Final Report

Run-Off-Road Collision Avoidance Countermeasures Using IVHS Countermeasures

TASK 1

Volume 1: Technical Findings

NOTE TO READER:

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Final Report

Run-Off-Road Collision Avoidance Countermeasures Using IVHS Countermeasures

TASK 1

Volume 1: Technical Findings

Contracting Officer's Technical Representative's Precis

This report provides a basis for disseminating the preliminary contract results on a timely basis resulting in the information being available before the contract final reports are produced. Research performed during the remainder of the contract may support and/or modify the results, therefore, the material contained in this report should not be consider to be final. The current schedule calls for the completion of this research project by the third quarter of 1999.

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16. Abstract

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program is to address the single vehicle crash problem through application of technology to prevent and/or reduce the severity of these crashes.

This report describes and documents the analysis sequence completed for Task 1. The sequence included three distinct analysis types which may be summarized as follows:

* Statistical Analyses - The GES and FARS national crash databases were examined to provide an updated estimate of problem size and to establish characteristics of the nation crash population.

* Clinical Analyses - 201 hard copy case reports from the NASS CDS crash database were evaluated to determine crash causation factors and to establish the circumstances in which these crashes occur.

* Engineering Analyses - A subset of the NASS CDS case reports were examined to establish the dynamic scenarios associated with the clinical sample. These scenarios were represented as situation trees which delineated the specific combination of driver, vehicle, and environmental factors in wach crash and driver response to critical events.

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FORWARD

The Run-Off-Road Collision Avoidance Using MIS Countermeasures program is to address the single vehicle crash problem through application of technology to prevent, and/or reduce the severity of, these crashes. The prime contractor for this effort is Carnegie Mellon University (CMU) operating under Contract No. DTNH22-93-C-07023. Members of the project team include Battelle Memorial Institute, Calspan Corporation, and the University of Iowa.

The program consists of a sequence of nine related tasks to be completed in three distinct program phases. Phase I of this effort is currently fully funded and is comprised of the first four program tasks. Primary task completion responsibiity has been assigned to individual team members with Calspan conducting Tasks 1 and 2, CMU conducting Task 3, and Battelle conducting Task 4. As prime contractor, CMU provides guidance and oversight to all subcontractor effort.

This report describes and documents the analysis sequence completed for Task 1. The sequence included three distinctive analysis types which may be summarized as follows:

- Statistical Analyses - Mass databases were examined to provide an updated estimate of problem size and to establish characteristics of the national crash population.

- Clinical Analyses - Hard copy case reports were evaluated to determine crash causation factors and to establish the circumstances in which these crashes occurred.

- Engineering Analyses - Hard copy case reports were examined to establish the dynamic scenarios associated with each crash contained in the clinical sample. These scenarios were represented as situation trees which delineated the specific combination of driver, vehicle, and environmental factors in each crash and driver responses to critical events.

One of the findings of this effort is that it is essential to conduct all three of the analyses, as described above, to fully explore and document the crash problem. Technical results from the analysis sequence will be utilized in subsequent tasks to develop functional goals for potential countermeasure technologies (Task 2), to develop test plans for existing countermeasure technologies (Task 3), and to develop computer simulation models to determine countermeasure effectiveness (Task 4). In addition, it is anticipated that this volume and other support volumes will function as a resource reference for Phase II and II tasks.

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1.0 Introduction

Single vehicle run-off-road crashes represent the most serious crash problem within the national crash population. Preliminary estimates by the National Highway Traffic Safety Administration (NHTSA) indicate that approximately 1.27 million police-reported crashes of this type occur each year. This number represents approximately 20.8 percent of all police-reported crashes that occur. In addition, in 1991 there were 15,553 fatalities associated with this crash type. This number represents approximately 37.4 percent of the total crash fatalities for that year (Source: Knipling and Wang, 1993). Obviously, this crash type is overrepresented in terms of crash frequency and crash severity.

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program has been developed to address this crash problem through application of technology to prevent, or reduce the severity of, these crashes. Advances in sensor design and data transmission/processing capabilities over the past decade allow the collection and processing of extensive data sets obtained from the vehicle's operating environment. In addition, support technologies such as the Global Positioning System (GPS) permit the positions of vehicles to be determined with an increasing degree of accuracy. Application of these technologies and other emerging technologies is an integral part of a program intended to dramatically improve automobile safety. This program, broadly titled Intelligent Vehicle Highway Systems (IVHS), will address the run-off-road problem and a fairly broad spectrum of other crash types.

The current program consists of a sequence of nine related tasks to be completed in three distinct program phases. Phase I of this effort is fully funded and is comprised of the four tasks summarized below.

- Task 1: Thoroughly Analyze the Crash Problem
- Task 2: Establish Functional Goals
- Task 3: Conduct Hardware Testing of Existing Technologies
- Task 4: Develop Preliminary Performance Specifications Based on Critical Factors and Models of Crash Scenarios

The Phase I work flow is linear in nature in that the output of one task is utilized as an input to the next successive task and to subsequent tasks. In Task 1, for example, data analyses are conducted to determine the circumstances associated with run-off-road collisions and the causal factors or reasons why these crashes occur. Engineering evaluations are also completed to establish the dynamic states of involved vehicles and the specific scenarios that are associated with these crashes. Results of this analysis sequence are used in Task 2 to determine changes in the dynamic states/crash circumstances which would prevent the crash. These results are also utilized in Task 3 to develop appropriate test plans. Task 2 results are used in Task 3 to develop test evaluation criteria and are used in Task 4 to conceptualize countermeasure system(s). The conceptualized systems are then evaluated via mathematical modeling to determine the probable effectiveness of each concept in terms of eliminating or reducing the severity of run-off-road crashes. These results, in turn, are utilized in the subsequent effort to develop preliminary performance specifications for run-off-road countermeasure systems.

Subsequent phases of this program will continue the development sequence. For example, in Phase II the contract team is to perform state-of-the-art technology reviews and design test bed systems. The test bed systems are then evaluated in Phase III and the preliminary performance specifications, initially developed in Task 4, are modified as appropriate.

The analysis sequence conducted for Task 1 has been completed. The focus of this report is to describe and document the analysis sequence and analysis results. Specific design implications of these results will also be addressed. The report format and section content are as follows:

Section 2.0 Approach

This section describes the methodology applied to the run-off-road crash problem in terms of data sources, analysis techniques, and potential uses of analysis results in Task 1 and subsequent tasks. Potential design implications of these results are also addressed.

Section 3.0 Problem Size Definition

The General Estimates System (GES) database for the 1992 data collection year and the Fatal Accident Reporting System (FARS) database for the 1992 data collection year are utilized to establish the magnitude of the run-off-road collision problem. Particular emphasis is given to identification of crash subtypes which comprise the crash population since the clinical sample composition will parallel national population characteristics.

Section 4.0 Definition of Dynamic Scenarios

An essential part of the development sequence for run-off-road countermeasures involves specification of the dynamic scenarios associated with these crashes. The scenarios incorporate existing environmental conditions, driver state, vehicle state, and actions initiated by the driver prior to and following roadway departure. For this effort, dynamic scenarios are represented as situation trees. Each element of the situation tree is defined in this section.

Situation trees were generated for each case contained in the clinical sample. Trees with similar branches will be grouped and further analyzed in Section 5.0. Results of this analysis will be utilized during the system design phase to closely evaluate opportunities for intervention through countermeasure application.

Section 5.0 Analysis of Run-Off-Road Collision Problem

The magnitude or siie of the run-off-road collision problem was established in Section 3 .O. This section examines the characteristics and circumstances associated with the national crash population (statistical analysis), examines these same factors within the clinical case sample (clinical analysis), and establishes the dynamic scenarios associated with the clinical sample (engineering analysis). In effect, the statistical and clinical analyses set the stage and feed the engineering analysis. This analysis sequence is documented as follows:

5.1 Statistical Analyses

The 1992 GES database is accessed to establish major characteristics of the national crash population. Characteristics of interest include the nature of the crash environment (e.g., urban/rural, divided/nondivided, etc.), roadway characteristics (e.g., number of travel lanes, straight/curve, level/grade, wet/dry, etc.), weather conditions, time of day, and pre-crash vehicle movement. Analysis results are presented as a distinct series of univariate, bivariate, and trivariate displays and tabulations. The emphasis here is to establish a detailed profile which can be compared to the profile established for the clinical sample.

5.2 Clinical Analyses

A characteristics profile is established for the clinical database and then compared to the statistical profile to verify that the clinical sample is reasonably representative of the run-off-road crash population. Results of the causal factor analysis and the cluster variable analysis are also presented and discussed in detail. The presentation sequence parallels the univariate, bivariate, and trivariate sequence generated for statistical analyses. Design implications of these findings are addressed.

5.3 Engineering Analysis

In this section scenarios with similar situation trees are grouped and analyzed to establish common patterns which can be addressed through countermeasure intervention. Differences between these groups are also discussed in terms of specific countermeasure design implications.

Section 6.0 Comparison of VNTSC OMNI and Run-Off-Road Analysis Results

The VNTSC-sponsored OMNI program also examined the single vehicle roadway departure crash type. Results of that causal factor analysis are compared to results from the current program. The OMNI program used data from the 1991 NASS CDS file and the clinical sample for the current program was selected from the 1993 NASS CDS file. Comparison of causal factor determinations between these programs provides an assessment of the stability of these determinations over time.

This section also provides a comparison of the dynamic scenarios evaluated in these two programs. This comparison is limited since the OMNI program did not focus on dynamic scenarios or the description of these scenarios.

Section 7.0 Definition of Benefit Analysis Sample

Countermeasures developed for the run-off-road program may prevent other crash types with dynamics similar to roadway departure crashes. Examples of dynamically similar crashes are the head-on and sideswipe/angle (lateral move) crash types. This section describes all relevant crash types amenable to application of countermeasures developed for the current effort. The resulting grouping of crash types is defined as the benefit analysis sample. This sample will be used in conjunction with the models developed in Task 4 to derive the potential benefit of run-off-road crash avoidance countermeasure concepts.

Section 8.0 Summary and Conclusion

A summary of the Task 1 effort is provided with particular emphasis placed on the groups of similar dynamic scenarios identified in Section 5.4. Conclusions with respect to the design implications of these scenarios and associated causal factors are also provided.

Volume II of this report is a companion volume which provides hard copies of the situation trees developed for each case in the clinical sample. The reader may find these coding sheets very useful in that, where appropriate, additional supplementary notes have been recorded directly on the forms. Hard copies of the coded data variables contained in the clinical database are also provided in this volume.

2.0 Approach

Successful development of run-off-road countermeasures requires a thorough analysis of these crashes. The analysis determines the types of run-off-road crashes that occur (crash subtypes), the circumstances in which these crashes occur, how these crashes occur (dynamic scenarios), and why these crashes occur (causal factors). With this base of information, it becomes feasible to determine specific intervention points at which countermeasure application is likely to be successful, the intervention type (i.e., audio warning, visual warning, assume automated control, etc.) that is likely to be successful, and the technologies which are most appropriate/consistent with respect to achieving these goals.

This section describes the methodology that was applied to the Task 1 analysis sequence. Data sources for various task analyses are identified, individual analyses and the goals of these analyses are described, and the role of each specific analysis type is defined. A discussion of the Task 1 output and how these results will be used in subsequent tasks is also provided.

Figure 2-l summarizes the Task 1 methodological sequence. As indicated in the figure, the first step involved identification of problem parameters including development of a problem size estimate and specification of crash configurations which comprised the target crash population. Statistical examination of mass databases was used to satisfy both objectives. In this case, the project team selected the GES and FARS databases for the 1992 data collection year to determine the problem size and associated crash configurations. The intent here was to be consistent, in terms of data sources, with earlier problem size estimates generated by NHTSA. During the course of developing the problem size estimate, it was necessary to define the target crash population and crash types which comprised this population. Again, to be consistent with earlier NHTSA work, applicable crash type designations were accepted as defined in the Knipling and Wang (1993) report.

Early statistical tabulations were used to develop case selection criteria for assembling the clinical case sample. These criteria were then forwarded to personnel in NHTSA's Office of Crash Avoidance Research (OCAR) who provided a listing of applicable cases contained in the 1993 NASS Crashworthiness Data System (CDS) file. The final 201 case sample was selected from this listing.

Prior to conducting the clinical analyses, the project team defined the elements/variables that would be examined during the engineering analysis to establish dynamic scenarios for run-off-road crashes. This action was completed at this point to ensure that these variables/elements were available in the electronic database that was being assembled for this effort. The process was iterative in nature and required several cycles to complete. In general, increasing levels of detail were added with each iteration.

The clinical analysis sequence was completed in three distinct stages. In the first stage, data reduction formats were developed, tested, and validated using applicable cases available through Calspan's NASS Zone Center operation. In the second stage, all remaining cases in the sample were analyzed at the NASS data storage contractor located in Washington, D.C. In the third stage, a repeat visit was made to the storage contractor to record additional variables that were determined to be essential and to reanalyze a number of cases where coding inconsistencies were detected.

All clinical analyses completed for this effort were conducted by highly experienced accident investigation/reconstruction personnel. In addition to recording variables designated for inclusion in the dynamic scenario analysis, analysts also recorded crash characteristics/circumstances intended for use in construction of a detailed profile of the clinical sample. These analysts also conducted a detailed causal factor analysis to determine the reason(s) why each crash occurred (see Section 5.2.3).

While the clinical analysis was being completed, additional statistical analyses of the GES database were undertaken to establish a profile of characteristics/circumstances for the national run-off-road crash population. This profile consisted of a distinct series of univariate, bivariate, and trivariate distributions. The profile established for the clinical sample, which contained the same series of analysis distributions, was then compared to this statistical profile to verify that the clinical sample was reasonably representative of the national crash population.

The descriptive profiles derived from the statistical and clinical analyses, the causal factor analysii, and other elements available as a result of the clinical analysis effort (e.g., corrected scaled schematics depicting additional roadside features) provided additional support data to the engineering analysis conducted to establish dynamic scenarios. An expanded overview of this sequence is provided in Figure 2-2. The project staff elected to represent individual case dynamic scenarios as situation trees. These trees delineate existing conditions related to crash occurrence, driver/vehicle actions or events, driver corrective actions initiated to avoid the crash, and vehicle responses to these corrective actions. A more detailed description of these data reduction formats is provided in Section 4.1. Engineering analysis results are presented in Section 5.4.

As a result of the Task 1 effort, a comprehensive electronic database has been assembled. This database documents characteristics of run-off-road crashes, documents the circumstances in which these crashes occur, describes the crash types contained within this target population, documents the reasons why these crashes occur, and documents the dynamic scenario associated with each crash. This information will be used in Task 2 to formulate functional goals for run-off-road countermeasures, in Task 3 to establish viable hardware test and evaluation plans, and in Task 4 to develop effective computer modeling simulations. The database will also function as a reference resource in subsequent program phases. For example, this file could be used to determine the likely effect of countermeasure design modifications to accommodate emerging technologies.

The Task 1 database is, of course, only one of a number of data sources that will be developed during Phase I and does not contain a number of critical data elements. For example, to produce a final set of performance specifications, the man-machine interface must also be considered. This area will be addressed further is subsequent program tasks. It may be feasible to incorporate these types of inputs into the database at that point, however, it is more likely that man-machine interface inputs will be incorporated directly into the modeling effort scheduled for Task 4.

3.0 Problem Size Definition

Mass databases, reflecting national crash population characteristics, were accessed to define the scope of the single vehicle, run-off-road crash problem. Specifically, the 1992 GES and FARS files were utilized for this effort. The GES file consists of over forty-six thousand police reported accidents selected from statistically representative areas of the United States. The FARS file is a census of fatal crashes and contains sufficient detail to determine the conditions/circumstances in which these crashes occurred.

3.1 Examination of Run-Off-Road Crash Problem

The GES database classifies crashes by vehicle actions prior the crash event. These vehicle actions are defined as crash or accident types. The specific GES accident types relevant to the single vehicle crash problem are shown in Figure 3-l. This figure also provides the data retrieval specification used to access the database.

Tabulation results are provided in Table 3-l. The N/A designation in cells under the On Roadway column indicates that these cells are considered to be not applicable since the cell references are logically contradictory (e.g., Right Roadway Departure, Impact Occurred on Roadway). In reality, the GES database does contain a small number of cases in these cells. The latter cases represent aberrations (e.g., vehicle departs right edge of roadway, subsequently returns to the roadway, and then rolls over or is involved in an impact on the roadway). To be consistent with earlier NHTSA analyses, the N/A designation is retained and these cells are eliminated from consideration for the run-off-road crash problem.

Of the crashes which occurred off the roadway, the most dominant crash types were Drive Off Road (left/right departure), Control/Traction Loss (left/right departure), Avoid Collision With Veh, Pedacyclist, Animal (left/right departure), and Forward Impact to Parked Vehicle.. Events/circumstances typically involved in these crash types may be summarized as follows:

- Drive Off Road - The subject vehicle is in a tracking attitude at the point of roadway departure. Steering control has been maintained and it is possible to alter the vehicle's trajectory. The most common off-road impact configuration involves contact with the vehicle's frontal plane. If the length of pre-impact off-road travel is extensive, however, vehicle control and the associated vehicle trajectory may deteriorate such that side impacts/rollovers occurs. A typical pattern for this crash type, selected from the clinical database, is shown in Figure 3-2.

- Control/Traction Loss - This crash type is often associated with adverse weather/surface conditions (e.g., wet, snow, ice). Due to the control/traction loss, steering control has not been maintained. At the point of roadway departure, the subject vehicle is typically in a longitudinal skid or in a yaw pattern. The most common off-road impact configurations involve the vehicle's side planes or angular strikes to the frontal plane. Non-collision events such as rollovers are also common. A typical pattern for this crash type, selected from the clinical database, is shown in Figure 3-3.

Category	Configuration	ACCIDENT TYPES (Includes Intent)					
I Single Driver	A. Rigth Roadside Departure	01 Drive Off Road	02 Control/ Traction Loss	03 Avoid Collision With Veh. Ped. Anim.	04 Specifics Other	05 Specifics Unknown	
	B. Left Roadside Departure	06 Drive Off Road	07 Control/ Traction Loss	08 Avoid Collision With Veh. Ped. Anim.	09 Specifics Other	10 Specifics Unknown	
	C. Forward Impact	11 Parked Vehicle	12 Sta. Object	13 Pedestrian/ Animal	14 End Departure	15 Specifics Other	16 Specifics Unknown
VI Miscellaneous	M. Backing Etc.	32 Backing Vehicle	33 Other Vehicle or Object	94 Other Accident Type 98 Unknown Accident Type 00 No Impact			

Data Retrieval Specification (Single Vehicle Crashes)

Number of Vehicles (A3, Veh._Invl.)	= 1
Accident Type (V23,Acc._Type)	=1–16,92,93
Relation to Roadway (A10, Rel._Rwy.)	=1 (On Roadway)
	= 2–4 (Off Roadway)
	= 5–9 (Other and Unknown)

Figure 3–1 GES ACCIDENT TYPES AND DATA RETRIEVAL SPECIFICATION

Table 3-1
Relation to Roadway by Crash Type
Single Vehicle Crashes*

Crash Type		On Roadway	Off Roadway Shoulder	Other &Unknown
		Relation To Roadway		
Right Roadway Departure	Drive Off Road	N/A	237,000	1,000
	Control/Traction Loss	N/A	224,000	1,000
	Avoid Collision With Veh, Ped/Cyclist, Animal	N/A	47,000	0
	Other or Unknown Specifies	N/A	6,000	0
Left Roadway Departure	Drive Off Road	N/A	137,000	2,000
	Control/Traction Loss	N/A	174,000	0
	Avoid Collision With Veh, Ped/Cyclist, Animal	N/A	32,000	0
	Other or Unknown Specifies	N/A	5,000	1,000
Forward Impact	Forward Impact to Parked Vehicle	0	308,000	5,000
	Forward Impact to Stationary Object	22,000	2,000	0
	Forward Impact to Pedestrian/Animal	356,000	8,000	2,000
	Forward Impact, End Departure	0	29,000	0
	Other or Unknown Specifies	7,000	5,000	1,000
Backing	Backing Vehicle	2,000	76,000	1,000
	Total	**387,000**	**1,290,000**	**14,000**

* All crash statistics are rounded to the nearest 1,000.

