comprehensive for their intended purpose. However, they lack details pertaining to the roadway and roadside which are critical for the purpose of NCHRP Project 17-22. Some of the data elements can be estimated from manual review of the hard copies and photographs of the cases. However, there are some data elements that are not attainable through this manual review process. It is, therefore, necessary to collect additional field data to supplement the case materials.

Two data collection forms were developed for this supplemental data collection effort:

1. Supplemental data form – for data elements pertaining to roadway and roadside characteristics.

2. Struck object data form – for data elements pertaining to the struck objects.

This manual provides the instructions for the coding of the data elements and applicable field data collection procedures for these two data forms. Note that the two data forms are found under separate cover. Further, note that additional photographic coverage of the crash sites is necessary.

CODING INSTRUCTIONS AND FIELD PROCEDURES FOR SUPPLEMENTAL DATA FORM

Coding instructions and field procedures are provided for each of the 20 data elements or variables on this supplemental data form. The data elements are grouped under four general headings:

1. Case Identification,
2. General Highway Data,
3. Roadside Data, and
4. Slope Data.

For each group of data elements, there is a brief introduction followed by information on the individual data elements within the group. The following information is provided for each of the data elements:

Variable Number(s)
Variable Name(s)
Format
Codes
    Range
    Individual codes or responses
Coding Instructions
    Descriptions and definitions for individual codes or responses
    Illustrations (if applicable)
Field Procedures (if applicable)

CASE IDENTIFICATION VARIABLES

Data elements 1 through 3 are case identification variables, including: year, Primary Sampling Unit, and case number-stratum. These variables should be identical to those for the NASS CDS case so that the supplemental field data can be properly merged with the NASS CDS data.

1. Variable Name: Year

   Format: 2 column numeric

   Codes: 00 or 01

   Coding Instructions: Code the last two digits of the year of the accident.

2. Variable Name: Primary Sampling Unit

   Format: 2 column numeric

   Codes: 02, 11, 12, 13, 45, 48, 73, 75, 76 or 78

   Coding Instructions: Code the Primary Sampling Unit in which the accident occurred.

3. Variable Name: Case Number-Stratum

   Format: 4 column alphanumeric

   Coding Instructions: Code the case number and stratum, which should be the same as those for the NASS CDS case.

GENERAL HIGHWAY DATA VARIABLES

Variables 4 through 11 pertain to general highway data, including: land use, class trafficway, access control, average lane width, roadway alignment at point of departure, radius of curve, roadway profile at point of departure, and vertical grade. The data elements Land Use, Class Trafficway, and Access Control pertain to the highway in general. The data elements Average Lane Width, Roadway Alignment, and Roadway Profile pertain to the point of departure. For the data elements Radius of Curve and Vertical Grade, the measurements are to be taken both at the point of departure and the maximum point within 100 meters upstream of the point of departure.

The point of departure is the point where the vehicle departed from the travelway (or encroaches beyond the edge of the travelway). The edge of travelway is defined as the center of the edge line if it is present, or the edge of the pavement if there is no edge line.

4. Variable Name: Land Use

Format: 1 column numeric

Codes: (1) Urban
(2) Rural
(9) Unknown

Coding Instructions: Select the code that best describes the land use around the crash site. An urban area (code 1) is defined as within the limits of a city or an incorporated area and the land use is typically residential or commercial in nature. A rural area (code 2) is defined as outside the limits of a city or an incorporated area and the land use is typically agricultural in nature. Code 9 if the land use is unknown or cannot be determined.

5. Variable Name: Class Trafficway

Format: 1 column numeric

Codes: (1) Interstate
(2) U. S. route
(3) State route
(4) County road
(5) City street
(8) Other: ___________________

Coding Instructions: Select the code that best describes the type of highway on which the accident occurred. The codes are arranged in descending order of preference. If the highway has multiple designations, e.g., U. S. 87 and State Route 38, code the highest preference, which would be U. S. Highway (code 2) for this example. Code 8 if the class trafficway does not fit into any of the classes, e.g., private drive, and enter the information in the space provided.

6. Variable Name: Access Control

Format: 1 column numeric

Codes: (1) Full
(2) Partial
(3) Uncontrolled

Coding Instructions: Select the code that best describes the type of access control for the highway on which the accident occurred. Full access control (code 1) pertains to interstate highways and freeways in which access to the highway, i.e., entrance and exit, is limited to designated interchanges. Partial access control (code 2) pertains to expressways and divided highways where access to the highway is limited to intersections and designated crossovers. Uncontrolled access (code 3) pertains to highways where access to the highway from adjoining properties is not limited or controlled.

7. Variable Name: Average Lane Width

Format: 3 column numeric with one decimal place

Codes: (3.0) 3 m or narrower
(3.1 - 4.9) Code actual lane width to nearest 0.1 m
(5.0) 5 m or wider

Coding Instructions: Measure and record the lane width to the nearest 0.1 meter for the main travel lanes at the point of departure. Do not include the width of auxiliary lanes, such as entrance and exit lane, passing lane, two-way left-turn lane, etc. If the lane widths for the lanes are different, calculate and record the average lane width.

8. Variable Name: Roadway Alignment at Point of Departure

Format: 1 column numeric

Codes: (1) Straight
(2) Curve right
(3) Curve left

Coding Instructions: Select the code that best describes the roadway alignment at the point where the vehicle departed from the travelway. Curve right or left is in reference to the direction of vehicle travel prior to departing from the travelway.

9. Variable Name: Radius of Curve

Format: 4 column numeric

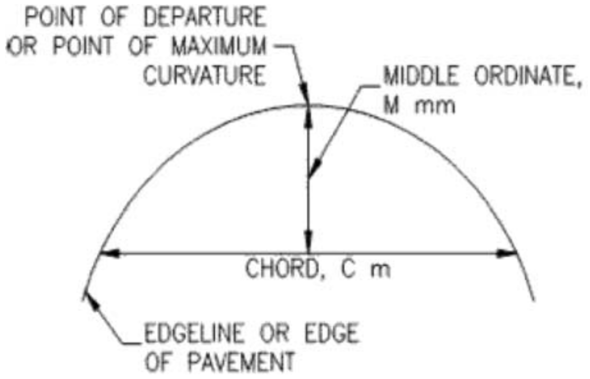
Codes: (0000) Straight
(0001 - 9999) Calculated radius of curve

Coding Instructions: Measure the radius of curve using the middle ordinate method as described below. The radius of curve should be measured at both the point where the vehicle departed the travelway and at the point of maximum curvature (determined visually) within 100 meters upstream of the point of departure in the direction of vehicle travel prior to departing from the travelway. Note that the radius of curve is rarely less than 50 or more than 2,000 meters.

Field Procedure:

Using the edge line or the edge of the pavement where the vehicle departed from the travelway as the reference line, stretch a chord (i.e., a straight line) of known length with a tape, as shown in the following diagram. The chord should be straight with the two ends at the reference line. For the radius of curve at the point of departure, the middle of the chord should correspond to the point of departure. Similarly, for the radius of curve at the point of maximum curvature, the middle of the chord should correspond to the point of maximum curvature. Note that a chord length of 30 meters or longer is preferred. However, a shorter chord length is acceptable if a longer chord length is not feasible or practical, e.g., at sharp curves where a longer chord length would intrude too much into the travelway. Record the length of the chord in meters in the space provided.

Use another tape to measure the middle ordinate, i.e., the distance from the center of the chord to the reference line, as shown in the following diagram. Record the length of the middle ordinate in millimeters in the space provided.



Calculate the radius of curve using the following formula and enter the radius in the space provided:

where R = Radius of curve in meters
C = Length of chord in meters
M = Middle ordinate in millimeters

10. Variable Name: Roadway Profile at Point of Departure

Format: 1 column numeric

Codes: (1) Level (< 2%)
(2) Upgrade
(3) Downgrade
(4) Crest
(5) Sag

Coding Instructions: Select the code that best describes the roadway profile at the point where the vehicle departed from the travelway. Code 1 (level) if level or the vertical grade is less than 2 percent. Upgrade (code 2) or downgrade (code 3) is in reference to the direction of vehicle travel prior to departing from the travelway. Crest (code 4) is at the top of a hill and sag (code 5) is at the bottom of a hill.

11. Variable Name: Vertical Grade

Format: 5 column numeric, first column +/- sign, and one decimal place.

Codes: (+ 00.0) Level (vertical grade < 2%)
(+/- 00.1 - 99.9) Calculated vertical grade

Coding Instructions: Measure the vertical grade using the digital inclinometer method as described below. The vertical grade should be measured at both the point where the vehicle departed the travelway and at the point of maximum vertical grade (determined visually) within 100 meters upstream of the point of departure in the direction of vehicle travel prior to departing from the travelway. Upgrade is coded as (+) and downgrade is coded as (-). Note that vertical grades, either upgrade or downgrade, are rarely steeper than 15 percent.

Coding for this variable should correspond to the coding of Variable 10, "Roadway Profile at Point of Departure," as shown in the following table:

Code for	Code for Variable 11, "Vertical Grade"	
Variable 10	Point of Departure	Maximum Vertical Grade
1 - Level	Code +00.0	Code +00.0
2 - Upgrade	Code actual upgrade	Code maximum upgrade
3 - Downgrade	Code actual downgrade	Code maximum downgrade
4 - Crest	Code actual grade	Code maximum grade
5 - Sag	Code actual grade	Code maximum grade

If Variable 10 is coded as "1 - Level", no measurement of vertical grade is necessary. Code the vertical grades at both the point of departure and the point of maximum vertical grade as +00.0.

If Variable 10 is coded as "2 - Upgrade" or "3 - Downgrade", code the actual upgrade or downgrade at the point of departure and the maximum upgrade or downgrade within 100 m upstream of the point of departure for the maximum vertical grade, respectively.

If Variable 10 is coded as "4 - Crest", code the actual grade at the point of departure, which may be level, upgrade or downgrade. Code the maximum grade within 100 m upstream of the point of departure for the maximum vertical grade. Note that the maximum vertical grade for a crest is typically an upgrade.

If Variable 10 is coded as "5 - Sag", code the actual grade at the point of departure, which may be level, upgrade or downgrade. Code the maximum grade within 100 m upstream of the point of departure for the maximum vertical grade. Note that the maximum vertical grade for a sag is typically a downgrade.

Field Procedure:

Place the digital inclinometer on the roadway surface parallel to the roadway at the point where vertical grade is to be measured and record the vertical grade. If the roadway surface is very uneven, it may be a good idea to place a 4-ft level on the roadway surface and then place the digital inclinometer on top of the 4-ft level for the grade measurement.

ROADSIDE DATA VARIABLES

Variables 12 through 15 pertain to general roadside data, including: Curb Presence, Curb Height, Shoulder Type, and Shoulder Width. These general roadside data are intended for identification of the degree of influence their presence or absence have on single-vehicle, ran-off-road accidents. All roadside data should be collected at the point of departure and on the same side of the roadway where the vehicle ran off the travelway.

12. Variable Name: Curb Presence

Format: 1 column numeric

Codes: (0) No curb
(1) Barrier curb
(2) Mountable curb

Coding Instructions: Record the presence or absence of a curb and the curb type at the point where the vehicle departed from the travelway. Code 0 if there is no curb present. If a curb is present, identify the curb type and code as appropriate.

Barrier curbs (code 1) are relatively high (ranging from 150 to 250 mm or more in height) and steep faced (generally not exceeding a ratio of 3:1 vertical to horizontal), and designed to inhibit, or at least discourage, vehicles from leaving the roadway. The upper corner may be slightly rounded.

Mountable curbs (code 2) are 150 mm or less in height and have well rounded or plane sloping faces and are designed so that vehicles can cross over them with relative ease.

13. Variable Name: Curb Height

Format: 3 column numeric

Codes: (000) No curb
(001-998) Code actual curb height to the nearest mm.

Coding Instructions: If there is no curb present, code 000. If a curb is present, code the actual curb height to the nearest mm.

To measure the curb height, place one end of a level on top of the curb and, while maintaining it in a level attitude, record the vertical distance from the bottom of the level to the toe of the curb or the gutter.

14. Variable Name: Shoulder Type

Format: 1 column numeric

Codes: (0) No shoulder

(1) Paved shoulder
(2) Gravel/Dirt shoulder
(3) Grassy shoulder

Coding Instructions: Record the presence or absence of a shoulder and the shoulder type at the point where the vehicle departed from the travelway. Code 0 if there is no shoulder present. If a shoulder is present, code the type of material used for the shoulder: paved with concrete or asphalt (code 1), gravel or dirt (code 2), or sod (code 3).

15. Variable Name: Shoulder Width

Format: 3 column numeric with one decimal place

Codes: (0.0) No shoulder
(0.1-9.8) Code actual shoulder width to the nearest 0.1 m.

Coding Instructions: If there is no shoulder present, code 0.0. If a shoulder is present, code the actual shoulder width to the nearest 0.1 meter.

SLOPE DATA VARIABLES

Variables 16 through 20 pertain to the roadside slope data, including: Roadside Cross Section, Number of Slopes, and for each slope, the Lateral Offset to Beginning of Slope, Rate of Slope, and Width of Slope. These roadside slope data are intended to describe the roadside cross section and terrain and to assess their influence on single-vehicle, ran-off-road accidents. All roadside slope data should be collected at the point of departure and on the same side of the roadway where the vehicle ran off the travelway.

The variables roadside cross section and number of slopes provide a qualitative description of the roadside cross section from the edge of the travelway, i.e., edge line or edge of pavement, to one of the following, whichever occurs first:

a. The first non-traversable feature, such as a longitudinal barrier, a vertical drop-off, a rock wall, or a line of closely spaced trees,

b. The right-of-way line, which is typically defined by a fence, or

c. If the right-of-way line is not clearly defined or more than 30 meters from the edge of the travelway and there is no non-traversable feature, use 30 meters as the limit.

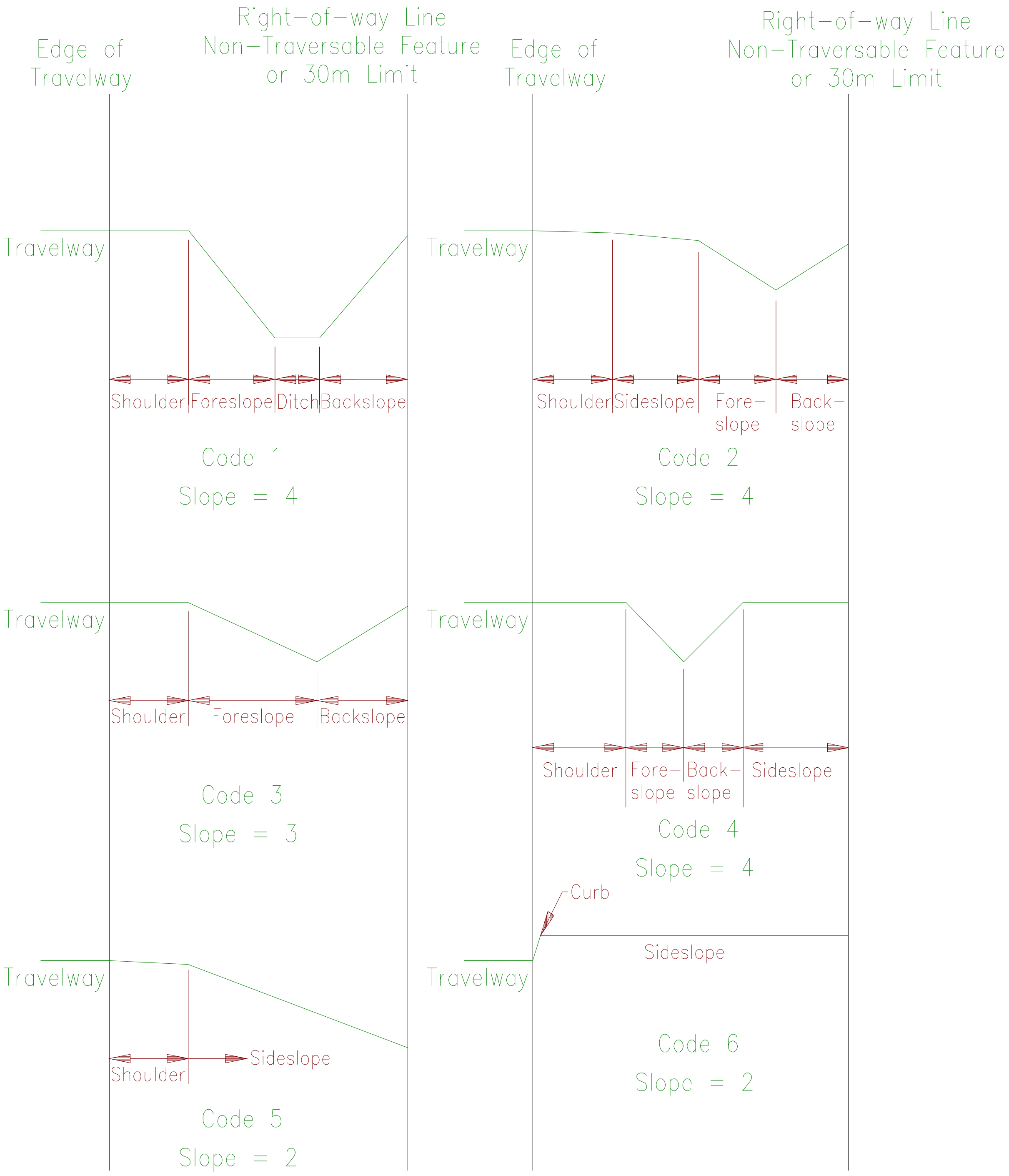
Spaces are provided for recording data on up to six slopes. If there are more than six slopes between the roadway edge and the first non-traversable feature, the right-of-way line, or 30 meters, then only data for the first six slopes will be coded. There is at least one slope between the roadway edge and the first non-traversable feature, the right-of-way line, or 30 meters. This first slope is usually a curb or a shoulder, followed by a foreslope, a ditch, and then a backslope. For each slope, record the following information: lateral offset to beginning of slope, rate of slope, and width of slope.

16. Variable Name: Roadside Cross Section at Point of Departure

Format: 1 column numeric

Codes: (1-6) Typical roadside cross sections
(8) Other (Sketch)

Coding Instructions: Select the cross section that best describes the actual roadside cross section at the point of departure from the list of typical roadside cross sections shown in the diagram on the following page. If the actual roadside cross section does not fit into any of the typical cross sections, code 8 and sketch in the cross section in the space below Variable 20 or on a separate sheet of paper.



TYPICAL ROADSIDE CROSS SECTIONS

17. Variable Name: Number of Slopes

Format: 1 column numeric

Codes: (1-6) Actual number of slopes
(7) 7 or more slopes

Coding Instructions: Code the actual number of roadside slopes. If there are more than six slopes, code 7 and enter data for Variables 18 through 20 for the first six slopes.

18. Variable Name: Lateral Offset to Beginning of Slope

Format: 4 column numeric with one decimal place

Codes: (00.0-30.0) Actual lateral offset of beginning of slope to the nearest 0.1 m.

Coding Instructions: Measure and record the actual lateral offset, i.e., the distance from the edge of the travelway (edge line or edge of pavement) to the beginning of the slope, to the nearest 0.1 meter. The measurement is to be made on the environmental surface. Note that the lateral offset for the first slope is necessarily 00.0 since it starts at the edge of the travelway. Also, note that the lateral offsets for subsequent slopes are cumulative, i.e., the lateral offset for the beginning of the second slope equals the width of the first slope, the lateral offset for the third slope equals the sum of the widths of the first and second slopes, etc.

Field Procedure: Stretch a 30-m tape from the edge of the travelway to the right-of-way line or the 30-m point perpendicular to the roadway. Identify the slopes and the transition points. Read and record the lateral offset for each slope.

19. Variable Name: Rate of Slope

Format: 5 column numeric, first column +/- sign, and one decimal place.

Codes: (+ 00.0) Level
(+/- 00.1 - 99.9) Calculated rate of slope

Coding Instructions: Measure the rate of slope for each slope using the digital inclinometer method as described for vertical grade. The rate of slope should be measured at the point where the vehicle departed the travelway. Upward slope is coded as (+) and downward slope is coded as (-).
Field Procedure:

Place a 4-ft level on the slope perpendicular to the roadway at the point where the rate of slope is to be measured. Place the digital inclinometer on top of the 4-ft level and record the rate the slope.

20. Variable Name: Width of Slope

Format: 4 column numeric with one decimal place

Codes: (00.0-30.0) Actual lateral offset of beginning of slope to the nearest 0.1 m.

Coding Instructions: Measure and record the actual width of the slope to the nearest 0.1 meter. The measurement is to be made on the environmental surface. Note that a curb is considered as a slope, but there is no physical width, so code the width for the curb as 00.0. Also, note that the width for a given slope is equal to the difference between the lateral offset of the beginning of the slope and the lateral offset of the beginning of the following slope. For example, if the lateral offsets of the beginning of slopes 3 and 4 are 7 and 15 meters, respectively, then the width of slope 3 is (15 - 7) or 8 meters.

CODING INSTRUCTIONS AND FIELD PROCEDURES
STRUCK OBJECT DATA FORM

Coding instructions and field procedures are provided for the data elements or variables on the struck object data form, which are grouped under four general headings:

1. Case Identification,
2. General Struck Object Data,
3. Dimensions of Struck Object, and
4. Photography. Data.

For each group of data elements, there is a brief introduction followed by information on the individual data elements within the group. The following information is provided for each of the data elements:

- Variable Number(s)
- Variable Name(s)
- Format
- Codes
  - Range
  - Individual codes or responses
- Coding Instructions
  - Descriptions and definitions for individual codes or responses
  - Illustrations (if applicable)
- Field Procedures (if applicable)

Due to the large number os potential roadside objects and features, the variables are very general without specific details. Instead, field investigators are asked to provide annotations or descriptions and photographs of the struck object. A form should be completed for each struck object.

It is recognized that some of the struck objects currently at the sites may be different from those at the time of the crash due to repairs or replacements for damages sustained in the impacts. However, given the retrospective nature of this supplemental data collection effort, data on the actual struck objects are no longer available. Thus, there is the implicit assumption that the struck objects were repaired to its original shape or replaced in kind. By comparing photographs taken during the initial investigation and this supplemental data collection effort, changes to the struck objects could be identified and assessed.

CASE IDENTIFICATION VARIABLES

Data elements 1 through 3 are case identification variables, including: year, Primary Sampling Unit, and case number-stratum. These variables should be identical to those for the NASS CDS case so that the supplemental field data can be properly merged with the NASS CDS data.

1. Variable Name: Year

   Format: 2 column numeric

   Codes: 00 or 01

   Coding Instructions: Code the last two digits of the year of the accident.

2. Variable Name: Primary Sampling Unit

   Format: 2 column numeric

   Codes: 02, 11, 12, 13, 45, 48, 73, 75, 76 or 78

   Coding Instructions: Code the Primary Sampling Unit in which the accident occurred.

3. Variable Name: Case Number-Stratum

   Format: 4 column alphanumeric

   Coding Instructions: Code the case number and stratum, which should be the same as those for the NASS CDS case.

GENERAL STRUCK OBJECT DATA VARIABLES

Variables 4 through 6 pertain to general struck object data, including: impact number, object type, and material.

4. Variable Name: Impact Number

Format: 1 column numeric

Codes: (1 - 8) Actual impact number
(9) Unknown

Coding Instructions: Code the impact number for the struck object, which should be the same as those for the NASS CDS case.

5. Variable Name: Object Type

Format: 1 column numeric

Codes: (1) Rigid Object
(2) Barrier
(3) Utility Pole
(4) Light Support
(5) Sign Support
(6) Crash Cushion
(7) Other
(9) Unknown or N/A

Coding Instructions: Select the code that best describes the type of object struck in this particular impact. The codes are not meant to be all inclusive. Only objects of specific interest to this study are included on the list. Code 7 for all other objects not listed. Code 9 if unknown or not applicable, i.e., struck object not found. Also, provide a brief description of the struck object, e.g., W-beam guardrail with wood posts, guardrail terminal, etc., in the space provided.

6. Variable Name: Material

Format: 1 column numeric

Codes: (1) Concrete
(2) Steel
(3) Wood
(4) Combination
(7) Other
(9) Unknown or N/A

Coding Instructions: Select the code that best describes the principal type of material for the struck object, i.e., concrete, steel and wood. Code 4 if a combination of materials are used, e.g., steel W-beam guardrail with wood posts, concrete barrier with steel rail on top, etc. Code 7 for all other materials not listed. Code 9 if unknown or not applicable, i.e., struck object not found. Also, provide a brief description of the materials for the struck object, e.g., W-beam guardrail with wood posts, guardrail terminal, etc., in the space provided.

DIMENSIONS OF STRUCK OBJECT

Enter dimensions of the struck object in the space provided. The required data vary depending on the object type, as listed below:

- Rigid Object
  - Enter the length, width and height of the object.

- Barrier
  - Enter height of barrier, measured from the ground to the top of the barrier. For barriers installed in soil, an average of several measurement may be necessary if the ground surface is uneven.
  - For barriers with posts, measure the cross section of the post, i.e., overall width and depth for rectangular wooden or steel I-beam posts and circumference or diameter of round wooden posts.
  - For barriers with posts, measure the spacing between the posts, center to center. Measurement should be taken in the standard section of the barrier areas where post spacing is uniform, and not in the area of the end terminal where post spacing may vary.

- Utility Pole
  - Enter the estimated height of the pole.
  - Measure the cross section of the base of the utility pole, i.e., overall width and depth for rectangular steel structures and circumference (or diameter) of round or polygonal poles.

- Light Support
  - Enter the estimated height of the support.
  - Measure the cross section of the base of the pole i.e., overall width and depth for rectangular poles and circumference (or diameter) of round or polygonal poles. For light supports that are designed to break away upon impact, the measurement should be taken just above the transformer base or the flange of the slip base.