ACCIDENT COLLISION DIAGRAM

PSU No. 09 Case Number - Stratum 006K Indicate North

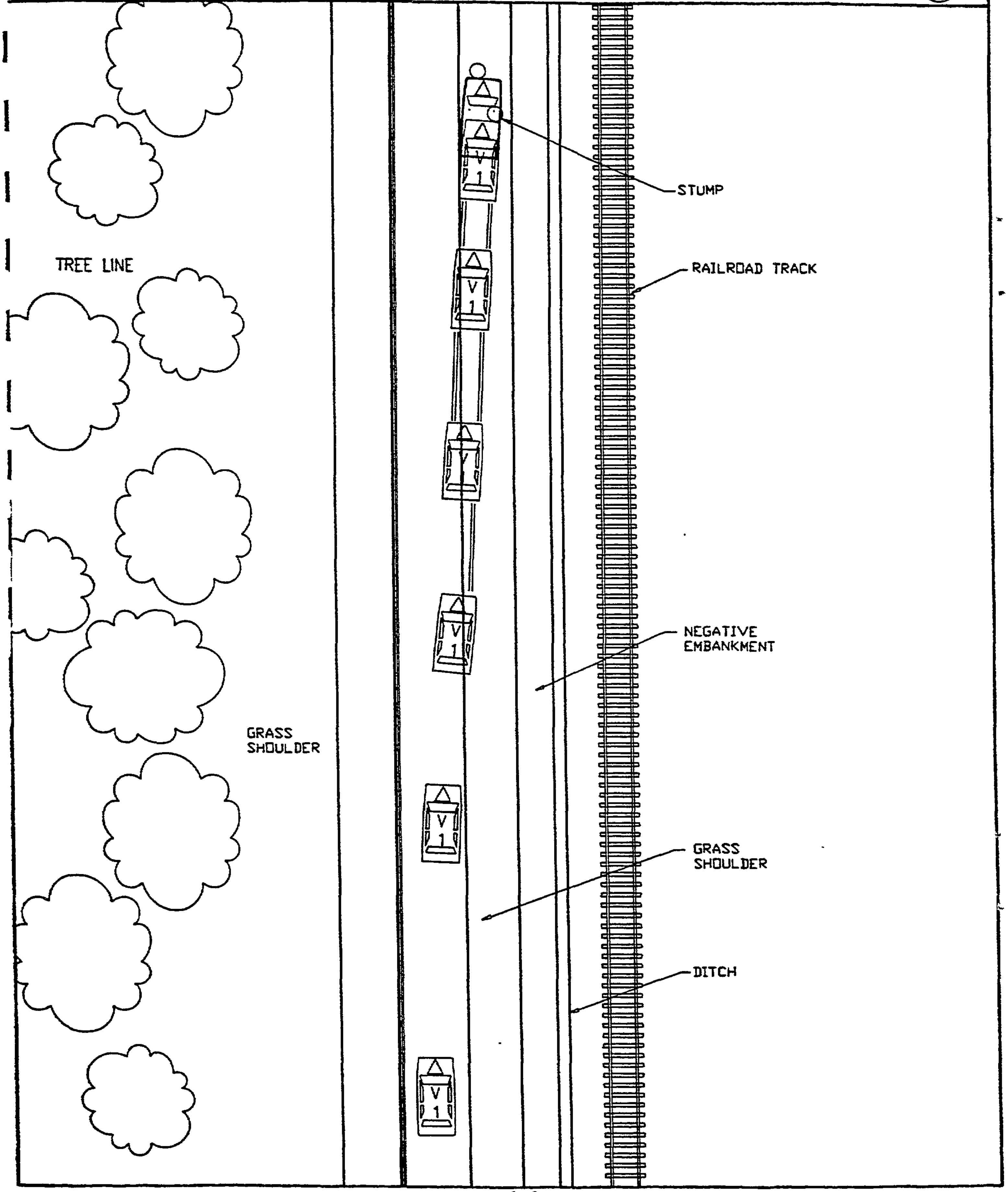


Figure 3-2

Scale: 1/250

ACCIDENT COLLISION DIAGRAM

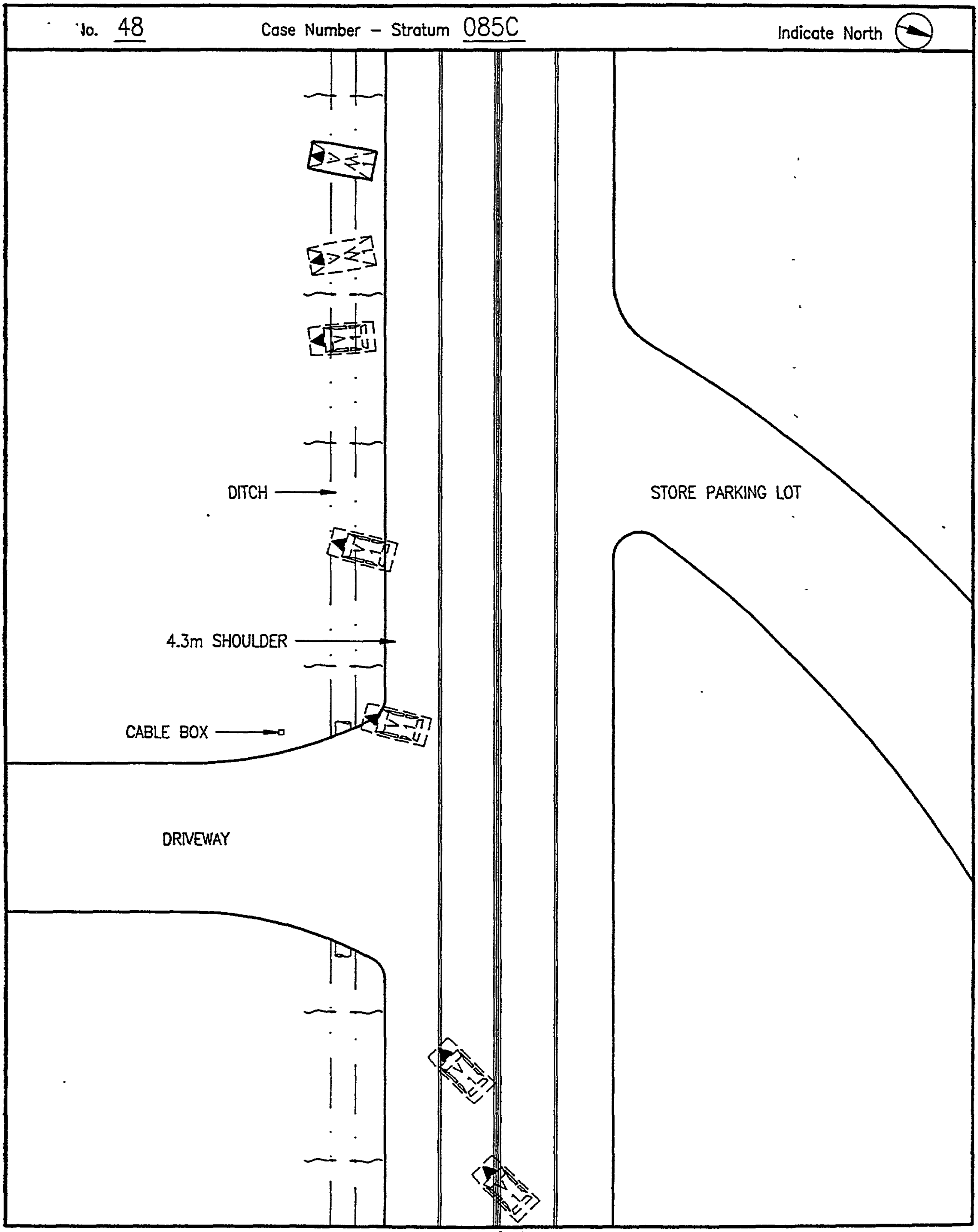


Figure 3-3

- Avoid Collision With Veh, Ped/Cyclist, Animal - In this crash type, the subject driver initiates an evasive maneuver to avoid a vehicle, pedestrian/cyclist, or animal that is in the roadway. Vehicle attitude at the point of roadway departure is dependent on the intensity of pre-departure steering and braking input and will, therefore range from a tracking attitude to very pronounced yaw patterns. The range of impact types, in turn, is also broad and many rollover events are noted. A typical pattern, involving a large pre-departure steering input, is shown in Figure 3-4.

- Forward Impact to Parked Vehicle - This crash type closely resembles the Drive Off Road crash type with the exception that the off-road impact involves a parked and unoccupied motor vehicle. The most common vehicle attitude at the point of roadway departure is tracking and the most frequent impact configuration involves contact with the subject vehicle's frontal plane. A typical pattern, selected from the clinical database, is shown in Figure 3-5.

Collectively, these four crash types account for approximately 90 percent (1,160,000) of the 1,291,000 single vehicle crashes that occur off the roadway. It will, therefore, be important to further examine and understand the specific circumstances in which these crashes occur.

As a final observation with respect to crash types, it is important to note that these categorizations provide a convenient mechanism for grouping crashes within the NASS GES and CDS databases. The project staff will utilize this mechanism to examine groups of crashes in the statistical and clinical analyses, particularly with respect to verifying that the clinical sample is representative of the larger target crash population. It is unlikely, however, that these designations will be utilized in the engineering analysis conducted to establish groups of similar dynamic scenarios since there is a broad range of crash circumstances contained within each defined crash type. Specifically, the engineering analysis will focus on developing smaller groups of crashes with well-defined and similar crash circumstances/conditions.

3.2 Identification of Single Vehicle Run-Off-Road Target Crash Population

The single vehicle crash population was delineated in Table 3-l. The target crash population that is the focus of this program is a subset of the single vehicle crash population. Specifically, this program is to address that subset of single vehicle crashes where the subject vehicle departs the roadway and is involved in a collision/non-collision event off the roadway. In effect, the target crash population is the center column (Off Roadway/Shoulder) of Table 3-l.

There are, however, additional factors which must be taken into consideration before specifying the population of interest. NHTSA is currently sponsoring a total of four Performance Specification programs (i.e., Rear-End, Lane Change/Merge, Intersection Collision, and Run-Off-Road). The backing vehicle cell in the center column of Table 3-l is currently part of the target crash population for the Lane Change/Merge Performance Specification program. The Forward Impact to Pedestrian/Animal cell is being reserved for a future near object detection countermeasure program. The single vehicle run-off-road target crash population is, therefore, defined as the center column of Table 3-l minus these two cells. The composition of the target crash population is shown in Table 3-2 where cells derived from applicable crash types and applicable crash locations have been shaded.

ACCIDENT COLLISION DIAGRAM

PSU No. 11 Case Number - Stratum 126E Indicate North

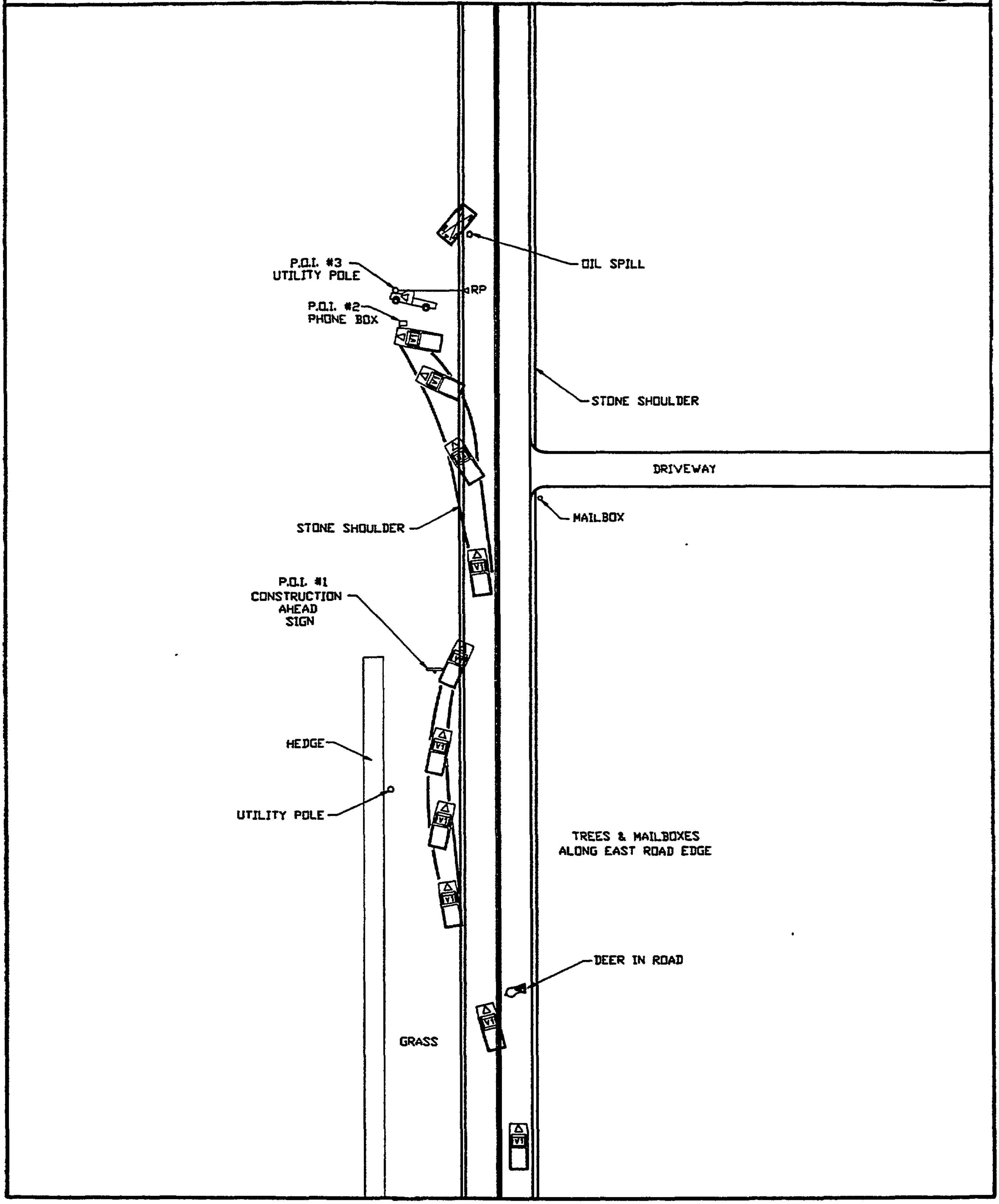


Figure 3-4

Scale: 1/500

ACCIDENT COLLISION DIAGRAM

PSU No. 04 Case Number – Stratum 005E Indicate North

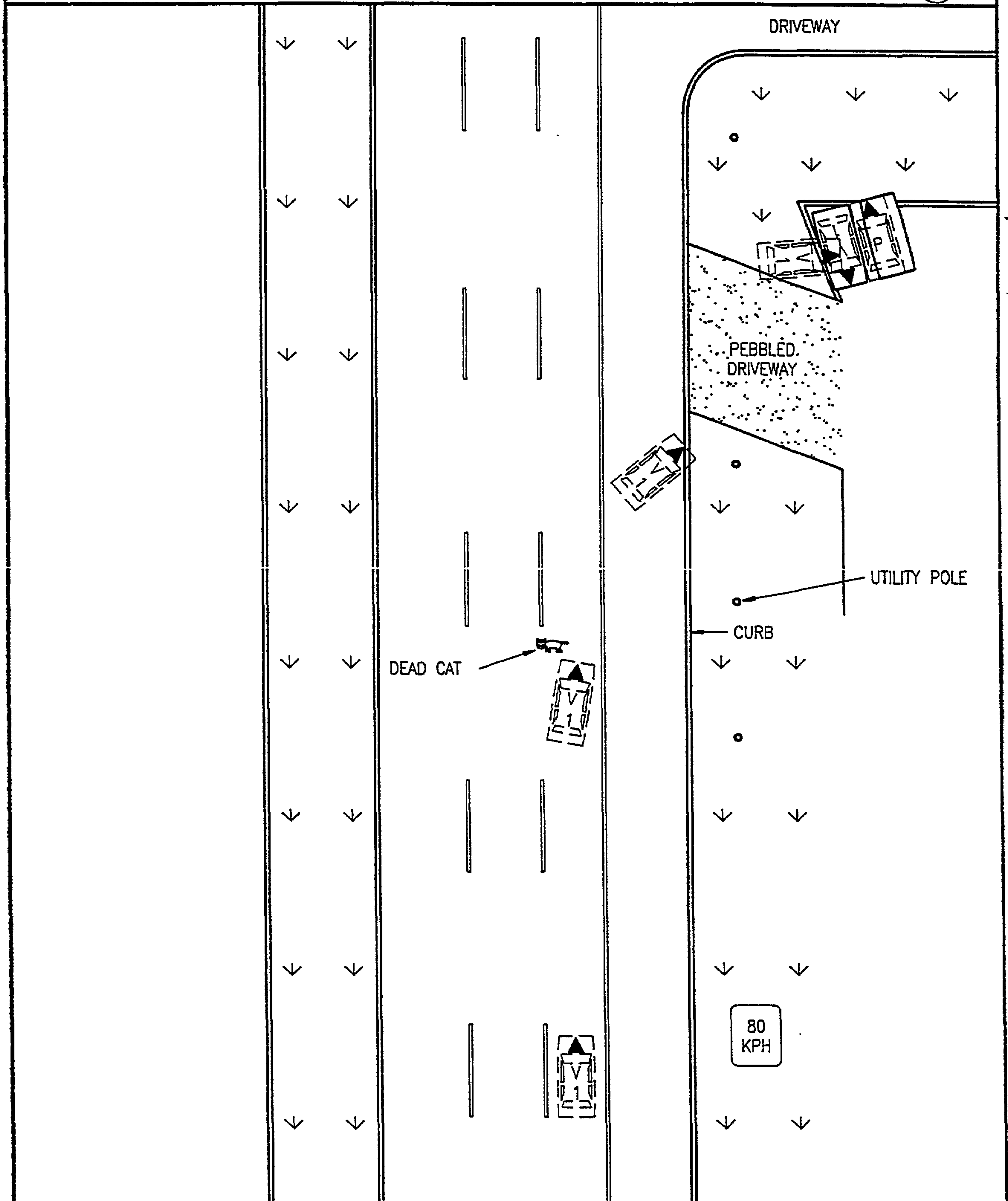


Figure 3-5

Table 3-2
Single Vehicle Run-Off-Road Crashes
Relation to Roadway by Crash Type

		Relation To Roadway		
Crash Type		On Roadway	Off Roadway/ Shoulder*	Other & unknown
Right Roadway Departure	Drive Off Road	N/A	237,000	1,000
	Control/Traction Loss	N/A	224,000	1,000
	Avoid Collision With Veh, Ped/Cyclist, Animal	N/A	47,000	0
	Other or Unknown Specifies	N/A	6,000	0
Left Roadway Departure	Drive Off Road	N/A	137,000	2,000
	Control/Traction Loss	N/A	174,000	0
	Avoid Collision With Veh, Ped/cyclist, Animal	N/A	32,000	0
	Other or Unknown Specifies	N/A	5,000	1,000
Forward Impact	Forward Impact to Parked Vehicle	0	308,000	5,000
	Forward Impact to Stationary Object	22,000	2,000	0
	Forward Impact to Pedestrian/Animal	356,000	8,000	2,000
	Forward Impact, End Departure	0	29,000	0
	Other or Unknown Specifies	7,000	5,000	1,000
Backing	Backing Vehicle	2,000	76,000	1,000
	Total	387,000	1,290,000	14,000

* Single Vehicle Run-Off-Road crashes (shaded) = 1,206,000 (71.3%)
Single Vehicle crashes/Not Run-Off-Road = 485,000 (28.7%)

Table 3-2 is further summarized in Table 3-3 which tabulates the target crash population by crash type irrespective of the direction of roadway departure. The four most dominant crash types constitute approximately 96 percent of the population. The other two crash types contained in this population (e.g., Forward Impact, End Departure - 2.4 percent and Forward Impact to Stationary Object - 0.2 percent) are relatively minor contributors. The Forward Impact, End Departure crash type typically involves the circumstances where a subject driver is approaching a T-intersection, traveling along the stem of the T. The subject driver fails to stop for the intersection, crosses the intersecting roadway, and then departs the roadway at the opposite side of the intersecting roadway (end departure). The most frequent impact configuration involves contact between a stationary object and the frontal plane of the subject vehicle. Rollovers are also a frequent event. The Forward Impact to Stationary Object crash type **is** again similar to the Drive Off Road crash type. In the forward impact scenario, however, the object is usually located at or very close to the edge of the roadway.

Table 3-3
Single Vehicle Run-Off-Road Crashes
Summary of Crash Types

	Relation To Roadway		
Crash Type	Off Roadway/Shoulder	%	Cum %
Drive Off Road	374,000	31.0	
Control/Traction Loss	398,000	33.0	64.1
Avoid Collision With Veh, Ped/cyclist, Animal	79,000	6.5	70.6
Forward Impact To Parked Vehicle	308,000	25.5	96.1
Forward Impact, End Departure	29,000	2.4	98.5
Forward Impact To Stationary Object	2,000	0.2	98.7
Other or Unknown Specifics	16,000	1.3	100.0
Total	1,206,000	**100.00**	

3 3 Rudimentary Characteristics of Target Crash Population

At this stage, it is informative to examine a few key characteristics of the target crash population. Table 3-4 provides the crash and injury/fatality distributions by vehicle type within the population. Note that the run-off-road crash is primarily a passenger vehicle problem in that this vehicle type (which includes light trucks, vans, and sport/utility vehicles) comprises approximately 86 percent of the target crash population.

Run-off-road target crashes comprise approximately 20.1 percent of the GES file crashes. As indicated in Table 3-4, more than 520,000 vehicle occupants are injured in run-off-road target crashes each year. This level of injury represents approximately 36.8 percent of the injured occupants in the GES file. Thus, in terms of injury frequency, the run-off-road target crash population is overrepresented. In a similar manner, the 14,031 fatalities sustained in run-off-road crashes (FARS data) represent approximately 41.5 percent of 33,846 in-vehicle fatalities that occurred in 1992. Thus, in terms of injury severity, the run-off-road target crash population is again overrepresented.

Table 3-4
Single Vehicle Run-Off-Road Crashes*
Crash and Injury/Fatality Distributions by Vehicle Type

		All Vehicles	Passenger Vehicles	C.U.T.	S.U.T.	Motor-cycles
Annual # PR Crashes (GES)	Total:	1,206,000	1,039,000	23,000	19,000	15,000
	Injury:	414,000	388,000	5,000	3,000	13,000
	PDO:	792,000	651,000	19,000	15,000	1,000
Annual # Fatalities (FARS)		14,031	12,637	221	77	935
Annual # Non-Fatal PR Injuries (GES)	Total:	523,000	495,000	5,000	4,000	14,000
	A:	108,000	100,000	1,000	1,000	4,000
	B:	227,000	213,000	2,000	2,000	8,000
	C:	188,000	182,000	2,000	1,000	2,000

* All crash statistics are rounded to the nearest 1,000

Legend:

C.U.T. Combination Unit Truck
S.U.T. Single Unit Truck
A Incapacitating Injuries
B Nonincapacitating Injuries
C Possible Injuries
PDO Property Damage Only
PR Police Reported

Tables 3-5 and 3-6 examine roadway alignment and roadway surface condition for fatal vs. all run-off-road crashes, respectively. In Table 3-5, the proportion of fatal crashes occurring on curves (42.4 percent) is significantly higher than the proportion of all run-off-road crashes occurring on curves (24.4 percent). In Table 3-6, the proportion of fatal crashes occurring on dry surfaces (81.4 percent) is again, higher than the proportion of all run-off-road crashes (63.6 percent). As will be demonstrated in Section 5.0, there is a reason for this dry/curve bias in more severe crashes. Specifically, this bias is associated with excessive vehicle speed and alcohol consumption factors that are associated with more severe crashes.

Table 3-5
Roadway Alignment
Fatal Vs. All Run-Off-Road Crashes

Roadway Alignment	FARS		GES	
	Fatal Crashes	% of Fatal Crashes	All Crashes	% of All Crashes
Straight	7,653	57.3	857,296	71.1
Curve	5,665	42.4	294,721	24.4
unknown	29	0.2	53,816	4.5
Total	13,347	99.9	1,205,833	100.0

Table 3-6
Roadway Surface Condition
Fatal Vs. All Run-Off-Road Crashes

Roadway Surface Condition	FARS		GES	
	Fatal Crashes	% of Fatal Crashes	All Crashes	%. of All Crashes
Dry	10,867	81.4	766,444	63.6
Wet	1,964	14.7	272,855	22.6
Snow/Slush	145	1.1	31,344	2.6
Ice	245	1.8	98,771	8.2
Sand/Dirt/Oil	17	0.1	5,004	0.4
Other	32	0.2	7,432	0.6
Unknown	77	0.6	23,98 1	2.0
Total	13,347	99.9	1,205,831	100.0

A more detailed statistical profile will be constructed for the GES database in Section 5.0. This profile will then be compared to the profile constructed for the clinical database in that same section to ensure that the clinical database is reasonably representative of the national crash population. Some of the biases noted here, with respect to severe crashes, will again be evident in that comparison since the NASS CDS database oversamples more severe crashes.

4.0 Definition Of Dynamic Scenarios

Section 3.0 established the siie of the single vehicle run-off-road target crash population and the specific crash types which comprise this population. This section establishes the analysis format that will be used to determine dynamic scenarios for all cases in the clinical sample and to subsequently compare groups of similar scenarios. The dynamic scenarios for individual cases involve specification of vehicle status during the immediate pre-crash sequence. The project staff believes that for this program, complete specification of the dynamic scenario for each case must include vehicle status both on-and off-road. This issue will be addressed further in the subsection which follows.

4.1 Dynamic Situation Trees

Dynamic scenario descriptions delineate existing conditions related to crash occurrence (driver state, vehicle state, environmental conditions), driver/vehicle actions or events, driver corrective actions initiated to avoid the crash, and vehicle responses to these corrective actions. In the ideal circumstance, many of the elements which would comprise a given dynamic scenario are available as analytical parameters. For example, the vehicle state is expressed in terms of steady state velocity units and subsequent accelerations and driver actions are expressed as precise units of steering (degrees of steering change) and braking (achieved braking efficiency) inputs. Availability of parameters of this type allows the crash sequence to be expressed in equation form. The advantages of this format with respect to evaluating various intervention opportunities/change mechanisms are rather obvious.

Unfortunately, the NASS CDS file and supporting hard copy case reports do not contain sufficient detail to allow parameters to be expressed with this degree of precision. This observation, is not intended as a criticism since the NASS data collection protocol was never intended to support evaluation efforts of this type. If less precise surrogate variables are used to indicate status/state for these scenarios, the NASS cases are a valuable and useful data source. The project staff selected the latter approach and designed a scenario documentation format which was descriptive, as opposed to analytical, in nature. The staff also elected to represent the dynamic scenarios as situation trees. The data entry/reduction format is shown in Figure 4-l.

Early versions of the format shown in Figure 4-l did not include provision for documenting the off-road dynamic state in individual cases. Coding tests performed with those formats indicated that virtually all cases were contained within three major groups and there were very small distinctions between the groups. To obtain stronger differences between cases and groups of cases, description of the off-road dynamic state was added. In addition **to** improving the degree of the differentiation between cases, this element allowed the project staff to evaluate the driver's response to roadway departure. Specific response patterns are discussed in Section 5.4.