- Sign Support
  - Enter the estimated height of the support.
  - Measure the cross section of the base of the pole i.e., overall width and depth for steel I-beam or channel posts or circumference (or diameter) of round or polygonal posts.. For sign supports with a slip base design, the measurement should be taken just above the flange of the slip base.

- Crash Cushion
  - Enter length of crash cushion, measured from the nose to the end of the crash cushion or the backup structure. For sand barrel type of crash cushion, note the number of rows and the number of barrels each row.

Field Procedure:

All dimensions are measurable using a tape measure except for heights of pole structures and sign supports. An infrared distance measuring device will be used to estimate the height of pole structures and sign support. Stand at a distance equal to or greater than the estimated height of the object and measure the distances to the top (D_t) and bottom (D_b) of the object. Calculate the height of the pole structure or sign support using the following formula:

$$\text{Height (in meters)} = 1.7 + \sqrt{[(D_t)^2 - (D_b)^2]}$$

Round off to the nearest 0.5 meter and enter the values in the space provided.

PHOTOGRAPHY

For each struck object, take photographs of the object from at least two different angles. For light and sign supports, take an additional photograph of the base. When appropriate, include a measuring tape in the photograph for reference purposes. A reminder to take the photographs is provided on the data form itself plus space for entering the photograph identification numbers.

7. Variable Name: Photographs taken?

Format: 1 column numeric

Codes: (1) Yes
(2) No

Coding Instructions: Code 1 if photographs are taken. This variable is intended only as a reminder and does not serve any other purposes. Code 2 if photographs are not taken for whatever reason.

Assign identification numbers to the photographs and enter the numbers in the space provided. These identification numbers would help to correlate the photographs with the struck objects.

NATIONAL ACCIDENT SAMPLING SYSTEM (NASS)

SUPPLEMENTAL FIELD DATA COLLECTION

RECONSTRUCTION CODING MANUAL

NCHRP Project 17-22
“Identification of Vehicular Impact Conditions
Associated with Serious Ran-Off-Road Crashes”

Prepared for

National Cooperative Highway Research Program
Transportation Research Board
Washington, D. C.

INTRODUCTION

Sample cases from the National Accident Sampling System (NASS) Crashworthiness Data System (CDS) are selected for use in clinical analysis under National Cooperative Highway Research Program (NCHRP) Project 17-22, "Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes." The objectives of the study are: (1) to identify the vehicle types, impact conditions, and site characteristics associated with serious injury and fatal crashes involving roadside features and safety devices, and (2) to create a robust relational database for future research.

The NASS CDS data are very comprehensive for their intended purpose. However, they lack details pertaining to the roadway and roadside which are critical for the purpose of NCHRP Project 17-22. Some of the data elements can be estimated from manual review of the hard copies and photographs of the cases. However, there are some data elements that are not attainable through this manual review process. It is, therefore, necessary to collect additional field data to supplement the case materials.

In addition to the supplemental field data collection effort, reconstruction of the sampled cases is needed to estimate their impact conditions. Note that the effort described herein does not cover impact speed and performance of struck object, which will be reconstructed separately. There are two coding forms associated with this portion of the reconstruction effort:

1. First event coding form – for coding of reconstruction data elements pertaining to the first event.
2. Subsequent event coding form – for coding of reconstruction data elements pertaining to subsequent events. One set of coding forms should be completed each subsequent event.

This manual provides the instructions for the coding of the data elements for these two coding forms. Sources for coding these reconstruction data elements include: completed NASS CDS data forms, scaled diagram, and photographic coverage.

CODING INSTRUCTIONS FOR FIRST EVENT CODING FORM

Coding instructions are provided for each of the 20 data elements or variables on this reconstruction coding form for the first harmful event (herein referred to as the first event). The data elements are grouped under six general headings:

1. Case Identification,
2. Encroachment Data,
3. Vehicle Trajectory Data,
4. Impact Conditions,
5. Separation Conditions, and
6. Subsequent Event/Final Rest.

For each group of data elements, there is a brief introduction followed by information on the individual data elements within the group. The following information is provided for each of the data elements:

- Variable Number(s)
- Variable Name(s)
- Format
- Codes
  - Range
  - Individual codes or responses
- Coding Instructions
  - Descriptions and definitions for individual codes or responses
  - Illustrations (if applicable)

CASE IDENTIFICATION VARIABLES

Data elements 1 through 3 are case identification variables, including: year, Primary Sampling Unit, and case number-stratum. These variables should be identical to those for the NASS CDS case so that the supplemental field data can be properly merged with the NASS CDS data.

1. Variable Name: Year

   Format: 2 column numeric

   Codes: 00 or 01

   Coding Instructions: Code the last two digits of the year of the accident.

2. Variable Name: Primary Sampling Unit

   Format: 2 column numeric

   Codes: 02, 11, 12, 13, 45, 48, 73, 75, 76 or 78

   Coding Instructions: Code the Primary Sampling Unit in which the accident occurred.

3. Variable Name: Case Number-Stratum

   Format: 4 column alphanumeric

   Coding Instructions: Code the case number and stratum, which should be the same as those for the NASS CDS case.

ENCROACHMENT DATA VARIABLES

Variables 4 and 5 pertain to encroachment data at the point of departure from the travelway, including: departure angle and vehicle heading angle. The point of departure is defined as the point where the vehicle departed from the travelway (or encroaches beyond the edge of the travelway). The edge of travelway is defined as the center of the edge line if it is present, or the edge of the pavement if there is no edge line.

4. Variable Name: Departure Angle

Format: 3 column numeric

Codes: (001-359) Actual departure angle
(999) Unknown

Coding Instructions: Enter the angle of the vehicle C. G. direction of travel at the point of departure. The departure angle is measured in relation to the edge of the travelway in the general direction of travel. Note that the departure angle must be between 1 and 90 degrees for a right-sided departure and between 270 and 359 degrees for a left-sided departure. The departure angle is typically measured from the scaled diagram and based on available scene evidence.

5. Variable Name: Vehicle Heading Angle

Format: 3 column numeric

Codes: (000 -360) Actual vehicle heading angle
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of departure. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle at the point of departure is typically measured from the scaled diagram and based on available scene evidence.

VEHICLE TRAJECTORY DATA VARIABLES

Variables 6 through 10 pertain to the vehicle trajectory data between the point of departure from the travelway to the point of the first event, including: driver action, longitudinal distance of travel, number of trajectory profile points, lateral offset of trajectory profile points and maximum lateral offset. The point of departure is defined as the point where the vehicle first departed from the travelway (or encroaches beyond the edge of the travelway). The edge of travelway is defined as the center of the edge line if it is present, or the edge of the pavement if there is no edge line.

Note that the vehicle trajectory is defined using the point of the vehicle that first left the travelway as the reference point. For example, the reference point for a tracking vehicle running off the right side of the roadway is typically the right front corner of the vehicle.

6. Variable Name: Driver Action

Format: 1 column numeric

Codes:
(1) None
(2) Braking Only
(3) Steering Only
(4) Braking and Steering
(9) Unknown

Coding Instructions: Select the code that best describes the action of the driver between the point of departure from the travelway to the point of impact for the first event. Information for coding this variable include: CDS coded variable, scene evidence, driver interview, and annotated data. Document the supporting data in the space provided as well as any additional information of interest, e.g., braking initially followed by steering and braking.

7. Variable Name: Longitudinal Distance of Travel

Format: 3 column numeric

Codes:
(000-997) Actual longitudinal distance of travel in meters
(999) Unknown

Coding Instructions: Record the longitudinal distance of travel, to the nearest meter, from the point of departure from the travelway to the point of impact for the first event. Note that this is the longitudinal distance as measured along the edge of the travelway and not the distance along the path of the vehicle. The longitudinal distance of travel is typically obtained from available scene measurements or measured from the scaled diagram .

8. Variable Name: Number of Trajectory Profile Points

Format: 2 column numeric

Codes: 06, 12 or 18

Coding Instructions: Enter the number of trajectory profile points used to define the vehicle trajectory from the point of departure to the point of impact for the first event. The number of trajectory profile points is a function of the longitudinal distance of travel. The general guidelines are as follows:

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

To locate the trajectory profile points, the longitudinal distance of travel is divided into equal parts based on the number of trajectory profile points. For example, if the longitudinal distance of travel is 55 m, which corresponds to 12 trajectory profile point according to the general guidelines, is 12, the longitudinal distance is divided into 11 equal spaces of 5 m each (55/11 = 5 m). The first trajectory profile point is at the point of departure. The second trajectory profile point is 5 m downstream, 10 m for the third trajectory profile point, ... , and the last trajectory profile point is at the point of impact for the first event.

9. Variable Name: Lateral Offset of Trajectory Profile Points

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m). At each of the trajectory profile point, measure the lateral distance from the edge of the travelway to the reference point on the vehicle that defines the vehicle path.

10. Variable Name: Maximum Lateral Offset

The maximum lateral offset along the vehicle path may or may or may not coincide with one of the trajectory profile points. Thus, a separate entry is provided for the maximum lateral offset. The point of maximum lateral offset is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway.

For the longitudinal measurement, L (max):

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(999) Unknown

For the lateral offset measurement, D(max):

Format: 3 column numeric with 1 decimal place

Codes: (00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter the location of the point of maximum lateral extent of encroachment. The location is defined by two measurements: longitudinal distance, L(max), measured from the point of departure to the point of maximum lateral extent of encroachment, and the extent of the maximum lateral offset , D(max).

IMPACT CONDITIONS (FIRST EVENT) DATA VARIABLES

Variables 11 through 14 pertain to the impact conditions of the first event, including: location, NASS CDS coded data elements, impact angle and vehicle heading angle at impact. The point of impact for the first event is defined as the point where the vehicle first impacted a roadside object or feature, or rolled over.

11. Variable Name: Location of Impact

The location of point of impact for the first event is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location of the point of impact for the first event is defined by the struck object and not by the vehicle reference point. Thus, while the longitudinal distance is the same as the last trajectory profile point, the lateral offset may differ.

For the longitudinal measurement:

Format: 3 column numeric

Codes: (001-997) Actual longitudinal distance to the nearest meter
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes: (00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter the location of the point of impact for the first event in relation to the struck object. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of impact for the first event and the lateral offset from the edge of the travelway.

12. NASS CDS Data

Copy the following data items from the applicable NASS CDS forms pertaining to the first event:

- Object Struck
- Collision Deformation Classification (CDC)
- Vehicle Damage Profile: Length of Damage (L) and Damage Profile (D1-D6)

Also, provide a narrative to describe the point of impact on the vehicle.

13. Variable Name: Impact Angle

Format: 3 column numeric

Codes: (001-359) Actual impact angle
(999) Unknown

Coding Instructions: Enter the angle of the vehicle C. G. direction of travel at the point of impact for the first event. The impact angle is measured in relation to the edge of the travelway in the general direction of travel. Note that the impact angle must be between 1 and 90 degrees for a right-sided departure and between 270 and 359 degrees for a left-sided departure. The impact angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object.

14. Variable Name: Vehicle Heading Angle at Impact

Format: 3 column numeric

Codes: (000 -360) Actual vehicle heading angle
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of impact for the first event. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object.

SEPARATION CONDITIONS (FIRST EVENT) DATA VARIABLES

Variables 15 through 17 pertain to the separation conditions of the first event, including: location, separation angle and vehicle heading angle at separation. The point of separation is defined as the point where the vehicle first separated from the struck roadside object or feature. Point of separation is typically applicable to only objects or features with some length, e.g., a guardrail or a concrete wall. For a point object such as a pole structure, the point of separation will essentially be the same as the point of impact. Also, in instances where the vehicle essentially came to rest against the struck object, there is no point of separation and variables 15 through 17 should be coded as “Not Applicable”.

15. Location of Separation

The location of separation for the first event is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location of separation for the first event is also defined by the struck object and not the vehicle reference point.

For the longitudinal measurement:

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(998) Not Applicable
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.8) Not Applicable
(99.9) Unknown

Coding Instructions: Enter the location of the point of separation for the first event in relation to the struck object. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of separation for the first event and the lateral offset from the edge of the travelway. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and the variable should be coded as “Not Applicable”.

16. Variable Name: Separation Angle

Format: 3 column numeric

Codes:
(000-360) Actual separation angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the angle of the vehicle C. G. direction of travel at the point of separation for the first event. The separation angle is measured in relation to the edge of the travelway in the general direction of travel. The separation angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and the variable should be coded as "Not Applicable".

17. Variable Name: Vehicle Heading Angle at Separation

Format: 3 column numeric

Codes: (000 -360) Actual vehicle heading angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of separation for the first event. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle at separation for the first event is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and code the variable as "Not Applicable".

SUBSEQUENT EVENT/FINAL REST DATA VARIABLES

Variables 18 through 20 pertain to the subsequent event or final rest data, including: subsequent event, location of final rest, and vehicle heading angle at final rest. The point of final rest is defined as the point where the vehicle came to a complete stop. In instances where there was subsequent event(s), there is no point of final rest and variables 19 and 20 should be skipped and left blank.

18. Variable Name: Subsequent Event

Format: 1 column numeric

Codes:
(1) Yes
(2) No - Final Rest

Code if there is any subsequent event (Code 1) or if the vehicle came to final rest after the first event (Code 2). If there is a subsequent event, code variables 19 and 20 as "Not Applicable" and proceed with coding of the subsequent event form for the second event. If the vehicle came to final rest after the first event, enter the applicable information for variables 19 and 20 on the point of final rest.

19. Variable Name: Location of Final Rest

The location of final rest is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location of final rest is defined by the vehicle center of gravity (C. G.).

For the longitudinal measurement:

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(998) Not Applicable
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.8) Not Applicable
(99.9) Unknown

Coding Instructions: Enter the location of the point of final rest in relation to the vehicle c. g. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of final rest and the lateral offset from the edge of the travelway. In instances where there was subsequent event(s), code the variable as "Not Applicable".

20. Variable Name: Vehicle Heading Angle at Final Rest

Format: 3 column numeric

Codes:
(000 -360) Actual vehicle heading angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of final rest. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle at final rest is typically measured from the scaled diagram and based on available scene evidence. In instances where there was subsequent event(s), code the variable as “Not Applicable”.

CODING INSTRUCTIONS FOR SUBSEQUENT EVENT CODING FORM

Coding instructions are provided for each of the 20 data elements or variables on this reconstruction coding form for subsequent events. The data elements are grouped under six general headings:

1. Case Identification,
2. Current Event Identification,
3. Vehicle Trajectory Data,
4. Impact Conditions - Current Event
5. Separation Conditions - Current Event, and
6. Subsequent Event/Final Rest.

For each group of data elements, there is a brief introduction followed by information on the individual data elements within the group. The following information is provided for each of the data elements:

- Variable Number(s)
- Variable Name(s)
- Format
- Codes
    - Range
    - Individual codes or responses
- Coding Instructions
    - Descriptions and definitions for individual codes or responses
    - Illustrations (if applicable)

CASE IDENTIFICATION VARIABLES

Data elements 1 through 3 are case identification variables, including: year, Primary Sampling Unit, and case number-stratum. These variables should be identical to those for the NASS CDS case so that the supplemental field data can be properly merged with the NASS CDS data.

1. Variable Name: Year

   Format: 2 column numeric

   Codes: 00 or 01

   Coding Instructions: Code the last two digits of the year of the accident.

2. Variable Name: Primary Sampling Unit

   Format: 2 column numeric

   Codes: 02, 11, 12, 13, 45, 48, 73, 75, 76 or 78

   Coding Instructions: Code the Primary Sampling Unit in which the accident occurred.

3. Variable Name: Case Number-Stratum

   Format: 4 column alphanumeric

   Coding Instructions: Code the case number and stratum, which should be the same as those for the NASS CDS case.

CURRENT EVENT IDENTIFICATION

Variables 4 and 5 pertain to identification of the current event being coded, including: event number and location.

4. Variable Name: Current Event Number

Format: 2 column numeric

Codes: (01-96) Actual event number

Coding Instructions: Enter the number of the current event as coded in the NASS CDS forms.

5. Variable Name: Current Event Location

The location of the current event is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location is defined in relation to the struck object.

For the longitudinal measurement:

Format: 3 column numeric

Codes: (001-997) Actual longitudinal distance to the nearest meter
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes: (00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter the location of the point of impact for the current event in relation to the struck object. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of impact for the current event and the lateral offset from the edge of the travelway.

VEHICLE TRAJECTORY DATA VARIABLES

Variables 6 through 10 pertain to the vehicle trajectory data between the point of separation for the previous event to the point of impact for the current event, including: driver action, longitudinal distance of travel, number of trajectory profile points, lateral offset of trajectory profile points and maximum lateral offset.

Note that the vehicle trajectory is still defined using the point of the vehicle that first left the travelway as the reference point. For example, the reference point for a tracking vehicle running off the right side of the roadway is typically the right front corner of the vehicle.

6. Variable Name: Driver Action

Format: 1 column numeric

Codes:
(1) None
(2) Braking Only
(3) Steering Only
(4) Braking and Steering
(9) Unknown

Coding Instructions: Select the code that best describes the action of the driver between the point of separation from the previous event to the point of impact for the current event. Information for coding this variable include: CDS coded variable, scene evidence, driver interview, and annotated data. Document the supporting data in the space provided as well as any additional information of interest, e.g., braking initially followed by steering and braking.

7. Variable Name: Longitudinal Distance of Travel

Format: 3 column numeric

Codes:
(000-997) Actual longitudinal distance of travel in meters
(999) Unknown

Coding Instructions: Record the longitudinal distance of travel, to the nearest meter, from the point of separation for the previous event to the point of impact for the current event. Note that this is the longitudinal distance as measured along the edge of the travelway and not the distance along the path of the vehicle. The longitudinal distance of travel is typically obtained from available scene measurements or measured from the scaled diagram .

8. Variable Name: Number of Trajectory Profile Points

Format: 2 column numeric

Codes: 06, 12 or 18

Coding Instructions: Enter the number of trajectory profile points used to define the vehicle trajectory from the point of separation for the previous event to the point of impact for the current event. The number of trajectory profile points is a function of the longitudinal distance of travel. The general guidelines are as follows:

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

To locate the trajectory profile points, the longitudinal distance of travel is divided into equal parts based on the number of trajectory profile points. For example, if the longitudinal distance of travel is 55 m, which corresponds to 12 trajectory profile point according to the general guidelines, is 12, the longitudinal distance is divided into 11 equal spaces of 5 m each (55/11 = 5 m). The first trajectory profile point is at the point of separation for the previous event. The second trajectory profile point is 5 m downstream, 10 m for the third trajectory profile point, ... , and the last trajectory profile point is at the point of impact for the current event.

9. Variable Name: Lateral Offset of Trajectory Profile Points

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m). At each of the trajectory profile point, measure the lateral distance from the edge of the travelway to the reference point on the vehicle that defines the vehicle path.

10. Variable Name: Maximum Lateral Offset

The maximum lateral offset along the vehicle path may or may or may not coincide with one of the trajectory profile points. Thus, a separate entry is provided for the maximum lateral offset. The point of maximum lateral offset is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway.

For the longitudinal measurement, L (max):

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(999) Unknown

For the lateral offset measurement, D(max):

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.9) Unknown

Coding Instructions: Enter the location of the point of maximum lateral extent of encroachment between the point of separation for the previous event to the point of impact for the current event. The location is defined by two measurements: longitudinal distance, L(max), measured from the point of departure to the point of maximum lateral extent of encroachment, and the extent of the maximum lateral offset , D(max).

IMPACT CONDITIONS (CURRENT EVENT) DATA VARIABLES

Variables 11 through 14 pertain to the impact conditions of the current event, including: location, NASS CDS coded data elements, impact angle and vehicle heading angle at impact. The point of impact for the current event is defined as the point where the vehicle first impacted a roadside object or feature, or rolled over, for the current event.

11. Variable Name: Location of Event

The location of point of impact for the current event is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location is defined by the struck object and not the vehicle reference point. Thus, while the longitudinal distance is the same as the last trajectory profile point, the lateral offset may differ.

For the longitudinal measurement:

Format:	3 column numeric
Codes:	(001-997) Actual longitudinal distance to the nearest meter (999) Unknown

For the lateral offset measurement:

Format:	3 column numeric with 1 decimal place
Codes:	(00.0-99.6) Actual lateral offset to the nearest 0.1 meter (99.7) 99.7 meters or greater (99.9) Unknown

Coding Instructions: Enter the location of the point of impact for the current event in relation to the struck object. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of impact for the current event and the lateral offset from the edge of the travelway.

12. NASS CDS Data

Copy the following data items from the applicable NASS CDS forms pertaining to the current event:

- Object Struck
- Collision Deformation Classification (CDC)
- Vehicle Damage Profile: Length of Damage (L) and Damage Profile (D1-D6)

Also, provide a narrative to describe the point of impact on the vehicle for the current event.

13. Variable Name: Impact Angle

Format: 3 column numeric

Codes: (001-359) Actual departure angle
(999) Unknown

Coding Instructions: Enter the angle of the vehicle C. G. direction of travel at the point of impact for the current event. The impact angle is measured in relation to the edge of the travelway in the general direction of travel. Note that the impact angle must be between 1 and 90 degrees for a right-sided departure and between 270 and 359 degrees for a left-sided departure. The impact angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object.

14. Variable Name: Vehicle Heading Angle at Impact

Format: 3 column numeric

Codes: (000 -360) Actual vehicle heading angle
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of impact for the current event. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object.

SEPARATION CONDITIONS (CURRENT EVENT) DATA VARIABLES

Variables 15 through 17 pertain to the separation conditions of the current event, including: location, separation angle and vehicle heading angle at separation. The point of separation is defined as the point where the vehicle first separated from the struck roadside object or feature. Point of separation is typically applicable to only objects or features with some length, e.g., a guardrail or a concrete wall. For a point object such as a pole structure, the point of separation will essentially be the same as the point of impact. Also, in instances where the vehicle essentially came to rest against the struck object, there is no point of separation and variables 15 through 17 should be coded as “Not Applicable”.

15. Location of Separation

The location of separation for the current event is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location of separation is also defined by the struck object and not the vehicle reference point.

For the longitudinal measurement:

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(998) Not Applicable
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.8) Not Applicable
(99.9) Unknown

Coding Instructions: Enter the location of the point of separation for the current event in relation to the struck object. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of separation for the current event and the lateral offset from the edge of the travelway. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and the variable should be coded as “Not Applicable”.

16. Variable Name: Separation Angle

Format: 3 column numeric

Codes:
(000-360) Actual separation angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the angle of the vehicle C. G. direction of travel at the point of separation for the current event. The separation angle is measured in relation to the edge of the travelway in the general direction of travel. The separation angle is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and the variable should be coded as "Not Applicable".

17. Variable Name: Vehicle Heading Angle at Separation

Format: 3 column numeric

Codes:
(000 -360) Actual vehicle heading angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of separation for the current event. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle at separation for the current event is typically measured from the scaled diagram and based on available scene evidence and damages to the vehicle and struck object. In instances where the vehicle essentially came to rest against the struck object, there is no point of separation and code the variable as "Not Applicable".

SUBSEQUENT EVENT/FINAL REST DATA VARIABLES

Variables 18 through 20 pertain to the subsequent event or final rest data, including: subsequent event, location of final rest, and vehicle heading angle at final rest. The point of final rest is defined as the point where the vehicle came to a complete stop. In instances where there was subsequent event(s), there is no point of final rest and variables 19 and 20 should be skipped and left blank.

18. Variable Name: Subsequent Event

Format: 1 column numeric

Codes:
(1) Yes
(2) No - Final Rest

Code if there is any subsequent event (Code 1) or if the vehicle came to final rest after the current event (Code 2). If there is a subsequent event, code variables 19 and 20 as "Not Applicable" and proceed with coding of the subsequent event form for the next event. If the vehicle came to final rest after the current event, enter the applicable information for variables 19 and 20 on the point of final rest.

19. Variable Name: Location of Final Rest

The location of final rest is defined by two measurements: the longitudinal distance from the point of departure and the lateral offset from the edge of the travelway. Note that the location of final rest is defined by the vehicle center of gravity (C. G.).

For the longitudinal measurement:

Format: 3 column numeric

Codes:
(001-997) Actual longitudinal distance to the nearest meter
(998) Not Applicable
(999) Unknown

For the lateral offset measurement:

Format: 3 column numeric with 1 decimal place

Codes:
(00.0-99.6) Actual lateral offset to the nearest 0.1 meter
(99.7) 99.7 meters or greater
(99.8) Not Applicable
(99.9) Unknown

Coding Instructions: Enter the location of the point of final rest in relation to the vehicle C. G. The location is defined by two measurements: longitudinal distance, measured from the point of departure to the point of final rest and the lateral offset from the edge of the travelway. In instances where there was subsequent event(s), code the variable as "Not Applicable".

20. Variable Name: Vehicle Heading Angle at Final Rest

Format: 3 column numeric

Codes: (000 -360) Actual vehicle heading angle
(998) Not Applicable
(999) Unknown

Coding Instructions: Enter the vehicle heading angle at the point of final rest. The vehicle heading angle is measured in relation to the edge of the travelway in the general direction of travel. The vehicle heading angle at final rest is typically measured from the scaled diagram and based on available scene evidence. In instances where there was subsequent event(s), code the variable as “Not Applicable”.

APPENDIX D

Database Content

Table D-1. Reconstruction Summary, Vehicle Data, and Event Statistics

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Reconstruction Summary	Case_Set	Reconstruction Set	17-22, 17-11, or FHWA	Descriptor identifying what case set the reconstructions were obtained from	No
	Case_Num	Case Number	Number	Identifier for case in NASS database	No
	Case_Year	Year	Number	Accident Year	No
	Case_PSU	PSU	Number	PSU Location Identifier	No
	Case ID	Case ID	Number	Case ID in indicated PSU	No
	Depart_Vel	Departure Velocity (km/h)	Number	Calculated velocity determined from accident reconstruction	No
	Depart_Vel_Eng	Departure Velocity (mph)	Number	Departure velocity in English units	No
	Depart_Angle	Departure Angle (deg)	Number	Angle between a tangent line to the road at the point of departure (POD) and vehicle CG trajectory	No
	Depart_Lat_Energy	Lateral Departure Energy (kJ)	Number	Vehicle's lateral energy with respect to roadway travel, $1/2*m*(v*\sin\theta)^2$	No
	Depart_Sideslip_Angle	Vehicle Sideslip Angle (deg)	Number	Difference between vehicle heading angle and CG trajectory; angles are positive when measured clockwise	No
	Rated_Wgt	Weighting Factor (RATWGT)	Number	Case weighted rating factor, used to determine how "normal" the impact was, as determined by NASS	No
Vehicle Data	Veh_Year	Year	Number	Vehicle year	No
	Veh_Make	Make	Name	Vehicle make (e.g. Chevrolet, Ford etc)	No
	Veh_Model	Model	Name	Vehicle model (e.g. Blazer, S-10 etc)	No
	Veh_VIN	VIN	Number	VIN Identifier	No
	Veh_Class	Class	See "NASS Naming Conventions"	Vehicle class defined based on wheelbase and width, as recorded on NASS website	No
	Veh_Wgt_Engl	Weight (lbs)	Number	Vehicle weight	No
	Veh_Mass	Mass (kg)	Number	Vehicle mass	No
	Veh_Drive	Drive Type	FWD / RWD / 4WD / Unk	Front, Rear, 4-Wheel Drive, or Unknown	No
Event Statistics	Into_Lanes_Opp	Encroach in Opposing Lanes	Y / N	Indicator for whether vehicle encroached into opposing travel lanes	No
	Struck_Veh_Opp	Struck Opposing Vehicle	Y / N	Indicator for whether vehicle struck opposing vehicle	No
	Most_Sev_Event	Most Severe Event	A / B / C / D / R	One of Impacts A through D or R (rollover, if not coded)	Yes / No

Table D-2. Road Characteristics (Part I)

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Road Characteristics	No_Lanes_POD	No. Travel Lanes at POD	Number	Number of travel lanes in direction of vehicle travel at POD	Yes
	No_Lanes_Opp_ POD	No. Travel Lanes in Opposite Direction	Number	Number of travel lanes in opposite direction of vehicle travel at POD	Yes
	Lane_Division	Lane Division	D / N / NLM / UNK / N/A	Lane division possibilities: Divided, Not Divided, No Lane Markings, Unknown, or Not Applicable	No
	Lane_Divider	Division Type	CB / GR / OM / CL / TH / N/A	Concrete barrier, guardrail, open median, center lane, other divider type, or not applicable	No
	Land_Use_1	Land Use	See "NASS Naming Conventions"	Regional area in which road is located, as determined by the NASS researchers	No
	Speed_Lim	Speed Limit (kph)	Number	Metric speed limit	No
	Speed_Lim_Eng	Speed Limit (mph)	Number	English speed limit	No
	Char_ADT	Characteristic Traffic Volume	Low / Med / High / Very High	This is based off of observations from photos, land use, travel lanes, and road wear pattern vs. age- Rural: Low- Urban low traffic, Med- Urban high traffic or interstate, High- 6+ lane roadway, Very High	Yes
	Road_Class_1	Class Trafficway	See "NASS Naming Conventions"	Roadway classification, as determined by NASS team	No
	Access_Cntl_1	Access Control	See "NASS Naming Conventions"	Type of access control on the roadway, as determined by NASS team	No
	Ave_LW_1	Average Lane Width (m)	Number	Average of lane widths on road, as determined by NASS team	No
	Road_Align_1	Alignment at POD	See "NASS Naming Conventions"	Roadway alignment, straight or curved	No
	ROC_POD_1	Radius of Curvature (ROC) at POD (m)	Number	Radius of roadway curvature at POD No. 1	No
	ROC_LOC_1	Length of Chord at POD (m)	Number	Length of choord of roadway curve at POD No. 1	No
	ROC_MO_1	Middle Ordinate at POD (mm)	Number	Length of middle ordinate of roadway curve at POD No. 1	No
	ROC_Max_1	ROC at Point of Max Curvature (m)	Number	Radius of roadway curvature at point of max curvature within 100 m of POD	No
	ROC_LOC_Max_1	Length of Chord at Max Curvature (m)	Number	Length of choord of roadway curve at point of max curvature within 100 m of POD	No
	ROC_MO_Max_1	Middle Ordinate at Max Curvature (mm)	Number	Length of middle ordinate of roadway curve at point of max curvature within 100 m of POD	No

Table D-3. Road Characteristics (Part II)

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Road Characteristics	Initial_Depart_Side	Departure Side	L / R	Side of the road that the vehicle departed, left or right	No
	Road_Profile_1	Roadway Profile	See "NASS Naming Conventions"	Qualitative description of vertical road slope, based on hills, crests, and valleys, determined by NASS team	No
	Grade_POD_1	Vertical Grade at POD (%)	Percentage	Percent vertical grade at POD No. 1	No
	Grade_Max_1	Max Grade (%)	Percentage	Maximum vertical grade near POD No. 1	No
	Vis_Block	Visibility Constraint	Name	Objects which may obscure view of road or other vehicles, based on photographic evidence	Yes
	Lighting	Lighting	Y / N / N/A	Yes, street lights; No, no road lighting; N/A, does not affect case	Yes
	Curb_1	Curb Presence	Y / N / U	Is curb present: Yes, No, or Unknown	No
	Curb_Height_1	Curb Height (mm)	Number	Height of curb from road	No
	Shoulder_Type_1	Shoulder Type	See "NASS Naming Conventions"	Material used to construct shoulder, as determined by NASS researchers	No
	Shoulder_Wid_1	Shoulder Width (m)	Number	Width from road to edge of defined shoulder	No
	CS_POD_1	Roadside Cross-Section at POD	See "NASS Naming Conventions"	Shape of the slope cross-section near roadside, as determined by NASS researchers	No
	No_Slopes_1	No. of Slopes	Number	Number of slopes measured with slope rates to be used in describing roadside cross-section	No

Table D-4. Road Characteristics (Part III)

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Road Characteristics	Slope_1_1	Slope 1 Start (m)	Number	Lateral location from edge of travel lane to SBP 1	No
	SR_1_1	Slope Rate (%)	Percentage	Slope rate of slope 1	No
	SW_1_1	Width (m)	Number	Total width of slope 1	No
	Slope_2_1	Slope 2 Start (m)	Number	Lateral location from edge of travel lane to SBP 2	No
	SR_2_1	Slope Rate (%)	Percentage	Slope rate of slope 2	No
	SW_2_1	Width (m)	Number	Total width of slope 2	No
	Slope_3_1	Slope 3 Start (m)	Number	Lateral location from edge of travel lane to SBP 3	No
	SR_3_1	Slope Rate (%)	Percentage	Slope rate of slope 3	No
	SW_3_1	Width (m)	Number	Total width of slope 3	No
	Slope_4_1	Slope 4 Start (m)	Number	Lateral location from edge of travel lane to SBP 4	No
	SR_4_1	Slope Rate (%)	Percentage	Slope rate of slope 4	No
	SW_4_1	Width (m)	Number	Total width of slope 4	No
	Slope_5_1	Slope 5 Start (m)	Number	Lateral location from edge of travel lane to SBP 5	No
	SR_5_1	Slope Rate (%)	Percentage	Slope rate of slope 5	No
	SW_5_1	Width (m)	Number	Total width of slope 5	No
	Slope_6_1	Slope 6 Start (m)	Number	Lateral location from edge of travel lane to SBP 6	No
	SR_6_1	Slope Rate (%)	Percentage	Slope rate of slope 6	No
	SW_6_1	Width (m)	Number	Total width of slope 6	No
	Slope_7_1	Slope 7 Start (m)	Number	Lateral location from edge of travel lane to SBP 7	No
	SR_7_1	Slope Rate (%)	Percentage	Slope rate of slope 7	No
	SW_7_1	Width (m)	Number	Total width of slope 7	No
	Slope_8_1	Slope 8 Start (m)	Number	Lateral location from edge of travel lane to SBP 8	No
	SR_8_1	Slope Rate (%)	Percentage	Slope rate of slope 8	No
	SW_8_1	Width (m)	Number	Total width of slope 8	No
	Road_Cond	Road Conditions	Wet / Snow / Slush / Dry / Unk	Roadway conditions at the time of departure	No
	Road_Surf	Road Surface	A / C / D / G / O	Roadway surface:A-asphalt, C-concrete, D-dirt, G-gravel, O-other	No

Table D-5. First Impact (Part I)

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
First Impact	Acc_Time	Time of Accident	NumberNumber: NumberNumber	Use military time (00:00 to 23:59)	No
	Acc_Month	Month	Name	Month in which accident occurred	No
	Acc_Weather	Weather Conditions	CL / SN / HA / SL / RN / UNK	Weather conditions based on accident reports at time of departure: clear, snow, hail, sleet, rain, unk	No
	Impact_No_A	Sequential Impact Number	Number	First impact recorded in impact sequence. If more than four impacts were recorded, this number indicates the first significant impact.	No
	Impact_Speed_A	Impact Speed A (km/h)	Number	Speed at impact for Impact A	No
	Impact_Speed_A_Eng	Impact Speed A (mph)	Number	Speed at impact for Impact A, English units	No
	Barrier_Angle_A	Impact Angle A wrt Barrier (deg)	Number	Vehicle trajectory angle with respect to barrier tangency (if applicable)	No
	Impact_Angle_A	Impact Angle A wrt Road (deg)	Number	Vehicle trajectory angle with respect to tangent line to road at POD	No
	IS_Barr_A	Impact Severity A wrt Barrier (kJ)	Number	Impact severity at impact A wrt barrier, $M/2(V\sin\theta_b)^2$ (if applicable)	No
	IS_Road_A	Impact Severity A wrt Road (kJ)	Number	Impact severity at impact A wrt roadway encroachment, $M/2(V\sin\theta_i)^2$	No
	Impact_Orient_A	Impact Orientation A (deg)	Number	Vehicle orientation angle with respect to road tangent line to road at POD	No
	Obj_Type_A	Object Type	See "NASS Naming Conventions"	Object classification as recorded in NASS file	No
	Obj_Mat_A	Material (if applicable)	See "NASS Naming Conventions"	Construction material for first object struck, as recorded by NASS	No
	Obj_Diam_A	Diameter (cm)	Number	Diameter of object in first coded impact	Yes / No
	Obj_Len_A	Length (cm)	Number	Length of object in first coded impact	Yes / No
	Obj_Wid_A	Width (cm)	Number	Width of object in first coded impact	Yes / No
	Obj_Hgt_A	Height (cm)	Number	Height of object in first coded impact	Yes / No
	Dim_Origin_A	Dimensions Obtained By	Measured/Estimated	Indicator for whether NASS team performed measurements or whether it was estimated from photographs	No
	Obj_Struck_A	Object Impacted	Name	Description of the first object impacted	Yes
	Rollover	Rollover	Y / N	Did a rollover occur at any point in the impact sequence, yes or no?Rollover did not have to occur at coded impact A.	No
	Rollover_Cause	Cause	Description	Brief description of what caused rollover, if applicable	Yes

Table D-6. First Impact (Part II), Lateral Offset from Roadway, and Impact Location from POD

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
First Impact	Photos_A	Photos	Y / N	Were photos taken of each object impacted	No
	Clarity_A	Clarity	Y / N	Measure of accuracy of dimensions, relative to use of measurement devices and number of photos used. Clarity is assumed to be present if the NASS researchers measured the object.	Yes
	Driver_Action_A	Driver Action	See "NASS Naming Conventions"	Evasive manuever performed by the driver prior to or during departure, as recorded by NASS	No
	Impact_Dist_Btwn_A	Impact Distance from POD (m)	Number	Distance from first coded impact to POD no. 1	No
Lateral Offset from Roadway	No_Traj_Pts_A	No. Trajectory Points	6 / 12 / 18	Number of equal increments used to determine the trajectory	No
	D1_A	D1	Number	Lateral distance to CG, trajectory point 1	No
	D2_A	D2	Number	Lateral distance to CG, trajectory point 2	No
	D3_A	D3	Number	Lateral distance to CG, trajectory point 3	No
	D4_A	D4	Number	Lateral distance to CG, trajectory point 4	No
	D5_A	D5	Number	Lateral distance to CG, trajectory point 5	No
	D6_A	D6	Number	Lateral distance to CG, trajectory point 6	No
	D7_A	D7	Number	Lateral distance to CG, trajectory point 7	No
	D8_A	D8	Number	Lateral distance to CG, trajectory point 8	No
	D9_A	D9	Number	Lateral distance to CG, trajectory point 9	No
	D10_A	D10	Number	Lateral distance to CG, trajectory point 10	No
	D11_A	D11	Number	Lateral distance to CG, trajectory point 11	No
	D12_A	D12	Number	Lateral distance to CG, trajectory point 12	No
	D13_A	D13	Number	Lateral distance to CG, trajectory point 13	No
	D14_A	D14	Number	Lateral distance to CG, trajectory point 14	No
	D15_A	D15	Number	Lateral distance to CG, trajectory point 15	No
	D16_A	D16	Number	Lateral distance to CG, trajectory point 16	No
	D17_A	D17	Number	Lateral distance to CG, trajectory point 17	No
	D18_A	D18	Number	Lateral distance to CG, trajectory point 18	No
Impact Location from POD (m)	Long_Impact_Loc_A	Longitudinal (m)	Number	Longitudinal distance from POD no. 1 to impact A	No
	Lat_Impact_Loc_A	Lateral (m)	Number	Lateral distance from POD no. 1 to impact A, measured from roadway tangency	No

Table D-7. Vehicle Damage and Vehicle Separation

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Vehicle Damage	CDC_A	CDC	Number String	CDC deformation classification from impact A	No
	Impact_Plane_A	Region of Impact	Name	Region of vehicle where impact was centralized at impact A:Roof/Top, Right or Left Side, Front, Bumper etc	No
	Damage_Len_A	Length of Damage	Number	Length of damage imparted to vehicle	No
	C1_A	C1 (cm)	Number	Crush depth along first measurement point	No
	C2_A	C2 (cm)	Number	Crush depth along second measurement point	No
	C3_A	C3 (cm)	Number	Crush depth along third measurement point	No
	C4_A	C4 (cm)	Number	Crush depth along fourth measurement point	No
	C5_A	C5 (cm)	Number	Crush depth along fifth measurement point	No
	C6_A	C6 (cm)	Number	Crush depth along sixth measurement point	No
Vehicle Separation	Sep_Long_Loc_A	Longitudinal Location (m)	Number	Longitudinal location where vehicle separated from object impacted in impact A	No
	Sep_Lat_Loc_A	Lateral Location (m)	Number	Lateral location where vehicle separated from object impacted in impact A	No
	Sep_Angle_A	Angle (deg)	Number	Angle between vehicle CG trajectory and a tangent line to the roadway at point of departure in impact A	No
	Sep_Veh_Head_Angle_A	Heading (deg)	Number	Direction of vehicle heading when vehicle separated from impact A wrt a tangent line to the roadway at the point of departure	No

Table D-8. Opposite Side Departure

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Opposite Side Departure (if Applicable)	Land_Use_2	Land Use	See "NASS Naming Conventions"	Regional area in which road is located, as determined by the NASS researchers, for second departure (if applicable)	No
	Road_Class_2	Class Trafficway	See "NASS Naming Conventions"	Roadway classification for second departure, as determined by NASS team (if applicable)	No
	Access_Cntl_2	Access Control	See "NASS Naming Conventions"	Type of access control on the roadway at departure 2, as determined by NASS team	No
	Ave_LW_2	Average Lane Width	Number	Average lane width , second departure (if applicable)	No
	Road_Align_2	Alignment at POD	See "NASS Naming Conventions"	Roadway alignment, straight or curved, second departure (if applicable)	No
	ROC_POD_2	Radius of Curvature	Number	Radius of roadway curvature at POD No. 2	No
	ROC_LOC_2	Length of Chord at	Number	Length of choord of roadway curve at POD No. 2	No
	ROC_MO_2	Middle Ordinate at POD (mm)	Number	Length of middle ordinate of roadway curve at POD No. 2	No
	ROC_Max_2	ROC at Point of Max Curvature (m)	Number	Radius of roadway curvature at point of max curvature within 100 m of POD	No
	ROC_LOC_Max_2	Length of Chord at Max Curvature (m)	Number	Length of choord of roadway curve at point of max curvature within 100 m of POD	No
	ROC_MO_Max_2	Middle Ordinate at Max Curvature (mm)	Number	Length of middle ordinate of roadway curve at point of max curvature within 100 m of POD	No
	Road_Profile_2	Departure Side	L / R	Side of the road that the vehicle departed, left or right	No
	Grade_POD_2	Vertical Grade at POD (%)	Percentage	Percent grade at POD No. 1, second departure (if applicable)	No
	Grade_Max_2	Max Grade (%)	Percentage	Maximum grade near POD No. 1, second departure (if applicable)	No
	Curb_2	Curb Presence	Y / N / U	Yes, No, or Unknown, second departure (if applicable)	No
	Curb_Hgt_2	Curb Height (mm)	Number	Height of curb from road , second departure (if applicable)	No
	Shoulder_Type_2	Shoulder Type	See "NASS Naming Conventions"	Shoulder material, second departure (if applicable)	No
	Shoulder_Wid_2	Shoulder Width (m)	Number	Width from road to edge of defined shoulder, second departure (if applicable)	No
	CS_POD_2	Roadside Cross-Section at POD	See "NASS Naming Conventions"	Shape of the slope cross-section near roadside, second departure (if applicable)	No
	No_Slopes_2	No. of Slopes	Number	Number of slope rates described for roadside cross-section, second departure (if applicable)	No

Table D-9. Second Impact

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Second Impact	Impact_No_B	Sequential Impact Number	Number	Second impact recorded in impact sequence. If more than four impacts were recorded, this number indicates	No
	Impact_Speed_B	Impact Speed B	Number	Speed At impact for Impact B	No
	Impact_Speed_B_En	Impact Speed B	Number	Speed At impact for Impact B, English units	No
	Barrier_Angle_B	Impact Angle B wrt	Number	Vehicle trajectory angle with respect to barrier tangency	No
	Impact_Angle_B	Impact Angle B wrt	Number	Vehicle trajectory angle with respect to tangent line to	No
	IS_Barr_B	Impact Severity B	Number	Impact severity at impact B wrt barrier, $M/2(V\sin\theta_b)^2$ (if	No
	IS_Road_B	Impact Severity B	Number	Impact severity at impact B wrt roadway encroachment,	No
	Impact_Orient_B	Impact Orientation B (deg)	Number	Vehicle orientation angle with respect to tangent line to road at POD	No
	Obj_Diam_B	Diameter (cm)	Number	Diameter of object in second coded impact	Yes / No
	Obj_Len_B	Length (cm)	Number	Length of object in second coded impact	Yes / No
	Obj_Wid_B	Width (cm)	Number	Width of object in second coded impact	Yes / No
	Obj_Hgt_B	Height (cm)	Number	Height of object in second coded impact	Yes / No
	Obj_Struck_B	Object Impacted	Description	Description of object struck in impact B	No
	Photos_B	Photos	Y / N	Were photos taken of each object impacted	No
	Clarity_B	Clarity of Dimensions	Y / N	Measure of accuracy of dimensions, relative to use of measurement devices and number of photos used. Clarity is assumed to be present if the NASS researchers measured the object.	No
	Driver_Action_B	Driver Action	See "NASS Naming Conventions"	Evasive manuever performed by the driver prior to or during impact B, as recorded by NASS	No
	Impact_Dist_Btwn_B	Distance Traveled Between Impacts (m)	Number	Distance from impact B to POD no. 1	No

Table D-10. Lateral Offset from Roadway, Impact Location from POD, and Vehicle Damage

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Lateral Offset from Roadway	No_Traj_Pts_B	No. Trajectory Points	6 / 12 / 18	Number of equal increments used to determine the trajectory	No
	D1_B	D1	Number	Lateral distance to CG, trajectory point 1, between impacts A and B	No
	D2_B	D2	Number	Lateral distance to CG, trajectory point 2, between impacts A and B	No
	D3_B	D3	Number	Lateral distance to CG, trajectory point 3, between impacts A and B	No
	D4_B	D4	Number	Lateral distance to CG, trajectory point 4, between impacts A and B	No
	D5_B	D5	Number	Lateral distance to CG, trajectory point 5, between impacts A and B	No
	D6_B	D6	Number	Lateral distance to CG, trajectory point 6, between impacts A and B	No
	D7_B	D7	Number	Lateral distance to CG, trajectory point 7, between impacts A and B	No
	D8_B	D8	Number	Lateral distance to CG, trajectory point 8, between impacts A and B	No
	D9_B	D9	Number	Lateral distance to CG, trajectory point 9, between impacts A and B	No
	D10_B	D10	Number	Lateral distance to CG, trajectory point 10, between impacts A and B	No
	D11_B	D11	Number	Lateral distance to CG, trajectory point 11, between impacts A and B	No
	D12_B	D12	Number	Lateral distance to CG, trajectory point 12, between impacts A and B	No
	D13_B	D13	Number	Lateral distance to CG, trajectory point 13, between impacts A and B	No
	D14_B	D14	Number	Lateral distance to CG, trajectory point 14, between impacts A and B	No
	D15_B	D15	Number	Lateral distance to CG, trajectory point 15, between impacts A and B	No
	D16_B	D16	Number	Lateral distance to CG, trajectory point 16, between impacts A and B	No
	D17_B	D17	Number	Lateral distance to CG, trajectory point 17, between impacts A and B	No
	D18_B	D18	Number	Lateral distance to CG, trajectory point 18, between impacts A and B	No
Impact Location from POD (m)	Long_Impact_Loc_B	Longitudinal Location (m)	Number	Longitudinal distance from POD no. 1 to impact B	No
	Lat_Impact_Loc_B	Lateral Location (m)	Number	Lateral distance from POD no. 1 to impact B, measured from roadway tangency	No
Vehicle Damage	CDC_B	CDC	Number String	CDC deformation classification, impact B	No
	Impact_Plane_B	Region of Impact	Name	Region of vehicle where impact was centralized:Roof/Top, Right or Left Side, Front, Bumper etc, impact B	No
	Damage_Len_B	Length of Damage (cm)	Number	Length of damage imparted to vehicle, impact B	No
	C1_B	C1 (cm)	Number	Crush depth along first measurement point, impact B	No
	C2_B	C2 (cm)	Number	Crush depth along second measurement point, impact B	No
	C3_B	C3 (cm)	Number	Crush depth along third measurement point, impact B	No
	C4_B	C4 (cm)	Number	Crush depth along fourth measurement point, impact B	No
	C5_B	C5 (cm)	Number	Crush depth along fifth measurement point, impact B	No
	C6_B	C6 (cm)	Number	Crush depth along sixth measurement point, impact B	No

Table D-11. Vehicle Separation and Third Impact

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Vehicle Separation	Sep_Long_Loc_B	Longitudinal Location (m)	Number	Longitudinal location where vehicle separated from object impacted in impact B	No
	Sep_Lat_Loc_B	Lateral Location (m)	Number	Lateral location where vehicle separated from object impacted in impact B	No
	Sep_Angle_B	Angle (deg)	Number	Angle between vehicle CG trajectory and a tangent line to the roadway at point of departure in impact B	No
	Sep_ Head_Angle_B	Heading (deg)	Number	Direction of vehicle heading when vehicle separated from impact B wrt a tangent line to the roadway at the point of departure	No
Third Impact	Impact_No_C	Sequential Impact Number	Number	Third impact recorded in impact sequence. If more than four impacts were recorded, this number indicates the third significant impact.	No
	Impact_Speed_C	Impact Speed C (km/h)	Number	Speed At impact for Impact C	No
	Impact_Speed_C_Eng	Impact Speed C (mph)	Number	Speed At impact for Impact C, English units	No
	Barrier_Angle_C	Impact Angle C wrt Barrier (deg)	Number	Vehicle trajectory angle with respect to barrier tangency (if applicable)	No
	Impact_Angle_C	Impact Angle C wrt Road (deg)	Number	Vehicle trajectory angle with respect to tangent line to road at POD	No
	IS_Barr_C	Impact Severity C wrt Barrier (kJ)	Number	Impact severity at impact C wrt barrier, $M/2(V\sin\theta b)2$ (if applicable)	No
	IS_Road_C	Impact Severity C wrt Road (kJ)	Number	Impact severity at impact C wrt roadway encroachment, $M/2(V\sin\theta i)2$	No
	Impact_Orient_C	Impact Orientation C (deg)	Number	Vehicle orientation angle with respect to tangent line to road at POD	No
	Obj_Diam_C	Diameter (cm)	Number	Diameter of object in third coded impact	Yes / No
	Obj_Len_C	Length (cm)	Number	Length of object in third coded impact	Yes / No
	Obj_Wid_C	Width (cm)	Number	Width of object in third coded impact	Yes / No
	Obj_Hgt_C	Height (cm)	Number	Height of object in third coded impact	Yes / No
	Obj_Struck_C	Object Impacted	Description	Description of object struck in impact C	Yes / No
	Photos_C	Photos	Y / N	Were photos taken of each object impacted	No
	Clarity_C	Photo Clarity	Y / N	Measure of accuracy of dimensions, based on number of photos and obtained measurements. Clarity is assumed to be present if the NASS researchers measured the object.	No
	Driver_Action_C	Driver Action	See "NASS Naming Conventions"	Evasive manuever performed by the driver prior to or during impact C, as recorded by NASS	No
	Impact_Dist_Btwn_C	Distance Traveled Between Impacts (m)	Number	Distance from impact C to POD no. 1	No

Table D-12. Lateral Offset from Roadway, Impact Location from POD, and Vehicle Damage