It is important to note that the final format incorporates unintended driver actions. During preliminary case evaluations it was noted that drivers, on occasion, imparted steering input that was not associated with attempted avoidance maneuvers. For example, in cases where the driver relinquished steering control, the vehicle might depart the roadway at a departure angle that was larger than angles typically associated with vehicle drift trajectories. In these cases, it was obvious

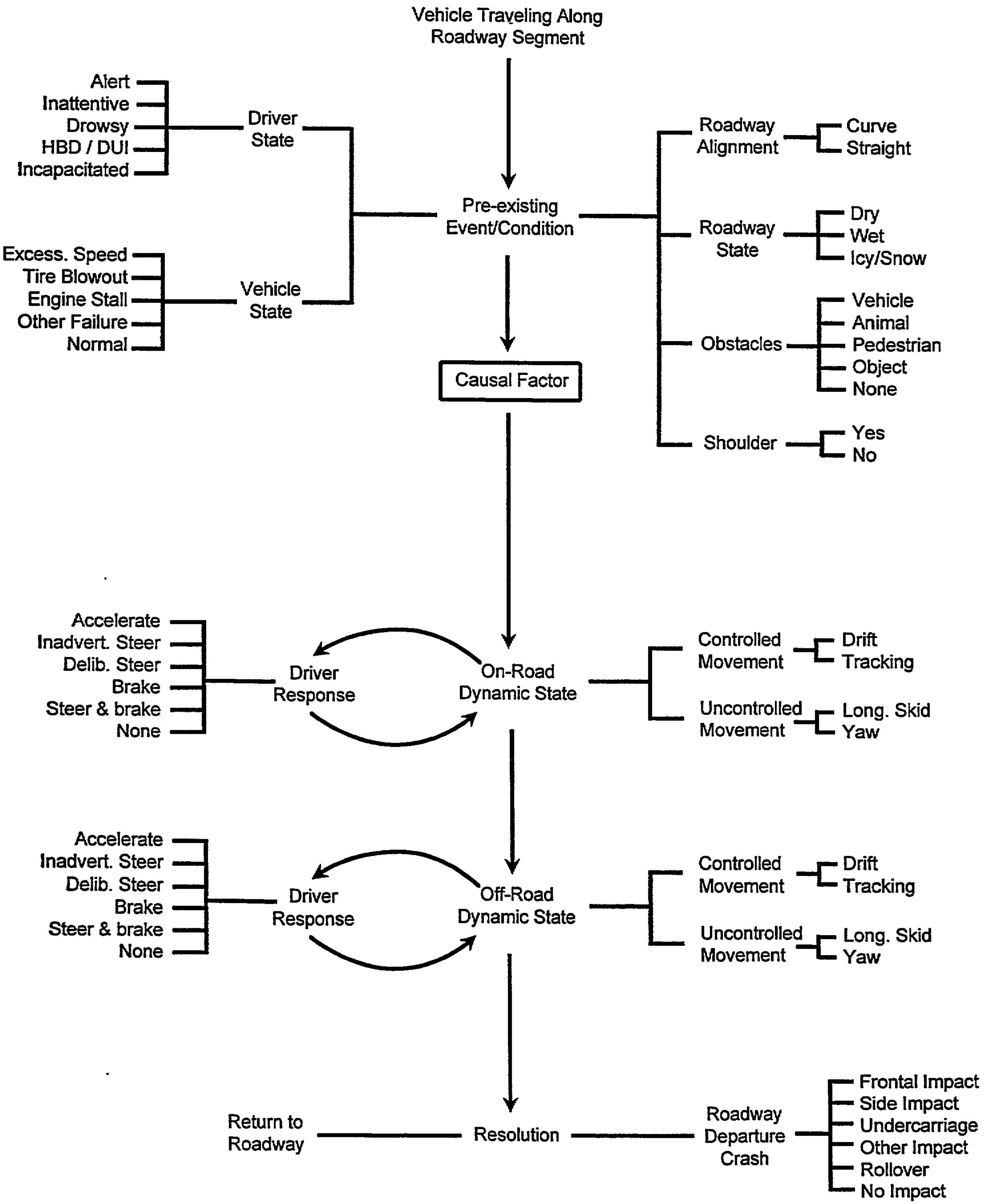


Figure 4-1 Vehicle Dynamic Scenario

that the driver had initiated an unintended or inadvertent steering input. If there is no on-road avoidance maneuver, the inadvertent steering input is noted to indicate that the departure trajectory diiers from drift trajectories and to indicate the source of this variance.

The causal factor designation in this figure represents the subset of pre-existing events/conditions which directly contribute to crash occurrence. These pre-existing events/conditions may or may not reflect the critical event which triggers crash occurrence. For example, in a case where the causal factor is relinquishing steering control, the causal factor and the critical event are synonymous. However, in a case where the causal factor is excessive vehicle speed, there is usually a separate critical event (e.g., passing the point where the driver can safely decelerate to the design speed of the curve).

The engineering analysis conducted to determine dynamic scenarios is described in the subsection which follows. That discussion is followed by a discussion of how analysis results and this specific analysis sequence will be incorporated in Task 2.

4.2 Application of Dynamic Situation Trees

Dynamic situation trees were developed for each case contained in the clinical database. Primary information sources for the analysis included the coded data variables recorded for each case, the case description/summary prepared for each case, and the scaled accident schematic prepared for each case. The case summary and scaled accident schematic for a typical case (Case No. 13-165C) have been abstracted from the clinical database. The case summary is presented below and the scaled schematic is provided in Figure 4-2.

Case No. 13-l 65C
Case Summary

This crash occurred on a four lane, dry, asphalt, divided interstate. The four lanes were divided into two, two lane, one-way limited access roadways and were separated by a tree Iined median. The road was level and in good condition with a solid yellow Ieft road edge line, white broken lane lines and a solid white right edge line. AII pavement markings were in new condition. Reflective delineators were onIy present on the right side. The weather was clear with no adverse daylight conditions. The driver apparently fell asleep while driving in the left lane at a speed of 105-113 kph (65-70 mph) based on calculations using the radius of sideslip curvature formula. The vehicle exited the left side of the roadway crossed the I.2 m (4 ft) paved shoulder and traveled on the grass area adjacent to the shoulder At some point along this travel path (approximately 50 m) the driver steered to the right which started the vehicle into a clockwise rotation and reversed the travel path back onto the roadway. It traveled across the roadway and departed the right side where it began a right over left rollover sequence after the left side tires furrowed into the ground The vehicle then contacted two trees with its left side after one complete rollover. The finaI rest position of the vehicle was against three trees which were approximately 12 m (40 ft) from the road edge line. The causalfactor was relinquished steering control, fell asIeep.

ACCIDENT COLLISION DIAGRAM

CU No. 13 Case Number – Stratum 165C Indicate North

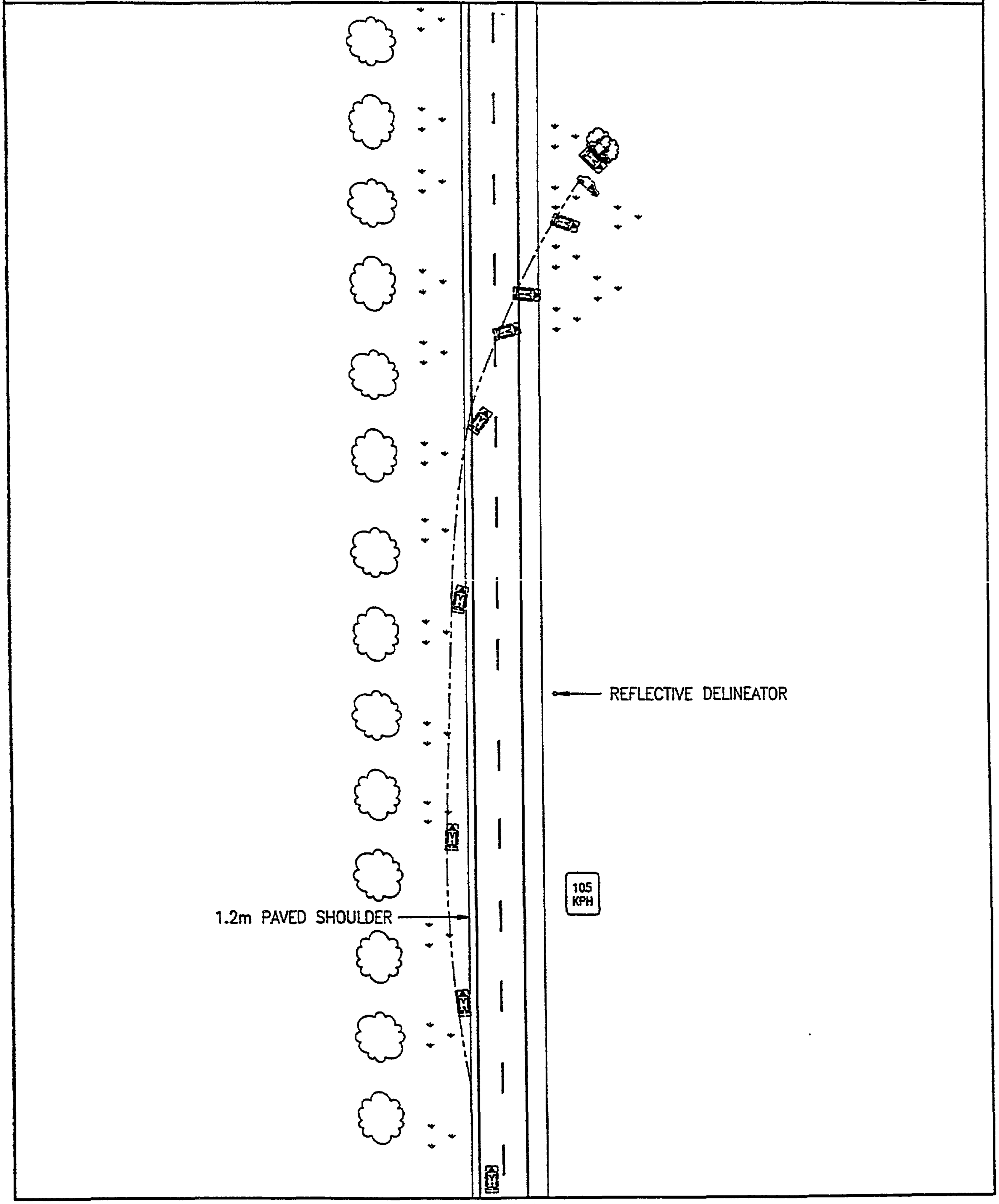


Figure 4-2

Scale: 1/750

In this example case, the driver fell asleep rehnquishing steering control. The subject driver apparently woke as the vehicle traversed a grassy area adjacent to the shoulder and initiated a sharp steering correction to the right in an attempt to regain the roadway. This steering correction induced a clockwise yaw as the subject vehicle reentered the roadway. Steering control was lost at the point of yaw initiation and the vehicle is considered to be non-recoverable (in terms of steering control) from this point through final rest position.

The completed situation tree for this example case is provided in Figure 4-3. Specific variable selections on this format are self-explanatory. The most interesting aspect of this particular case is the driver's response to roadway departure (steering correction) and the subsequent vehicle response (yaw). As will be discussed in Section 5.4, the circumstance where drivers initiate steering corrections (as avoidance actions) which result in or induce vehicle yaw responses is fairly common, This tendency, in turn, has negative design implications with respect to countermeasure/concepts that require or assume that the driver will respond appropriately to simple warnings. These design implications which are addressed in Section 5.4.4, are not considered to be a detriment to successful design concepts nor will they seriously impede countermeasure effectiveness. The project team, however, must be aware of the implications and avoid overly simplistic approaches.

Situation trees were completed for the entire 201 case clinical sample. These trees were recorded in the electronic database and subsequently grouped and analyzed. Analysis results are reported in section 5.4. These results include distribution frequencies for all blocks of variables shown in Figure 4- 1.

4.3 Extension of Analysis Sequence

The situation trees developed in Task 1 will be carried forward to Task 2 to carefully evaluate opportunities for intervention through countermeasure application. Figure 4-4 illustrates one potential set of intervention opportunities where the attendant intensity of action ranges from informing the driver of poor roadway conditions to assuming control of the vehicle to prevent roadway departure/recover from roadway departure. Figure 4-4 represents only one potential set of actions. Other intervention opportunities, depending on the specific combination of elements within the situation tree, could be selected. For example, the countermeasure may sense appropriate indicators in the driver's state or the vehicle's state and issue advisories as appropriate. Similarly, the system may sense the off-road dynamic situation and respond accordingly.

In Task 2, siiar situation trees will again be grouped and analyzed to determine the most suitable opportunities for intervention within each similar group. An integral part of this effort will involve preparation of timeline histories for the crash event sequences contained in the clinical database. At the present time, it appears that there is sufficient information in the case files to reconstruct timelines for a substantial portion of the clinical sample (i.e., 84 of the 201 cases in the sample contain sufficient detail to provide reasonably accurate time histories). This information and associated analytical parameters (e.g., velocity and achieved braking efficiencies) will be used in conjunction with the dynamic scenario trees to identify viable functional goals. The analytical parameters associated with the timeline histories will establish a quantitative basis for the functional goal development process.

13-165C

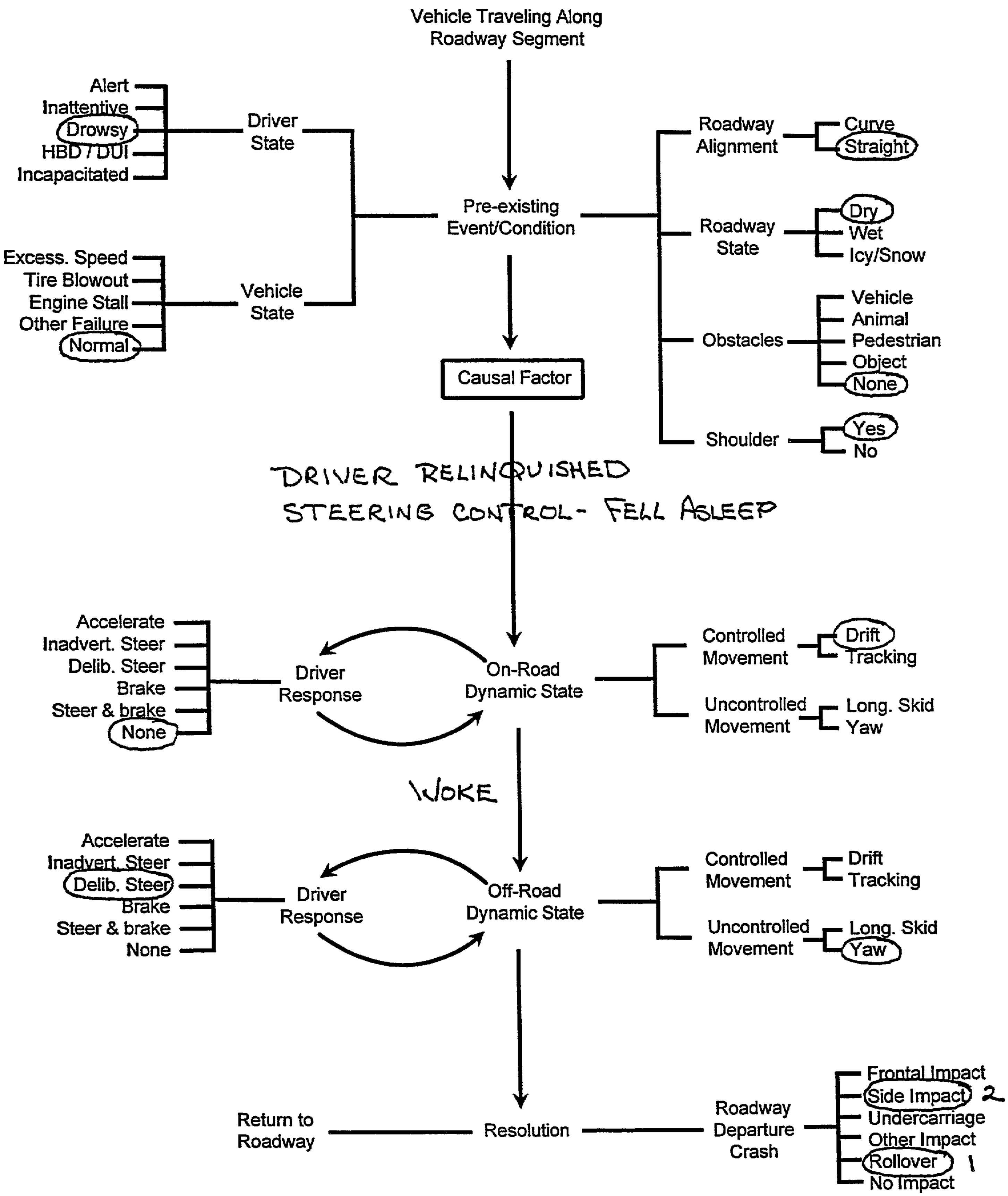


Figure 4-3 Vehicle Dynamic Scenario

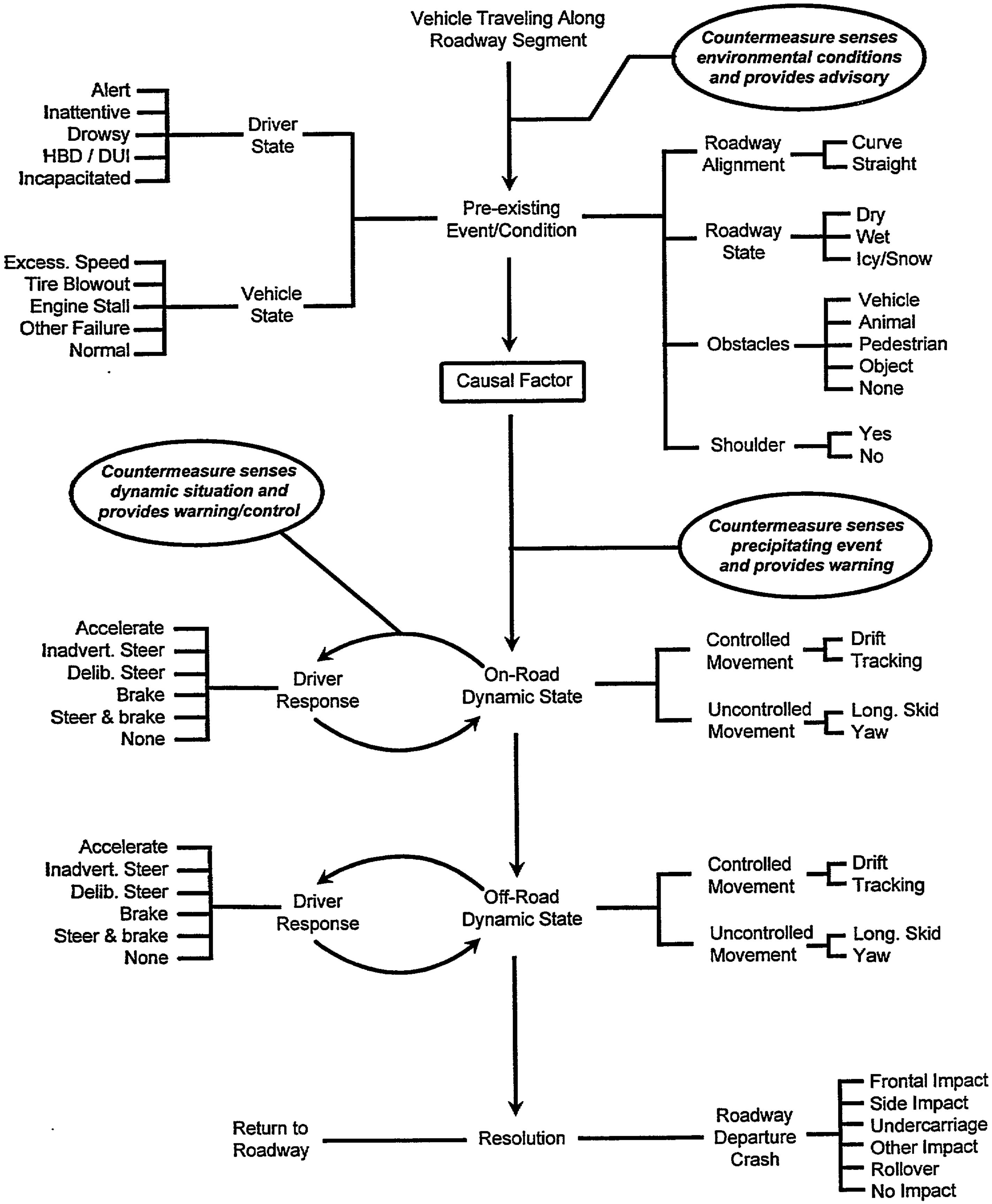


Figure 4-4 **Vehicle Dynamic Scenario with Opportunities for Intervention Identified**

The functional goals developed in Task 2 will be appropriately matched with specific intervention opportunities identified within groups of similar situation trees. In the early stages of this development sequence, functional goals will be expressed as logical statements or sets of logical statements. As common sets of goals are identified, these sets will be merged. All sets remaining at the end of this process will, to the extent possible, be converted to mathematical expressions.

The situation trees and summaries of the characteristics of similar groups of situation trees, developed in Task 1, will also be useful to scheduled Task 3 and Task 4 activities. Specifically, this information source will be used to develop evaluation scenarios in Task 3. These scenarios will be used in a simulator environment to evaluate performance characteristics and the potential effectiveness of existing countermeasure systems/prototypes. In Task 4, this same data will be used to develop computer models. These models, in turn, will be used to evaluate the potential effectiveness levels of countermeasure concepts.

5.0 Analysis Of Run-Off-Road Crash Problem

The magnitude or size of the run-off-road crash problem was established in Section 3.0. This section examines the characteristics and circumstances associated with the national crash population (statistical analysis), examines these same factors within the clinical case sample (clinical analysis), establishes causal factors within the clinical case sample (clinical analysis), and establishes the dynamic scenarios associated with the clinical sample (engineering analysis). As noted in Section 2, the statistical and clinical analyses set the stage and feed the engineering analysis. The objectives of each component of the analysis sequence and of the overall analysis sequence are presented in Section 5.1 which follows. The results of these analyses are presented in subsequent subsections.

5.1 Objectives of Analysis Sequence

The overall objective of this sequence is to analyze the crash problem with sufficient depth ***to*** ensure that the project team and the sponsor understand the nature of the problem, the specific parameters/circumstances/characteristics associated with the problem, and the points in these crash sequences where countermeasure application is most likely to succeed. Unfortunately, there is no single analysis type/form which provides the required depth of understanding and clarity of insight to this crash problem or to any of the other crash problems under consideration in the current round of performance specification programs. To satisfy the overall analysis objective, individual analysis types and results must be combined in a **logical** format. The project team has selected a combination of statistical, clinical, and engineering analysis sequences to provide the required depth of understanding and clarity of insight for the run-off-road crash problem. Each of these analysis types, in turn, has its own objectives and provides a diiering perspective of the overall crash problem. The outputs of the analyses also diier. Specific objectives and anticipated output of the selected analysis types are described below:

5.1.1 Statistical Analysis

- ***Objectives***
  - Establish circumstances in which these crashes occur and characteristics of these crashes for the national population of run-off-road crashes.
  - Determine if there are relationships between variables or groups of variables describing crash circumstances/characteristics.
- ***Anticipated Output***
  - Profile of characteristics/circumstances associated with the national population of run-off-road crashes.
  - Delineation of the relationships between key variables contained in the GES database for this crash type (e.g., series of bivariate and trivariate analyses).

- ***Discussion***

The profile of characteristics/circumstances is used in a dual capacity. This information provides insight to the nature of run-off-road crashes and, therefore, increases the knowledge base with respect to these crashes. In addition, this same profile functions as a comparison standard to determine if the clinical sample examined in this sequence is representative for the national crash population.

Delineation of the relationships between variables in mass databases, such as the GES file, is particularly important with respect to providing insight to the nature of the crash problem. A rudimentary example of this type of analysis was provided in Section 3.0 where the relationship between crash severity (injury level), horizontal roadway alignment, and roadway surface condition was examined. In that analysis, it was noted that fatal crashes were over-represented in terms of occurring on curves where the road surface was dry. There are two points which should be made with respect to this finding. First, the analysis sequence in Section 3.0 could have been completed with a single trivariate analysis rather than the series of analyses that were used. These more complex analyses will be completed and examined in this section. Secondly, the finding is relatively important since it indicates that weather is not a major factor in more severe crashes. As will be demonstrated in this section, the more severe crashes tend to be related to driver factors such as excessive speed and alcohol consumption. Findings of this type are clearly required to develop an in-depth understanding of the crash problem,

5.1.2 Clinical Analysis

- ***Objective***
  - \+ Establish circumstances in which these crashes occur and characteristics of these crashes for the selected clinical sample.
  - \+ Establish causal factors for cases contained in the clinical sample.
  - \+ Examine crash circumstances to determine if there are similarities between crashes which allow identification of crash subtypes.

- ***Anticipated Output***
  - \+ Profile of crash circumstances/characteristics associated with the clinical sample of run-off-road crashes.
  - \+ Causal factors for each case contained in the clinical sample.

- ***Discussion***

The profile of crash circumstances/characteristics established for the clinical sample is compared to the previously established statistical profile to verify that the clinical sample is reasonably representative of the national crash population. Differences between the profiles must be explained. The process of accounting for differences and determining if specific levels of over - or underrepresentation are acceptable provides additional insight to the nature of the data sources and the crash problem.

There is insufficient detail available in mass databases to establish causal factors. These factors are established through clinical evaluation of hard copy case reports. The process involves use of most of the major case components, however, heavy emphasis is placed on a number of critical elements such as police accident reports, scaled schematics, driver and witness interview statements, and case slides documenting vehicle damage patterns and physical evidence patterns. The analysis sequence is described in more detail in Section 5.3.3.

The evaluation sequence used to identify possible crash subtypes within run-off-road crashes is very top level at this point. The primary intent is to determine if there are a few key descriptors which allow the cases to be grouped in a logical fashion. There is no defined output for this effort since final determination of crash subtypes is reserved for the engineering analysis effort. Preliminary observations in this area are noted and incorporated into the engineering analysis.

5.1.3 Engineering Analysis

- ***Objectives***
  - Establish dynamic scenarios for all cases contained in the clinical sample.
  - Establish crash subtypes by grouping similar dynamic scenarios.
  - Establish parameters within subtypes and between subtypes which are similar and identify major differences.
- ***Anticipated Output***
  - Dynamic scenarios expressed as situation trees for all cases in the clinical sample.
  - Identification of crash subtypes as derived from groupings of similar dynamic scenarios.
  - Identification of trends in key parameters (velocity, acceleration, steering inputs, braking inputs) associated with groups of similar dynamic scenarios.
- ***Discussion***

Situation trees are generated for each case contained in the clinical sample and similar trees are grouped to identify crash subtypes. Two types of general evaluations are then conducted. First, parameters within groups are compared to establish characteristics/trends within each group. Subsequently, these same parameters are compared across groups to identify similarities and differences. Similarities between groups may allow common countermeasure concept application and major differences between groups are likely to result in development of separate countermeasure concepts. Specific implications of findings are addressed within these evaluation efforts.

The project staff will complete a top-level evaluation of analytical parameter characteristics associated with groups of similar trees as part of the engineering analysis. The parameters of interest include subject vehicle velocity, driver steer input, and driver brake input. The assessments provided will be qualitative in nature rather than quantitative. A more detailed evaluation of these parameters will be completed a part of the Task 2 effort where timeline histories will be generated. These timelines will provide a quantitative basis for parameter descriptions in that task.

The next three subsections present findings associated with the analysis sequence discussed here. The presentation order of these discussions parallels the order in which the analysis sequence is described (e.g., statistical, clinical, and engineering).

5.2 Statistical Analysis

The 1992 GES database was accessed to establish the circumstances in which run-off-road crashes occur, to establish characteristics of these crashes, and to examine the strength of relationships between variables contained in the database. Three types of outputs were produced as a result of the analysis (e.g., univariate, bivariate, and trivariate distributions). Findings associated with each of these outputs are summarized below. A separate interpretation subsection is provided with each set of outputs to ensure that the findings are not contaminated by the project staff's evaluation of these findings.

5.2.1 Summary of Univariate Distributions

Univariate distributions produced as part of this analysis effort have been converted to graphical displays. These displays are provided as Figures 5-l to 5-9. Major points indicated by these displays may be summarized as follows:

- Most run-off-road crashes (approximately 75 percent) occur in suburban (43.4 percent) or rural (3 1.8 percent) environments (Figure 5-l).

- Most of these crashes occur on trafficways that are not divided (55.0 percent) and that are comprised of two travel lanes (57.3 percent). Crashes occurring on divided roadways (15.8 percent) do not appear to be a major factor, in terms of frequency, within this crash type (Figure 5-2). If the unknown values in these two charts are eliminated or distributed in the same portion as known values, the relative proportions noted here will increase significantly.

- Most run-off-road crashes occur on straight roadway segments (56.5 percent). Similarly, a predominant proportion of these crashes (61.1 percent) occur on segments having either a positive or negative grade (Figure 5-3). The observation with respect to unknown values in Figure 5-2 also applies here.

- The predominant proportion of run-off-road crashes occur in conditions where the road surface is dry (61.7 percent). Wet road surfaces (23.7 percent), however, also account for a significant portion of the crashes. Less than 12 percent of the crashes involve snow or ice covered surfaces (Figure 5-4).

- Weather conditions at the time of these crashes are predominantly clear (no adverse conditions - 73.0 percent). Rainy conditions (16.8 percent) and snow conditions (5.0 percent) contribute to a less significant degree (Figure 5-5).

- In terms of time of day, run-off-road crashes are distributed over the entire 24-hour time frame. There is, however, a distinctive pattern associated with these crashes. Crash frequency peaks in the 4 PM - 8 PM time block (20.5 percent), declines slightly in the next two blocks (8 PM - 12 AM: 19.7 percent, 12 AM - 4 AM : 17.8 percent), bottoms out in the 4 AM - 8 AM time block (11.5 percent), and then rises again in the next two time blocks (8 AM - 12 PM: 12.7 percent, 12 PM - 4 PM: 16.8 percent) as the peak time is once again approached (Figure 5-6).

- Light conditions at the time of the crash are approximately evenly distributed between daylight (45.9 percent) and night crashes (48.0 percent). Slightly less than half of those crashes occurring during the hours of darkness occur on roadway segments that are lighted (Figure 5-7).

- Most drivers involved in run-off-road crashes do not attempt a pre-roadway departure corrective action (69.3 percent). When corrective actions are attempted, braking (9.7 percent) and steering left or right (11.3 percent) are the primary actions initiated (Figure 5-8).

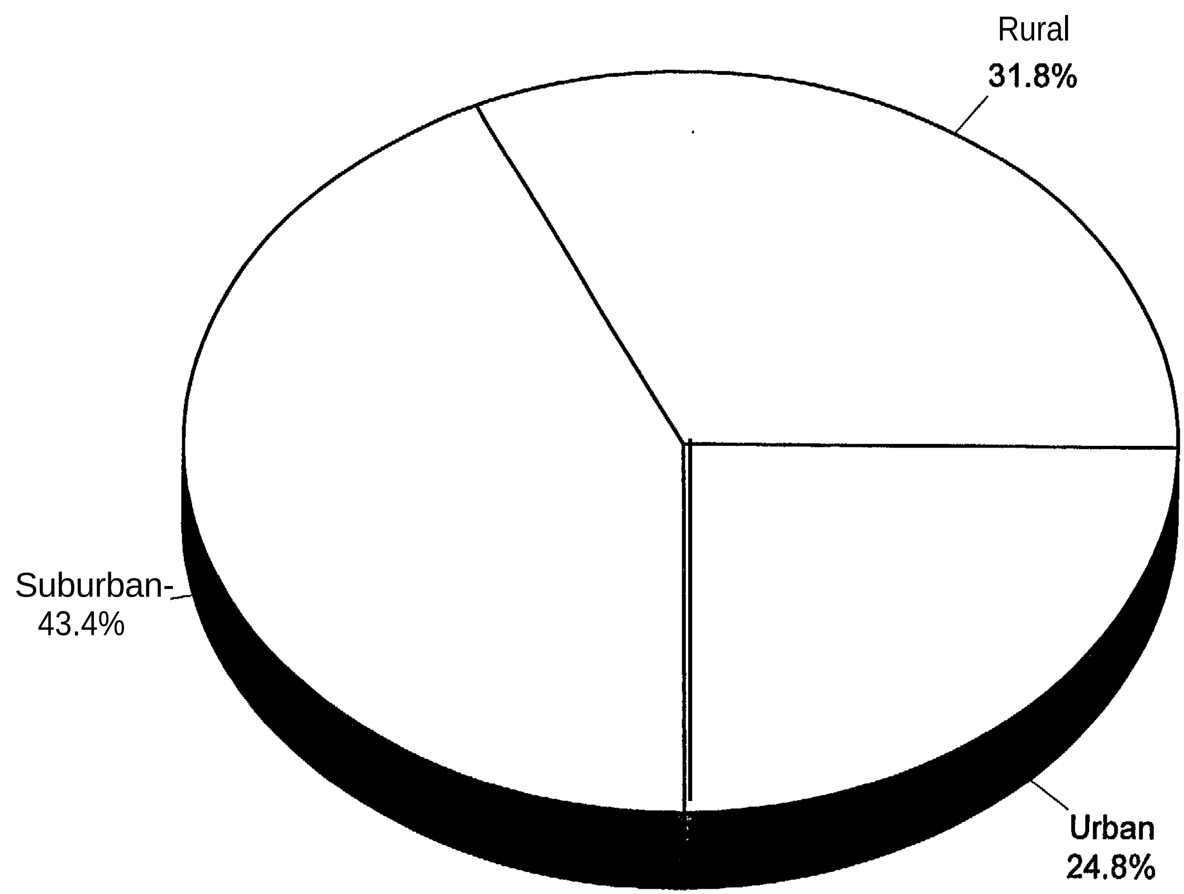
- Most run-off-road crashes do not result in citations being issued to the involved drivers (56.8 percent). In those crashes where citations are issued, drivers tend to be cited for alcohol/drug ingestion (8.3 percent), speeding (6.6 percent), combinations of these factors (1 .0 percent), reckless driving (3.5 percent), and failure to yield (3.0 percent). Other citations types issued in these crashes are typically not related to crash causation (e.g., suspended/revoked license, hit and run - Figure 5-9).

5.2.2 Interpretation of Univariate Results

There are indications in this data set that run-off-road crashes are likely to be associated with severe injury consequences. First, these crashes tend to occur in suburban and rural settings as opposed to urban environments. Speed limits, particularly in rural environments, are significantly higher than those found in urban areas. Secondly, these crashes tend to occur on dry road surfaces with no adverse weather conditions. Therefore, drivers are more likely to be traveling at or above posted speed limits. Finally, citations issued in these crashes tend to be associated with alcohol/drug

Land Use Distribution of Run-Off-Road Crashes

Weighted Percentages



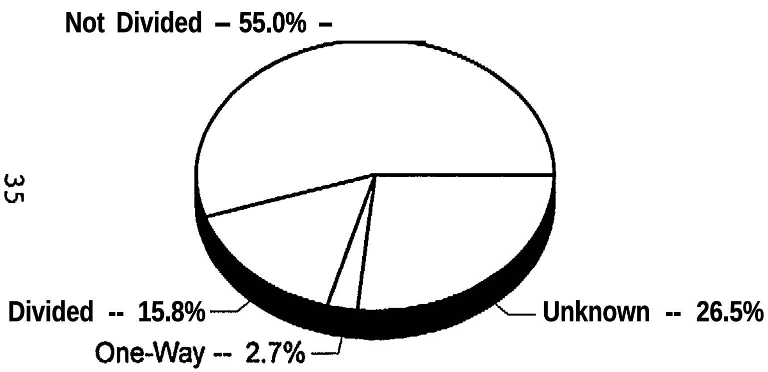
1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-1

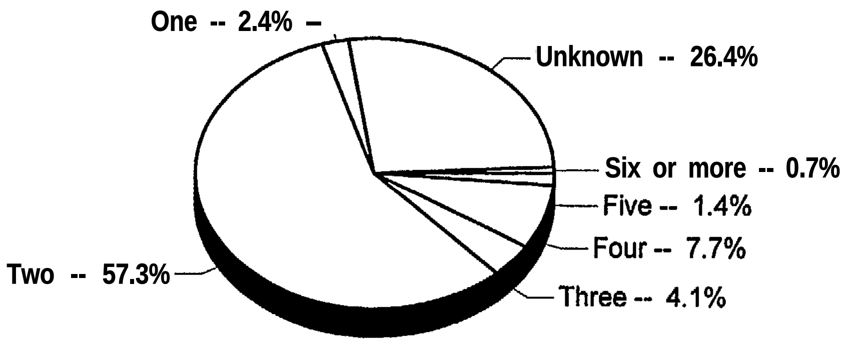
Roadway Characteristics of Run-Off-Road Crashes

Weighted Percentages

Type of Trafficway



No. of Travel Lanes



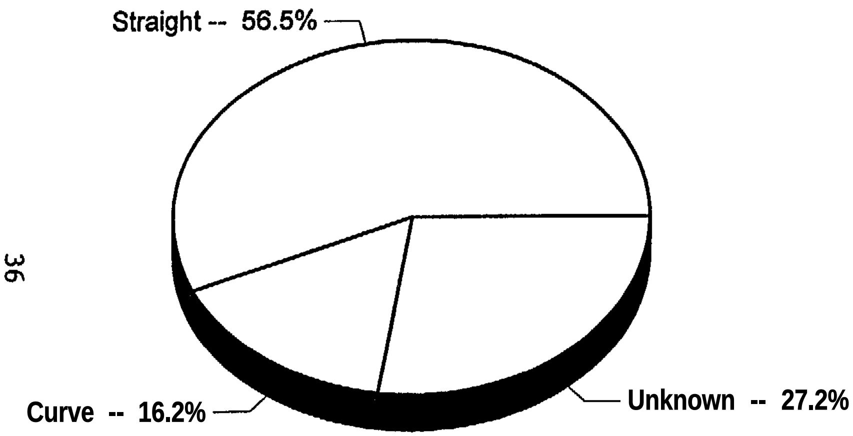
1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-2

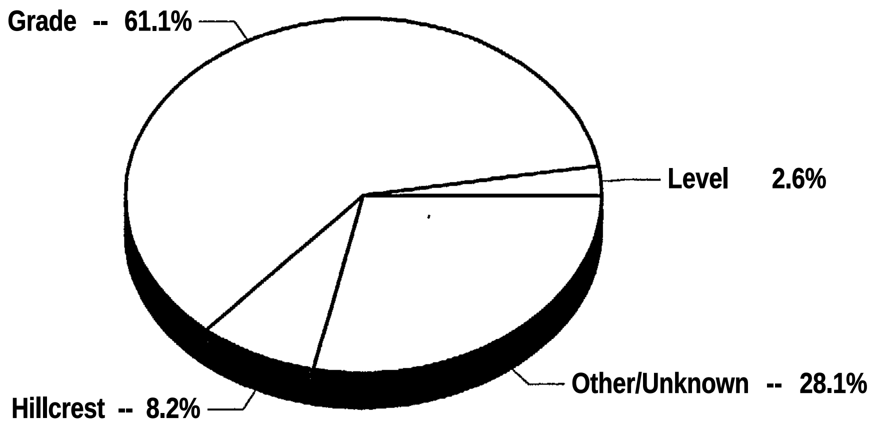
Roadway Alignment in Run-Off-Road Crashes