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Lateral Offset from Roadway	No_Traj_Pts_C	No. Trajectory Points	6 / 12 / 18	Number of equal increments used to determine the trajectory	No
	D1_C	D1	Number	Lateral distance to CG, trajectory point 1, between impacts B and C	No
	D2_C	D2	Number	Lateral distance to CG, trajectory point 2, between impacts B and C	No
	D3_C	D3	Number	Lateral distance to CG, trajectory point 3, between impacts B and C	No
	D4_C	D4	Number	Lateral distance to CG, trajectory point 4, between impacts B and C	No
	D5_C	D5	Number	Lateral distance to CG, trajectory point 5, between impacts B and C	No
	D6_C	D6	Number	Lateral distance to CG, trajectory point 6, between impacts B and C	No
	D7_C	D7	Number	Lateral distance to CG, trajectory point 7, between impacts B and C	No
	D8_C	D8	Number	Lateral distance to CG, trajectory point 8, between impacts B and C	No
	D9_C	D9	Number	Lateral distance to CG, trajectory point 9, between impacts B and C	No
	D10_C	D10	Number	Lateral distance to CG, trajectory point 10, between impacts B and C	No
	D11_C	D11	Number	Lateral distance to CG, trajectory point 11, between impacts B and C	No
	D12_C	D12	Number	Lateral distance to CG, trajectory point 12, between impacts B and C	No
	D13_C	D13	Number	Lateral distance to CG, trajectory point 13, between impacts B and C	No
	D14_C	D14	Number	Lateral distance to CG, trajectory point 14, between impacts B and C	No
	D15_C	D15	Number	Lateral distance to CG, trajectory point 15, between impacts B and C	No
	D16_C	D16	Number	Lateral distance to CG, trajectory point 16, between impacts B and C	No
	D17_C	D17	Number	Lateral distance to CG, trajectory point 17, between impacts B and C	No
	D18_C	D18	Number	Lateral distance to CG, trajectory point 18, between impacts B and C	No
Impact Location from POD (m)	Long_Impact_Loc_C	Longitudinal Location (m)	Number	Longitudinal distance from POD no. 1 to impact C	No
	Lat_Impact_Loc_C	Lateral Location (m)	Number	Lateral distance from POD no. 1 to impact C, measured from roadway tangency	No
Vehicle Damage	CDC_C	CDC	Number String	CDC deformation classification, impact C	No
	Impact_Plane_C	Region of Impact	Name	Region of vehicle where impact was centralized in impact C:Roof/Top, Right or Left Side, Front, Bumper etc	No
	Damage_Len_C	Length of Damage (cm)	Number	Length of damage imparted to vehicle	No
	C1_C	C1 (cm)	Number	Crush depth along first measurement point	No
	C2_C	C2 (cm)	Number	Crush depth along second measurement point	No
	C3_C	C3 (cm)	Number	Crush depth along third measurement point	No
	C4_C	C4 (cm)	Number	Crush depth along fourth measurement point	No
	C5_C	C5 (cm)	Number	Crush depth along fifth measurement point	No
	C6_C	C6 (cm)	Number	Crush depth along sixth measurement point	No

Table D-13.Vehicle Separation and Fourth Impact

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Vehicle Separation	Sep_Long_Loc_C	Longitudinal Location (m)	Number	Longitudinal location where vehicle separated from object impacted in impact C	No
	Sep_Lat_Loc_C	Lateral Location (m)	Number	Lateral location where vehicle separated from object impacted in impact C	No
	Sep_Angle_C	Angle (deg)	Number	Angle between vehicle CG trajectory and a tangent line to the roadway at point of departure in impact C	No
	Sep_Head_Angle_C	Heading (deg)	Number	Direction of vehicle heading when vehicle separated from impact C wrt a tangent line to the roadway at the point of departure	No
Fourth Impact	Impact_No_D	Sequential Impact Number	Number	Fourth impact recorded in impact sequence. If more than four impacts were recorded, this number indicates the fourth significant impact.	No
	Impact_Speed_D	Impact Speed D (km/h)	Number	Speed At impact for Impact D	No
	Impact_Speed_D_Eng	Impact Speed D (mph)	Number	Speed At impact for Impact D, English units	No
	Barrier_Angle_D	Impact Angle D wrt Barrier (deg)	Number	Vehicle trajectory angle with respect to barrier tangency (if applicable)	No
	Impact_Angle_D	Impact Angle D wrt Road (deg)	Number	Vehicle trajectory angle with respect to tangent line to road at POD	No
	IS_Barr_D	Impact Severity D wrt Barrier (kJ)	Number	Impact severity at impact D wrt barrier, M/2(Vsinθb)2 (if applicable)	No
	IS_Road_D	Impact Severity D wrt Road (kJ)	Number	Impact severity at impact D wrt roadway encroachment, M/2(Vsinθi)2	No
	Impact_Orient_D	Impact Orientation D (deg)	Number	Vehicle orientation angle with respect to tangent line to road at POD	No
	Obj_Diam_D	Diameter (cm)	Number	Diameter of object in fourth coded impact	Yes / No
	Obj_Len_D	Length (cm)	Number	Length of object in fourth coded impact	Yes / No
	Obj_Wid_D	Width (cm)	Number	Width of object in fourth coded impact	Yes / No
	Obj_Hgt_D	Height (cm)	Number	Height of object in fourth coded impact	Yes / No
	Obj_Struck_D	Object Impacted	Description	Description of object struck in impact D	No
	Photos_D	Photos	Y / N	Were photos taken of each object impacted	No
	Clarity_D	Photo Clarity	Y / N	Measure of accuracy of dimensions, based on number of photos and obtained measurements. Clarity is assumed to be present if the NASS researchers measured the object.	No
	Driver_Action_D	Driver Action	See "NASS Naming Conventions"	Evasive manuever performed by the driver prior to or during impact D, as recorded by NASS	No
	Impact_Dist_Btwn_D	Distance Traveled	Number	Distance from impact C to POD no. 1	No

Table D-14. Lateral Offset from Roadway, Impact Location from POD, Vehicle Damage, and Vehicle Separation

Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Lateral Offset from Roadway	No_Traj_Pts_D	No. Trajectory Points	6 / 12 / 18	Number of equal increments used to determine the trajectory	No
	D1_D	D1	Number	Lateral distance to CG, trajectory point 1, between impacts C and D	No
	D2_D	D2	Number	Lateral distance to CG, trajectory point 2, between impacts C and D	No
	D3_D	D3	Number	Lateral distance to CG, trajectory point 3, between impacts C and D	No
	D4_D	D4	Number	Lateral distance to CG, trajectory point 4, between impacts C and D	No
	D5_D	D5	Number	Lateral distance to CG, trajectory point 5, between impacts C and D	No
	D6_D	D6	Number	Lateral distance to CG, trajectory point 6, between impacts C and D	No
Impact Location from POD (m)	Long_Impact_Loc_D	Longitudinal Location (m)	Number	Longitudinal distance from POD no. 1 to impact D	No
	Lat_Impact_Loc_D	Lateral Location (m)	Number	Lateral distance from POD no. 1 to impact D, measured from roadway tangency	No
Vehicle Damage	CDC_D	CDC	Number String	CDC deformation classification for impact D	No
	Impact_Plane_D	Region of Impact	Name	Region of vehicle where impact was centralized:Roof/Top, Right or Left Side, Front, Bumper etc	No
	Damage_Len_D	Length of Damage (cm)	Number	Length of damage imparted to vehicle from impact D	No
	C1_D	C1 (cm)	Number	Crush depth along first measurement point	No
	C2_D	C2 (cm)	Number	Crush depth along second measurement point	No
	C3_D	C3 (cm)	Number	Crush depth along third measurement point	No
	C4_D	C4 (cm)	Number	Crush depth along fourth measurement point	No
	C5_D	C5 (cm)	Number	Crush depth along fifth measurement point	No
	C6_D	C6 (cm)	Number	Crush depth along sixth measurement point	No
Vehicle Separation	Sep_Long_Loc_D	Longitudinal Location (m)	Number	Longitudinal location where vehicle separated from object impacted in impact D	No
	Sep_Lat_Loc_D	Lateral Location (m)	Number	Lateral location where vehicle separated from object impacted in impact D	No
	Sep_Angle_D	Angle (deg)	Number	Angle between vehicle CG trajectory and a tangent line to the roadway at point of departure in impact D	No
	Sep_Head_Angle_D	Heading (deg)	Number	Direction of vehicle heading when vehicle separated from impact D wrt a tangent line to the roadway at the point of departure	No

Table D-15. Occupants, Number of Injuries, Final Position from POD, Length of First Departure, and Length of Second Departure

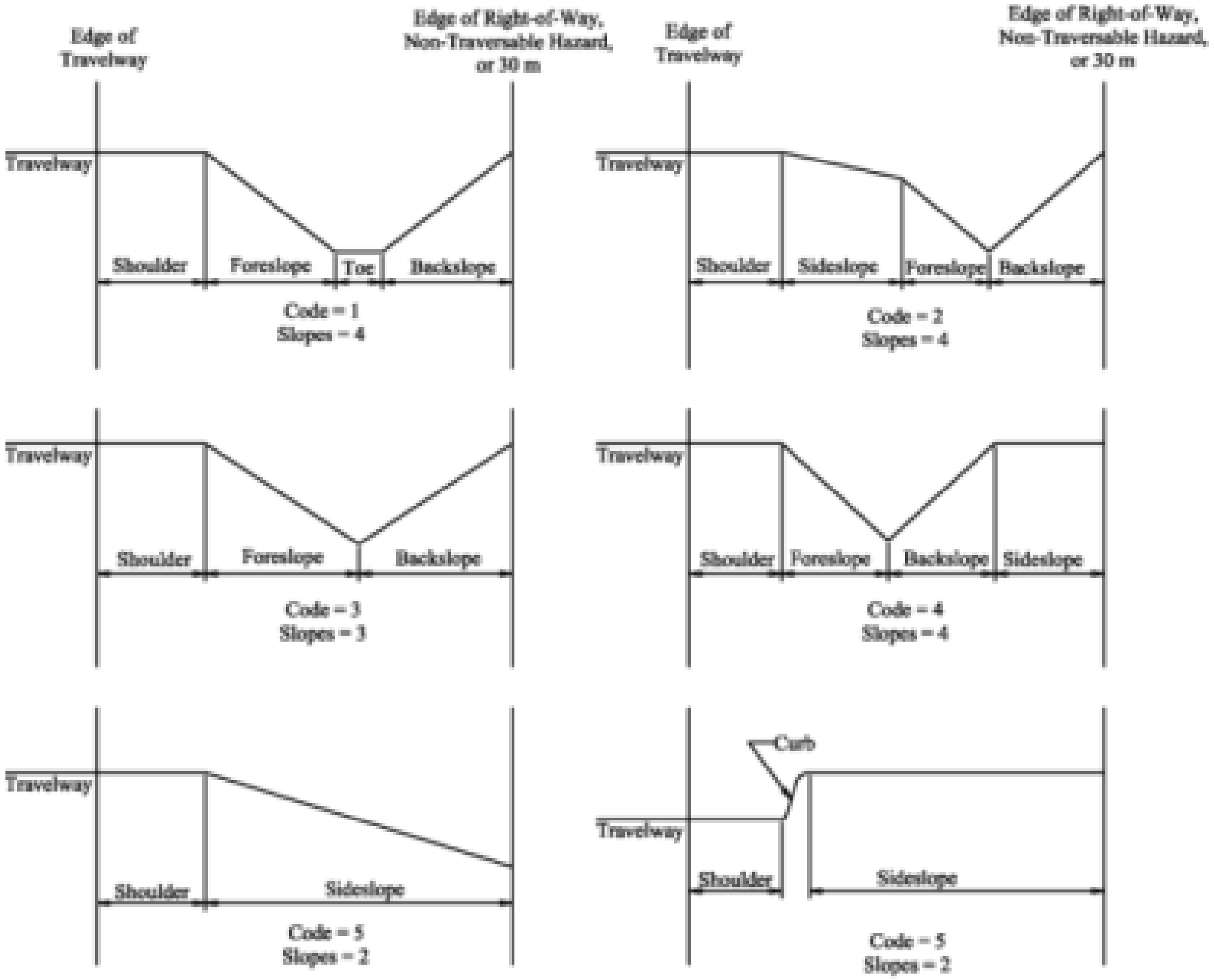
Group Title	Cell Title	Description	Data Type	NOTES	Based on Photographic Evidence?
Occupants	Alcohol	Alcohol Presence	Y / N	Was alcohol a factor in the crash?	No
	BAC	BAC	Number	Blood Alcohol Content, if applicable (driver)	No
	Substances	Other Substances	Y / N	Any additional controlled substances used	No
	Distractions	Distractions	Description	Driver distractions causing inattention to the road	No
	No_Occupants	No. Occupants	Number	Number of occupants in the vehicle	No
	Fatality	Fatality	Y / N	Did a fatality occur in the crash?	No
	Belted_Driver	Belted Driver	Y / N	Was the driver belted?	No
	No_Belted_Pass	No. Belted Passengers	Number	Number of occupants wearing safety belts	No
	Eject	Ejection	Y / N	Were any occupants ejected from the vehicle?	No
Number of Injuries	Inj_Fatality	Number of Fatalieis	Number	Number of fatalities in crash	No
	Inj_A	Number of Incapacitating Injuries	Number	Number of occupants with incapacitating injuries	No
	Inj_B	Number of Non-Incapacitating Injuries	Number	Number of occupants with non-incapacitating injuires	No
	Inj_C	Number of Possible Injured	Number	Number of occupants with possible injuries	No
	Inj_Uninjured	Number Uninjured	Number	Number of occupants uninjured	No
	Inj_Unknown	Number Unknown	Number	Number of occupants with unknown injuires	No
	Inj_PDO	Number PDO	Number	Binary; indicates whether or not it was a property-damage-only crash	No
Final Position from POD	FP_Long	Longitudinal (m)	Number	Final resting place longitudinally from POD 1	No
	FP_Lat	Lateral (m)	Number	Final resting place laterally from POD 1	No
	FP_Heading_Angle	Heading Angle (deg)	Number	Final rest heading angle between vehicle and roadway tangency from POD 2 (1 if only one POD)	No
Length of First Departure	LOD_Lr1	Longitudinal (m)	Number	Maximum longitudinal offset from POD 1	No
	LOD_Ll1	Lateral (m)	Number	Maximum lateral offset from POD 1	No
Length of Second Departure	LOD_Lr2	Longitudinal (m)	Number	Maximum longitudinal offset from POD 2 (if applicable)	No
	LOD_Ll2	Lateral (m)	Number	Maximum lateral offset from POD 2 (if applicable)	No

Table D-16. NASS Naming Conventions (Part I)

Variable Title	Coded Parameter	NASS Researcher Description
Vehicle Class:	C	Compact
	S	Subcompact
	I	Intermediate
	D	Sedan
	F	Full-Size Sedan
	L	Largest Size
	CP	Compact Pickup
	LP	Large Pikup
	OP	Other Pickup Type
	UP	Unknown Pickup Type
	CU	Compact Utility
	SU	Stationwagon Utility
	LU	Large Utility
	MV	Minivan
	FV	Full-Size Van
	LV	Large Van
Land Use:	1	Urban
	2	Rural
	9	Unknown
Class Trafficway:	1	Interstate
	2	US Route
	3	State Route
	4	County Road
	5	City Street
	8	Other (specify)
Access Control:	1	Full
	2	Partial
	3	Uncontrolled
Roadway Alignment:	1	Straight
	2	Curve Right
	3	Curve Left
Roadway Profile:	0	Level
	1	Upgrade
	2	Downgrade
	3	Crest
	4	Sag
Curb Presence:	0	No Curb
	1	Barrier Curb
	2	Mountable Curb
Shoulder Type:	0	No shoulder
	1	Paved Shoulder
	2	Gravel/Dirt Shoulder
	3	Grassy Shoulder
	4	Paved and Gravel/Dirt Shoulders side by side (Shoulder width is combined width of both)

Table D-17. NASS Naming Conventions (Part II)

Variable Title	Coded Parameter	NASS Researcher Description
Roadside Cross-Section (see diagram):	1	V-ditch with flat transition between foreslope and backslope
	2	V-ditch with two foreslopes
	3	V-ditch with single foreslope and backslope
	4	V-ditch with two backslopes
	5	Single foreslope
	6	Curb and sidewalk
	8	Other



TYPICAL ROADSIDE CROSS SECTIONS

Table D-18. NASS Naming Conventions (Part III)

Variable Title	Coded Parameter	NASS Researcher Description
Object Type:	1	Rigid Object
	2	Barrier
	3	Utility Pole
	4	Light Support
	5	Sign Support
	6	Crash Cushion
	7	Other
	9	Unknown or N/A
Material	1	Concrete
	2	Steel
	3	Wood
	4	Combination
	7	Other
	9	Unknown or N/A
Driver Action:	1	None
	2	Braking Only
	3	Steering Only
	4	Braking and Steering
	9	Unknown
Ejections	Y	There were ejections
	N	No ejections
	P	Partial Ejections
	P/Y	Partial and Full ejections

APPENDIX E

Additional Tables, Plots, and Analysis Results

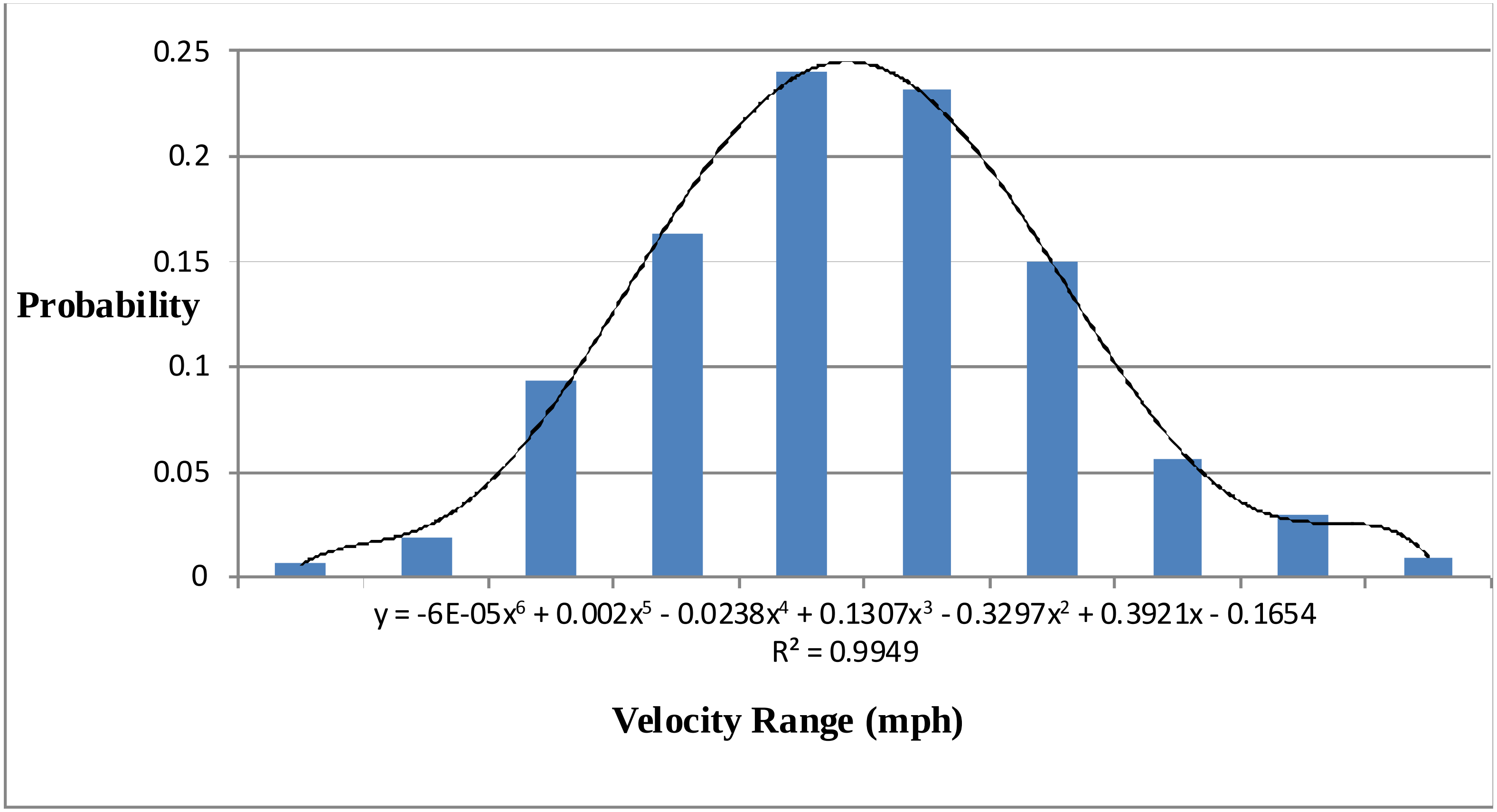


Figure E-1. Departure Velocity for All Data

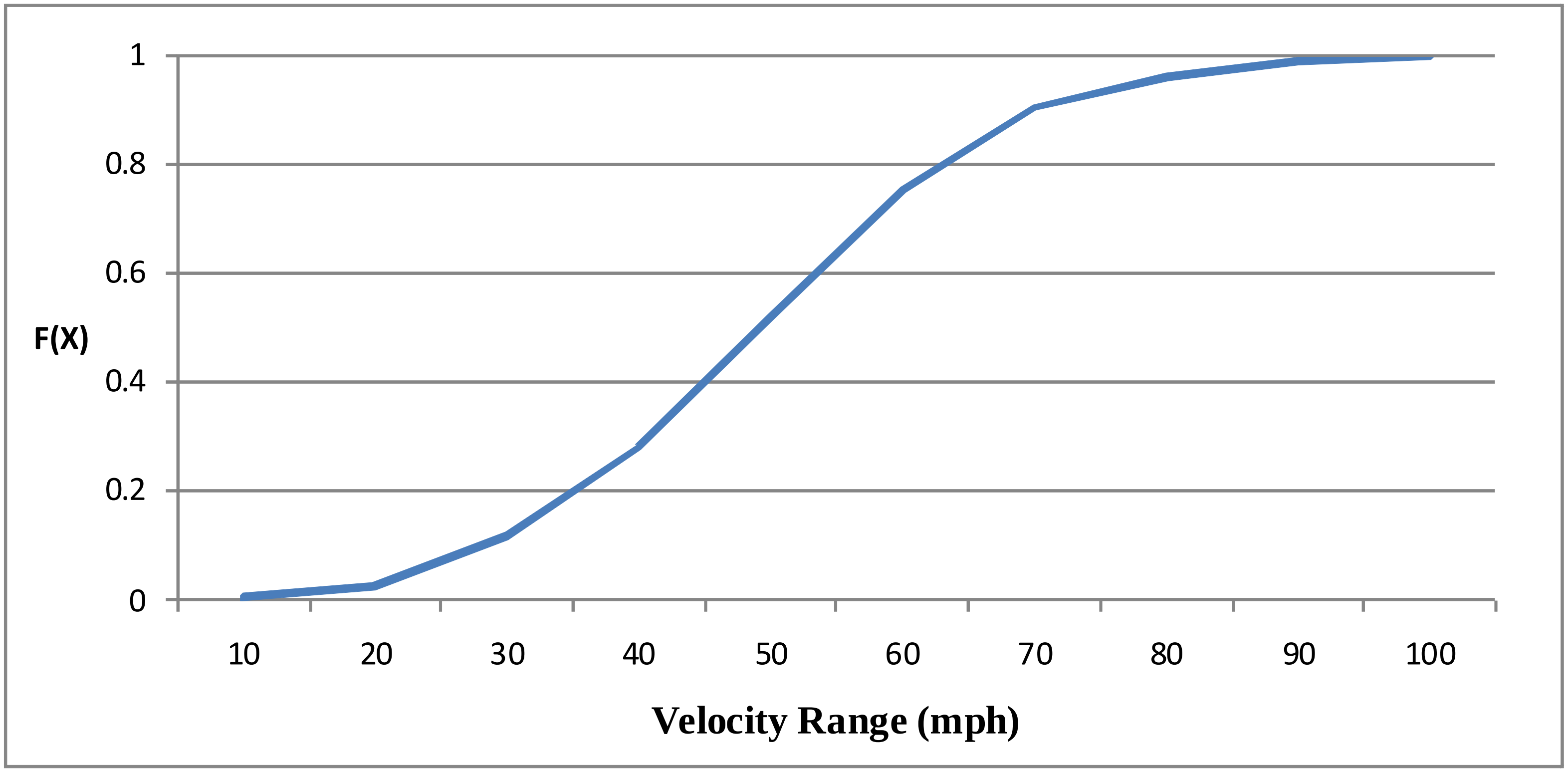


Figure E-2. Departure Velocity Cumulative Distribution for All Data

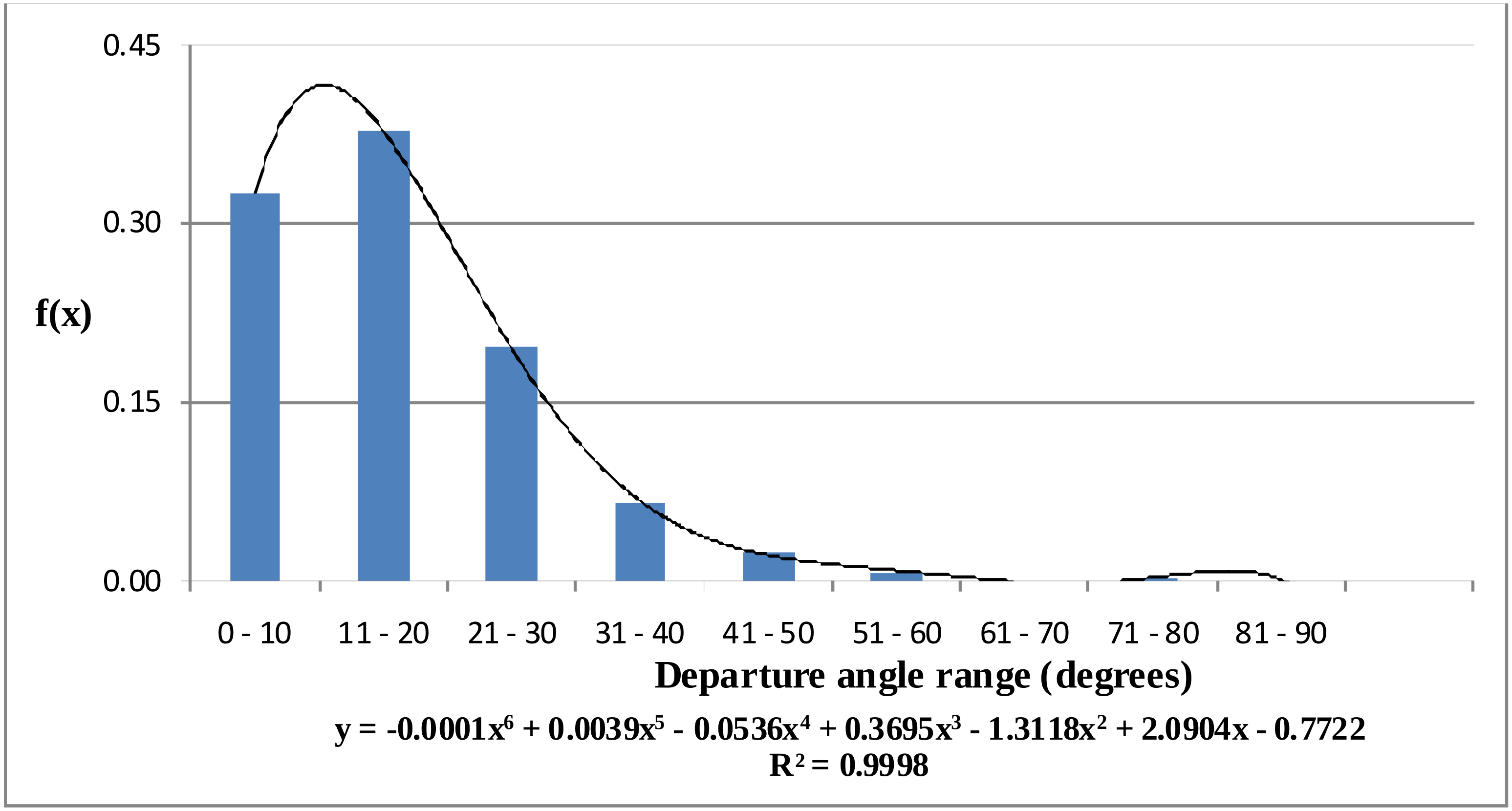


Figure E-3. Departure Angle Probability Distribution for All Data

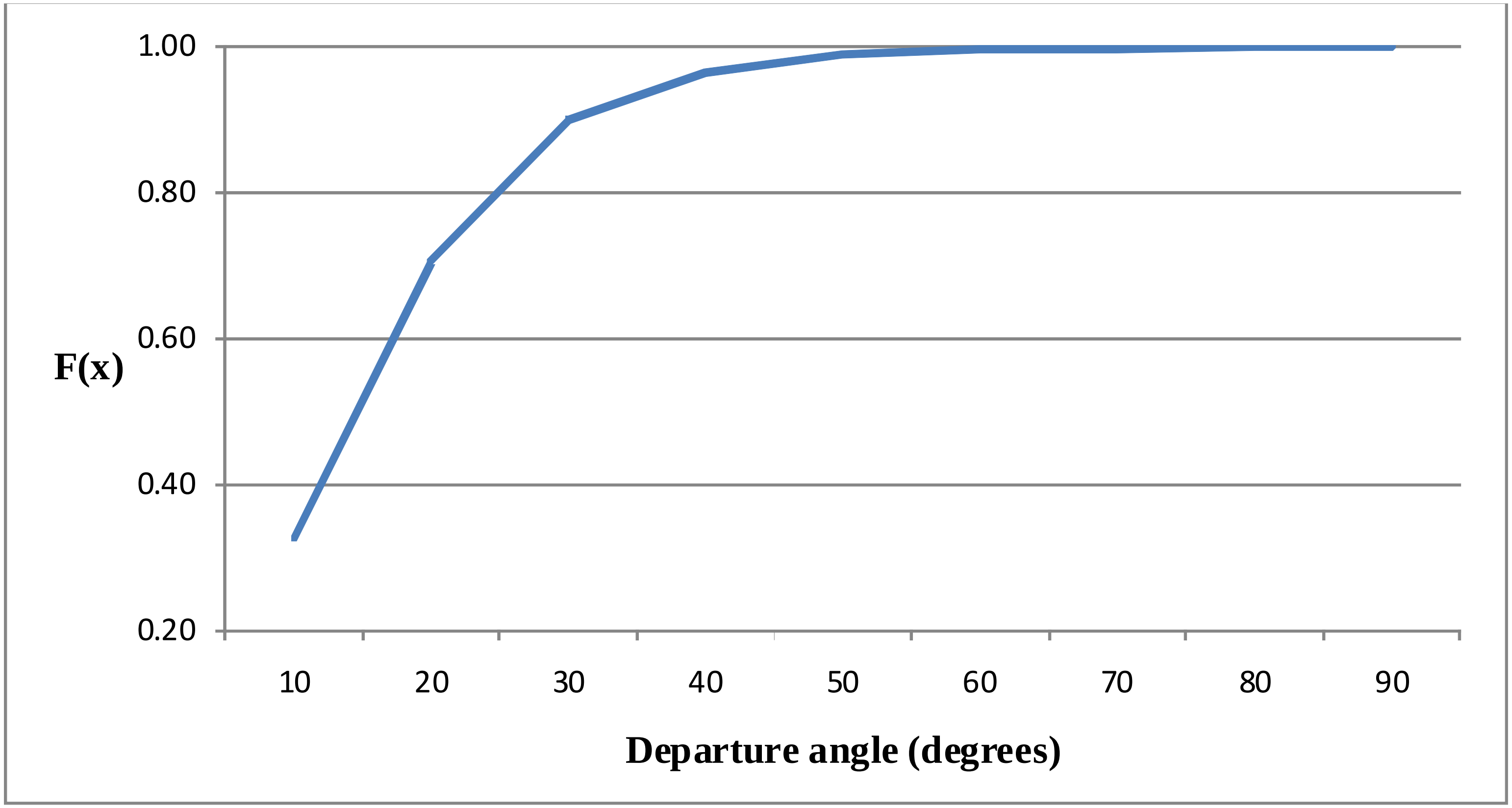


Figure E-4. Departure angle cumulative distribution for all data

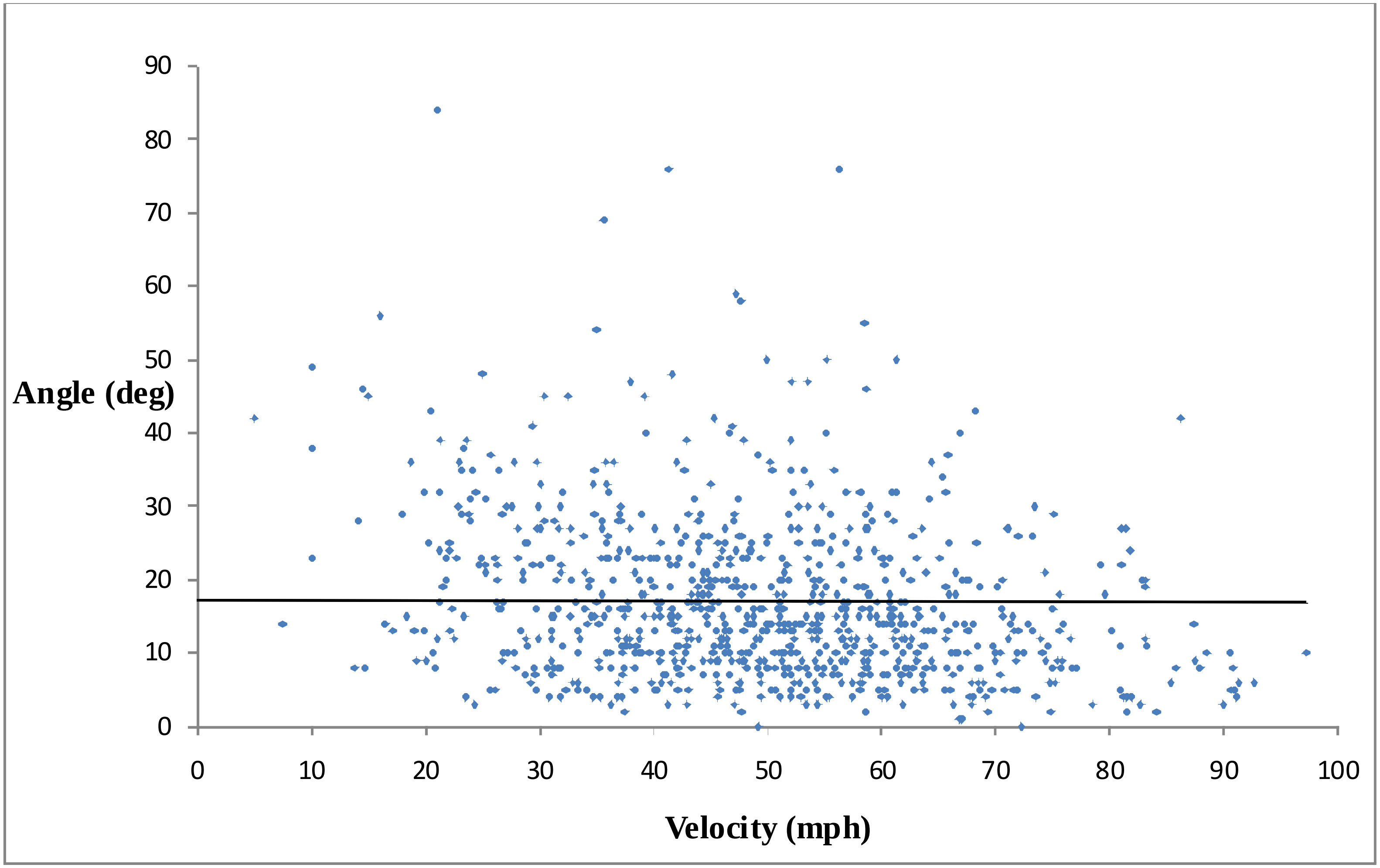


Figure E-5. Scatter plot of the departure velocity (x axis) and departure angle (y axis)

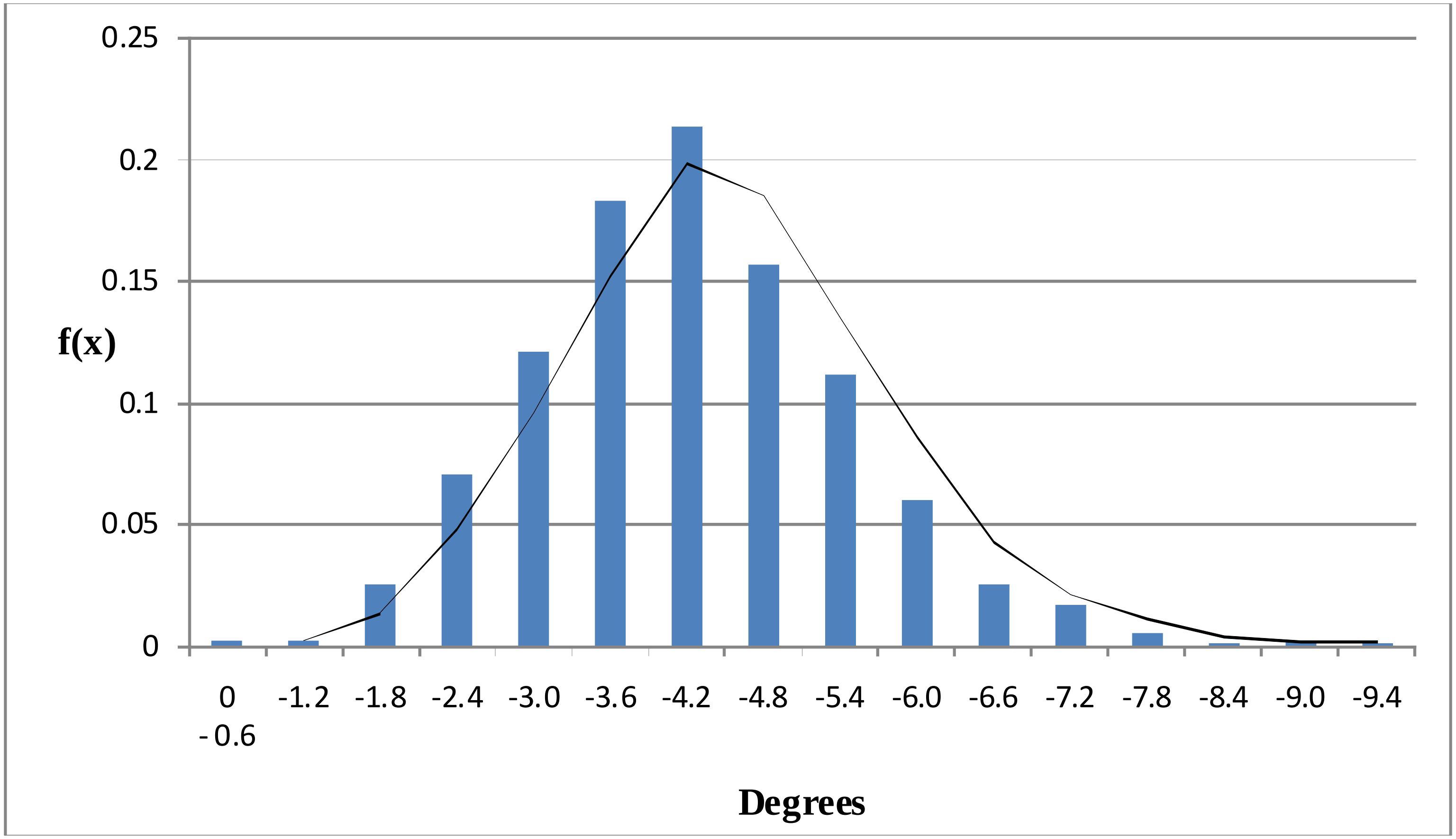


Figure E-6. Distribution of square root of angle

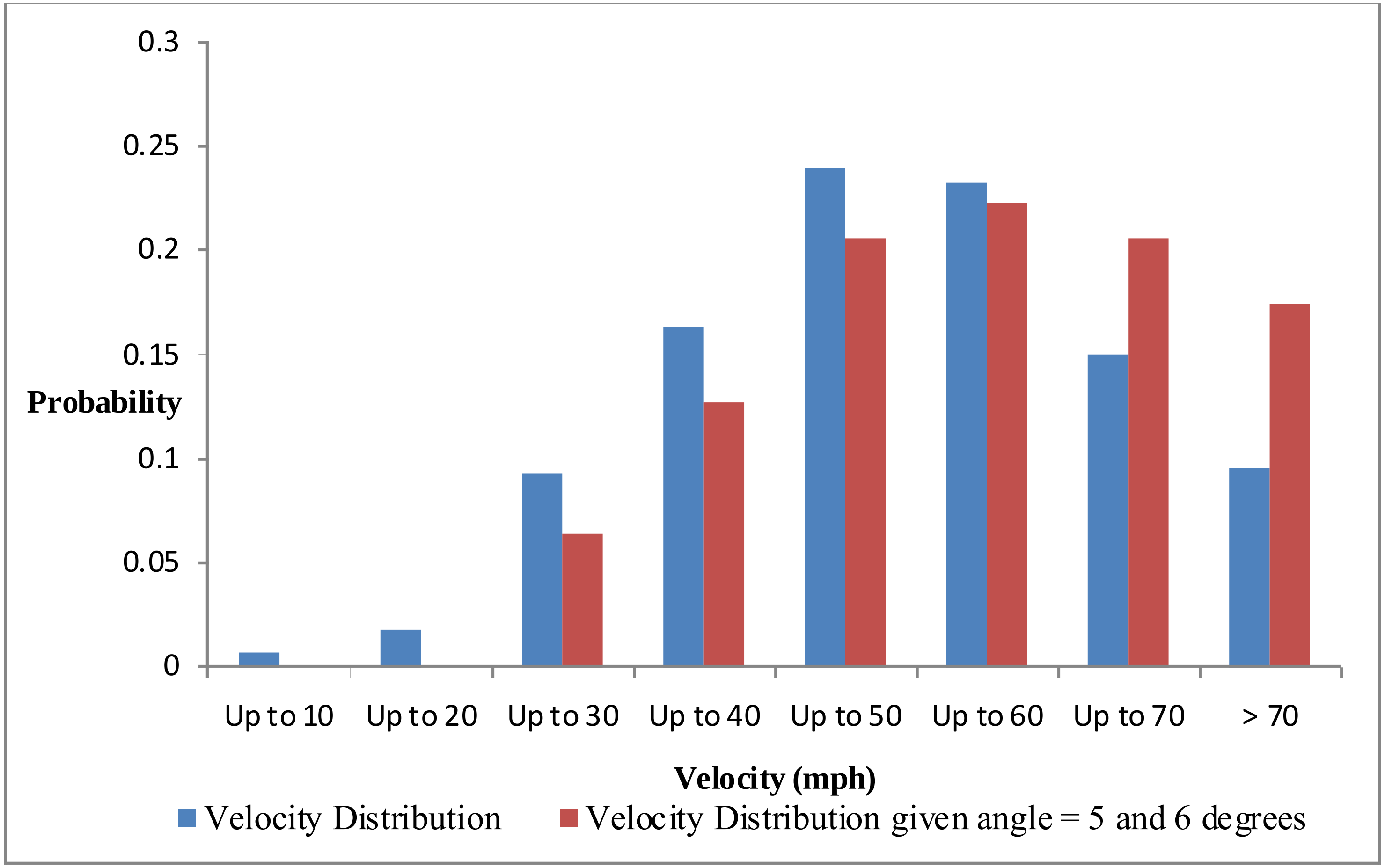


Figure E-7. Conditional probability from Bivariate Normal Distribution (5-6 degrees)

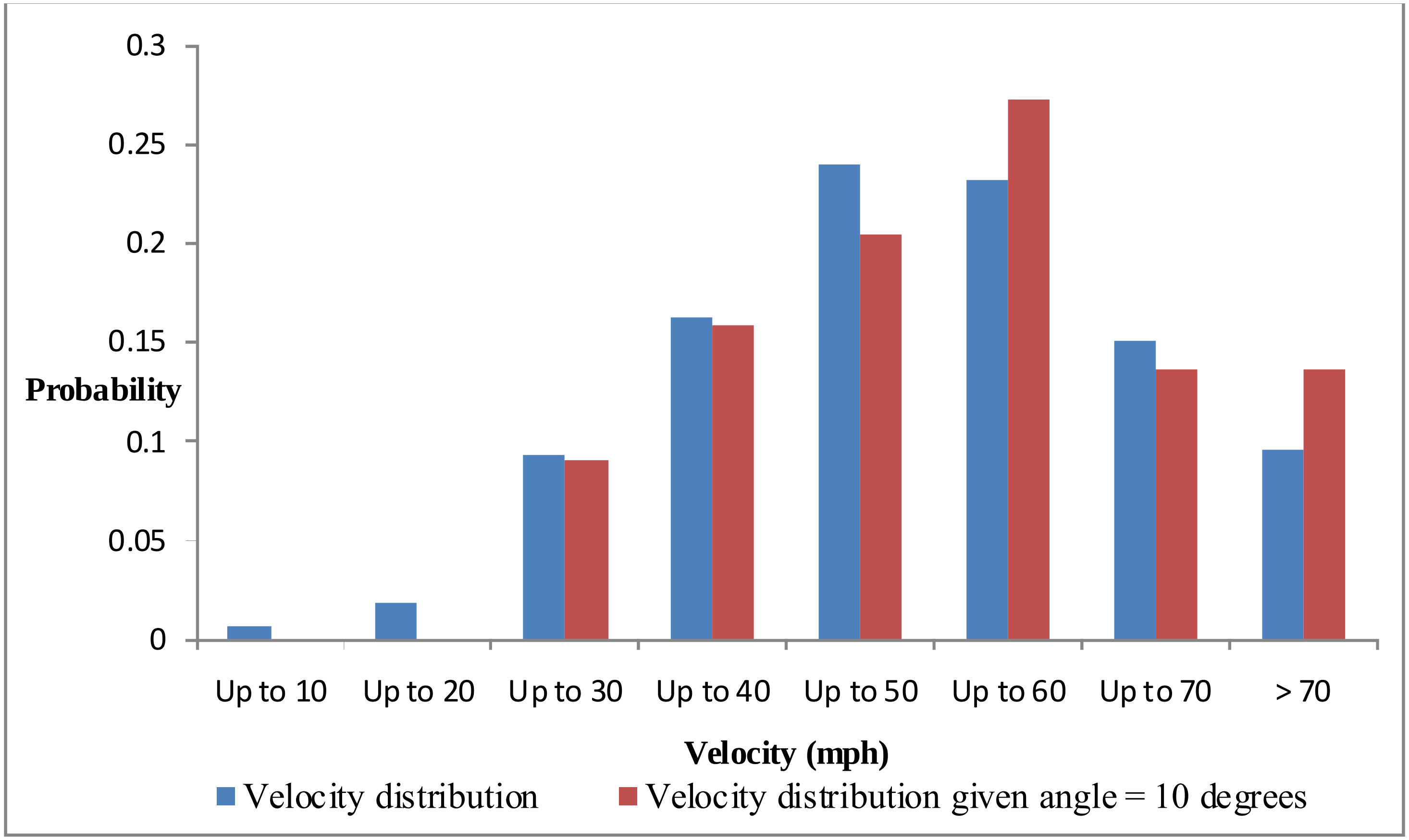


Figure E-8. Conditional probability from Bivariate Normal Distribution (10 degrees)

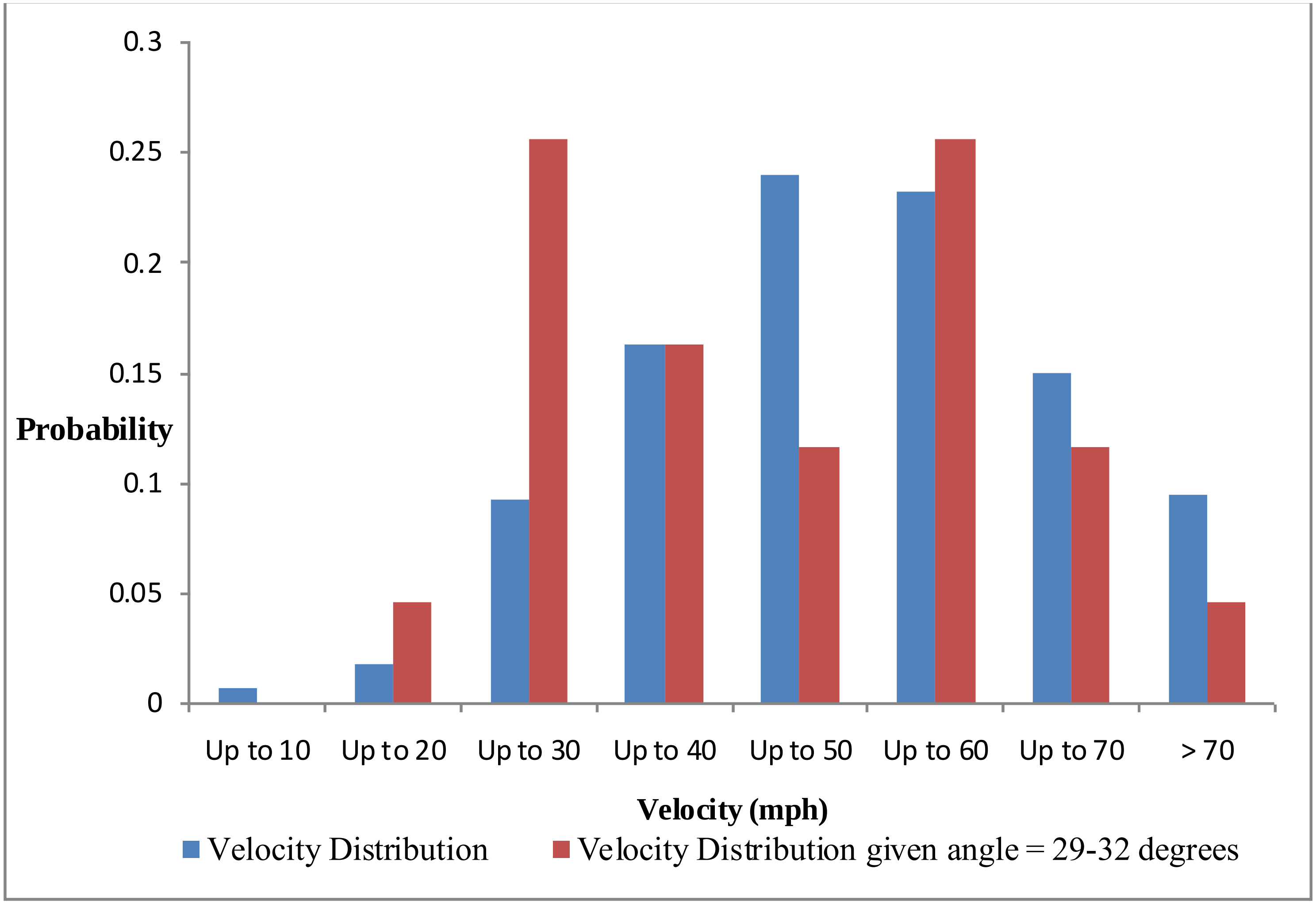


Figure E-9. Conditional probability from Bivariate Normal Distribution (29-32 degrees)