Weighted Percentages

Horizontal Alignment



Vertical Alignment

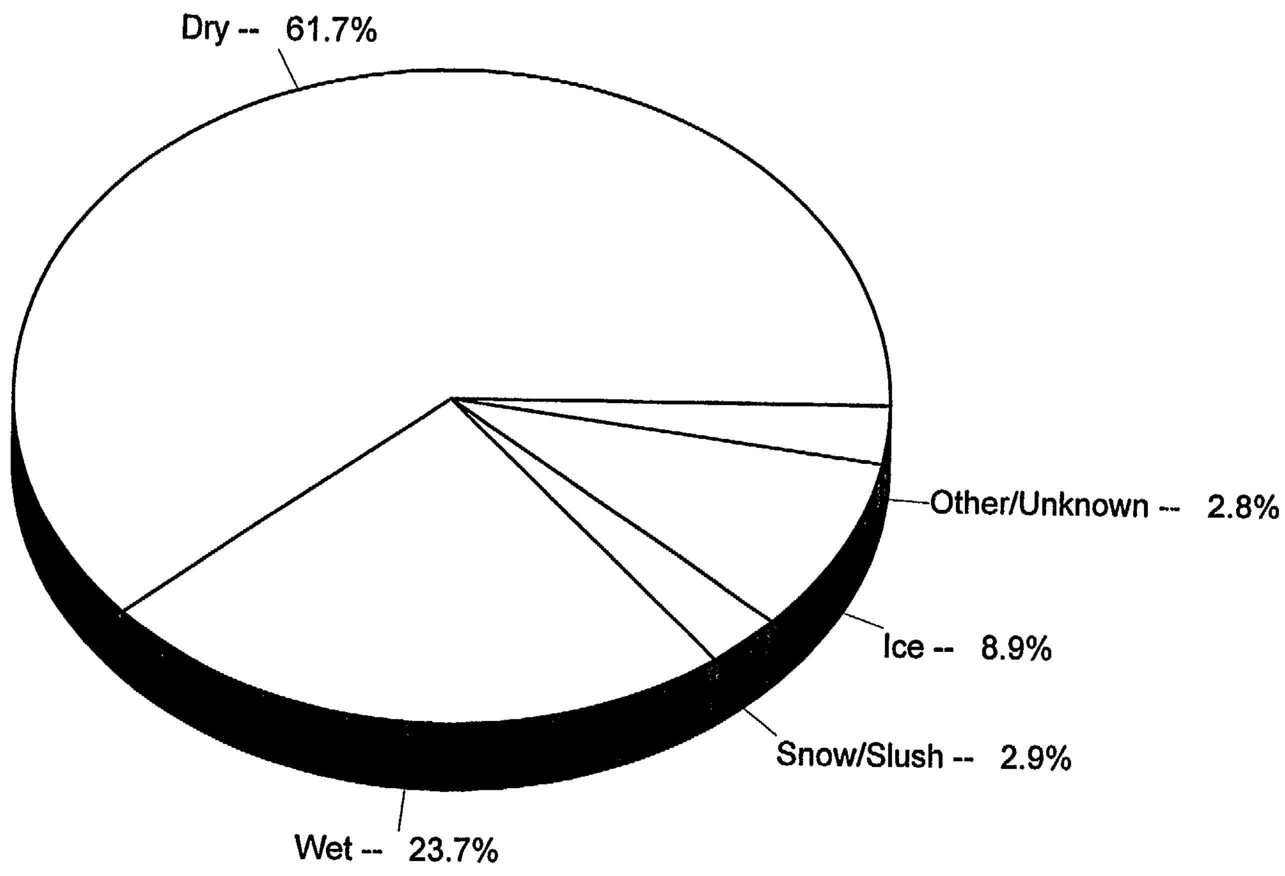


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-3

Surface Condition in Run-Off-Road Crashes

Weighted Percentages

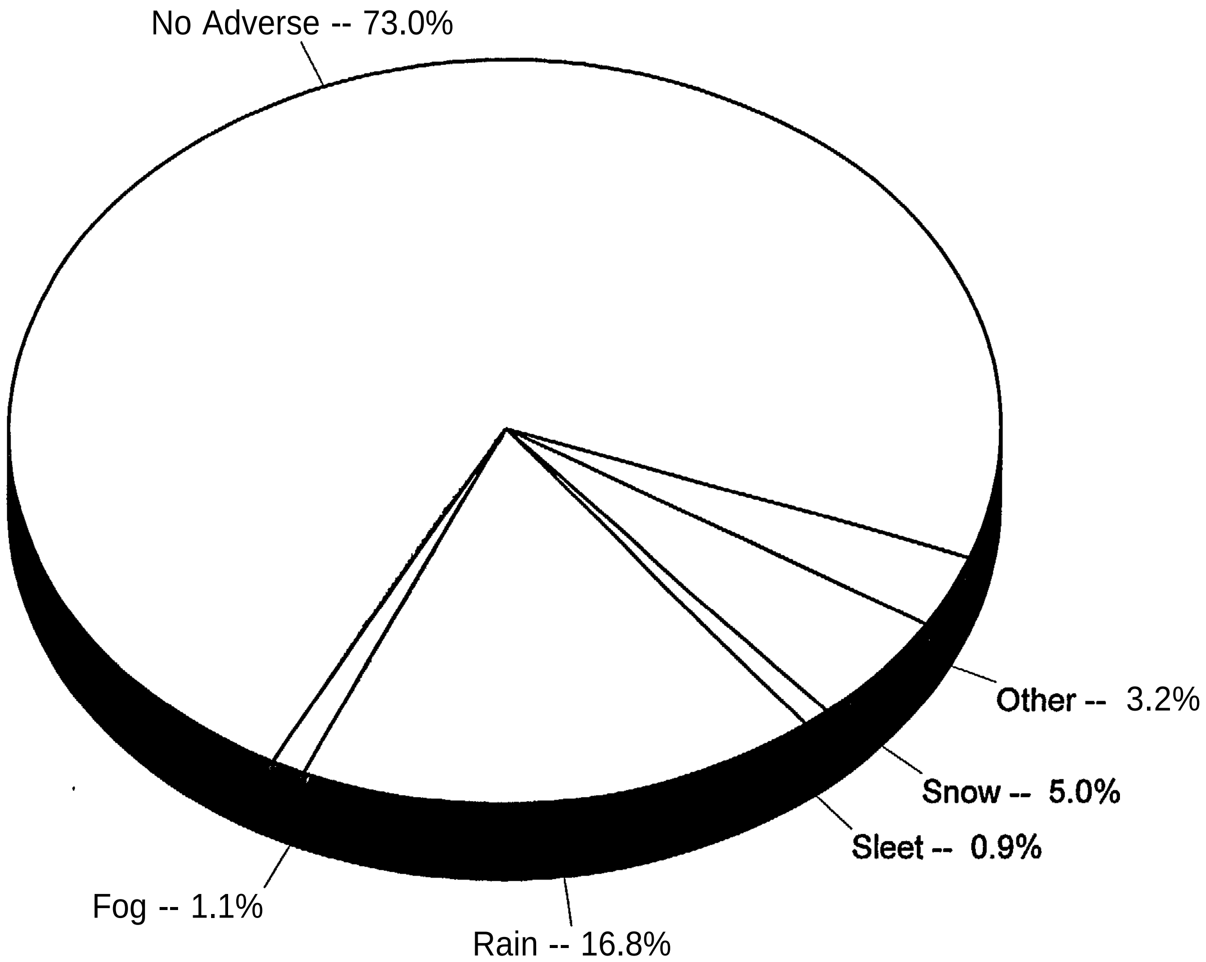


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-4

Weather Condition in Run-Off-Road Crashes

Weighted Percentages

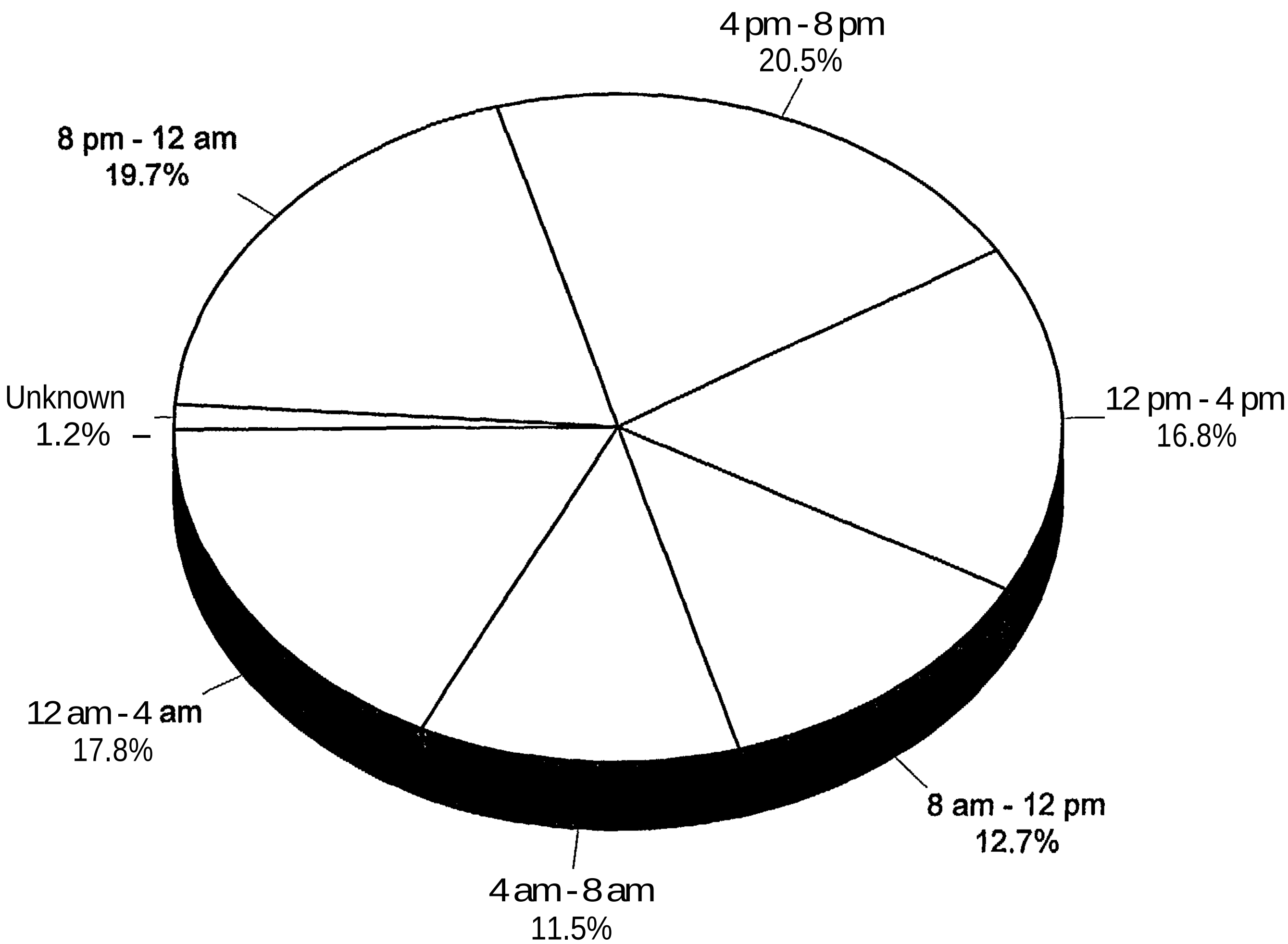


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-5

Time Distribution of Run-Off-Road Crashes

Weighted Percentages

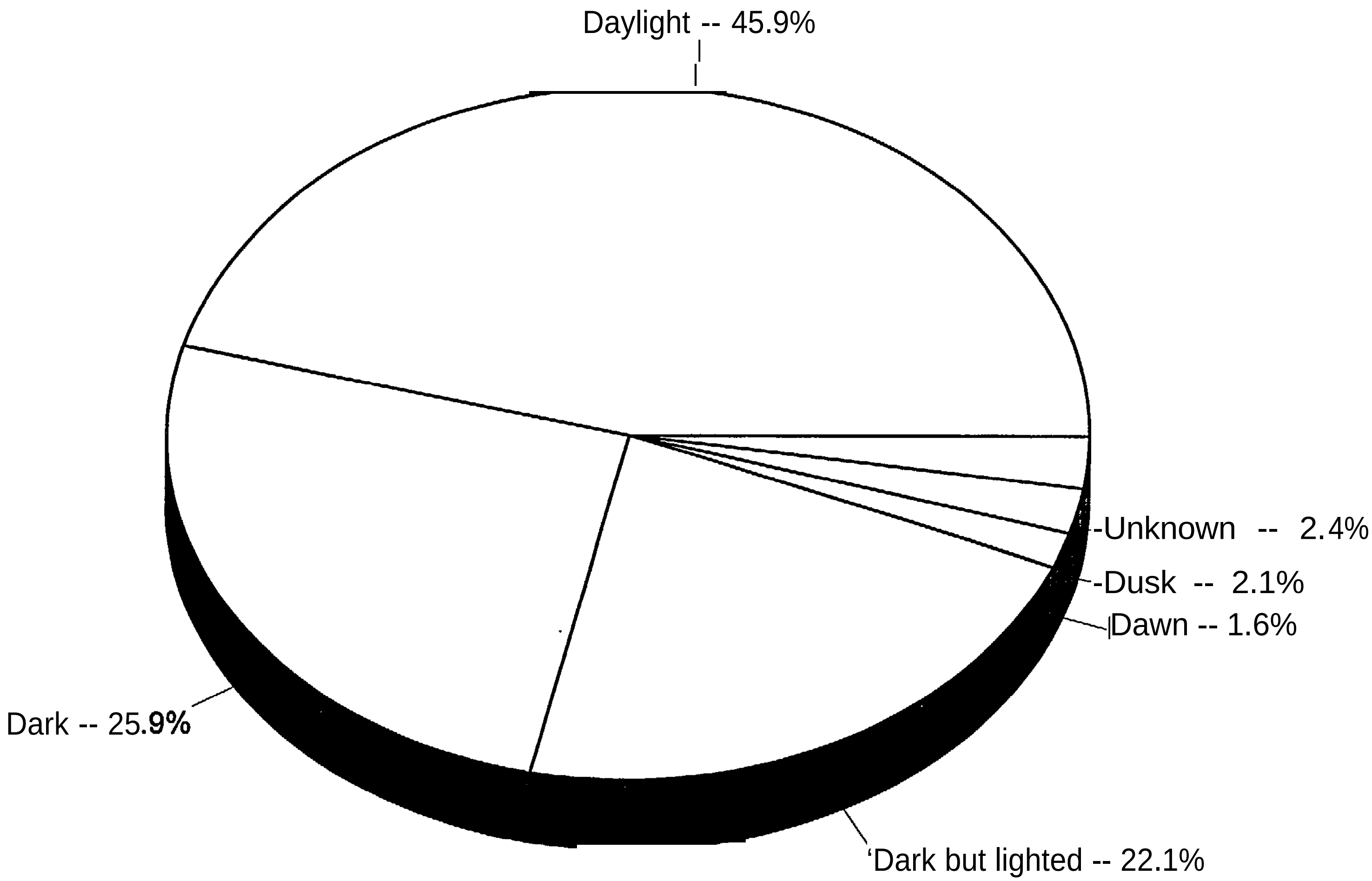


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-6

Lighting Condition in Run-Off-Road Crashes

Weighted Percentages

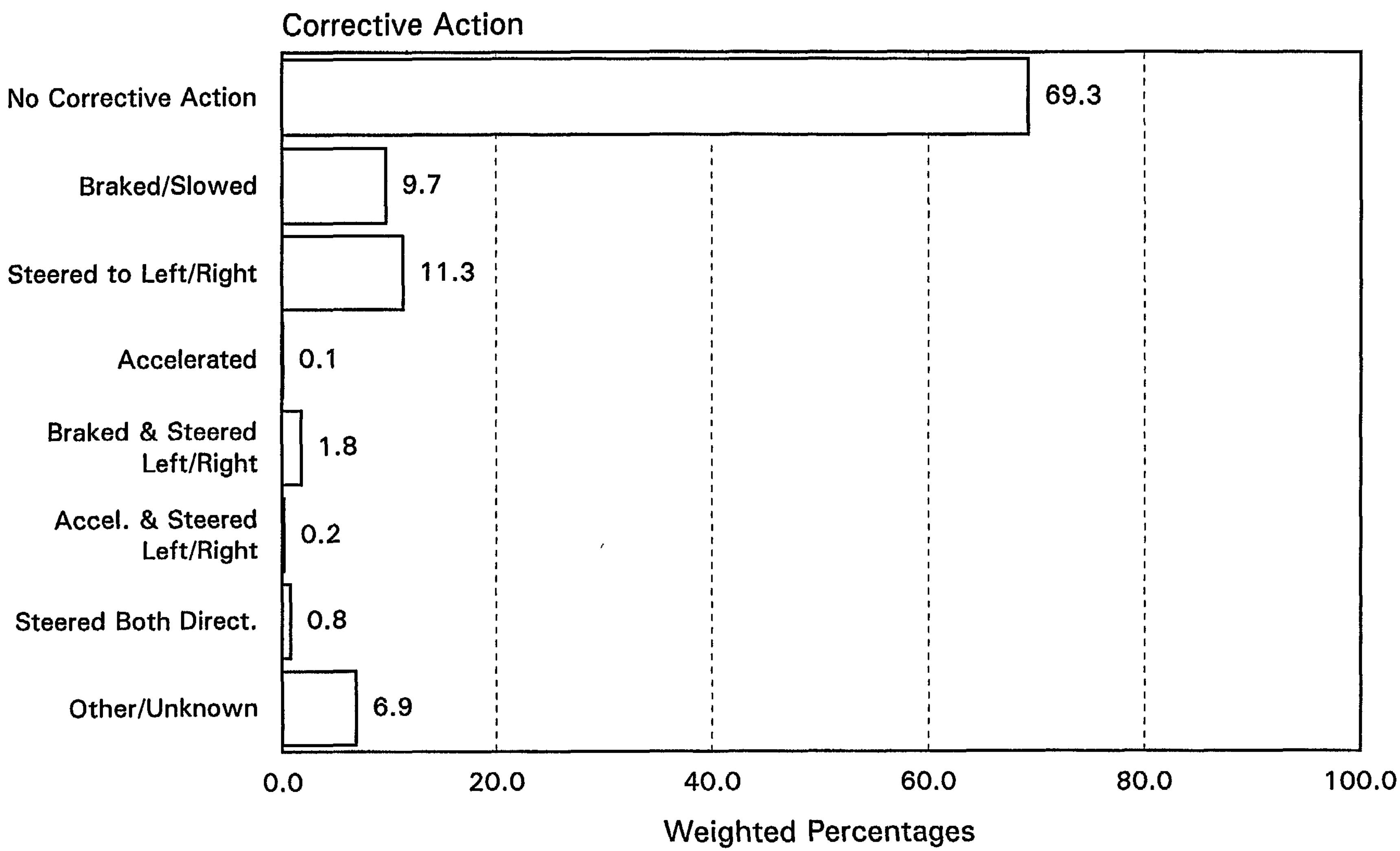


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-7

Attempted Corrective Action in Run-Off-Road Crashes

Weighted Percentages

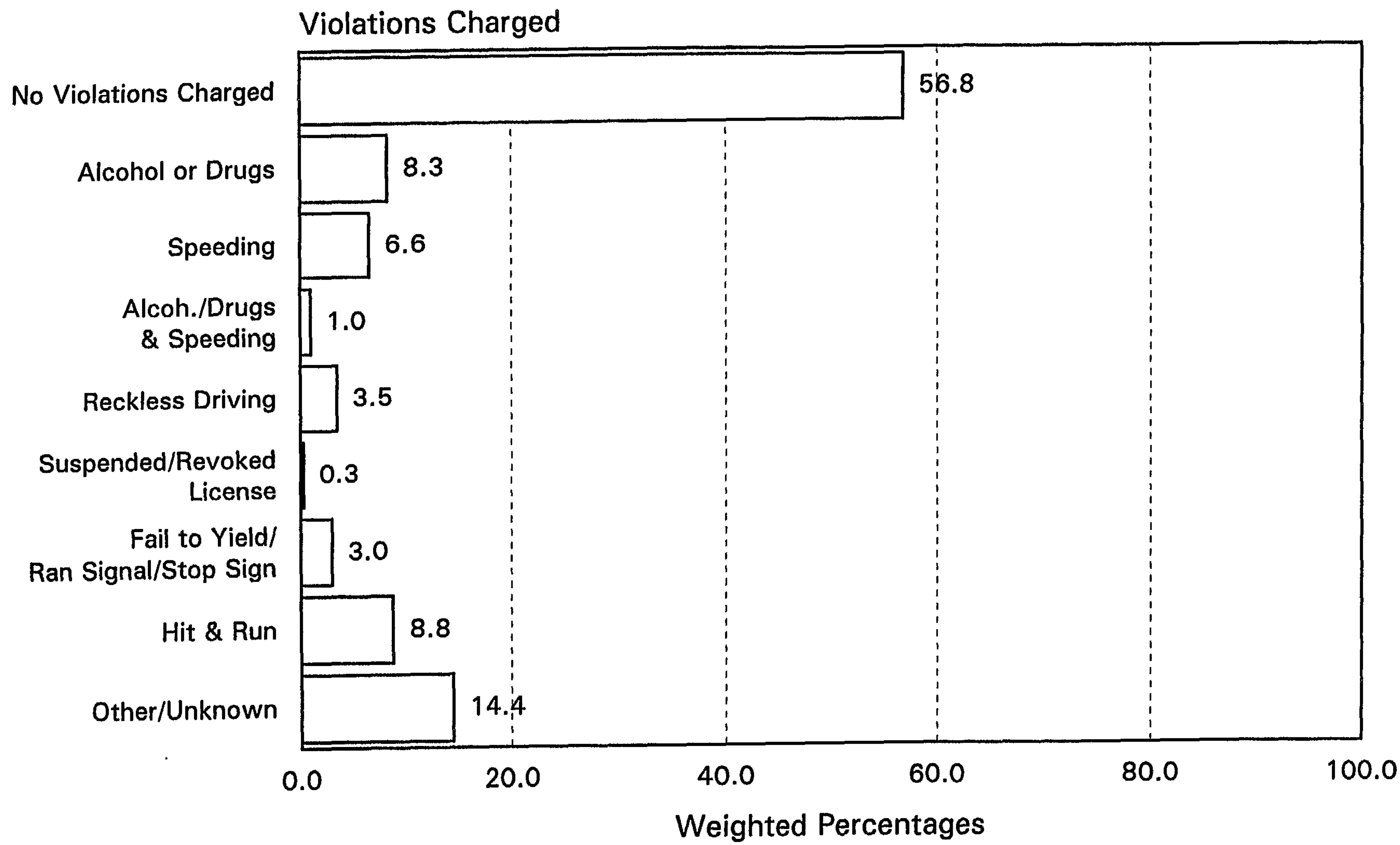


1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-8

Violations Charged in Run-Off-Road Crashes

Weighted Percentages



1,039,007 vehicles
Based on 1992 GES weighted data

Figure 5-9

ingestion and vehicle travel speed. This particular combination of driver factors has been shown to be associated with severe injury crashes in a number of studies conducted for that topic area.

In the discussion developed for Figure 5-3, it is noted that a relatively high proportion of run-off-road crashes, contained in the GES database, involve crash locations that are coded as having a vertical grade (61.1 percent). For this file, the presence of a positive or negative grade is coded directly from the police accident report. Thus, coded values reflect the investigating officer's judgement and are likely to include a substantial number of very shallow grades. The specific proportion noted for the GES database is of the same order of magnitude found in the clinical sample (Figure 5-12 -54.2 percent) where grades of 1.0 percent or more were recorded directly from the scaled schematics submitted with each NASS CDS case. Analysis of the clinical sample indicated the presence of a grade at the crash location typically does not contribute directly to crash causation. The single exception to this circumstance involves crashes where the causal factor is lost directional control on a wet/snow-covered surface. For these cases, the presence of a negative grade would reduce friction values and could conceivably contribute to crash causation.

The difference between the proportion of crashes occurring on dry surfaces (61.7 percent) and the proportion of crashes occurring without adverse weather conditions (73 .O percent) does not represent a discrepancy. This difference reflects circumstances where the weather is clear, but the road surface is wet from a preceding rainfall or is snow/ice covered as a result of preceding snow/ice accumulations. The relative proportions of dry surface crashes and no adverse weather conditions, in fact, have positive design implications in that optical sensors are not precluded in concept designs as a result of weather considerations.

The relatively high proportion of drivers who do not initiate a pre-roadway departure corrective action (69.3 percent) could have a number of associated interpretations. At this point, however, the project staff believes that the most logical explanation is that these drivers are either unaware of the impending departure (e.g., inattention, incapacitation, etc.,) or become aware with insufficient time to initiate corrective action prior to departure. This issue will be examined in both the clinical and engineering analyses to determine if additional clarification is feasible.

5.2.3 Summary of Bivariate Distributions.

Bivariate distributions produced as part of this analysis effort are presented as tabular formats in Table 5-l to 5-16. Major points indicated by these distributions may be summarized as follows:

- Irrespective of crash location, most run-off-road crash events do not result in injury to vehicle occupants (55.4 percent-rural, 59.5 percent-suburban, 53.1 percent-urban). Of those crashes resulting in injury (nonincapacitating, incapacitating, and fatal), the highest proportions of injured occupants at all severity levels are consistently associated with rural crashlocations (19.2 percent, 8.3 percent, and 1.2 percent, respectively). Similarly, the proportions ofinjured occupants in suburban crash locations (13.4 percent, 8.0 percent, and 0.9 percent, respectively) are consistently higher than the equivalent proportions (13.2 percent, 5.4 percent, and 0.6 percent, respectively) for urban crashes. A degree of caution must be used in interpreting this pattern since the proportion of unknown values increases dramatically when proceeding from rural to urban locations (Table 5-l).

- The proportions of occupants sustaining injury at all three reported injury levels (nonincapacitating, incapacitating, and fatal) are consistently higher in crashes occurring on curved roadway segments (17.5 percent, 10.2 percent, and 1.4 percent, respectively) as compared to crashes occurring on straight roadway segments (14.6 percent, 6.6 percent, and 0.8 percent, respectively). A degree of caution must again be used in interpreting this pattern due to the relative proportions of unknown values (Table 5-2).

  Table 5-2A provides a horizontal tabulation format for this same distribution. Note that the highest proportion of injuries are consistently sustained on straight segments as opposed to curved segments. Patterns within the straight and curve segment categories, however, are exactly reversed. Specifically, as injury severity increases, the proportion of crashes occurring on straight segments decreases and the proportion of crashes occurring on curved segments increases. Given the distribution of crashes occurring on straight and curved segments (Figure 5-3), curves are overrepresented at each reported injury level.

- The proportions of occupants sustaining injury at all three reported injury levels (nonincapacitating, incapacitating, and fatal) are consistently higher in crashes occurring on dry roadway segments (16.8 percent, 8.6 percent, and 1.2 percent, respectively) as compared to siiar proportions (14.1 percent, 6.5 percent, and 0.4 percent, respectively) associated with roadway segments that are wet (Table 5-3).

  A horizontal tabulation format for this distribution is provided in Table 5-3A which reinforces the point made with respect to injury in the preceding discussion. Specifically, the largest proportion of injuries are sustained on dry surfaces (68.3 percent, 7 1.9 percent, and 78.8 percent, respectively) as compared to all other surface conditions. Also note that the proportions of injuries occurring on dry surfaces consistently increase as injury severity increases.

- The proportions of occupants sustaining injury at all three reported injury levels (nonincapacitating, incapacitating, and fatal) are consistently higher in crashes involving left roadway departures (16.8 percent, 8.7 percent, and 1.4 percent, respectively) and right roadway departures (17.0 percent, 8.8 percent, and 0.9 percent, respectively) as compared to crashes involving forward impacts (9.2 percent, 2.8 percent, and 0.3 percent, respectively). The proportions of occupants sustaining injury in left roadway departures are similar to the proportions sustained in right roadway departures (Table 5-4).

  A horizontal tabulation format for his distribution **is** provided in Table 5-4 A. The highest proportions of nonincapacitating and incapacitating injuries (51.4 percent and 54.5 percent) occur in right roadside departure crashes. The highest proportion for fatal injuries (48.2 percent) is associated with left roadside departure crashes, although the proportion associated with right roadside departure crashes (45.0 percent) is also of this order of magnitude.

- The proportions of crashes occurring on straight and curved roadway segments are very similar for left roadway departures (65.0 percent and 32.3 percent, respectively) and right roadway departures (65.9 percent and 3 1.3 percent, respectively). However, both sets of proportions differ considerably from similar proportions (84.9 percent and 6.9 percent, respectively) associated with forward impacts. Within this crash type, a considerably higher proportion of crashes occur on straight roadway segments and a correspondingly lower proportion occur on curved segments (Table 5-5).

  NOTE: The accident type categories in Table 5-5 have collapsed to indicate the three major configurations used in the GES accident typing methodology. An expanded version of these categories is provided in Table 5-5A where the configurations are further subdivided to indicate major accident types involved within each configuration.

  In Table 5-5A, the pattern displayed within left roadside departure crashes is very similar to the pattern displayed within right roadside departure crashes. For example, within both configurations departures from straight roadway segments peak in the Drive Off Road (66.9 percent-left and 69.1 percent-right) crash type and then peak a second time in the Avoid Collision (76.9 percent-left and 75.8 percent-right) crash type. In addition, within both configurations, departures from curved roadway segments peak in the Control/Traction Loss (3 5.8 percent-left and 3 8.4-right) crash types.

  A horizontal tabulation format for this distribution is provided in Table 5-5B. The highest proportions for crashes occurring on straight and curved segments (43.3 percent and 54.9 percent) are associated with the right roadside departure accident type.

- The proportions of crashes occurring on dry surfaces are similar between left roadway departure crashes (58.6 percent) and right roadway departure crashes (59.6 percent), however, this same proportion for forward impacts is much higher (70.4 percent). Conversely, the proportions of crashes occurring on wet surfaces for left roadway departure crashes (25.6 percent) and right roadway departure crashes (25.5 percent) are higher than the proportion of crashes occurring on wet surfaces (17.4 percent) within forward impact crashes as are the proportions associated with ice-covered surfaces (Table 5-6).

  NOTE: The accident type categories in Table 5-6 have been collapsed to indicate the three major configurations used in the GES accident typing methodology. An expanded version of these categories is provided in Table 5-6A where the configurations are further subdivided to indicate major accident types included within each configuration.

  In Table 5-6A, the pattern displayed within left roadside departure crashes is very similar to the pattern displayed within right roadside departure crashes. In both configurations, departures from dry roadway segments peak in the Drive Off Road (69.1 percent-left and 70.6 percent-right) crash type and then peak a second time in the Avoid Collision (71.8 percent-left and 67.7 percent-right) crash type. For these same configurations, departure from wet roadway segments peak in the Control/Traction Loss (29.9 percent-left and 29.7 percent-right) crash type. This same peak in the Control/Traction Loss crash type occurs for slush/ice covered surfaces (15.6 percent-left and 15.2 percent-right).

A horizontal tabulation format for this distribution is provided in Table 5-6B. As indicated in this table, the highest proportions of crashes occurring on each listed surface condition are associated with the right roadside departure accident type.

- In the distribution of violations charged by accident type, the patterns for left roadside departure and right roadside departure are, again, very similar. Most drivers in both accident types are not charged with a violation (59.7 percent-left and 60.5 percent-right). Of those drivers issued citations, the combination of alcohol consumption, speeding, and/or reckless driving accounts for the most significant proportion of violations charged (20.9 percent-left and 20.9 percent-right). Hit and run violations also account for a significant proportion of the citations (5.3 percent-left and 4.7 percent-right). In the forward impact accident type, less than half of the drivers are issued citations (44.7 percent) and hit and run violations (22.2 percent account for most of the citations issued (Table 5-7).

- In the distribution of corrective action attempted by accident type, the patterns for left roadside departure and right roadside departure are, again, very similar. Most drivers do not attempt to initiate a corrective action (66.8 percent-left and 67.6 percent-right). When corrective actions are attempted, three actions (braking, steering left, and steering right) account for the largest proportion of driver reactions (24.2 percent-left and 24.8 percent-right). The correlation in these patterns between steering left/left roadside departure and steering right/right roadside departure is counter-intuitive. The relationship is explained in Subsection 5.2.4.

  In this same distribution, the proportion of drivers not attempting a corrective action is largest in the forward impact accident type (76.4 percent) and the only significant corrective action initiated is braking (4.8 percent). A degree of caution should be used when comparing patterns across these accident types due to the relatively large proportion of unknowns associated with the forward impact (14.7 percent) accident type (Table 5-8).

- The pattern, with respect of time of day, noted in the univariate distributions is also apparent in the distribution of accident type by time of day. The incidence rate for run-off-road crashes tends to peak in the 4 PM to 8 PM time frame and tends to bottom out in the 4 AM to 8 AM time frame. There are, however, differences between the accident types. For example, the incidence rate for right roadside departure crashes peaks in the 4 PM to 8 PM time frame (21.0 percent), however, peak incidence rates for left roadside departure (19.7 percent) crashes and forward impact (21.3 percent) crashes are noted in the 8 PM to 12 AM time frame. Similar types of variations are noted for the lowest level incidence rates associated with the 4 AM to 8 AM time frame (Table 5-9).

- In the light condition by accident type distribution, all three accident types demonstrate similar rates with respect to occurring during daylight conditions (44.3 percent, 44.5 percent, and 47.7 percent, respectively). These accident types also demonstrate similar incidence rates with respect to occurring during the hours of darkness (47.1 percent, 50.6 percent, and 46.6 percent, respectively). There is however, considerable variability between the accident types with respect to the specific darkness condition (e.g., dark or dark but lighted). Peak values for right roadside departure (30.5 percent) crashes and forward impact (28.0 percent) crashes occur in the dark condition. The peak value for left roadside departure (32.1 percent) crashes occurs in the dark but lighted condition (Table 5- 10).

A horizontal tabulation format for this distribution is provided in Table 5-10A. As indicated in this table, the highest proportions of crashes occurring in each listed light condition are associated with the right roadside departure accident type.

- In the light condition by land use distribution, incidence rates during daylight conditions are approximately equal for crashes occurring in rural (46.8 percent) areas, suburban (46.9 percent) areas, and urban (43.2 percent) areas. The variability between these locations with respect to the darkness condition is again considerable. In rural areas, crashes tend to occur in dark (not lighted) conditions (38.7 percent). In urban areas, crashes tend to occur in dark but lighted (3 5.4 percent) conditions and in suburban areas, crashes tend to occur in with similar frequencies (24.3 percent and 23.5 percent) in both conditions (Table 5-l 1). This same pattern is evident in Table 5-l 1A which provides an alternative horizontal tabulation format for this distribution.

- With respect to the violations charged by time of day distribution, virtually all charged violations tend to peak in the late afternoon to early morning time frame (4 PM to 4 AM). This trend is particularly evident for alcohol/drug citations (13.0 percent - 8 PM to 12 AM and 18.2 percent - 12 AM to 4 AM) and for hit/run citations (11.2 percent - 8 PM to 12 AM and 11.9 percent - 12 AM to 4 AM). Trends for other citations are less dramatic (Table 5-12).

- In the violations charged by horizontal alignment distribution, the proportion for no violations charged in crashes occurring on straight roadway segments (56.4 percent) is similar to the proportion associated with curved roadway segments (57.8 percent) and this same similarity is noted for alcohol citations (8.5 percent and 8.1 percent, respectively). However, the proportions associated with speeding/reckless driving (9.4 percent-straight and 16.0 percent-curve) citations differ considerably (Table 5-13).

- The proportion of corrective actions initiated in crashes occurring on straight and curved roadway segments are similar with the exception of the incidence of braking. The incidence rate in crashes occurring on curves (15.0 percent) is considerably higher than the rate (8.0 percent) associated with crashes occurring on straight roadway segments (Table 5-14).