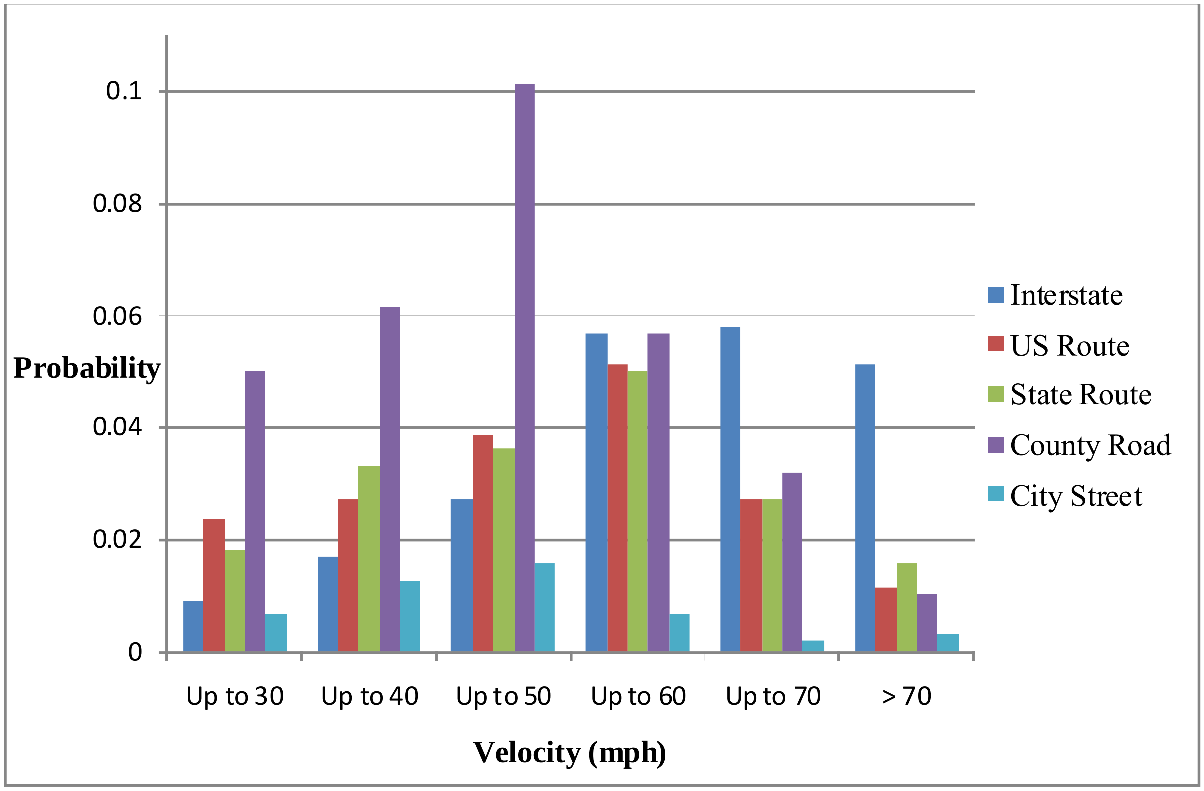


Figure E-10. Graphical Representation of Data from Table E-1

Observed Percentages								
Velocity/Highway Class	Interstate	US Route	State Route	County Road	City Street	Other	Unknown	Total
< 30	0.00912	0.02395	0.01824	0.05017	0.00684	0.00342	0.00570	0.11745
30.1-40.0	0.01710	0.02737	0.03307	0.06157	0.01254	0.00114	0.00684	0.15964
40.1-50.0	0.02737	0.03877	0.03649	0.10148	0.01596	0.00228	0.01596	0.23831
50.1-60.0	0.05701	0.05131	0.05017	0.05701	0.00684	0.00342	0.00684	0.23261
60.1-70.0	0.05815	0.02737	0.02737	0.03193	0.00228	0.00000	0.00228	0.14937
> 70	0.05131	0.01140	0.01596	0.01026	0.00342	0.00000	0.00228	0.09464
Unknown	0.00114	0.00228	0.00228	0.00114	0.00114	0.00000	0.00000	0.00798
Total	0.22121	0.18244	0.18358	0.31357	0.04903	0.01026	0.03991	1.00000

Table E-1. Velocity probabilities by Highway Class

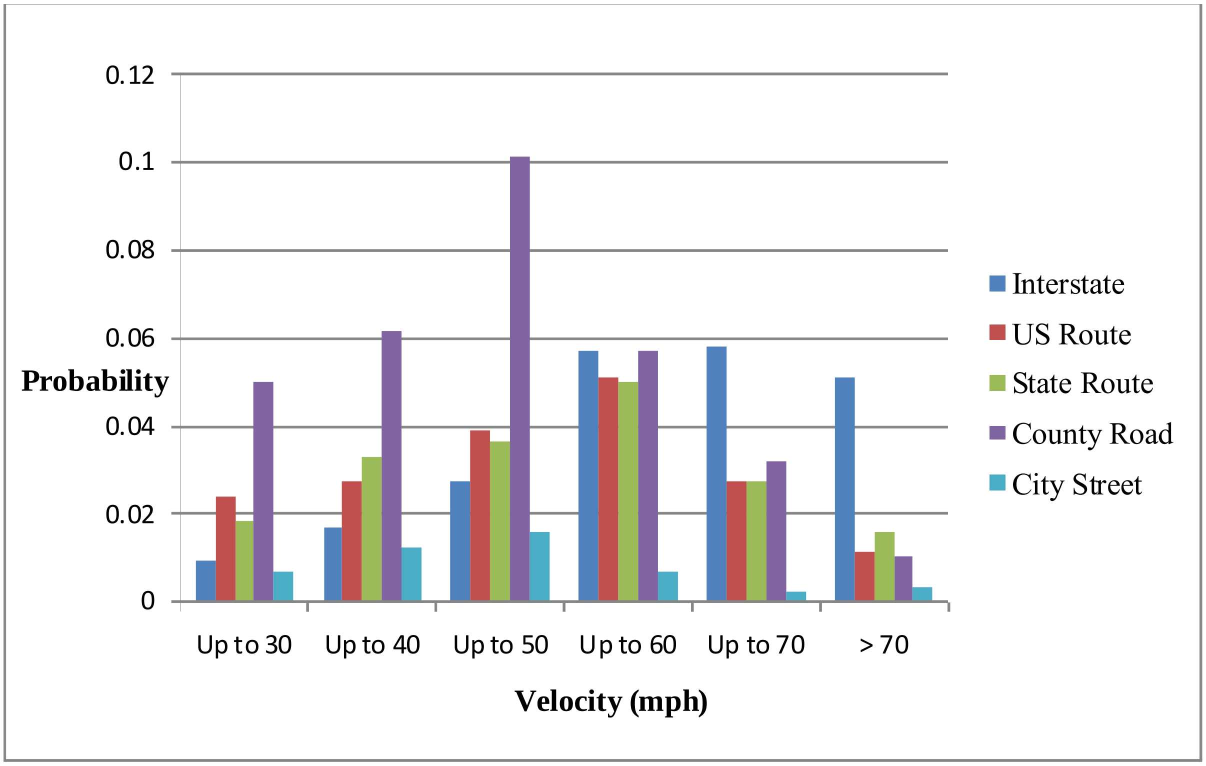


Figure E-11. Graphical Representation of Data from Table E-2

Observed Percentages								
Angle/Highway Class	Interstate	US Route	State Route	County Road	City Street	Other	Unknown	Total
0-5	0.02737	0.01824	0.01482	0.03079	0.00456	0.00228	0.00228	0.10034
6-10	0.04219	0.04903	0.04789	0.07070	0.00798	0.00114	0.00684	0.22577
11-15	0.04789	0.03079	0.02965	0.09008	0.01482	0.00114	0.00342	0.21779
16-20	0.04105	0.02509	0.03421	0.04447	0.01026	0.00000	0.00456	0.15964
21-25	0.02166	0.01824	0.02166	0.03079	0.00798	0.00228	0.00798	0.11060
> 25	0.04105	0.04105	0.03535	0.04675	0.00342	0.00228	0.01596	0.18586
Total	0.22121	0.18244	0.18358	0.31357	0.04903	0.00912	0.04105	1.00000

Table E-2. Angle probabilities by Highway Class

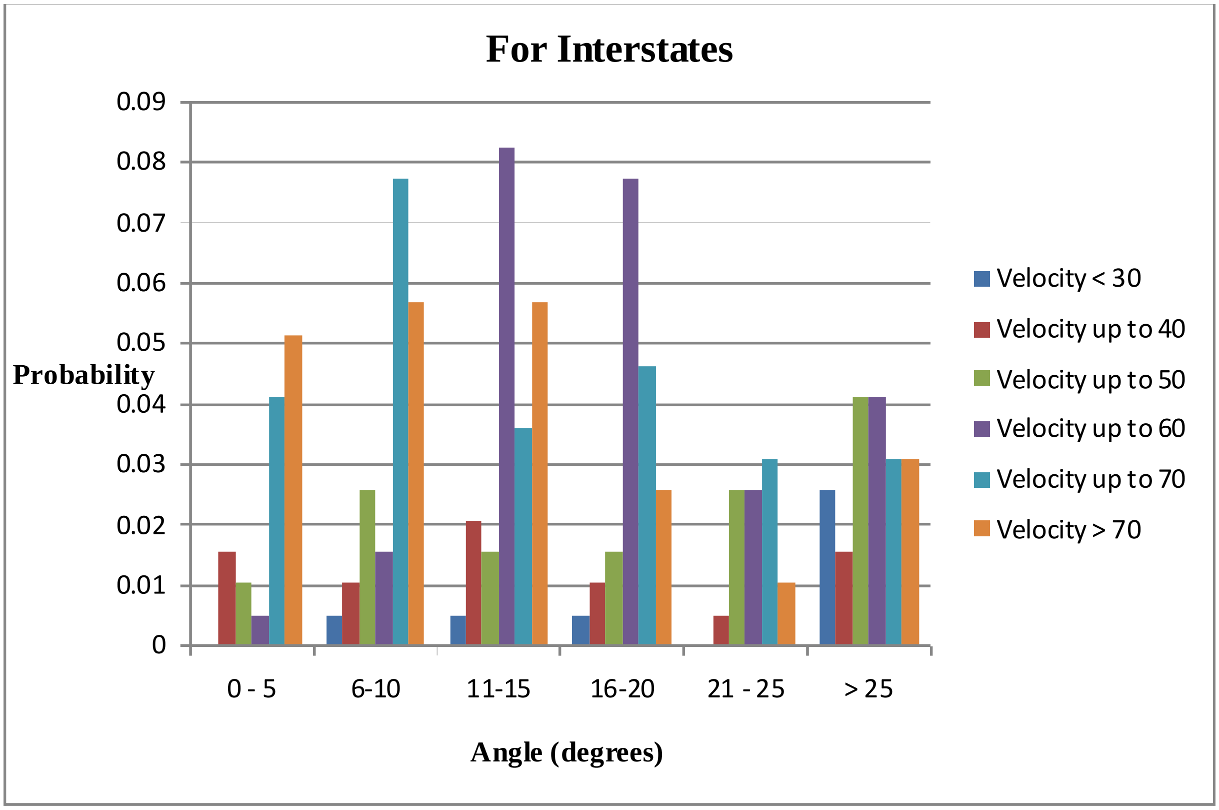


Figure E-12. Graphical Representation of Data in Table E-3

Observed Percentages for Interstate							
Velocity/Angle	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25	> 25	Total
< 30	0.00000	0.00515	0.00515	0.00515	0.00000	0.02577	0.04124
30 - 40	0.01546	0.01031	0.02062	0.01031	0.00515	0.01546	0.07732
40 - 50	0.01031	0.02577	0.01546	0.01546	0.02577	0.04124	0.13402
50 - 60	0.00515	0.01546	0.08247	0.07732	0.02577	0.04124	0.24742
60 - 70	0.04124	0.07732	0.03608	0.04639	0.03093	0.03093	0.26289
> 70	0.05155	0.05670	0.05670	0.02577	0.01031	0.03093	0.23196
Unknown	0.00000	0.00000	0.00000	0.00515	0.00000	0.00000	0.00515
Total	0.12371	0.19072	0.21649	0.18557	0.09794	0.18557	1.00000

Table E-3. Joint probabilities for Interstates

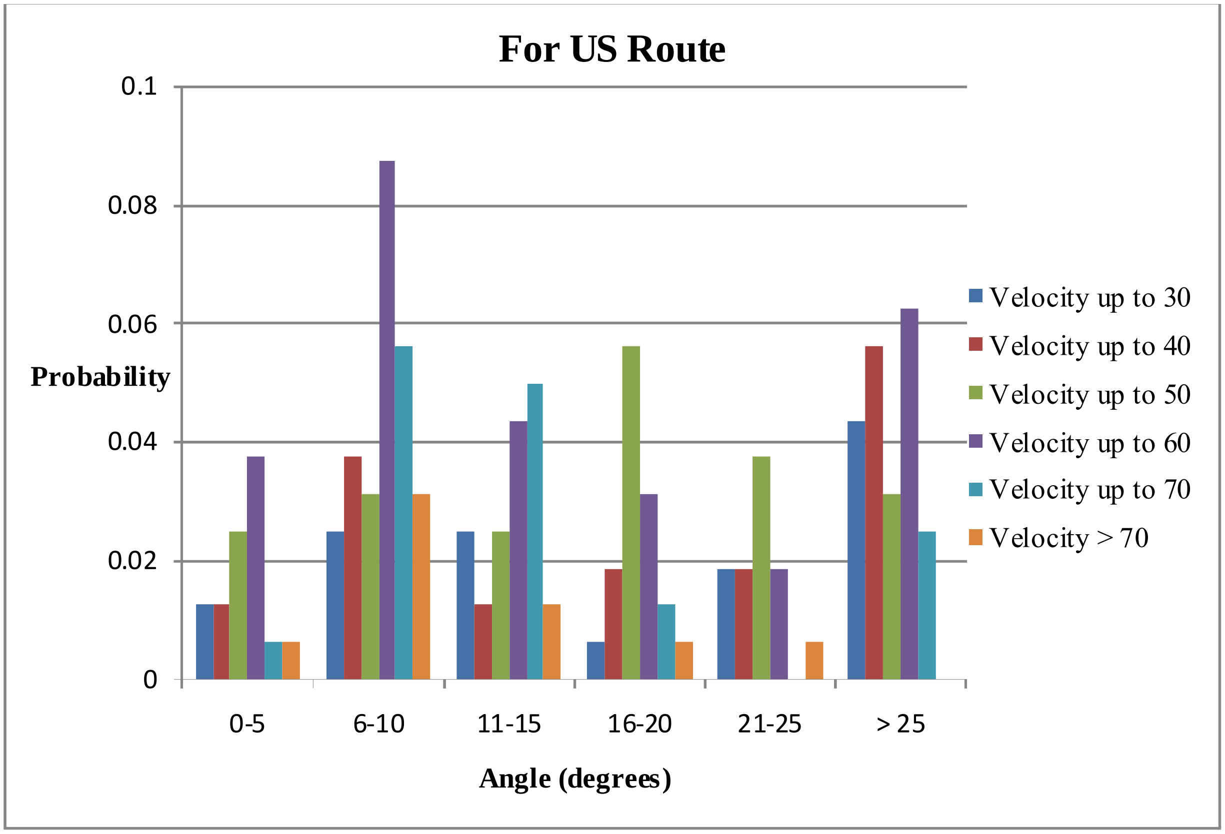


Figure E-13. Graphical Representation of Data in Table E-4

Observed Percentages for US Route							
Velocity /Angle	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25	> 25	Total
< 30	0.01250	0.02500	0.02500	0.00625	0.01875	0.04375	0.13125
30 - 40	0.01250	0.03750	0.01250	0.01875	0.01875	0.05625	0.15625
40 - 50	0.02500	0.03125	0.02500	0.05625	0.03750	0.03125	0.20625
50 - 60	0.03750	0.08750	0.04375	0.03125	0.01875	0.06250	0.28125
60 - 70	0.00625	0.05625	0.05000	0.01250	0.00000	0.02500	0.15000
> 70	0.00625	0.03125	0.01250	0.00625	0.00625	0.00000	0.06250
Unknown	0.00000	0.00000	0.00000	0.00625	0.00000	0.00625	0.01250
Total	0.10000	0.26875	0.16875	0.13750	0.10000	0.22500	1.00000

Table E-4. Joint probabilities for US Route Highways

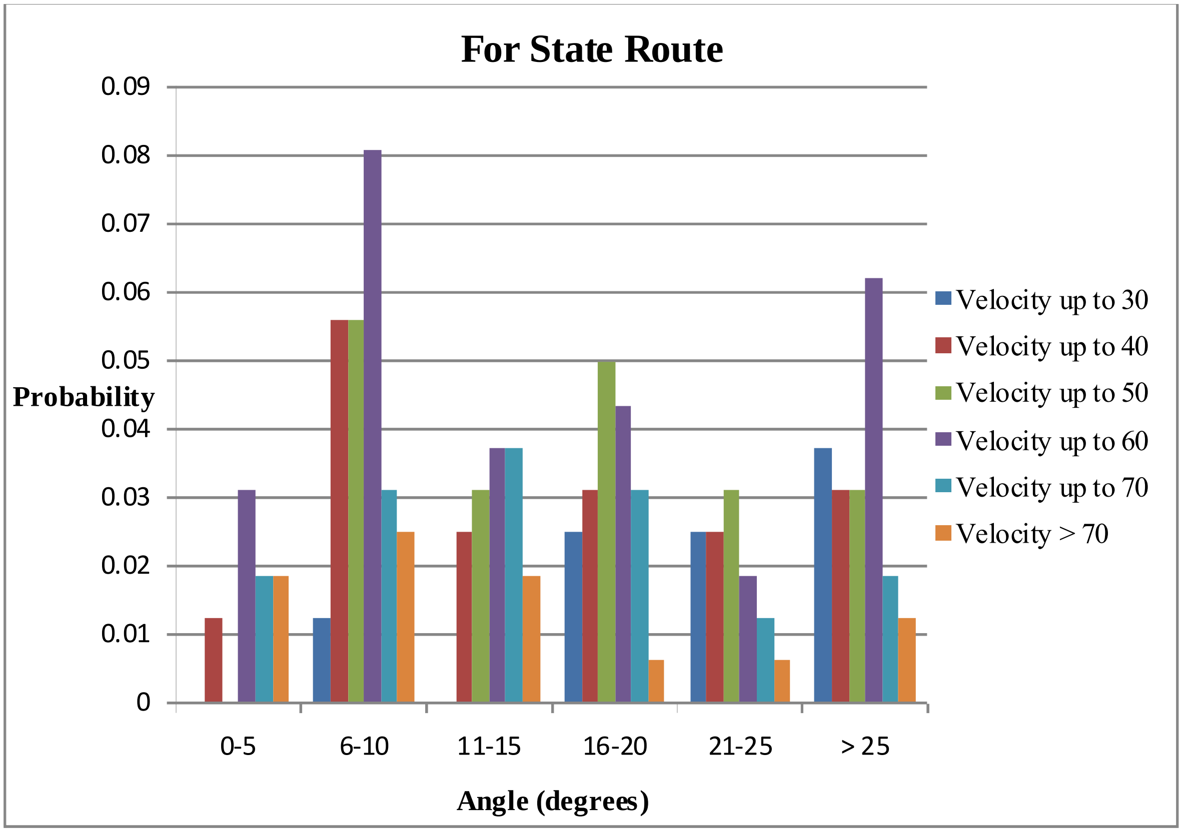


Figure E-14. Graphical Representation of Data in Table E-5

Observed Percentages for State Route							
Velocity /Angle	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25	> 25	Total
< 30	0.00000	0.01242	0.00000	0.02484	0.02484	0.03727	0.09938
30 - 40	0.01242	0.05590	0.02484	0.03106	0.02484	0.03106	0.18012
40 - 50	0.00000	0.05590	0.03106	0.04969	0.03106	0.03106	0.19876
50 - 60	0.03106	0.08075	0.03727	0.04348	0.01863	0.06211	0.27329
60 - 70	0.01863	0.03106	0.03727	0.03106	0.01242	0.01863	0.14907
> 70	0.01863	0.02484	0.01863	0.00621	0.00621	0.01242	0.08696
Unknown	0.00000	0.00000	0.01242	0.00000	0.00000	0.00000	0.01242
Total	0.08075	0.26087	0.16149	0.18634	0.11801	0.19255	1.00000

Table E-5. Joint probabilities for State Route Highways

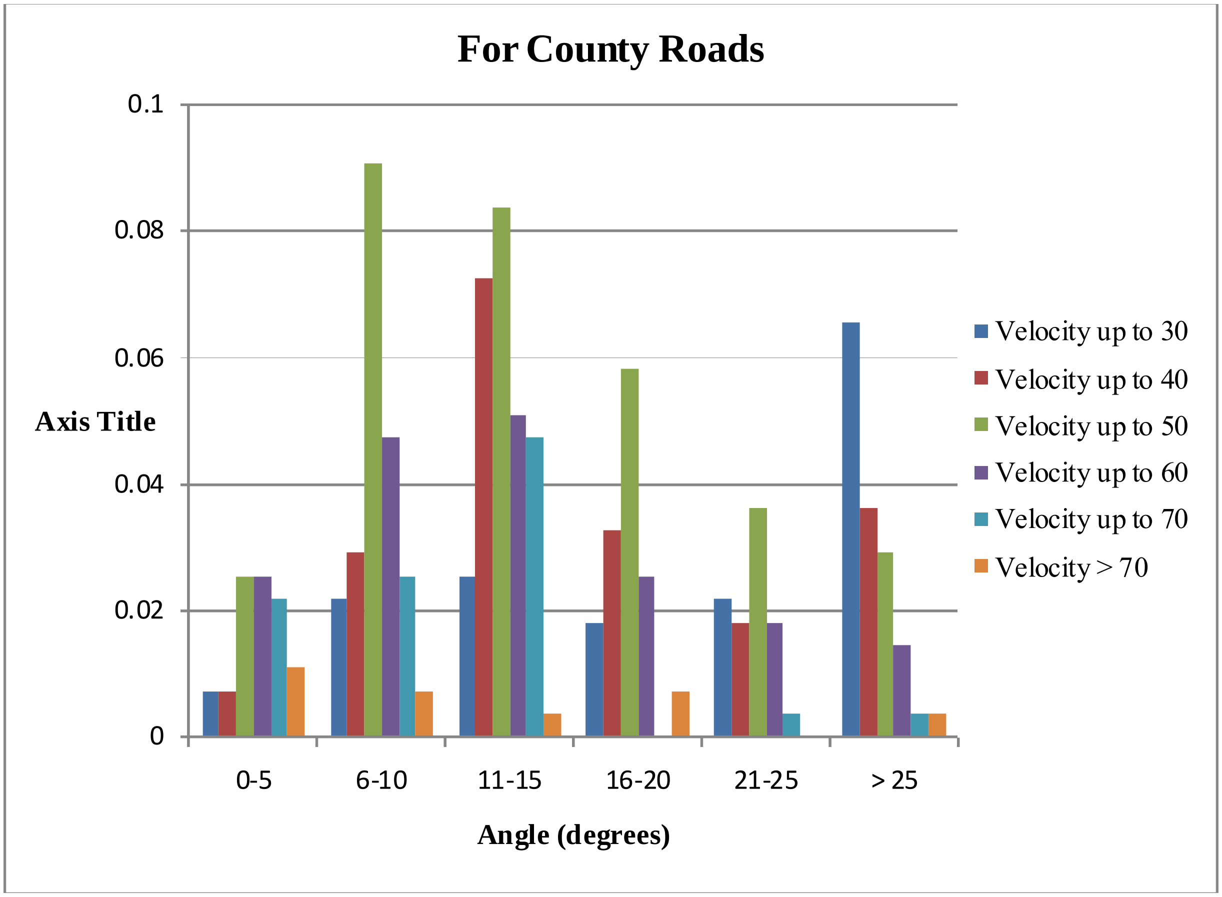


Figure E-15. Graphical Representation of Data in Table E-6

Observed Percentages for County Road							
Velocity /Angle	0 – 5	6 - 10	11 - 15	16 - 20	21 - 25	> 25	Total
< 30	0.00727	0.02182	0.02545	0.01818	0.02182	0.06545	0.16000
30 - 40	0.00727	0.02909	0.07273	0.03273	0.01818	0.03636	0.19636
40 - 50	0.02545	0.09091	0.08364	0.05818	0.03636	0.02909	0.32364
50 - 60	0.02545	0.04727	0.05091	0.02545	0.01818	0.01455	0.18182
60 - 70	0.02182	0.02545	0.04727	0.00000	0.00364	0.00364	0.10182
> 70	0.01091	0.00727	0.00364	0.00727	0.00000	0.00364	0.03273
Unknown	0.00000	0.00364	0.00000	0.00000	0.00000	0.00000	0.00364
Total	0.09818	0.22545	0.28364	0.14182	0.09818	0.15273	1.00000

Table E-6. Joint probabilities for County roads

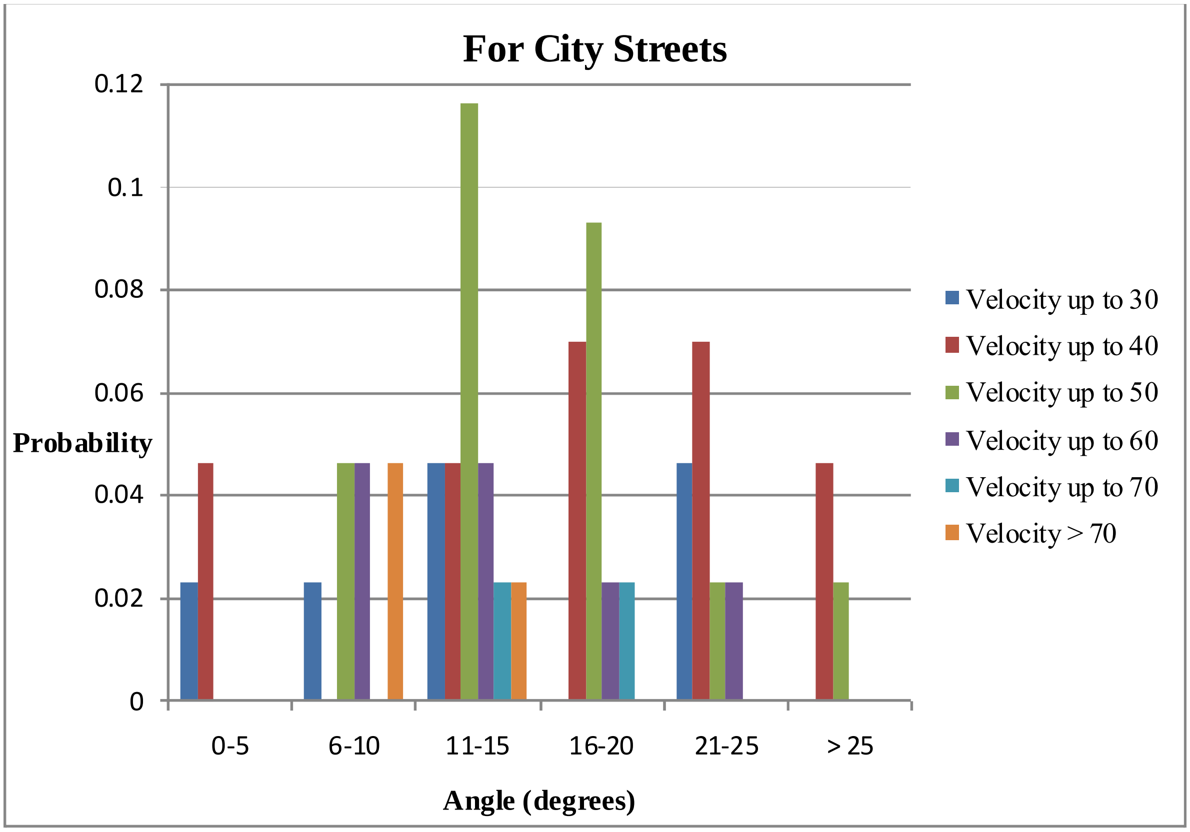


Figure E-16. Graphical Representation of Data in Table E-7

Observed Percetanges for City Street							
Velocity /Angle	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25	> 25	Total
< 30	0.02326	0.02326	0.04651	0.00000	0.04651	0.00000	0.13953
30 - 40	0.04651	0.00000	0.04651	0.06977	0.06977	0.04651	0.27907
40 - 50	0.00000	0.04651	0.11628	0.09302	0.02326	0.02326	0.30233
50 - 60	0.00000	0.04651	0.04651	0.02326	0.02326	0.00000	0.13953
60 - 70	0.00000	0.00000	0.02326	0.02326	0.00000	0.00000	0.04651
> 70	0.00000	0.04651	0.02326	0.00000	0.00000	0.00000	0.06977
Unknown	0.02326	0.00000	0.00000	0.00000	0.00000	0.00000	0.02326
Total	0.09302	0.16279	0.30233	0.20930	0.16279	0.06977	1.00000

Table E-7. Joint probabilities for City streets

APPENDIX F

Proposed Data Collection Forms

Continuous Sampling Subsystem

PROPOSED DATA COLLECTION FORMS - CONTINUOUS SAMPLING SUBSYSTEM

The proposed field data collection forms for the continuous sampling subsystem of the long-term field data collection effort are presented in this Appendix. The proposed data collection forms are similar to those used in the current study, as previously shown in Appendix C.