- One of the major features of the corrective action attempted by surface condition distribution is the relatively high incidence rate of braking on wet surfaces (12.7 percent) as compared to braking on dry surfaces (8.8 percent), snow/slush covered surfaces (5.9 percent), or on ice covered surfaces (8.4 percent). An even higher incidence rate, noted for crashes occurring on sand/dirt/oil surfaces (23.1 percent), is associated with dual anomalies which are discussed in Section 5.2.4 (Table 5-15).

Table 5-1
Maximum Injury Severity in Vehicle by Land Use

	Land Use		
Maximum Injury Severity	*Rural*	*Suburban*	*Urban*
No Injury	55.4	59.5	53.1
Possible Injury	13.1	11.9	9.6
Nonincapacitating Injury	19.2	13.4	13.2
Incapacitating Injury	8.3	8.0	5.4
Fatal Injury	1.2	0.9	0.6
Other/Unknown	2.8	6.2	18.1
Total	**100.0**	**99.9**	**100.0**

Table 5-2
Maximum Injury Severity in Vehicle by Horizontal Alignment

	Horizontal Alignment	
Maximum Injury Severity	*Straight*	*Curve*
No Injury	57.5	52.3
Possible Injury	10.9	14.7
Nonincapacitating Injury	14.6	17.5
Incapacitating Injury	6.6	10.2
Fatal Injury	0.8	1.4
Other/Unknown	9.7	3.8
Total	**100.1**	**99.9**

Table 5-2A
Maximum Injury Severity in Vehicle by Horizontal Alignment

	Horizontal Alignment			
Maximum Injury Severity	*Straight*	*Curve*	*Unknown*	**Total**
No Injury	70.9	24.2	4.9	**100.0**
Possible Injury	65.0	33.0	2.0	**100.0**
Nonincapacitating Injury	67.3	30.3	2.4	**100.0**
Incapacitating Injury	62.0	36.1	1.9	**100.0**
Fatal Injury	59.1	39.9	1.0	**100.0**
Unknown	82.4	12.3	5.3	**100.0**

Table 5-3
Maximum Injury Severity in Vehicle by Surface Condition

Maximum Injury Severity	Surface Condition Dry	Wet	Snow/ Slush	Ice	Sand/ Dirt/Oil	Other
No Injury	51.7	60.6	70.4	74.1	70.5	58.3
Possible Injury	11.9	12.5	10.2	10.2	0.0	17.0
Nonincapacitating Injury	16.8	14.1	9.1	9.7	19.4	19.6
Incapacitating Injury	8.6	6.5	3.5	3.2	2.5	2.4
Fatal Injury	1.2	0.4	0.3	0.5	0.0	1.4
Other/Unknown	9.7	5.8	6.4	2.3	7.5	1.5
Total	99.9	99.9	99.9	100.0	99.9	100.2

Table 5-3A
Maximum Injury Severity in Vehicle by Surface Condition

Maximum Injury Severity	Surface Condition Dry	Wet	Snow/ Slush	Ice	Sand/ Dirt/Oil	Other/ Unknown	Total
No Injury	56.3	25.4	3.6	11.6	0.6	2.6	100.1
Possible Injury	62.7	25.3	2.5	7.7	0.0	1.7	99.9
Nonincapacitating Injury	68.3	22.1	1.7	5.6	0.6	1.7	100.0
Incapacita ting Injury	71.9	20.8	1.4	3.8	0.2	2.0	100.1
Fatal Injury	78.8	11.0	1.0	5.0	0.0	4.2	100.0
Unknown	74.1	17.3	2.3	2.5	0.0	3.8	100.0

Table 5 4
Maximum Injury Severity in Vehicle by Accident Type

Maximum Injury Severity	Accident Type		
	Left Roadside Departure	Right Roadside Departure	Forward Impact
No Injury	55.1	55.4	61.3
Possible Injury	12.9	13.6	6.1
Nonincapacitating Injury	16.8	17.0	9.2
Incapacitating Injury	8.7	8.8	2.8
Fatal injury	1.4	0.9	0.3
Other/Unknown	5.1	4.2	20.5
Total	100.0	99.9	100.2

Table 5-4A
Maximum Injury Severity in Vehicle by Accident Type

Maximum Injury Severity	Accident Type			Total
	Left Roadside Departure	Right Roadside Departure	Forward Impact	
No injury	31.0	44.9	24.0	99.9
Possible Injury	35.2	53.3	11.5	100.0
Nonincapacitating Injury	35.2	51.4	13.4	100.0
Incapacita ring Injury	37.2	54.5	6.3	100.0
Fatal Injury	46.2	45.0	6.6	100.0
Unknown	20.7	23.2	56.1	100.0

Table 5-5
Horizontal Alignment by Accident Type

Horizontal Alignment	Accident Type: *Left Roadside Departure*	*Right Roadside Departure*	*Forward Impact*
Straight	65.0	65.9	84.9
Curve	32.3	31.3	6.9
Unknown	2.7	2.6	6.2
Total	**100.0**	**100.0**	**100.0**

Table 5-5A
Horizontal Alignment by Accident Type

	Accident Type								
	Left Roadside Departure			*Right Roadside Departure*			*Forward Impact*		
Horizontal Alignment	*Drive Off Road*	*Control/ Traction Loss*	*Avoid Collision*	*Drive Off Road*	*Control/ Traction Loss*	*A void Collision*	*Parked Vehicle*	*Stationary Object*	*End Departure?*
Straight	66.9	62.0	76.9	69.1	59.3	75.8	86.5	93.9	76.0
Curve	29.7	35.8	21.0	27.7	38.4	22.1	5.6	0.0	14.7
Unknown	3.4	2.2	2.0	3.1	2.3	2.1	7.8	6.1	9.4
Total	**100.0**	**100.0**	**99.9**	**99.9**	**100.0**	**100.0**	**99.9**	**100.0**	**100.1**

Table 5-5B
Accident Type by Horizontal Alignment

Horizontal Alignment	**Accident Type:** *Left Roadside Departure*	*Right Roadside Departure*	*Forward Impact*	**Total**
Straight	29.7	43.3	27.0	**100.0**
Curve	39.3	54.9	5.8	**100.0**
Unknown	21.9	32.0	46.1	**100.0**

Table 5-6
Surface Condition by Accident Type

Surface Condition	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
Dry	58.7	59.6	70.4
Wet	25.6	25.5	17.4
Snow/Slush	3.2	3.0	2.1
Ice	10.0	9.5	5.8
Other/Unknown	2.6	2.4	4.3
Total	**100.1**	**100.0**	**100.0**

Table 5-6A
Surface Condition by Accident Type

Surface Condition	Accident Type								
	iefr Roadside Departure			*Right Roadside Departure*			*Forward Impact*		
	Drive Off Road	*Control/ Traction Loss*	*Avoid Collision*	*Drive Off Road*	*Control/ Traction Loss*	*A void Collision*	*Parked Vehicle*	*Stationary Object*	*End Departure*
Dry	69.1	47.7	71.8	70.6	47.4	67.7	71.9	58.6	59.1
Wet	22.2	29.9	20.5	20.4	29.7	26.1	16.0	29.2	27.8
Snow	2.1	4.1	2.2	2.1	4.5	0.8	2.2	6.2	0.1
Slush/Ice	4.7	15.6	3.1	4.9	15.2	5.0	5.7	0.0	7.1
Other/ Unknown	1.8	2.8	2.4	2.0	3.2	0.4	4.2	6.1	5.9
Total	**99.9**	**100.1**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.1**	**100.0**

Table 5-6B
Accident Type by Surface Condition

Surface Condition	Accident Type			Total
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*	
Dry	30.3	44.3	25.3	99.9
Wet	34.4	49.3	16.3	100.0
Snow/Slush	35.8	48.2	15.9	99.9
Ice	36.1	49.4	14.5	100.0
Unknown	17.6	33.0	49.4	100.0

Table 5-7
Violations Charged by Accident Type

Violations Charged	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
None	59.7	60.5	44.7
Alcohol or drugs	8.2	7.9	8.9
Speeding	7.4	8.0	2.6
Alcoh. or drugs & speeding	1.3	1.0	0.6
Reckless Driving	4.0	4.0	1.9
Suspend/Revoked License	0.6	0.3	0.2
Fail to yield Right-of-way	0.2	0.1	0.0
Ran signal/stop sign	0.0	0.1	0.6
Hit & Run	5.3	4.7	22.2
Other/Unknown	13.2	13.3	18.1
Total	**99.9**	**99.9**	**99.8**

Table 5-8
Corrective Action Attempted by Accident Type

Corrective Action Attempted	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
None	66.8	67.6	76.4
Braked/Slowed	11.1	11.0	4.8
Steered Left	11.3	2.3	0.9
Steered Right	1.8	11.5	2.5
Accelerated	0.1	0.2	0.0
Backed	0.1	0.0	0.0
Braked & Steered Left	2.1	0.2	0.2
Braked & Steered Right	0.2	1.9	0.1
Accel. & Steered Left	0.3	0.0	0.0
Accel. & Steered Right	0.0	0.1	0.0
Steered Both Directions	1.0	1.1	0.0
Correct. Action but no details	1.4	0.9	0.4
Other/Unknown	3.8	3.1	14.7
Total	**100.0**	**99.9**	**100.0**

Table 5-9
Time of Day by Accident Type

Time of Day	Accident Type: Left Roadside Departure	Right Roadside Departure	Forward Impact
12am - 4am	19.1	17.2	16.8
4am - 8am	12.7	11.4	9.8
8am - 12pm	12.1	13.0	12.7
12pm - 4pm	15.7	17.0	17.9
4pm - 8pm	19.5	21.0	20.8
8pm - 12am	19.7	18.8	21.3
Unknown	1.2	1.5	0.6
Total	100.0	99.9	99.9

Table 5-10
Lighting Condition by Accident Type

Lighting Condition	Accident Type: Left Roadside Departure	Right Roadside Departure	Forward Impact
Daylight	44.3	44.5	47.7
Dark	15.0	30.5	28.0
Dark but Lighted	32.1	20.1	18.6
Dawn	1.1	1.8	1.7
Dusk	2.5	1.5	2.3
Unknown	5.0	1.5	1.7
Total	100.0	99.9	100.0

Table 5-l OA
Accident Type by Light Condition

Light Condition	Accident Type: Left Roadside Departure	Right Roadside Departure	Forward Impact	Total
Daylight	30.9	47.7	21.4	100.0
Dark	37.6	49.5	12.9	100.0
Dark but Lighted	29.0	38.7	32.3	100.0
Dawn	35.3	49.1	15.6	100.0
Dusk	23.5	50.1	26.4	100.0
Unknown	20.4	33.3	46.3	100.0

Table 5-l 1
Lighting Condition by Land Use

Lighting Condition	Land Use		
	Rural	*Suburban*	*Urban*
Daylight	46.8	46.9	43.2
Dark	38.7	24.3	12.3
Dark but Lighted	9.8	23.5	35.4
Dawn	1.9	1.4	1.5
Dusk	2.0	2.0	2.4
Unknown	0.8	1.9	5.3
Total	**100.0**	**100.0**	**100.1**

Table 5-l 1 A
Light Condition by Land Use

Light Condition	Land Use			Total
	Rural	*Suburban*	*Urban*	
Daylight	32.4	44.3	23.3	**100.0**
Dark	47.5	40.7	11.7	**99.9**
Dark but Lighted	14.1	46.1	39.7	**99.9**
Dawn	37.5	38.6	23.9	**100.0**
Dusk	30.9	41.0	28.2	**100.1**
Unknown	11.1	34.5	54.5	**100.1**

Table 5-12
Violations Charged by Time of Day

Violations Charged	Time of Day: 12am-4am	4am-8am	8am-12pm	12pm-4pm	4pm-8pm	8pm-12am
None	40.3	63.0	65.9	67.2	62.1	48.3
Alcohol or drugs	18.2	5.9	1.5	2.3	5.9	13.0
Speeding	6.4	5.5	8.2	7.1	6.5	6.4
Alcoh. or drugs & speeding	1.6	1.1	0.4	0.4	1.0	1.5
Reckless Driving	4.7	3.0	3.5	3.0	2.6	4.2
Suspend/Revoked License	0.6	0.3	0.3	0.1	0.3	0.4
Fail to yield Right-of-way	0.2	0.3	0.1	0.1	0.2	0.0
Ran signal/stop sign	0.1	0.4	0.2	0.1	0.2	0.1
Hit & Run	11.9	6.8	4.8	6.1	8.1	11.2
Other/Unknown	16.1	13.7	15.2	13.6	12.9	14.8
Total	**100.1**	**100.0**	**100.1**	**100.0**	**99.8**	**99.9**

Table 5-13
Violations Charged by Horizontal Alignment

Violations Charged	Horizontal Alignment: Straight	Curve	Unknown
None	56.4	57.8	57.3
Alcohol or drugs	8.5	8.1	4.8
Speeding	5.2	10.2	6.7
Alcoh. or drugs & speeding	0.8	1.7	0.7
Reckless Driving	3.4	4.1	2.2
Suspend/Revoked License	0.4	0.4	0.0
Fait to yield Right-of-way	0.2	0.0	0.0
Ran signal/stop sign	0.2	0.0	0.2
Hit & Run	10.3	4.2	11.2
Other/Unkno wn	14.6	13.4	16.8
Total	100.0	99.9	99.9

Table 5-14
Corrective Action Attempted by Horizontal Alignment

Corrective Action Attempted	Horizontal Alignment		
	Straight	*Curve*	*Unknown*
None	70.0	68.3	63.7
Braked/Slowed	8.0	15.0	3.4
Steered Left	5.1	4.6	3.3
Steered Right	6.7	6.1	3.6
Accelerated	0.1	0.1	0.0
Backed	0.0	0.0	0.0
Braked & Steered Left	0.9	0.8	0.3
Braked & Steered Right	1.2	0.5	0.0
Accel. & Steered Left	0.1	0.0	0.0
Accel. & Steered Right	0.1	0.0	0.0
Steered Both Directions	0.9	0.9	0.0
Correct. Action but no details	1.0	1.1	0.0
Other/Unknown	6.0	2.5	25.7
Total	**100.1**	**99.9**	**100.0**

Table 5-15
Corrective Action Attempted by Surface Condition

Corrective Action Attempted	Surface Condition				
	Dry	*Wet*	*Snow/Slush*	*Ice*	*Sand/Dirt/Oil*
None	67.3	70.2	72.5	80.3	54.8
Braked/Slowed	8.8	12.7	5.9	8.4	23.1
Steered Left	5.5	4.4	5.2	1.9	6.8
Steered Right	7.3	5.7	6.8	2.4	0.0
Accelerated	0.1	0.1	0.3	0.1	0.0
Backed	0.0	0.0	0.0	0.0	0.0
Braked & Steered Left	0.7	1.1	0.0	1.0	2.4
Braked & Steered Right	1.1	0.7	1.6	0.7	0.0
Accel. & Steered Left	0.1	0.0	0.0	0.0	7.5
Accel. & Steered Right	0.1	0.1	0.0	0.0	0.0
Steered Both Directions	1.0	0.6	0.0	0.6	0.0
Correct. Action but no details	1.0	1.0	0.9	1.1	0.0
Other/Unknown	7.0	3.4	6.9	3.5	5.4
Total	**100.0**	**100.0**	**100.1**	**100.0**	**100.0**

Table 5-16
Violations Charged by Corrective Action Attempted

Violations Charged	Corrective Action Attempted								
			Steered			Braked & Steered		Accel. & Steered	
	None	Braked/ Slowed	Left	Right	Both	Left	Right	Left	Right
None	54.3	56.4	84.0	83.3	49.8	77.0	71.7	43.8	84.9
Alcohol or drugs	10.3	5.5	2.9	1.7	6.8	3.0	1.3	0.0	0.0
Speeding	6.5	12.9	3.6	2.0	25.2	4.8	11.3	43.6	15.1
Alcoh. /drugs & speeding	1.0	3.3	0.6	0.0	0.0	0.3	0.0	0.0	0.0
Reckless Driving	4.2	4.2	0.9	1.2	1.2	4.5	1.0	0.0	0.0
Suspend/Revoked License	0.3	0.5	0.4	0.2	1.2	4.6	0.0	0.0	0.0
Fail ro yield Right-of-Way	0.1	0.1	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Ran signal/stop sign	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hit & Run	6.6	6.2	0.8	0.1	0.0	2.2	5.5	0.0	0.0
Violation but no details	4.6	2.4	3.3	5.0	5.0	1.3	3.1	0.0	0.0
Other	11.5	7.7	3.2	5.4	10.9	2.2	6.0	12.6	0.0
Unknown	0.5	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0
Total	100.1	100.1	99.9	100.0	100.1	99.9	99.9	100.0	100.0

- In the violations charged by ‘corrective action attempted distribution, the highest incidence rate of alcohol/drug ingestion citations is associated with no corrective action attempted (10.3 percent). The highest incidence rates for speeding citations occur when the driver is braking (12.9 percent), steers in both directions (25.9 percent), or brakes and steers to the right (11.3 percent). The very high rate associated with the accelerated and steered category (43.6 percent) is both a characteristic of this category and an anomaly associated with small numbers of crashes (Table 5-16).

5.2.4 Interpretation of Bivariate Results

The results reported for Tables 5-l through 5-3 tend to support the observation first noted in Section 3.3 and expanded in Section 5.2.2. Specifically, the observation is that there is a subset of run-off-road crashes which is associated with severe injury consequences. As indicated in Table 5-l through 5-3 that subset may be defined as crashes occurring in rural/suburban areas, on curved roadway segments where the road surface is dry. An indication of the specific reasons for crash occurrence within this subset of run-off-road crashes can be derived from Table 5-l 3 which indicates that alcohol/speeding citations are issued in approximately 24.0 percent of the crashes which occur on curves. Given the distribution of times those types of citations are issued (Table 5-12), it is also probable that many of these more severe crashes are occurring in late evening/early morning time frames (e.g. darkness) when drivers are operating vehicles in conditions of reduced visibility.

There are a number of interrelated points which should be made with respect to Tables 5-l through 5-3. These points may be summarized as follows:

- In Table 5-1, the higher proportions of occupants sustaining injury and sustaining more severe injuries, in rural and suburban crashes as compared to urban crashes, are associated with the higher speed limits and related travel speeds inherent to rural and suburban crash locations.

- In Table 5-2, the higher proportions of occupants sustaining injury and sustaining more severe injuries, in crashes occurring on curved as compared to straight roadway segments, are associated with the fact that curve related crashes tend to occur in rural/suburban environments having higher associated speed limits and travel speeds. In a separate support analysis conducted for this effort, it was found that 44.2 percent of curve related crashes occur in rural areas, 42.5 percent occur in suburban areas, and only 13.3 percent occur in urban areas.

- In Table 5-3, the higher proportions of occupants sustaining injury and sustaining more severe injuries, in crashes occurring on dry as compared to wet roadway surfaces, are associated with the higher travel speeds maintained on dry surfaces as compared to wet surfaces.

A supplementary data tabulation was completed to verify the above interpretation. Specifically, the analysis staff generated a cross-tabulation of surface condition by estimated travel speed. The proportions of vehicles with estimated travel speeds of 60 mph (97 kph) or higher were 7.5 percent for dry surfaces, 3.9 percent for wet surfaces, 2.2 percent snow/slush covered surfaces, and 1.3 percent for icy surfaces. Corresponding proportions for vehicles with estimated travel speeds of 50-59 mph (SO-95 kph) were 11 .O percent for dry surfaces, 10.8 percent for wet surfaces, 8.6 percent for snow/slush covered surfaces, and 4.7 percent for icy surfaces. At speeds below this level, the trend reverses with higher proportions noted for inclement weather/road surface conditions.

Table 5-4 indicated that the proportions of occupants sustaining injury at all three reported injury levels (nonincapacitating, capacitating, and fatal) are consistently higher in crashes involving left and right roadway departures as compared to crashes involving forward impacts. This finding is related to the nature of the impacts associated with these accident types. As implied by the accident type label, most forward impacts involve contact to the subject vehicle's frontal plane. The left and right roadway departure accident types involve relatively larger numbers of rollover events (the most severe injury producing collision event) and side impacts. While not shown directly in the analysis conducted in this section, the differences in impact types is at least suggested in Table 5-6A in the Control/Traction Loss types contained in the left and right roadside departure categories. In most instances of control/traction loss, the subject vehicle departs the roadway in a non-tracking attitude increasing the risk of rollover and/or exposure to side impacts. In addition, nearly half of the control/traction losses occur on dry surfaces and are therefore, likely to be associated with higher travel speeds.

The low proportion of crashes occurring on curves in the forward impact accident type (Table 5, 5A, 6, and 6A), is again, related to the definition of this accident type. As noted previously, forward impacts typically involve contact to the vehicle's frontal plane. Many curve related crashes involve control/traction loss with subsequent rollover events and side impacts.

In the discussion developed for Table 5-8, it is noted that the correlation between steering left and left roadside departure and steering right and right roadside departure is counter-intuitive. For the circumstance where steering corrections are initiated, the corrective actions are typically initiated with respect to an event/object in the roadway and not with respect to the impending road departure. For example, a driver suddenly becomes aware that there is a vehicle stopped in the travel lane in front of him He initiates a steering input to the right and departs the right edge of the roadway. In this case, the corrective steering input to the right is initiated to avoid the stopped vehicle and is not -initiated to avoid the subsequent roadway departure. The much smaller proportions in Table 5-8 associated with steering inputs in the opposite direction of roadway departure (e.g., steered right - 1.8 percent - left roadside departure) are typically associated with steering inputs to avoid the impending roadway departure.

Verification of the above interpretation is derived from examination of the critical events associated with these crashes. A separate data run was performed to examine the critical events in those crashes in Table 5-8 where the driver steered left/departed the left edge of the roadway or steered right/departed the right edge of the roadway. In 72.4 percent of the crashes in this category in the left roadside departure accident type, the critical event is initiated by another vehicle in the subject vehicle's lane or by a pedestrian, pedalcyclist, animal, or object. The corresponding proportion for those cases involving right roadside departure is 77.1 percent. Briefly, the subject drivers in these cases are initiating evasive/avoidance maneuvers.

In the discussion for Table 5-13, it is noted that the proportion of crashes in which speeding/reckless driving citations are issued is higher in crashes occurring on curved roadway segments (16.0 percent) than in crashes occurring on straight roadway segments (9.4 percent). This finding is somewhat artificial in nature. Drivers do not suddenly increase travel speeds when approaching curves. The experience of our in-depth accident investigation teams has been that investigating police officers are more willing to establish or use a prima facie interpretation of speeding in relation to crashes occurring on curves (i.e., the driver did not track the curve and, therefore, must have been speeding). This circumstance does not imply that the incidence rate of speeding in curve related crashes is overstated. It does imply, however, that the incidence rate of speeding for crashes on straight roadway segments is probably underestimated.

The higher incidence rate for braking in crashes occurring on curves (15.0 percent) as compared to the incidence rate for braking in crashes occurring on straight roadway segments, noted in Table 5-14, is undoubtedly related to natural tendencies in these crashes. Specifically, drivers are more likely to be reducing their travel speed as they approach a curve and therefore, are more likely to continue braking as the crash sequence develops.

In the discussion for Table 5-15, it is noted that the high incidence rate for braking on sand/dirt/oil surfaces (23.1 percent) is associated with dual anomalies. These anomalies are not interrelated. First, there are a relatively small number of crashes which occur on these surfaces. Secondly, evidence of braking is highly visible on these surfaces and, therefore, is more likely to be noted by the investigating officer as compared to other surface conditions.

The relatively high incidence rate of alcohol/drug ingestion citations associated with no corrective action attempted (10.3 percent) in Table 5-16 is consistent with gross intoxication (e.g., BACs > 0.10) responses observed in in-depth investigations. Grossly intoxicated drivers often relinquish steering control and do not respond to events developing in the crash sequence.

5.2.5 Summary of Trivariate Distributions

Trivariate distributions produced as part of this analysis effort are presented as tabular formats in Tables 5-17 to 5-20. Major points indicated by these distributions may be summarized as follows:

- In the accident type by violations charged by horizontal alignment distribution, the proportions noted for straight roadway segments are relatively similar when comparing left roadside departure crashes and right roadside departure crashes. A somewhat greater degree of variability is noted for curved roadway segments within these same two accident types, however, the curved roadway segment distributions remain reasonably similar. A much greater degree of variability is noted when comparing the curve and straight distributions within accident types. For example, within the left roadside departure crash type, the relative proportions noted for alcohol/drug citations are reasonably similar (8.3 percent-straight and 8.8 percent-curve). These same proportions for the three categories indicating speeding/reckless driving (10.0 percent-straight and 17.4 percent-curve) differ appreciably. Similar differences are observed in the right roadside departure accident type where these same three categories indicate appreciable differences between straight and curved segments (11.8 percent-straight and 16.0 percent-curve).

Within this same distribution, similar differences are noted in alcohol/drug citations (9.2 percent-straight and 10.9 percent-curve) and in the incidence rates for hit and run citations (23.6 percent-straight and 9.1 percent-curve) for the forward impact accident type. As indicated, in the discussion of bivariate distributions, the forward impact accident type diiers considerably from the left and right roadside departure accident types. These differences are reflected in the distributions of violations charged. Forward impacts tend to involve much lower incidence rates of speeding/reckless driving (Table 5-17).

- In the horizontal alignment by violations charged by corrective action distribution, there is some variability between crashes occurring on straight and curved segments. This variability, however, tends to be a matter of degree rather than substantive differences. For example, when no corrective action is initiated by the driver, alcohol/drug citations (10.7 percent) dominate the violations charged categories for crashes occurring on straight roadways. For crashes occurring on curves, speeding violations are most prominent (9.9 percent), however, alcohol/drug violations remain at a significant level (9.7 percent). When the driver corrective action is braking or slowing on straight segments, speeding violations (9.0 percent) dominate as they do on curved segments (18.1 percent). Similar differences occur in the steered left and steered right categories. Observations for all other categories must be tempered by the very small numbers of cases in those categories - see Figure 5-8. Specifically the last five columns in the table account for approximately 3.0 percent of the run-off-road crash population (Table 5-l 8).

- In the horizontal alignment by maximum injury severity by surface condition distribution, the proportions of occupants sustaining injury (no&capacitating, incapacitating, or fatal) in crashes occurring on curved segments consistently exceed similar proportions for crashes occurring on straight segments. For example, in the circumstance of dry surface conditions the proportions of occupants sustaining injury in crashes occurring on curved segments are 19.4 percent, 13.0 percent, and 2.1 percent, respectively. Similar proportions for crashes occurring on straight segments are 16.3 percent, 7.5 percent, and 1 .0 percent, respectively. Recalling that the dry surface condition is prevalent for run-off-road crashes (see Figure 5-4), it is apparent that curve related crashes result in larger proportions of the more severe injury level crashes than are associated with crashes occurring on straight segments.

  This same relationship holds for crashes occurring on wet surfaces, snow/slush covered surfaces, and ice covered surfaces. The condition of sand/dirt/oil must be interpreted very carefully since this category contains relatively few cases (Table 5-l 9).

- In the horizontal alignment by maximum injury by time of day distribution, there are again very interesting and distinctive patterns evident when comparing crashes occurring on curves with crashes occurring on straight segments. During the peak hours of run-off-road crash occurrence (4 PM to 4 AM), the proportions of occupants sustaining injury at all three reported injury levels (nonincapacitating, incapacitating, and fatal) are consistently higher for crashes occurring on curves as compared to crashes occurring on straight segments. For example, in the 12 AM to 4 AM time frame the proportions associated with curve related crashes are 21.3 percent, 13.4 percent and 3.4 percent, respectively. Comparable proportions for crashes occurring on straight segments are 18.1 percent, 8.1 percent, and 0.8 percent, respectively.

  The pattern described above does not hold in off-peak hours (4 AM to 4 PM). For example, in the 4 AM to 8 AM time frame, the pattern reverses. The proportions of occupants sustaining injury in curve related crashes are 13.9 percent, 8.4 percent and 0.7 percent, respectively. Comparable proportions for crashes occurring on straight segments are 15.9 percent, 6.9 percent and 1.2 percent, respectively. This time frame, however, is the period when the fewest run-off-road crashes occur (Table 5-20).

Table 5-17
Accident Type by Violations Charged by Horizontal Alignment

Accident Type	Violations Charged	Horizontal Alignment		
		Straight	Curve	Unknown
Left Roadside Departure	None	61.8	55.7	58.1
	Alcohol or drugs	8.3	8.8	0.0
	Speeding	5.0	11.3	17.2
	Alcoh. or drugs & speeding	1.1	1.7	2.3
	Reckless Driving	3.9	4.4	1.4
	Suspend/Revoked License	0.6	0.7	0.0
	Fail to yield Right-of-way	0.3	0.0	0.0
	Ran signal/stop sign	0.0	0.0	0.0
	Hit & Run	5.6	4.2	9.7
	Violation but no details	4.5	4.7	7.6
	Other/Unknown	8.9	8.5	3.7
	Total	100.0	100.0	100.0
Right Roadside Departure	None	60.4	60.0	68.8
	Alcohol or drugs	8.2	7.3	7.8
	Speeding	7.0	10.2	7.7
	Alcoh. or drugs & speeding	0.8	1.7	0.0
	Reckless Driving	4.0	4.1	2.9
	Suspend/Revoked License	0.3	0.2	0.0
	Fail to yield Right-of-way	0.2	0.1	0.0
	Ran signal/stop sign	0.1	0.0	0.0
	Hit & Run	5.3	3.8	1.6
	Violation but no details	4.1	2.8	1.7
	Other/Unknown	9.7	9.8	9.5
	Total	100.1	100.0	100.0
Forward Impact	None	43.9	50.2	48.9
	Alcohol or drugs	9.2	10.9	5.1
	Speeding	2.7	3.6	1.1
	Alcoh. or drugs & speeding	0.7	0.6	0.4
	Reckless Driving	1.8	2.6	2.1
	Suspend/Revoked License	0.2	0.0	0.0
	Fail to yield Right-of-way	0.0	0.0	0.0
	Ran signal/stop sign	0.7	0.0	0.5
	Hit & Run	23.6	9.1	18.5
	Violation but no details	4.2	6.2	11.1
	Other/Unknown	13.0	16.9	12.4
	Total	100.0	100.1	100.1

Table 5-18
Horizontal Alignment by Violations Charged by Corrective Action Attempted

Horizontal Alignment	Violations Charged	Corrective Action Attempted								
				Steered			Braked & Steered		Accel. & Steered	
		None	*Braked/ Slowed*	*Left*	*Right*	*Both*	*Left*	*Right*	*Left*	*Right*
Straight	*None*	54.3	57.9	85.2	82.0	51.5	79.8	68.9	43.8	82.5
	Alcohol or drugs	10.7	6.0	2.1	1.7	4.7	4.1	0.4	0.0	0.0
	Speeding	5.2	9.0	3.6	1.9	22.1	4.9	12.7	43.6	17.5
	Alcoh./drugs & speeding	0.8	3.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0
	Reckless Driving	4.0	4.3	1.0	1.0	0.0	3.2	1.2	0.0	0.0
	Suspend/Revoked License	0.2	0.7	0.6	0.2	1.7	4.5	0.0	0.0	0.0
	Fail to yield Right-of-way	0.1	0.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0
	Ran signal/stop sign	0.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hit & Run	7.6	7.3	0.8	0.2	0.0	0.0	6.3	0.0	0.0
	Violation but no details	4.6	2.8	3.1	5.3	6.9	0.0	3.6	0.0	0.0
	Other/Unknown	12.2	7.1	3.6	6.9	13.1	3.0	6.9	12.6	0.0
	Total	**99.9**	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**	**100.0**	**100.0**	**100.0**
Curve	*None*	54.6	53.6	80.5	87.4	45.5	72.5	90.8	0.0	100.0
	Alcohol or drugs	9.7	4.9	5.5	1.7	12.2	0.0	7.4	0.0	0.0
	Speeding	9.9	18.1	3.3	1.7	33.0	4.8	1.8	0.0	0.0
	Alcoh./drugs & speeding	1.4	3.4	2.4	0.0	0.0	0.0	0.0	0.0	0.0
	Reckless Driving	4.8	4.1	0.8	1.7	4.1	8.6	0.0	0.0	0.0
	Suspend/Revoked License	0.5	0.2	0.0	0.0	0.0	5.1	0.0	0.0	0.0
	Fail to yield Right-of-way	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
	Ran signal/stop sign	0.0	0.0	0.0	0.0	0.0	8.9	0.0	0.0	0.0
	Hit & Run	3.4	4.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0
	Violation but no details	4.1	1.9	3.3	4.7	0.0	0.0	0.0	0.0	0.0
	Other/Unknown	11.6	9.0	3.2	2.3	5.2	0.0	0.0	0.0	0.0
	Total	**100.0**	**100.0**	**100.0**	**100.1**	**100.0**	**99.9**	**100.0**	**0.0**	**100.0**

Table 5-19
Horizontal Alignment by Maximum Injury Severity by Surface Condition

Horizontal Alignment	Maximum Injury Severity	Surface Condition				
		Dry	*Wet*	*Snow/Slush*	*Ice*	*Sand/Dirt/Oil*
Straight	*No Injury*	52.9	62.0	72.3	75.6	53.3
	Possible Injury	11.1	11.3	9.4	8.9	0.1
	Nonincapacitating Injury	16.3	12.5	8.5	9.4	38.4
	Incapacitating Injury	7.5	6.2	1.8	2.8	4.1
	Fatal Injury	1.0	0.4	0.5	0.3	0.0
	Other/Unknown	11.2	7.7	7.6	2.9	4.2
	Total	**100.0**	**100.1**	**100.1**	**99.9**	**100.1**
Curve	*No Injury*	45.9	56.7	62.0	70.4	80.8
	Possible Injury	15.2	14.9	14.3	13.5	0.0
	Nonincapacitating Injury	19.4	17.5	10.6	10.0	0.0
	Incapacitating Injury	13.0	7.4	9.9	4.6	1.6
	Fatal Injury	2.1	0.4	0.0	1.1	0.0
	Other/Unknown	4.4	3.0	3.1	0.5	17.7
	Total	**100.0**	**99.9**	**99.9**	**100.1**	**100.1**

Table 5-20
Horizontal Alignment by Maximum Injury Severity by Time of Day

Horizontal Alignment	Maximum Injury Severity	Time of Day 12am - 4am	4am - 8am	8am - 12pm	12pm - 4pm	4pm - 8pm	8pm - 12am
Straight	*No Injury*	50.2	55.8	62.5	62.3	62.4	53.3
	Possible Injury	10.6	12.6	12.4	11.4	8.4	11.5
	Nonincapacitating Injury	18.1	15.9	13.9	11.8	11.9	16.9
	Incapacitating Injury	8.1	6.9	4.8	6.0	7.0	6.4
	Fatal Injury	0.8	1.2	0.3	1.2	0.7	0.6
	Other/Unknown	12.2	7.5	6.0	7.3	9.6	11.3
	Total	**100.0**	**99.9**	**99.9**	**100.0**	**100.0**	**100.0**
Curve	*No Injury*	46.2	54.9	59.1	55.9	55.8	46.8
	Possible Injury	11.3	18.6	17.1	17.3	12.6	13.6
	Nonincapacitating Injury	21.3	13.9	13.5	12.7	19.0	21.8
	Incapacitating Injury	13.4	8.4	8.9	8.8	9.8	11.1
	Fatal Injury	3.4	0.7	0.7	0.9	0.5	2.0
	Other/Unknown	4.4	3.4	0.6	4.3	2.3	4.6
	Total	**100.0**	**99.9**	**99.9**	**99.9**	**100.0**	**99.9**

5.2.6 Interpretation of Trivariate Results

The patterns evident in the trivariate distributions support the profile previously established in the bivariate analyses. Briefly this profile may be summarized as follows:

- The more severe run-off-road crashes tend to be curve related and the curve related crashes tend to occur in rural/suburban areas.
- These crashes tend to occur on dry surfaces.
- These crashes tend to occur in the evening hours (e.g., 4 PM to 4 AM).
- These crashes tend to be related to increased levels of alcohol consumption and to an increased incidence of speeding.

Obviously, this profile of the more severe crashes does not apply to the full spectrum of run-off-road crashes. Briefly, there is insufficient detail in the GES file and other mass databases to establish a complete picture of this crash type. Additional detail concerning causal factors, driver actions, and crash characteristics will be developed in the clinical analyses and the engineering analyses documented in the subsections which follow.

5.3 CIinical Analysis

A sample of hard copy case reports was selected from the NASS CDS file and subsequently analyzed to establish a detailed profile of causal factors and crash characteristics. The selection process used to establish the clinical sample is described in the subsection which follows. That discussion is then followed by a presentation of analysis results. The format for analysis results parallels the format used in the statistical analysis discussion.

5.3.1 Selection of Clinical Sample

The project staff has conducted several clinical analyses similar to the analysis required for the current program. The most recent of these analyses was completed for the OMNI IVHS program sponsored by NHTSA and administered by the Volpe National Transportation Systems Center (VNTSC). In that effort, NASS CDS case reports were examined to produce a causal factor profile and the crash circumstances associated with the single-vehicle roadway departure crash type. This analysis was completed with a limited sample of 1991 NASS CDS case reports. To maintain consistency, the project staff proposed to use these same CDS files in the current program. We also suggested that the 1993 NASS CDS file be utilized for this purpose since use of the more recent files would allow comparison of analysis results over a three-year period.

When the target crash population was identified, as described in Section 3, a listing of the accident types comprising that population was submitted to the NHTSA COTR. Specifically, the target crash population consisted of the GES accident category “Single Driver” and accident configurations “Right Roadside Departure“, “Left Roadside Departure”, and “Forward Impact”. The accident typing scheme used in the NASS CDS and GES delineates accident types within these configurations. This allows crashes to be grouped by specific characteristics. With the target crash population established, the GES variable values could then be used to scan the 1993 CDS file for matching cases. To allow flexibility in sample selection, a listing of all relevant cases in the 1993 CDS file was requested. The search specification for the NASS CDS database was as follows:

CDS Zone Center:	1 or2
Quarter:	1, 2, or3
Accident Type:	01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 14, 15, 16

In response to submission of the search request, NHTSA produced a listing of all 1993 NASS CDS cases that conformed to the above restrictions. This listing contained a total of 105 1 cases. Of this total, 555 cases were classified as right roadside departure configurations, 391 cases were left roadside departure configurations, and 105 were forward impact configurations. This distribution of NASS CDS cases did not closely parallel the profile observed in the GES file for 1992 as illustrated in Table 5-21.

Table 5-21
Comparison of GES and NASS
Crash Configuration Distribution

Crash Configuration	1992 GES	1993 NASS CDS
Right Roadside Departure	45.90%	52.8%
Left Roadside Departure	31.90%	37.20%
Forward Impact	22.20%	9.99%
Total	100.00%	100.00%

Underrepresentation of the forward impact configuration in the NAS S CDS file is associated with the nature of these crashes. As indicated in the discussion of statistical analysis results, forward impacts tend to be the least severe crashes, in terms of injury consequence, of the three configurations under consideration. Since NASS oversamples more severe crashes, this crash configuration will be underepresented (i.e., the underrepresentation is inherent in the NASS sampling design).

In this case, the sample design problem was further compounded by the fact that most of the forward impact cases specified in the listing were crashes that occurred on the roadway and were, therefore, not applicable to the current effort. The project staff initially selected a clinical sample of 234 cases. Following deletion of not applicable cases, the final analysis sample contained 20 1 cases. The distribution of this sample with respect to crash configuration is as follows:

Crash Confirmation	Cases	Sample Proportion (%)
Right Roadside Departure	106	52.74
Left Roadside Departure	88	43.78
Forward Impact	7	3.48
	201	100.00

While the final sample composition profile does not match the GES profile, we believe that the degrees of under-and over-representation in this sample are within acceptable limits. The over-representation of the more severe right and left roadside departure crashes will require application of a weighting scheme to all clinical analysis results. The intent here will be to compensate for the injury severity bias of the selected sample. The specific weighting schemes applied to the clinical analysis distributions are provided in Appendix B.

Other factors considered in the sample selection process were regional diversity and time of year. These factors were considered to be less critical to the selection process since the program was limited to using cases generated in the first three quarters of 1993 and, therefore, an unbalanced sample could not be avoided. After examining the range of conditions in the final sample, the project staff believes that the first three quarters of data provides the ful range of environmental conditions typically associated with a complete data collection year. The distribution of sample cases with respect to Zone Center (e.g., regional diversity) is as follows:

Zone Center 1:	123 cases
Zone Center 2:	78 cases
	201 cases

The predominance of Zone Center 1 cases in the sample is due to logistical, as well as sample balance considerations. Calspan operates Zone Center 1 for the National Accident Sampling System. Therefore, we have more unrestricted access to Zone Center 1 case material as compared to Zone Center 2 (operated by Indiana University) since the latter case material can only be accessed at the NASS data storage contractor. Calspan did review the entire clinical case sample from both Zone Centers at the storage contractor in response to a NHTSA request to verify values for the cluster of collision avoidance variables. We believe that the final clinical sample reflects regional diversity since no major regional differences were detected in the cases reviewed.

5.3.2 Summary of Univariate Distributions

Univariate distributions produced from the clinical sample have been converted to graphical displays and a tabular format. These displays are provided as Figures 5-10 to 5-21 and the tabular format is provided as Table 5-22. Major points deriving from the displays and the table may be summarized as follows:

- As indicated in the discussion in Section 5.3.1, the left roadside departure and right roadside departure crash configurations dominate the clinical sample: Within these configurations, control/traction loss crashes (27.4 percent-left and 29.9 percent-right) are the most prevalent accident types. Drive off road crashes (11.8 percent-left and 19.7 percent-right) also comprise a significant portion of the sample (Figure 5-10).

- Most of the run-off-road crashes contained in the clinical sample occur on trafficways that are not divided (66.3 percent) and which are comprised of two travel lanes (62.2 percent). The relative proportions of divided roadways and multi-Iane roadways exceed the proportions noted in the GES database (Figure 5-l 1).

- Most of the run-off-road crashes contained in the clinical sample occur on curved roadway segments (58.1 percent) and on roadway segments where a vertical grade (54.2 percent) is present (Figure 5-12).

- Most of the run-off-road crashes contained in the clinicaI sample occur on dry roadway segments (63.1 percent). Wet surfaces (23.7 percent) and snow/ice covered surfaces (13.1 percent) also comprise a significant proportion of the sample (Figure 5-13).

- Crashes occurring during daylight hours comprise 48.7 percent of the clinical sample. Most of the crashes occur during periods of darkness (5 1.3 percent) with 3 1.1 percent occurring without artificial lighting and with 20.2 percent occurring in locations where the roadway was lighted (Figure 5-14).

- Most of the run-off-road crashes contained in the clinical sample occur in settings where the ambient weather conditions are clear (64.4 percent). Rainy environments (20.1 percent) and snow conditions (9.5 percent) also comprise a significant proportion of the sample (Figure 5- 15).

- Most drivers in this sample do not attempt a pre-crash avoidance maneuver (41.5 percent). Of those drivers who initiate avoidance maneuvers, the most common actions are steering (23.2 percent), braking and steering (14.2 percent), and braking only (11.8 percent). These rates are considerably higher than similar rates contained in the GES database (Figure 5-l 6).

- Figures 5-17 to 5-20 are graphical displays pertaining to the remaining four collision avoidance cluster variables (attempted avoidance maneuvers are described in Figure 5-16). Key aspects of these displays may be summarized as follows:

  Figure 5-17

  The pre-event movement of most drivers was either going straight (40.2 percent) or negotiating a curve (40.2 percent).

  Figure 5-18

  The most common critical precrash events are lane/roadway departure (48.6 percent) and loss of vehicle control (37.7 percent).

Figure 5-19

For those drivers initiating avoidance maneuvers, the most common vehicle states following the maneuvers are skidding (24.7 percent) and tracking (23.3 percent).

Figure 5-20

For those drivers initiating avoidance maneuvers, the most common consequence of the maneuver is roadway departure (48.6 percent).

- There is a wide range of causal factors associated with the clinical sample. The most prevalent factor is vehicle speed (32.0 percent) followed by relinquished steering control (20.1 percent), lost directional control (16.0 percent), evasive maneuver (15.7 percent), and driver inattention (12.7 percent). Vehicle failures (3.6 percent) are a relatively minor contributor to the causal profile (Figure 5-21).

  A more detailed distribution of these causal factors is provided in tabular format in Table 5-22.

5.3.3 Interpretation of Univariate Results

The presence of the drive off road accident type within the left and right roadside departure configurations (Figure 5-10) minimizes the impact of the very small proportion of forward impacts included in the clinical sample. As indicated in discussions in Sections 3.1 and 3 -2, the forward impact accident type is very similar to the drive off road accident type in many respects. Previous work indicates that the causal factors associated with these accident types are also similar with each accident type having relatively high rates of driver inattention and relinquishing steering control. Therefore, the risk of missing causal factor types or crash characteristics associated with the forward impact configuration is minimal.

The incidence rates noted for the control/traction loss accident type associated with left roadside departure crashes (27.4 percent) and right roadside departure crashes (29.9 percent), in Figure 5-10, exceed corresponding rates noted in the GES target crash population (14.4 percent and 18.6 percent, respectively). These elevated rates are associated with the relatively high proportion of cases in the clinical sample that were selected from the first data collection quarter. The project staff is aware of the unbalanced nature of the sample.

The proportions of crashes occurring on non-divided two lane roadways (Figure 5-ll), on curved roadway segments (Figure 5-12), and in periods of darkness (Figure 5-14) exceed the values for corresponding proportions noted in the GES database. These increased incidence rates in the clinical sample are consistent with the higher severity level of the NASS CDS file as compared to the GES file. Specifically, the larger proportions in the clinical database reflect increased proportions of crashes occurring on curved two lane rural roadways during periods of darkness.