There are basically two sets of data forms: One set is for use by PSU investigators in field data collection and Zone Center personnel for quality control. The second set is for use by the independent contractor to reconstruct the crashes to estimate impact conditions and to assess the impact performance of the struck object.

The field data collection forms include the following:

- Supplemental highway data collection form
- Object struck data collection forms:
    - Barrier
    - Crash Cushion
    - Embankment
    - Pole Support
    - Tree
    - Other Struck Object

In addition, photographs are to be taken to document the crash site, the struck object(s), available scene evidence such as vehicle trajectory, and the impacting vehicle.

The field data, scaled diagram, and photographs are then used by the independent contractor to reconstruct the crashes to estimate impact conditions and to assess the impact performance of the struck object. The following coding forms are provided:

- Reconstruction Coding Form:
    - First Harmful Event
    - Subsequent Harmful Event
- Performance Assessment Form (copies of the field data collection and coding forms are presented below)

Form Page
Supplemental Highway Data Collection Form F-4
Object Struck – Barrier Data Collection Form F-11
Object Struck – Crash Cushion Data Collection Form F-18
Object Struck – Embankment Data Collection Form F-20
Object Struck – Pole Support Data Collection Form F-22
Object Struck – Tree Data Collection Form F-28
Object Struck – Other Object Data Collection Form F-24
First Impact Coding Form F-25
Subsequent Impact Coding Form F-30
Performance Assessment Coding Form F-33

SUPPLEMENTAL HIGHWAY DATA FORM

Page 1

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

GENERAL HIGHWAY DATA

4. Land Use ___

___(1) Urban
___(2) Rural
___(9) Unknown

5. Class Trafficway ___

___(1) Interstate
___(2) U. S. route
___(3) State route
___(4) County road
___(5) City street
___(8) Other: (Specify) ________________

6. Highway Type ___

___(1) Two-lane undivided
___(2) Multi-lane undivided
___(3) Multi-lane divided
___(4) One-way roadway
___(5) Ramp
___(8) Other: (Specify) ________________

7. Access Control ___

___(1) Full
___(2) Partial
___(3) Uncontrolled

8. Illumination ___

___(0) None
___(1) Luminaire lighting
___(2) High mast lighting
___(8) Other: (Specify) ________________

9. Rumble Strip ___

___(0) None
___(1) Right side only
___(2) Left side only
___(3) Both sides

10. Total Number of Lanes ___ ___

___ (1-16) Code actual number of lanes
___ (17) 17 or more slopes.

11. Average Lane Width ___ . ___ m

___(3.0) 3 m or narrower
___(3.1-4.9) Code actual lane width to nearest 0.1 m
___(5.0) 5 m or wider

12. Roadway Alignment at Point of Departure ___

___(1) Straight
___(2) Curve right
___(3) Curve left

13. Radius of Curve

Measure the radius of curve using the middle ordinate method.

At point of departure: R = ___ ___ ___ ___ m

Length of chord, C = _____________ m

Middle ordinate, M = ____________ mm

At point of maximum curvature within 100 m upstream of point of departure:

R = ___ ___ ___ ___ m

Length of chord, C = _____________ m

Middle ordinate, M = _____________ mm

14. Roadway Profile at Point of Departure ___

___(0) Level (< 2%)
___(1) Upgrade
___(2) Downgrade
___(3) Crest
___(4) Sag

15. Vertical Grade

Measure the vertical grade using a digital inclinometer. See Coding Manual for field procedures.

At point of departure: +/- ___ ___ . ___ %

At point of maximum vertical grade within 100 m upstream of point of departure:

+/- ___ ___ . ___ %

ROADSIDE DATA

16. Curb Presence ___

___(0) No curb
___(1) Barrier curb
___(2) Mountable curb

17. Curb Height ___ ___ ___ mm

___(000) No curb
___(001-998) Code actual curb height to nearest mm.

18. Shoulder Type ___

___(0) No shoulder
___(1) Paved shoulder
___(2) Gravel/Dirt shoulder
___(3) Grassy shoulder

19 Shoulder Width ___ . ___ m

___(0.0) No shoulder
___(0.1-9.8) Code actual shoulder width to nearest 0.1 m

SLOPE DATA

Slope data are to be collected at the point of departure and pertains to the first 100 m from the edge of the travelway.

20. Roadside Cross Section

___

___ Choose the diagram that best describes the roadside cross section.
___(8) Other (Sketch)

21. Number of Slopes ___

___ (1-6) Code actual number of slopes
___ (7) 7 or more slopes.

Code for each of the first six slopes the following data:

22. Lateral Offset to Beginning of Slope
Code actual lateral offset from edge of travelway to beginning of slope to nearest 0.1 m.

23. Rate of Slope
Measure the rate of slope using a smart level.
See Coding Manual for field procedures.

24. Width of Slope
Code actual width of slope to nearest 0.1 m.

Slope	(22) Lateral Offset to Beginning of Slope	(23) Rate of Slope	(24) Width of Slope
1	0 0 . 0 m	+/- ___ ___ . ___ %	___ ___ . ___ m
2	___ ___ . ___ m	+/- ___ ___ . ___ %	___ ___ . ___ m

3 ___ ___ . ___ m +/- ___ ___ . ___ % ___ ___ . ___ m

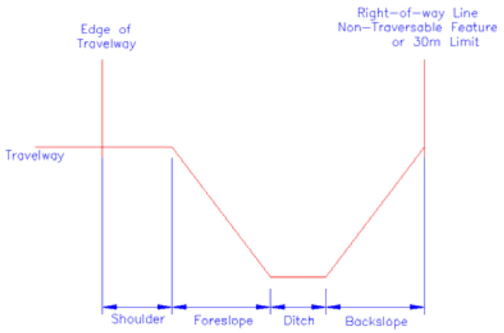
4 ___ ___ . ___ m +/- ___ ___ . ___ % ___ ___ . ___ m

5 ___ ___ . ___ m +/- ___ ___ . ___ % ___ ___ . ___ m

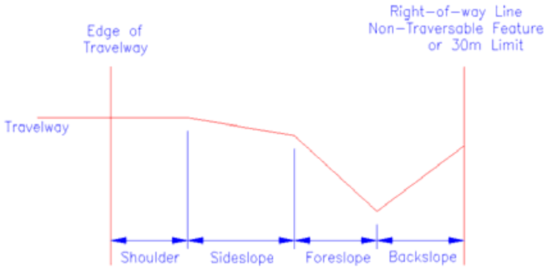
6 ___ ___ . ___ m +/- ___ ___ . ___ % ___ ___ . ___ m

25. Object at End of Last Slope ___

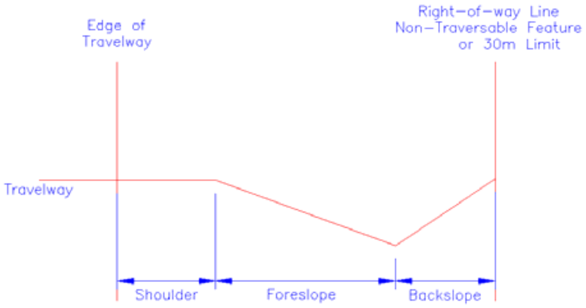
___(0) No Object (Another Slope)
___(1) Guardrail
___(2) Concrete Barrier
___(3) Rock Wall
___(4) Fence
___(5) Trees
___(6) Vertical Drop-Off
___(7) Other: (Specify) ________________



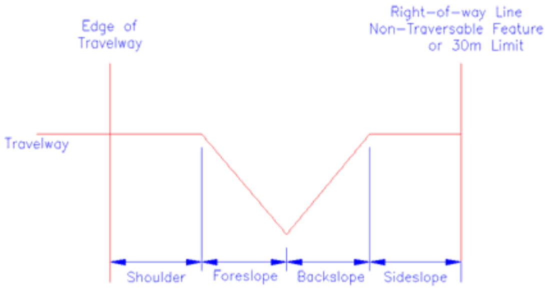
Code 1
Slope = 4



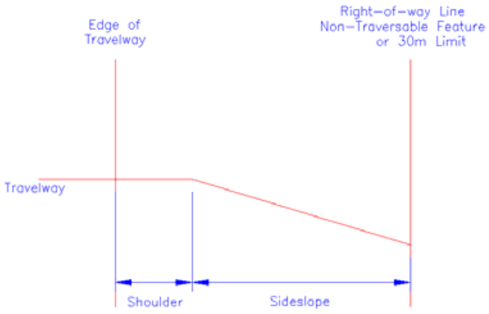
Code 2
Slope = 4



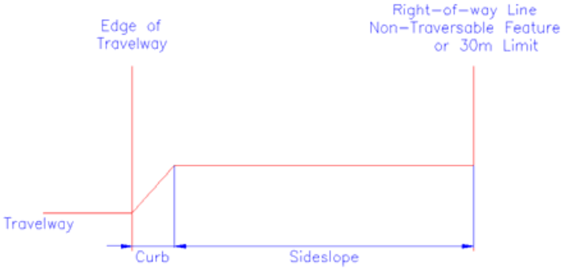
Code 3
Slope = 3



Code 4
Slope = 4



Code 5
Slope = 2



Code 6
Slope = 2

TYPICAL ROADSIDE CROSS SECTIONS

BARRIER DATA FORM Page 1

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. – Stratum ___ ___ ___ ___

4. Impact No. ___

GENERAL BARRIER DATA

5. Barrier Type ___

___(1) Cable Barrier
___(2) Box-beam Barrier
___(3) W-beam Barrier
___(4) Thrie-beam Barrier
___(5) Concrete Barrier
___(6) Bridge Rail
___(8) Other (specify) ________________
___(9) Unknown

6. Barrier Location ___

___(1) Guardrail, Roadside
___(2) Guardrail, Median
___(3) Median Barrier
___(4) Bridge Structure
___(8) Other (specify) ________________
___(9) Unknown

7. Construction Zone ___

___(1) Yes
___(2) No
___(9) Unknown

8. Lateral Offset ___ ___ . ___ m

Enter actual lateral offset distance from edge of travelway to face of undeformed barrier to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

9. Length of Damage/Contact

Direct ___ ___ . ___ m

Total ___ ___ . ___ m

Enter length of direct and total damage/contact to the barrier to the nearest 0.1 m.

___(0.1-99.7)	Actual length of damage/contact to nearest 0.1 m.
___(99.8)	99.8 m or more
___(99.9)	Unknown

10. Damage Profile

Enter extent of deflection or damage, D(i), of barrier, measured from the face of the undeformed barrier to the face of the deformed barrier

___(0.0-9.7)	Actual extent of deflection or damage to nearest 0.1 m.
___(9.9)	Unknown

D1 = ___ . ___ m

D2 = ___ . ___ m

D3 = ___ . ___ m

D4 = ___ . ___ m

D5 = ___ . ___ m

D6 = ___ . ___ m

11. Maximum Damage/Deflection ___ . ___ m

Enter maximum deflection/damage to nearest 0.1 m. Note that the location of the maximum deflection/ damage may or may not coincide with one of the damage profile points.

___(0.1-9.7)	Actual maximum deflection/damage to nearest 0.1 m.
___(9.9)	Unknown

SPECIFIC BARRIER DATA

A separate form is provided for each of the barrier types under Item 5. Continue and complete only the section on barrier characteristics for the applicable barrier type. Leave the other sections on barrier characteristics blank.

CABLE BARRIER CHARACTERISTICS

CB1. Barrier Height ___ ___ ___ ___ mm

Measure and enter rail height from ground to top of top cable.

___(250)	250 mm or lower
___(251-9997)	Actual height to nearest mm
___(9999)	Unknown

CB2. Number of Cables ___

Enter number of cables, which typically ranges from 1 to 4.

___(1-8)	Actual number of cables
___(9)	Unknown

CB3. Vertical Spacing ___ ___ ___ mm

Measure and enter the vertical spacing between consecutive pair of cables. If the spacing is not a constant, code the average value.

___(001-997)	Actual spacing to nearest mm.
___(998)	998 mm or more
___(999)	Unknown

CB4. Post Type ___

___(1)	Wood, round
___(2)	Wood, rectangle
___(3)	Steel, round
___(4)	Steel, I-beam
___(5)	Concrete
___(8)	Other (specify) ________________
___(9)	Unknown

CB5. Post Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter post dimensions. For round posts, enter the diameter and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.
___(998) 998 mm or more
___(999) Unknown or not applicable

CB6. Post Spacing ___ . ___ m

Measure and enter the spacing or distance between posts.

___(0.1-9.7) Actual post spacing to nearest 0.1 m.
___(9.8) 9.8 m or more
___(9.9) Unknown

CB7. Impact Location ___

___(1) Beyond 10 m from either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

CB8. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the center of the end post to the point of initial contact.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

BOX-BEAM BARRIER CHARACTERISTICS

BB1 Barrier Height ___ ___ ___ mm

Measure and enter rail height from ground to top of box beam.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm.
___(9998) 9998 mm or more
___(9999) Unknown

BB2. Rail Type ___

___(1) 6” x 6” Steel Tube
___(2) 6” x 8” Steel Tube
___(8) Other ______________________
___(9) Unknown

BB3. Post Type ___

___(1) Steel, I-beam
___(2) Steel, Other ____________
___(8) Other _________________
___(9) Unknown

BB4. Post Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter post dimensions. For round posts, enter the diameter and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.
___(998) 998 mm or more
___(999) Unknown or not applicable

BB5. Post Spacing ___ ___ . ___ m

Measure and enter the spacing or distance between posts.

___(0.1-9.7) Actual post spacing to nearest 0.1 m.
___(9.8) 9.8 m or more
___(9.9) Unknown

BB6. Impact Location ___

___(1) Beyond 10 m from either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

BB7. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the center of the end post to the point of initial contact.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

BB8. Rail Rupture ___

___(0) No
___(1) Yes, at splice
___(2) Yes, not at splice
___(8) Other (specify) ____________
___(9) Unknown

If yes and not at splice (Code 2), measure the point of rupture from the nearest splice. ___ . ___ m

___(9) Unknown

W-BEAM BARRIER CHARACTERISTICS

WB1. Barrier Height ___ ___ ___ mm

Measure and enter rail height from ground to top of W beam.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm.
___(9998) 9998 mm or more
___(9999) Unknown

WB2. Post Type ___

___(1) Wood, round
___(2) Wood, rectangle
___(3) Steel, I-beam
___(4) Steel, other (specify) ____________
___(8) Other (specify) _________________
___(9) Unknown

WB3. Post Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter post dimensions. For round posts, enter diameter and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.
___(998) 998 mm or more
___(999) Unknown or not applicable

WB4. Blockout Type ___

___(0) No blockout
___(1) Steel
___(2) Wood, routed
___(3) Wood, not routed
___(4) Composite, routed
___(5) Composite, not routed
___(8) Other (specify) _________________

WB5. Blockout Dimensions

Width (at connection to rail) ___ ___ ___ mm

Depth ___ ___ ___ mm

___(001-997) Actual dimension to nearest mm.
___(999) Unknown or not applicable

WB6. Post Spacing ___ ___ . ___ m

Measure and enter the spacing or distance between posts.

___(0.1-9.7) Actual post spacing to nearest 0.1 m.
___(9.8) 9.8 m or more
___(9.9) Unknown

WB7. Impact Location ___

___(1) Beyond 10 m from either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

WB8. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the center of the end post to the point of initial contact.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

WB9. Rail Rupture ___

___(0) No
___(1) Yes, at splice
___(2) Yes, not at splice
___(8) Other (specify) ____________
___(9) Unknown

If yes and not at splice (Code 2), measure the point of rupture from the nearest splice. ___ . ___ m

___(9) Unknown

THRIE-BEAM BARRIER CHARACTERISTICS

TB1. Barrier Height ___ ___ ___ mm

Measure and enter rail height from ground to top of thrie beam.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm.
___(9998) 9998 mm or more
___(9999) Unknown

TB2. Post Type ___

___(1) Wood, round
___(2) Wood, rectangle
___(3) Steel, I-beam
___(4) Steel, other (specify) ____________
___(8) Other (specify) ___________
___(9) Unknown

TB3. Post Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter post dimensions. For round posts, enter diameter and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.
___(998) 9998 mm or more
___(999) Unknown or not applicable

TB4. Blockout Type ___

___(0) No blockout
___(1) Steel
___(2) Wood, routed
___(3) Wood, not routed
___(4) Composite routed
___(5) Composite, not routed
___(8) Other (specify) _________________

TB5. Blockout Dimensions

Width (at connection to rail) ___ ___ ___ mm

Depth ___ ___ ___ mm

___(001-997) Actual dimension to nearest mm.
___(999) Unknown or not applicable

TB6. Post Spacing ___ ___ . ___ m

Measure and enter the spacing or distance between posts.

___(0.1-9.7) Actual post spacing to nearest 0.1 m.
___(9.8) 9.8 m or more
___(9.9) Unknown

TB7. Impact Location ___

___(1) Beyond 10 m from either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

TB8. Point of Initial Contact ___ ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the center of the end post to the point of initial contact.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

TB9. Rail Rupture ___

___(0) No
___(1) Yes, at splice
___(2) Yes, not at splice
___(8) Other (specify) ____________
___(9) Unknown

If yes and not at splice (Code 2), measure the point of rupture from the nearest splice. ___ . ___ m

CONCRETE BARRIER CHARACTERISTICS

CN1. Barrier Height ___ ___ ___ mm

Measure and enter barrier height from ground to top of barrier.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm.
___(9998) 9998 mm or more
___(9999) Unknown

CN2. Barrier Shape ___

___(1) Vertical wall
___(2) Single slope
___(3) Safety shaped
___(4) Other (specify) ______________
___(9) Unknown or N/A

CN3. Barrier Width ___ ___ ___ mm

Measure and enter width at top of barrier.

___(001-997) Actual width to nearest mm.
___(998) 998 mm or more
___(999) Unknown

CN4. Barrier Section Length ___ . ___ m

Measure and enter the length of the barrier section if the barrier is constructed in sections and connected at the adjoining ends. Enter 9.8 for a continuous concrete barrier.

___(0.1-9.6) Actual section length to nearest 0.1 m.
___(9.7) 9.7 m or more
___(9.8) Continuous concrete barrier
___(9.9) Unknown

CN5. Impact Location ___

___(1) Beyond 10 m of either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

CN6. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the end of the barrier to the point of initial contact.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

CN7. Temporary Barrier ___

___(1) Yes
___(2) No
___(9) Unknown

CN8. Barrier Rupture ___

___(0) No
___(1) Yes, at barrier section connection
___(2) Yes, crushed section of concrete
___(8) Other (specify) ____________
___(9) Unknown

BRIDGE RAIL CHARACTERISTICS

BR1. Bridge Rail Type ___

___(1) Steel, post-and-beam design
___(2) Concrete, post-and-beam design
___(3) Concrete, continuous design
___(8) Other (specify) _______________
___(9) Unknown

BR2. Bridge Rail Height ___ ___ ___ mm

Measure and enter barrier height from ground to top of bridge rail.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm.
___(9998) 9998 mm or more
___(9999) Unknown

BR3. Curb Presence ___

___(0) No curb
___(1) Barrier curb
___(2) Mountable curb

BR4. Curb Height ___ ___ ___ mm

___(000) No curb
___(001-998) Code actual curb height to nearest mm.

BR5. Curb Width ___ . ___ m

___(0.0) No curb
___(0.1-9.8) Code actual curb width to nearest 0.1 m.

BR6. Impact Location ___

___(1) Beyond 10 m of either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown

___(998) 998 mm or more
___(999) Unknown or not applicable

BR7. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the point of initial contact to the center of the end post for a post-and-beam design or to the end of the bridge rail for a continuous rail design.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

Post-and-Beam Design

For bridge rails of the post-and-beam design (i.e., codes 1 and 2 for Variable BR1), please enter the following information on rail and post characteristics.

BR8. Number of Rails ___

___(1-8) Code actual number of rail elements
___(9) Unknown

BR9. Rail Dimensions:

	Height	Depth
Top Rail	___ ___ ___ mm	___ ___ ___ mm
Second Rail	___ ___ ___ mm	___ ___ ___ mm
Third Rail	___ ___ ___ mm	___ ___ ___ mm
Fourth Rail	___ ___ ___ mm	___ ___ ___ mm

Measure and enter the dimensions for each applicable rail element, starting from the top. For round posts, enter diameter as height and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.

BR10. Vertical Spacing between Rails:

Top to Second Rail ___ ___ ___ mm

Second to Third Rail ___ ___ ___ mm

Third to Fourth Rail ___ ___ ___ mm

Measure and enter, to the nearest mm, the vertical spacing for the first three consecutive pairs of horizontal rail elements, starting from the top.

___(001-997) Actual spacing to nearest mm.
___(998) 998 mm or more
___(999) Unknown

BR11. Post Type ___

___(1) Steel, rectangle
___(2) Steel, I-beam
___(3) Concrete, rectangle
___(4) Other (specify) _______________
___(9) Unknown

BR12. Post Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter post dimensions. For round posts, enter diameter and code depth as 999 for not applicable.

___(001-997) Actual dimension to nearest mm.
___(998) 998 mm or more
___(999) Unknown or not applicable

BR13. Post Spacing ___ . ___ m

Measure and enter the spacing or distance between posts.

___(0.1-9.7) Actual post spacing to nearest 0.1 m.
___(9.8) 9.8 m or more
___(9.9) Unknown

BR14. Rail Rupture ___

___(0) No
___(1) Yes
___(8) Other (specify) ____________
___(9) Unknown

If yes, measure the point of rupture ___ . ___ m
from the upstream end of the bridge rail.

Concrete Bridge Rail

For concrete bridge rails of continuous construction (i.e., code 3 for Variable BR1), please complete this section on the concrete bridge rail characteristics.

BR15. Barrier Shape ___

___(1) Vertical wall
___(2) Single slope
___(3) Safety shaped
___(4) Other (specify) _____________
___(9) Unknown or N/A

BR16. Barrier Width ___ ___ ___ mm

Measure and enter width at top of barrier.

___(001-997) Actual width to nearest mm.
___(998) 998 mm or more
___(999) Unknown

BR17. Barrier Rupture ___

___(0) No
___(1) Yes, crushed section of concrete
___(8) Other (specify) ____________
___(9) Unknown

If yes, measure the point of rupture ___ . ___ m
from the upstream end of the bridge rail.

OTHER BARRIER CHARACTERISTICS

Please provide a description of the barrier:

____

____

____

____

____

OB1. Barrier Height ___ ___ ___ mm

Measure and enter rail height from ground to top of barrier.

___(250) 250 mm or lower
___(251-9997) Actual height to nearest mm
___(9999) Unknown

OB2. Impact Location ___

___(1) Beyond 10 m of either end
___(2) Within 10 m of downstream end
___(3) Within 10 m of upstream end
___(9) Unknown or N/A

OB3. Point of Initial Contact ___ . ___ m

If the impact location is within 10 m of the downstream or upstream end of the barrier, measure the distance from the point of initial contact to the center of the end post for a post-and-beam design or to the end of the bridge rail for a continuous rail design.

___(0.0-9.8) Actual distance to nearest 0.1 m.
___(9.9) Unknown

B4. Barrier Rupture ___

___(0) No
___(1) Yes
___(8) Other (specify) ____________
___(9) Unknown

If yes, measure the point of rupture from the end of the barrier. ___ . ___ m

PHOTOGRAPHY

As a minimum, the following photographs should be taken of the struck barrier:

- General views of barrier from at least two different angles.
- Close-up photograph(s) showing details of :
- Rail element.
- Post.
- For impacts within 10 m of the downstream or upstream end of barrier, close-up photograph(s) showing details of:
- End post.
- Anchorage.
- For concrete barrier, close-up photograph(s) showing details of:
- Barrier shape.
- Connection between barrier sections, if applicable.

All photographs should be taken with a scale to provide a frame of reference for the dimensions.

CRASH CUSHION DATA FORM

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

CRASH CUSHION DATA

5. Crash Cushion Location ___

___(1) Off right side of roadway
___(2) Off left side of roadway
___(3) In gore area
___(8) Other (specify) _______________
___(9) Unknown

6. Lateral Offset ___ ___ . ___ m

Enter actual lateral offset distance, measured from the edge of travelway to the center of the nose of the crash cushion to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

7. Crash Cushion Length ___ ___ . ___ m

Measure and enter the undeformed length from the nose to the base of the crash cushion along the centerline to the nearest 0.1 m.

___(0.1-19.9) Actual length to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

8. Crash Cushion Width

Nose ___ . ___ m

Base ___ . ___ m

Measure and enter the undeformed width of the crash cushion at the nose and at the base.

___(0.1-9.7) Actual width to nearest 0.1 m
___(9.9) Unknown

9. Width of Shielded Hazard ___ ___ . ___ m

Measure and enter the width of the shielded hazard.

___(0.1-9.7) Actual width to nearest 0.1 m.
___(9.9) Unknown

10. Deformed Crash Cushion Length ___ ___ . ___ m

Measure and enter the length from the deformed nose to the base of the crash cushion along the centerline to the nearest 0.1 m.

___(0.1-19.9) Actual length to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

11. Impact Location ___

___(1) Nose of crash cushion
___(2) Side of crash cushion
___(8) Other (Specify ________________)
___(9) Unknown

PHOTOGRAPHY

As a minimum, the following photographs should be taken of the struck crash cushion:

- General views of crash cushion from at least three different angles: nose, base, and side.
- General view of shielded hazard.

All photographs should be taken with a scale to provide a frame of reference for the dimensions.

EMBANKMENT DATA FORM

Page 3

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

GENERAL EMBANKMENT DATA

5. Embankment Location ___

___(1) Off right side of roadway
___(2) Off left side of roadway
___(3) In median
___(8) Other (specify) ___________________
___(9) Unknown or N/A

6. Lateral Offset ___ ___ . ___ m

Measure and enter the lateral offset distance from the toe of the struck embankment to the edge of the roadway to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

7. Embankment Height
___ ___ . ___ m

Measure or estimate the height of struck embankment to the nearest m.

___(01-19) Actual lateral offset distance to nearest 0.1 m.
___(20) 20 m or more
___(99) Unknown

8. Rate of Slope ___ . ___

___(0.0) Vertical Face
___(0.1-9.7) Actual rate of slope
___(9.8) 9.8:1 or flatter
___(9.9) Unknown

Enter the rate of slope of the struck embankment. The rate of slope is determined as horizontal versus vertical distance (= H/V : 1)

Horizontal Distance (H) = ___ . ___ m

Vertical Distance (V) = ___ . ___ m

H/V = ___ . ___

PHOTOGRAPHY

As a minimum, two general views of the struck embankment should be taken from two different angles. Multiple photographs should be taken for each view to provide as complete coverage as possible. All photographs should be taken with a scale to provide a frame of reference for the dimensions.

POLE SUPPORT DATA FORM

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

GENERAL POLE SUPPORT DATA

5. Pole Type ___

___(1) Utility pole
___(2) Luminaire pole
___(3) Sign support
___(8) Other (specify) ________________
___(9) Unknown

6. Pole Location ___

___(1) Off right side of roadway
___(2) Off left side of roadway
___(3) In median
___(8) Other (specify) ___________________
___(9) Unknown

7. Lateral Offset ___ ___ . ___ m

Enter extent of lateral offset from edge of roadway to face of pole to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

8. Pole Height ___ ___ m

Measure or estimate the pole height and enter the pole height to the nearest m.

___(01-97) Actual pole height to nearest m.
___(99) Unknown

9. Height of Concrete Base ___ ___ ___ mm

Enter height of concrete base above ground. If there are multiple concrete bases with varying heights, code the maximum height.

___(000)	No concrete base
___(001)	Concrete base flush with ground
___(002-997)	Actual height to nearest mm.
___(998)	998 mm or higher
___(999)	Unknown

SPECIFIC POLE SUPPORT DATA

A separate section is provided for each pole type under Item 5. Continue and complete only the section on pole characteristics for the applicable pole type. Leave other sections on pole characteristics blank.

UTILITY POLE CHARACTERISTICS

UP1. Pole Material ___

___(1) Wood
___(2) Steel, single pole
___(3) Steel, tower
___(4) Concrete
___(5) Other (Specify) ________________
___(9) Unknown or N/A

UP2. Pole Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter the cross-sectional dimensions of the pole at the base. Note that the cross-sectional dimensions are those of the pole support and not the concrete base. For round or polygonal poles, enter the diameter and code depth as 999 for not applicable. For steel towers, enter the outside dimensions.

___(001-997) Actual dimension to nearest mm.
___(998) 9998 mm or more
___(999) Unknown or not applicable

UP3. Pole Spacing ___ ___ ___ m

Measure and enter the spacing or distance between the poles to the nearest m.

___(001-997) Actual post spacing to nearest m.
___(999) Unknown

LUMINAIRE POLE CHARACTERISTICS

LP1. Pole Material ___

___(1) Wood
___(2) Steel, single pole
___(3) Steel, tower
___(4) Concrete
___(5) Other (Specify) ________________
___(9) Unknown or not applicable

LP2. Pole Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter the cross-sectional dimensions of the pole at the base. Note that the cross-sectional dimensions are those of the luminaire support and not the concrete base. For round or polygonal poles, enter the diameter and code depth as 999 for not applicable. For steel towers, enter the outside dimensions.

___(001-997) Actual dimension to nearest mm.
___(998) 998 mm or more
___(999) Unknown or not applicable

LP3. Pole Spacing ___ ___ . ___ m

Measure and enter the spacing or distance between consecutive luminaire poles.

___(001-997) Actual post spacing to nearest m.
___(999) Unknown

SIGN SUPPORT CHARACTERISTICS

SS1. Sign Support Configuration ___

___(1) Single support
___(2) Dual supports
___(3) Three supports
___(4) Overhead
___(5) Sign bridge
___(6) Other (specify) ________________
___(9) Unknown or N/A

SS2. Support Material ___

___(1) Wood
___(2) Steel
___(3) Concrete
___(4) Other (specify) ________________
___(9) Unknown or N/A

SS3. Support Cross-Sectional Shape ___

___(1) Round/polygon
___(2) Square/rectangle
___(3) I-beam
___(4) U-channel
___(5) Other (specify) ________________
___(9) Unknown

SS4. Support Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter the cross-sectional dimensions of the sign support at the base. Note that the cross-sectional dimensions are those of the support support and not those of the concrete base. For round or polygonal poles, enter the diameter and code depth as 999 for not applicable. For overhead or sign bridge supports, enter the outside dimensions of the sign support support.

___(001-997) Actual dimension to nearest mm.
___(998) 9998 mm or more
___(999) Unknown or not applicable

OTHER POLE SUPPORT

OP1. Description of pole support (Annotate)

____

____

____

____

____

OP2. Pole Material ___

___(1) Wood
___(2) Steel
___(3) Concrete
___(8) Other (Specify) ________________
___(9) Unknown or N/A

OP3. Pole Dimensions

Width or Diameter ___ ___ ___ mm

Depth ___ ___ ___ mm

Measure and enter the cross-sectional dimensions of the pole at the base. Note that the cross-sectional dimensions are those of the pole support and not the concrete base. For round or polygonal poles, enter the diameter and code depth as 999 for not applicable. For steel towers, enter the outside dimensions.

___(001-997) Actual dimension to nearest mm.
___(998) 9998 mm or more
___(999) Unknown or not applicable

PHOTOGRAPHY

As a minimum, the following photographs should be taken of the struck pole support:

- General views of struck pole support from at least two different angles.
- Close-up photograph(s) showing details of base of struck pole support from at least two different angles. If the pole support breaks away, close-up photographs of both the base of the separated pole structure and the stub remaining in the ground should be provided.

Multiple photographs should be taken for each view to provide as complete coverage as possible. All photographs should be taken with a scale to provide a frame of reference for the dimensions.

TREE DATA FORM

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

GENERAL TREE DATA

5. Configuration ___

___(1) Single tree
___(2) Cluster of trees
___(8) Other (specify) ________________
___(9) Unknown

6. Location ___

___(1) Off right side of roadway
___(2) Off left side of roadway
___(3) In median
___(4) Other (specify) ___________________
___(9) Unknown

7. Lateral Offset ___ ___ . ___ m

Enter actual lateral offset distance, measured from the edge of travelway to the edge of the tree closet to the roadway, to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

8. Diameter ___ ___ ___ mm

Measure and enter diameter of tree at the base. If there is a cluster of trees, enter the diameter of the largest tree.

___(100) 100 mm or less
___(101-997) Actual diameter to nearest mm.
___(998) 998 mm or more
___(999) Unknown

PHOTOGRAPHY

As a minimum, two general views of the struck tree should be taken from two different angles. Multiple photographs should be taken for each view to provide as complete coverage as possible. All photographs should be taken with a scale to provide a frame of reference for the dimensions.

OTHER OBJECT DATA FORM

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

GENERAL STRUCK OBJECT DATA

Please provide a description of the struck object:

____

____

____

____

____

5. Location ___

___(1) Off right side of roadway
___(2) Off left side of roadway
___(3) In median
___(8) Other (specify) ____________________
___(9) Unknown or N/A

6. Lateral Offset ___ ___ . ___ m

Enter extent of lateral offset the struck object to the edge of the roadway to the nearest 0.1 m.

___(0.1-19.9) Actual lateral offset distance to nearest 0.1 m.
___(20.0) 20 m or more
___(99.9) Unknown

7. Material ___

___(1) Wood
___(2) Steel
___(3) Concrete
___(4) Combination
___(8) Other (Specify) ___________________
___(9) Unknown or N/A

8. Dimensions

Length ___ ___ . ___ m

Width ___ ___ . ___ m

Height ___ ___ . ___ m

Measure and enter dimensions of the struck object.

___(0.1-99.7)	Actual lateral offset distance to nearest 0.1 m.
___(99.8)	99.8 m or more
___(99.9)	Unknown

PHOTOGRAPHY

As a minimum, two general views of the struck object should be taken from two different angles. Multiple photographs should be taken for each view to provide as complete coverage as possible. All photographs should be taken with a scale to provide a frame of reference for the dimensions.

RECONSTRUCTION CODING FORM
- FIRST EVENT

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

ENCROACHMENT DATA

4. Departure Angle ___ ___ ___°

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of departure.

5. Vehicle Heading Angle ___ ___ ___°

Enter vehicle heading angle in relation to edge of travelway at point of departure.

VEHICLE TRAJECTORY DATA

6. Driver Action ___

___(1) None
___(2) Braking only
___(3) Steering only
___(4) Braking and steering
___(9) Unknown

Supporting Data: ____________________________

____

____

7. Longitudinal Distance of Travel ___ ___ ___ m

Measure longitudinal distance of travel from point of departure to point of impact for first event and sketch the vehicle path in the space below:

RECONSTRUCTION CODING FORM - FIRST EVENT

8. No. of Trajectory Profile Points ___ ___

Enter number of points used for the trajectory profile.
General guidelines:

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

9. Lateral Offset of Trajectory Profile Points

Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m).

D1 = ___ ___ . ___ m
D2 = ___ ___ . ___ m
D3 = ___ ___ . ___ m
D4 = ___ ___ . ___ m
D5 = ___ ___ . ___ m
D6 = ___ ___ . ___ m
D7 = ___ ___ . ___ m
D8 = ___ ___ . ___ m
D9 = ___ ___ . ___ m
D10 = ___ ___ . ___ m
D11 = ___ ___ . ___ m
D12 = ___ ___ . ___ m
D13 = ___ ___ . ___ m
D14 = ___ ___ . ___ m
D15 = ___ ___ . ___ m
D16 = ___ ___ . ___ m
D17 = ___ ___ . ___ m
D18 = ___ ___ . ___ m

Comments:___________________________________

____

____

RECONSTRUCTION CODING FORM
- FIRST EVENT

10. Maximum Lateral Offset

Enter longitudinal distance, L(max), from point of departure to point of maximum lateral offset and extent of lateral offset , D(max).

L(max) ___ ___ ___ m

D(max) ___ ___ . ___ m

IMPACT CONDITIONS - FIRST EVENT

11. Location of Impact

Enter location of point of impact for first event in relation to point of departure for longitudinal location and to edge of travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

12. NASS CDS Data

Copy the following data items from the NASS CDS forms for first event:

Object Struck ___ ___

Collision Deformation Classification (CDC):

___ ___ ___ ___ ___ ___ ___

Point of Impact on Vehicle: ____________________

____

____

Vehicle Damage Profile:

Length of Damage (L): ___ ___ ___ ___ cm

Damage Profile (C1-C6):

C1 = ___ ___ . ___ cm C2 = ___ ___ . ___ cm

C3 = ___ ___ . ___ cm C4 = ___ ___ . ___ cm

C5 = ___ ___ . ___ cm C6 = ___ ___ . ___ cm

13. Impact Angle ___ ___ ___ °

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of impact for first event.

14. Vehicle Heading Angle at Impact ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of impact for first event.

SEPARATION CONDITIONS - FIRST EVENT

15. Location of Separation

Enter location of point of separation for first event in relation to point of departure for longitudinal location and edge of the travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

16. Separation angle ___ ___ ___ °

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of separation for first event.

17. Vehicle Heading Angle at Separation ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of separation for first event.

RECONSTRUCTION CODING FORM
- FIRST EVENT

RECONSTRUCTION CODING FORM
- FIRST EVENT

SUBSEQUENT EVENT/FINAL REST

18. Subsequent Event ___

___(1) Yes
___(2) No - Final Rest

If yes, code variables 19 and 20 as "Not Applicable" and proceed with coding of the subsequent event form for the second event. If no, continue with variables 19 and 20.

19. Location of Final Rest

Enter location of point of final rest.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

20. Vehicle Heading Angle at Final Rest ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of final rest.

RECONSTRUCTION CODING FORM
- SUBSEQUENT EVENT

CASE IDENTIFICATION

Longitudinal Distance of Travel	No. of Trajectory Profile Points
<= 30 m	6
30 – 100 m	12
> 100 m	18

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. - Stratum ___ ___ ___ ___

4. Impact No. ___

VEHICLE TRAJECTORY DATA

5. Driver Action ___

___(1) None
___(2) Braking only
___(3) Steering only
___(4) Braking and steering
___(9) Unknown

Supporting Data: ____________________________

____

____

6. Longitudinal Distance of Travel ___ ___ ___ m

Measure longitudinal distance of travel from point of separation of prior event and sketch the vehicle path in the space below:

7. No. of Trajectory Profile Points ___ ___

Enter number of points used for the trajectory profile. General guidelines:

RECONSTRUCTION CODING FORM - SUBSEQUENT EVENT

8. Lateral Offset of Trajectory Profile Points

Enter lateral offset, D(i), of each applicable trajectory project point to the nearest 0.1 meter (m).

D1 = ___ ___ . ___ m D2 = ___ ___ . ___ m

D3 = ___ ___ . ___ m D4 = ___ ___ . ___ m

D5 = ___ ___ . ___ m D6 = ___ ___ . ___ m

D7 = ___ ___ . ___ m D8 = ___ ___ . ___ m

D9 = ___ ___ . ___ m D10 = ___ ___ . ___ m

D11 = ___ ___ . ___ m D12 = ___ ___ . ___ m

D13 = ___ ___ . ___ m D14 = ___ ___ . ___ m

D15 = ___ ___ . ___ m D16 = ___ ___ . ___ m

D17 = ___ ___ . ___ m D18 = ___ ___ . ___ m

Comments: ________________________________

____

____

9. Maximum Lateral Offset

Enter longitudinal distance, L(max), from point of separation of prior event to point of maximum lateral offset and extent of lateral offset , D(max).

L(max) ___ ___ ___ m

D(max) ___ ___ . ___ m

IMPACT CONDITIONS

11. Location of Impact

Enter location of impact for this event in relation to point of separation for prior event for longitudinal location and to edge of travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

12. NASS CDS Data

Copy the following data items from the NASS CDS forms for first event:

Object Struck ___ ___

Collision Deformation Classification (CDC):

___ ___ ___ ___ ___ ___ ___

Point of Impact on Vehicle:

____

____

_

____

Vehicle Damage Profile:

Length of Damage (L): ___ ___ ___ ___ cm

Damage Profile (C1-C6):

C1 = ___ ___ . ___ cm C2 = ___ ___ . ___ cm

C3 = ___ ___ . ___ cm C4 = ___ ___ . ___ cm

C5 = ___ ___ . ___ cm C6 = ___ ___ . ___ cm

RECONSTRUCTION CODING FORM
- SUBSEQUENT EVENT

13. Impact Angle ___ ___ ___ °

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of impact.

14. Vehicle Heading Angle at Impact ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of impact.

SEPARATION CONDITIONS

15. Location of Separation

Enter location of point of separation for this event in relation to point of separation of prior event for longitudinal location and edge of the travelway for lateral offset.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

16. Separation angle ___ ___ ___ °

Enter vehicle C. G. direction of travel in relation to edge of travelway at point of separation.

17. Vehicle Heading Angle at Separation ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of separation.

SUBSEQUENT EVENT/FINAL REST

18. Subsequent Event

___

___(1) Yes
___(2) No - Final Rest

If yes, code variables 19 and 20 as “Not Applicable” and proceed with coding of the subsequent event form for the next event. If no, continue with variables 19 and 20.

19. Location of Final Rest

Enter location of point of final rest.

Longitudinal ___ ___ ___ m

Lateral ___ ___ . ___ m

20. Vehicle Heading Angle at Final Rest ___ ___ ___ °

Enter vehicle heading angle in relation to edge of travelway at point of final rest.

Complete this Performance Assessment Form for each impact involving the following safety devices:

- Barrier,
- Crash cushion, and
- Pole structure.

Note that this form is to be completed by the project staff responsible for the assessment of the impact performance of these safety devices, and not by NASS researchers.

CASE IDENTIFICATION

1. Year ___ ___

2. PSU No. ___ ___

3. Case No. – Stratum ___ ___ ___ ___

4. Impact No. ___

5. Safety Device Struck ___

___(1) Barrier
___(2) Crash Cushion
___(3) Pole Structure

Complete the corresponding section for the safety device struck and leave the other sections blank for not applicable.

BARRIER

B1. Barrier Type ___

___(1) Cable barrier
___(2) Box-beam barrier
___(3) W-beam barrier
___(4) Thrie-beam barrier
___(5) Concrete barrier
___(6) Bridge rail
___(8) Other barrier (specify) _______________
___(9) Unknown

Provide specific information on the barrier type and any pertinent barrier characteristics, e.g., standard G4(2S) W-beam guardrail with composite blocks. For proprietary products, identify manufacturer and trade name.

____

____

____

B2. Pre-existing Conditions? ___

___(1) Yes
___(2) No
___(9) Unknown

Identify and describe any pre-existing conditions that could potentially affect the impact performance of the barrier or its terminal, e.g., low barrier height, saturated soil, etc.

____

____

____

B3. Impact Location ___

___(1) Length-of-need
___(2) Terminal, length-of-need (LON)
___(3) Terminal, impact prior to LON
___(4) Terminal, end-on
___(4) Transition
___(8) Other (specify) ________________
___(9) Unknown

B4. Impact Conditions

Impact Speed = ___ ___ ___ . ___ km/h

Impact Angle = ___ ___ º

Vehicle Orientation = ___ º

Length-of-Need Impact

B5. Impact Performance (LON Impact) ___

___(1) Barrier contained and redirected impacting vehicle
___(2) Vehicle overrode barrier
___(3) Vehicle underrode barrier
___(4) Vehicle penetrated barrier
___(5) Vehicle rolled over
___(8) Other (specify) ________________
___(9) Unknown

Explain any unsatisfactory barrier impact performance.

____

____

____

B6. Rail Rupture ___

___(0) No
___(1) Yes, at splice
___(2) Yes, not at splice
___(8) Other (specify) ____________
___(9) Unknown

Terminal/Transition

Complete the following data elements if the impact involved the terminal or transition section; otherwise, leave this section blank.

B7. Terminal Type ___ ___

Cable Barrier
___(01) Non-breakaway end anchor
___(02) Breakaway end anchor

___(08) Other (specify) ________________

Box-Beam Barrier

___(11) Sloped end terminal
___(12) WYBET
___(13) BEAT
___(18) Other (specify) ________________

W-Beam Barrier

___(21) Blunt end
___(22) Turndown
___(23) BCT
___(24) Energy absorbing terminal
___(25) Gating terminal
___(28) Other (specify) ________________

Thrie-Beam Barrier

___(31) Blunt end
___(32) Turndown
___(33) Transition to W-beam barrier
___(38) Other (specify) ________________

Concrete Barrier

___(41) Blunt end
___(42) Sloped end
___(43) Shielded by approach guardrail
___(44) Shielded by crash cushion
___(48) Other (specify) _______________

Bridge Rail

___(51) Blunt end
___(52) Sloped end
___(53) Transitioned to approach guardrail
___(54) Shielded by crash cushion
___(58) Other (specify) _______________
___(98) Terminal for other barrier type
___(99) Unknown

Provide specific information on the terminal type and any pertinent terminal characteristics. For proprietary products, identify manufacturer and trade name.

____

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____

B8. Impact Performance (Terminal Impact) ___

___(1) Terminal brought vehicle to safe and controlled stop
___(2) Terminal gated as designed and vehicle came to safe and controlled stop
___(3) Vehicle was brought to abrupt stop
___(4) Element of terminal penetrated vehicle
___(5) Vehicle sustained excessive deformation/intrusion
___(6) Vehicle rolled over
___(8) Other (specify) ________________
___(9) Unknown

Explain any unsatisfactory terminal impact performance.

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B9. Non-Tracking Impact (End-on Terminal Impacts Only) ___

___(1) Yes
___(2) No
___(9) Unknown

CRASH CUSHION

C1. Crash Cushion Type ___

Identify the crash cushion type and specific information pertaining to the crash cushion. For proprietary products, identify manufacturer and trade name.

____

C2. Impact Conditions

Impact Speed = ___ ___ ___ . ___ km/h

Impact Angle = ___ ___ º

Vehicle Orientation = ___ ___ º

C3. Impact Location ___

___(1) Nose of crash cushion
___(2) Side of crash cushion, < L/2
___(3) Side of crash cushion, > L/2
___(4) Reverse direction impact
___(8) Other (specify) ________________
___(9) Unknown

C4. Pre-existing Conditions ___

___(1) Yes
___(2) No
___(9) Unknown

Identify any pre-existing conditions that could adversely affect the impact performance of the crash cushion.

____

____

____

____

C5. Crash Cushion Impact Performance ___

___(1) Vehicle brought to safe and controlled stop by crash cushion
___(2) Vehicle redirected by crash cushion and came to safe and controlled stop
___(3) Vehicle was brought to abrupt stop
___(4) Element of crash cushion penetrated vehicle
___(5) Vehicle sustained excessive deformation/intrusion
___(6) Vehicle rolled over
___(8) Other (specify) ________________
___(9) Unknown

Explain any unsatisfactory crash cushion impact performance.

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POLE STRUCTURE

P1. Breakaway Pole Structure? ___

___(1) Yes
___(2) No
___(9) Unknown

P2. Breakaway Device Type ___

___(1) Luminaire, frangible transformer base
___(2) Luminaire, slip base
___(3) Luminaire, other (specify) _____________
___(4) Sign support, frangible base
___(5) Sign support, uni-directional horizontal slip base
___(6) Sign support, omni-directional horizontal slip base
___(7) Sign support, sloped slip base
___(8) Sign support, other (specify) ___________
___(9) Unknown

Identify the breakaway device type and specific information pertaining to the device. For proprietary products, identify manufacturer and trade name.

____

____

____

____

P3. Impact Conditions

Impact Speed = ___ ___ ___ . ___ km/h

Impact Angle = ___ ___ °

Vehicle Orientation = ___ ___ °

P4. Pre-existing Conditions ___

Identify any pre-existing conditions that could adversely affect the impact performance of the breakaway device, e.g., approach slope, curb presence, etc.

____

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____

P5. Breakaway Device Impact Performance ___

___(1) Breakaway device functioned as designed
___(2) Breakaway device did not activate
___(3) Element of pole structure penetrated vehicle
___(4) Vehicle sustained excessive deformation/ intrusion
___(5) Vehicle rolled over
___(8) Other (specify) ________________
___(9) Unknown

Explain any unsatisfactory breakaway device impact performance.

____

____