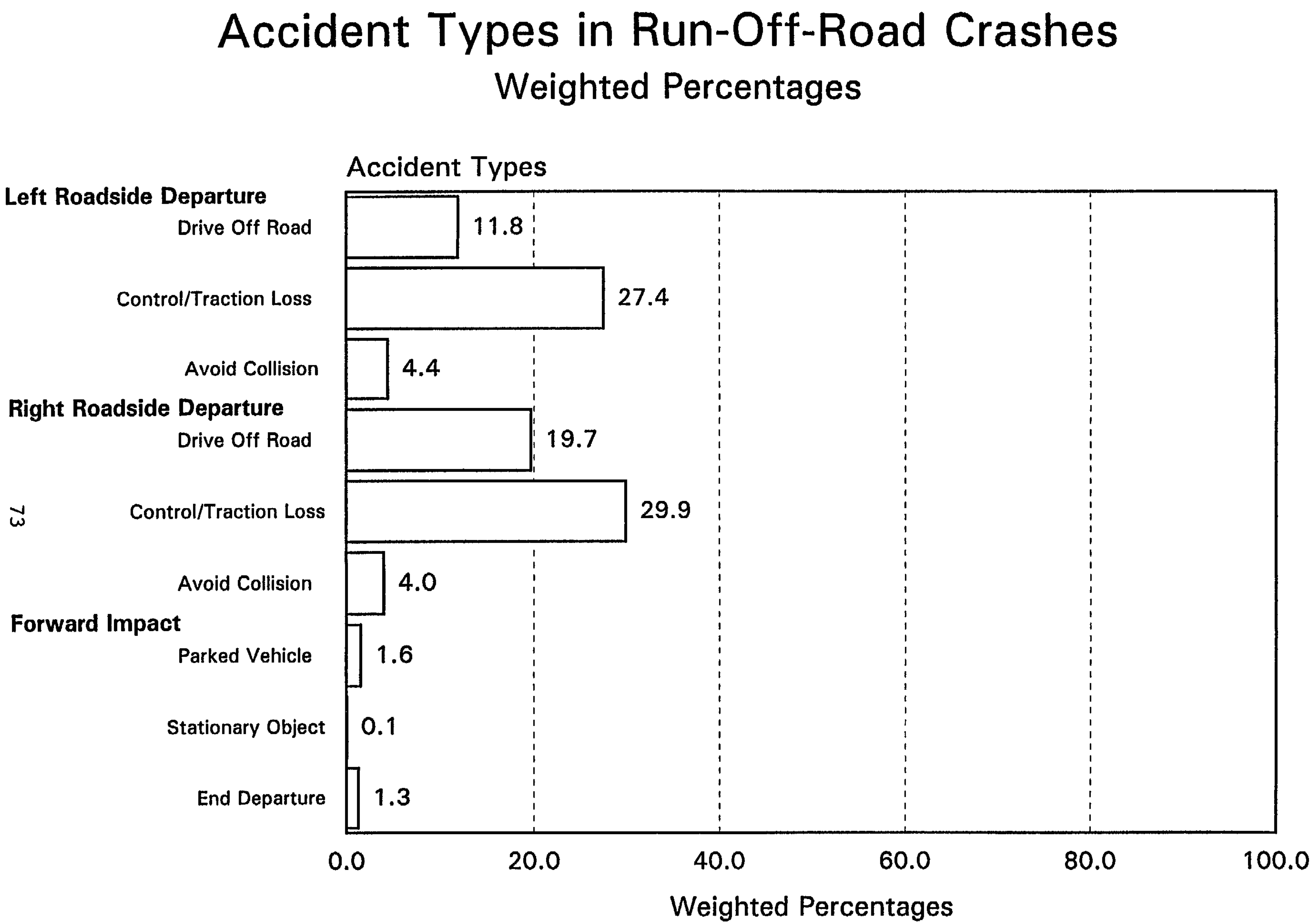
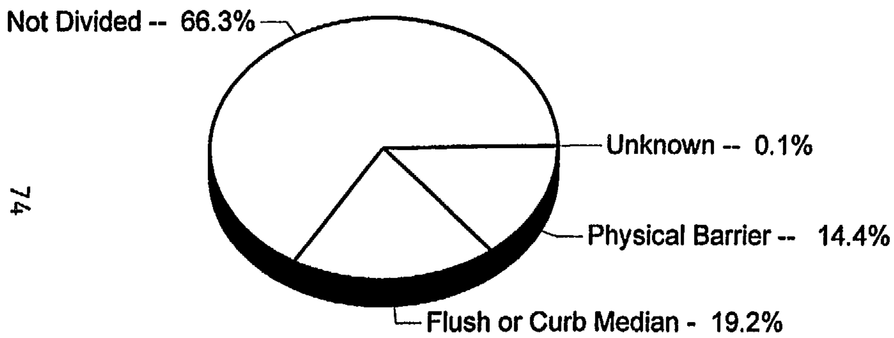

Accident Types in Run-Off-Road Crashes
Weighted Percentages
Accident Types
Left Roadside Departure
Drive Off Road
11.8
Control/Traction Loss
27.4
Avoid Collision
4.4
Right Roadside Departure
Drive Off Road
19.7
Control/Traction Loss
29.9
Avoid Collision
4.0
Forward Impact
Parked Vehicle
1.6
Stationary Object
0.1
End Departure
1.3
0.0
20.0
40.0
60.0
80.0
100.0
Weighted Percentages

Figure 5-10

Roadway Characteristics of Run-Off-Road Crashes

Weighted Percentages

Type of Trafficway



No. of Travel Lanes

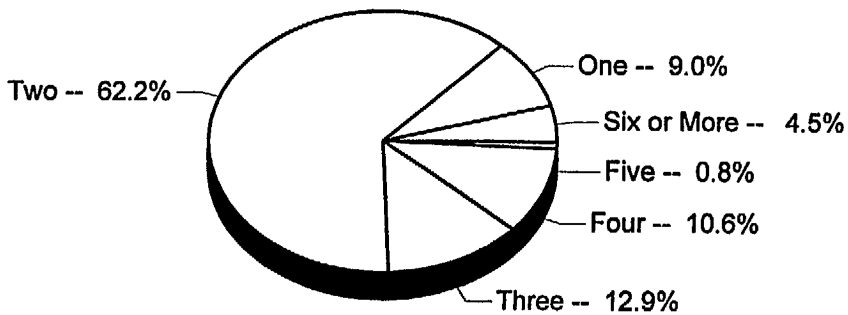


Figure 5-11

Roadway Alignment in Run-Off-Road Crashes

Weighted Percentages

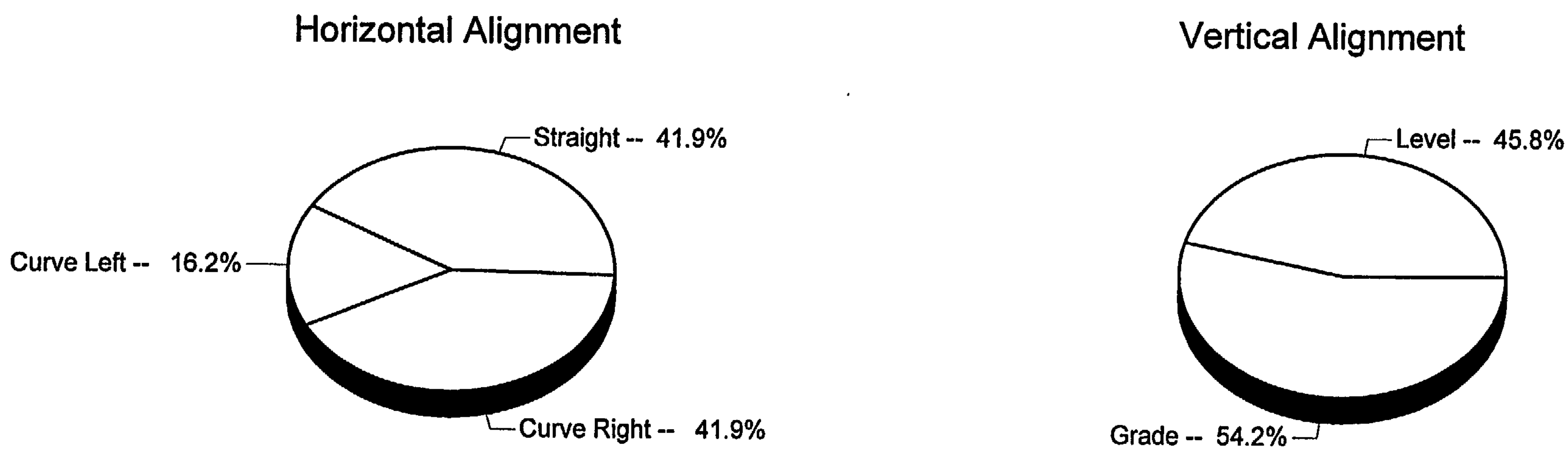


Figure 5-12

Surface Condition in Run-Off-Road Crashes

Weighted Percentages

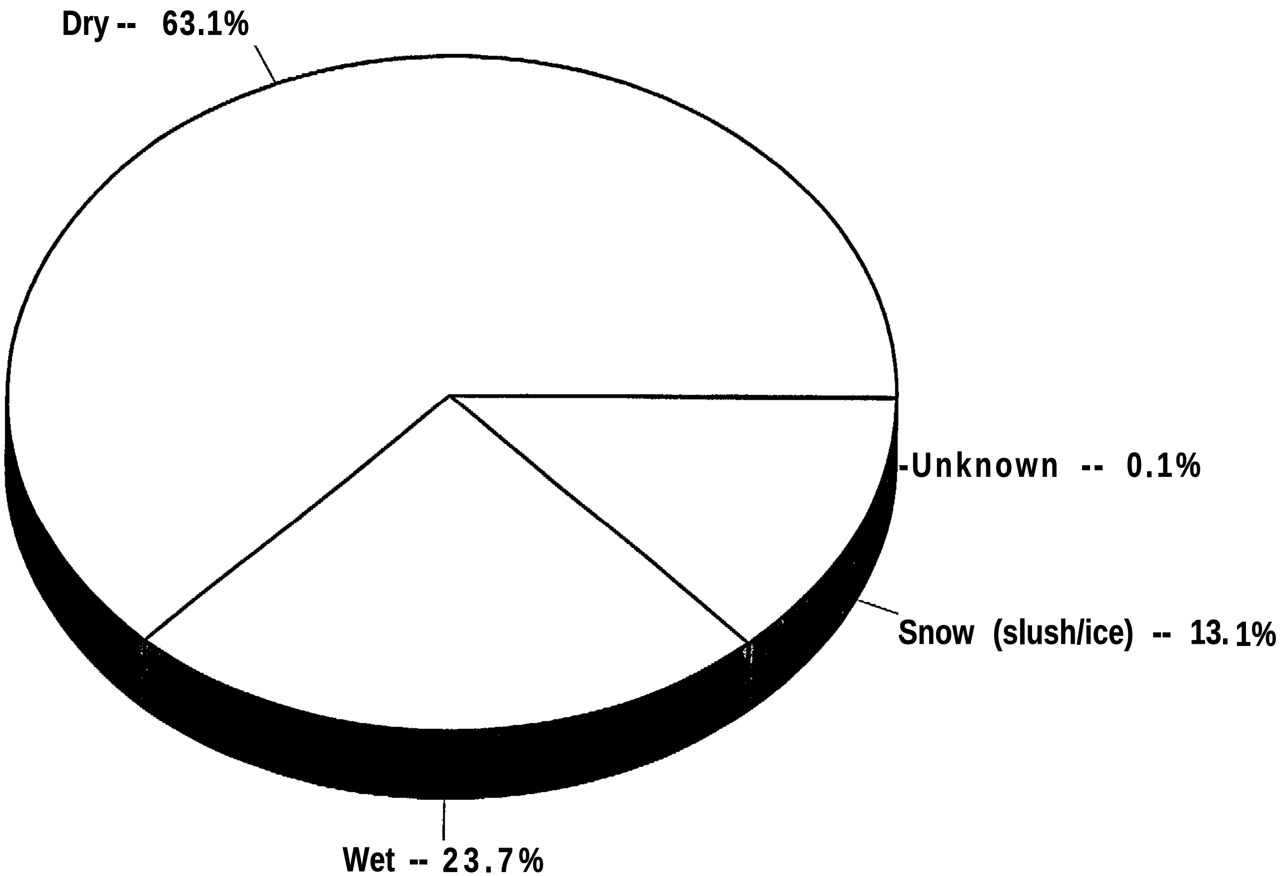


Figure 5-13

Lighting Condition in Run-Off-Road Crashes
Weighted Percentages

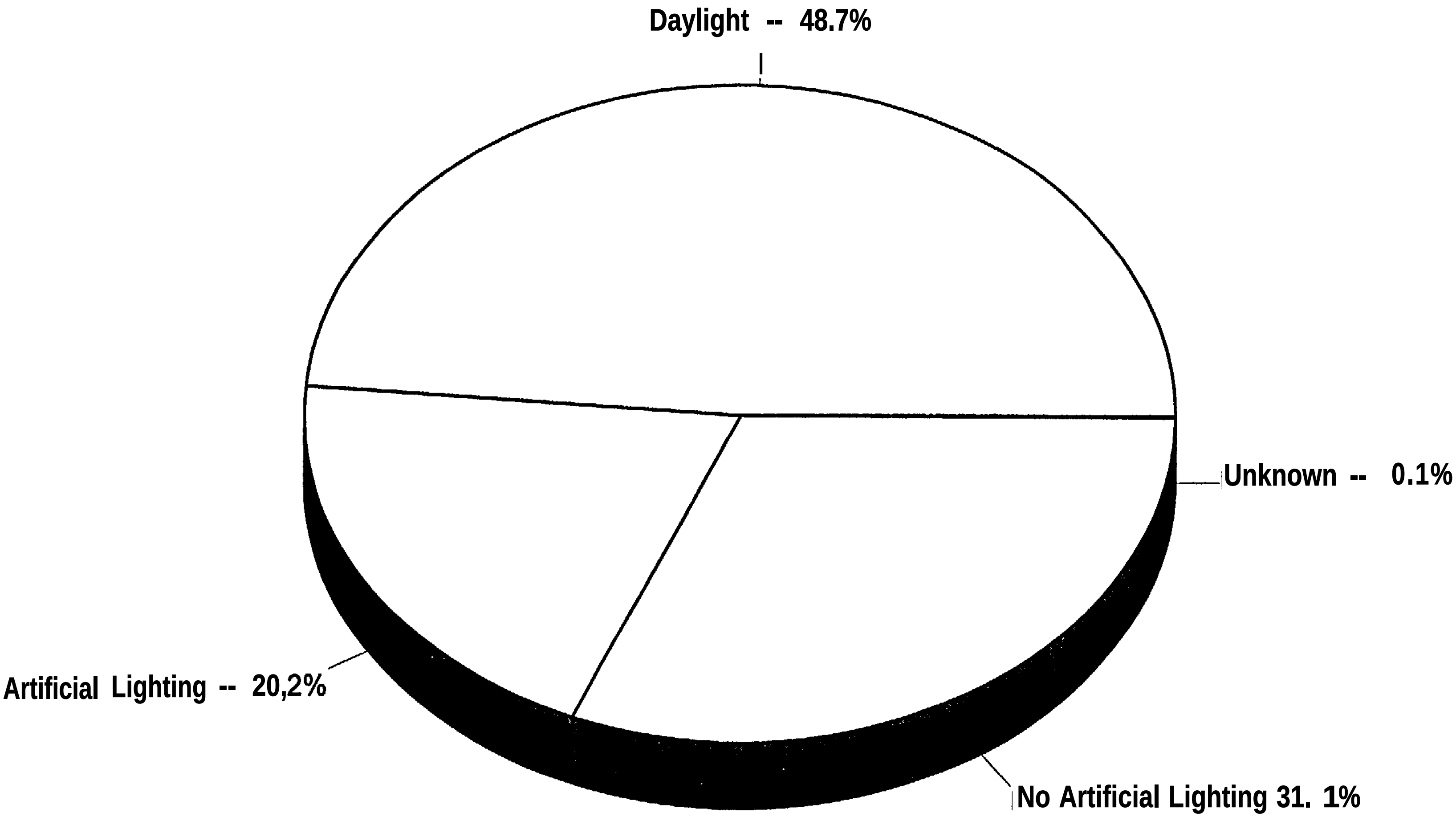


Figure 5-l 4

Ambient Weather Condition in Run-Off-Road Crashes

Weighted Percentages

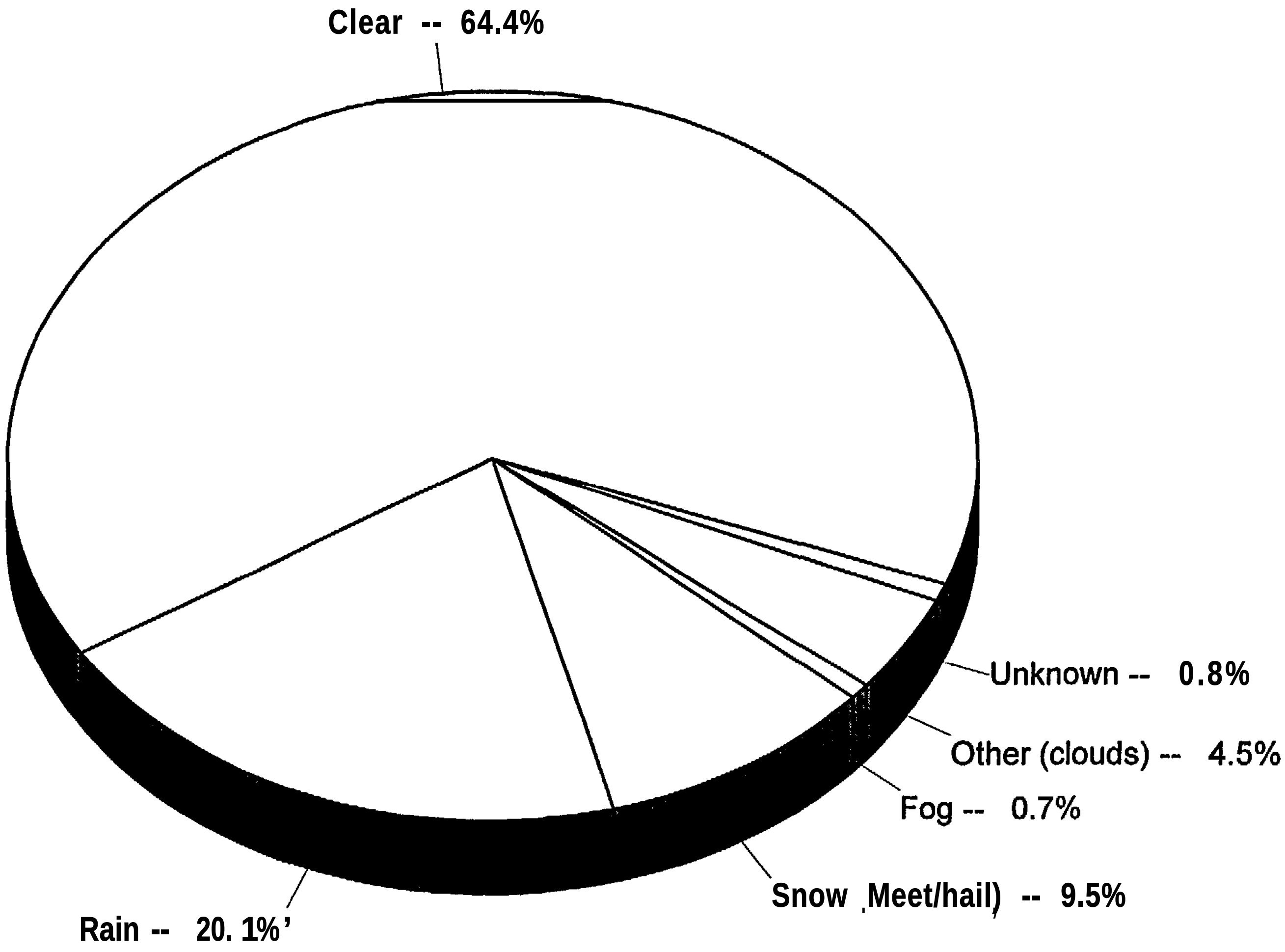


Figure 5-15

Attempted Avoidance Maneuver in Run-Off-Road Crashes

Weighted Percentages

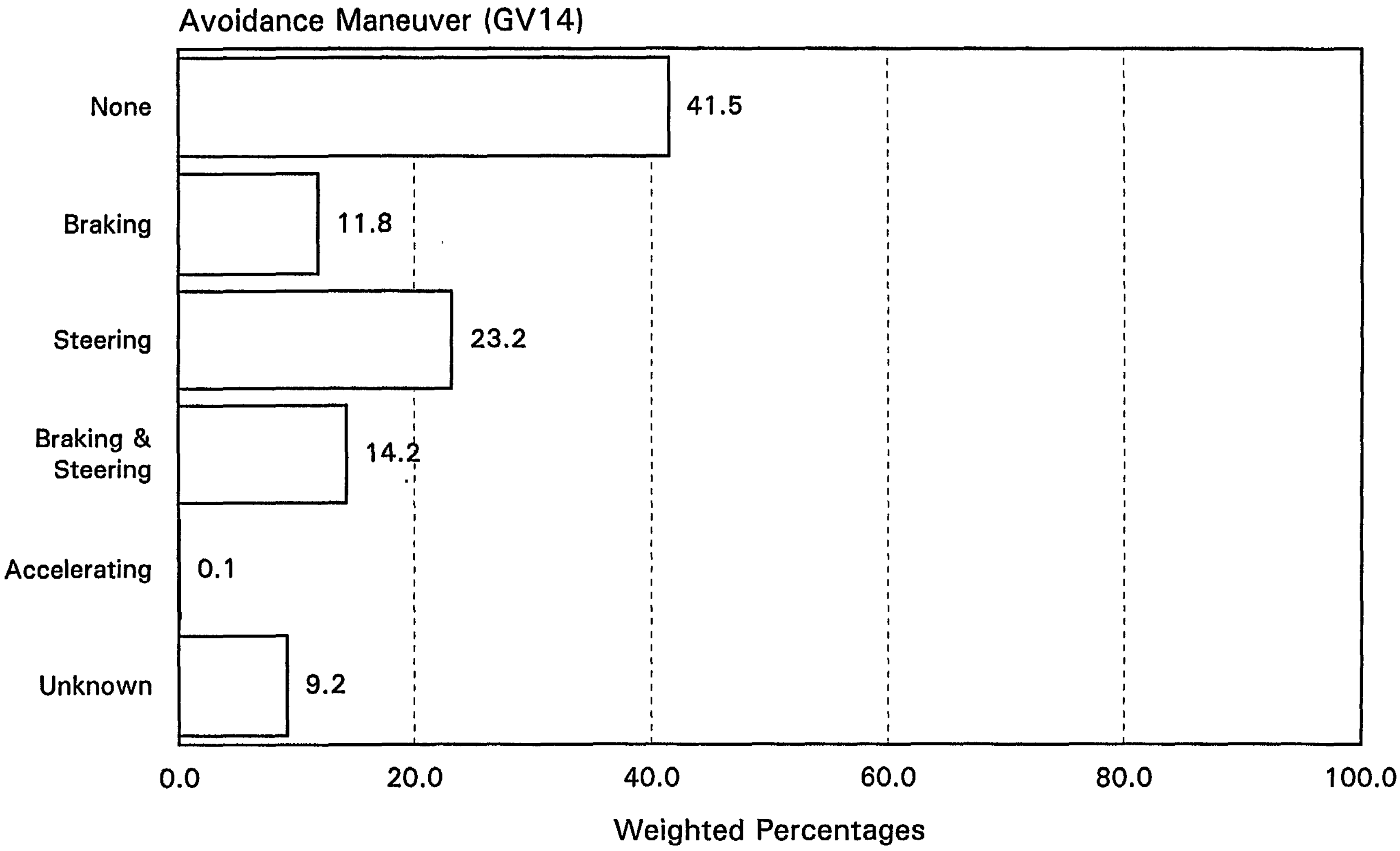


Figure 5-16

Pre-Event Movement in Run-Off-Road Crashes

Weighted Percentages

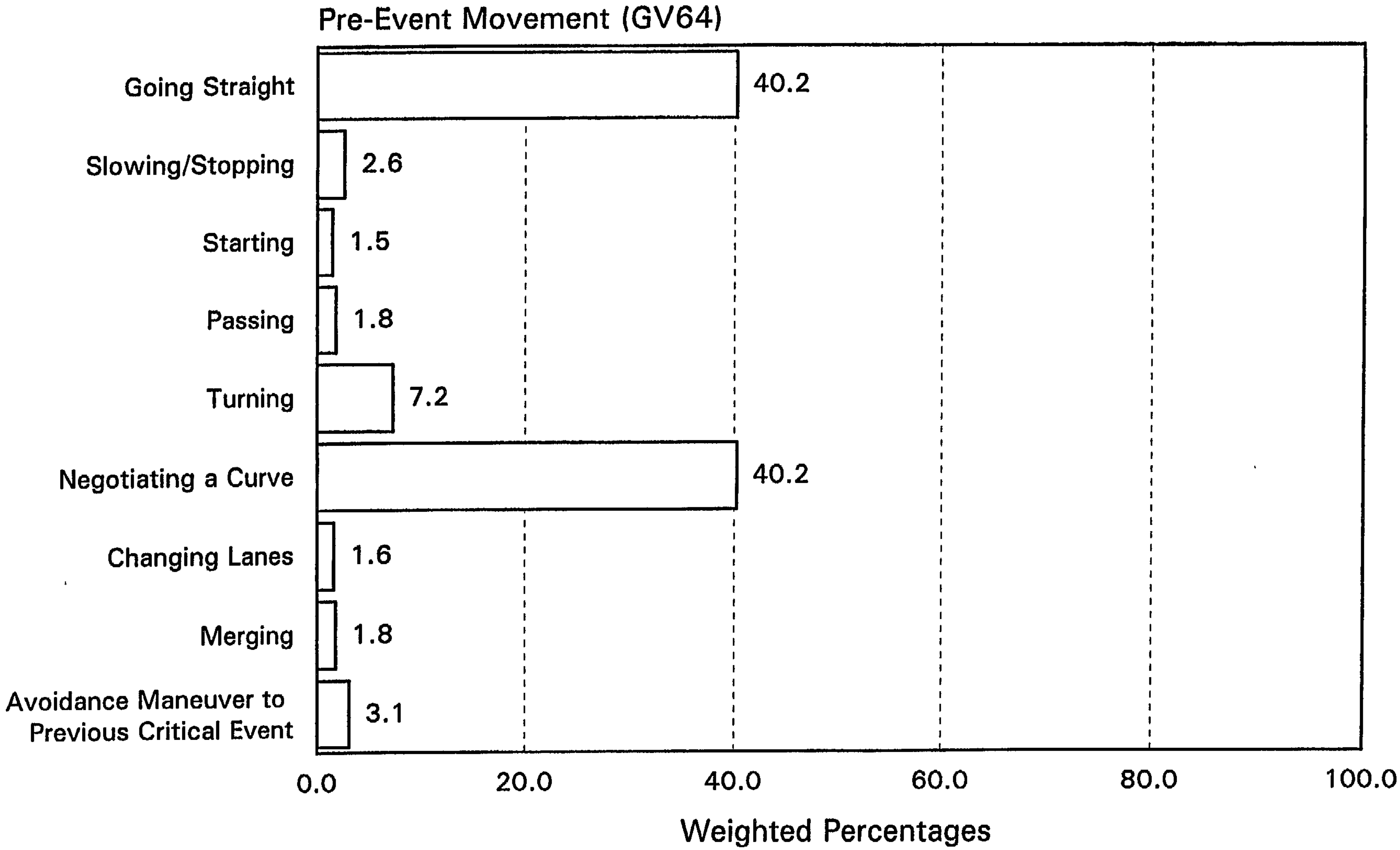


Figure 5-17

Critical Precrash Event in Run-Off-Road Crashes

Weighted Percentages

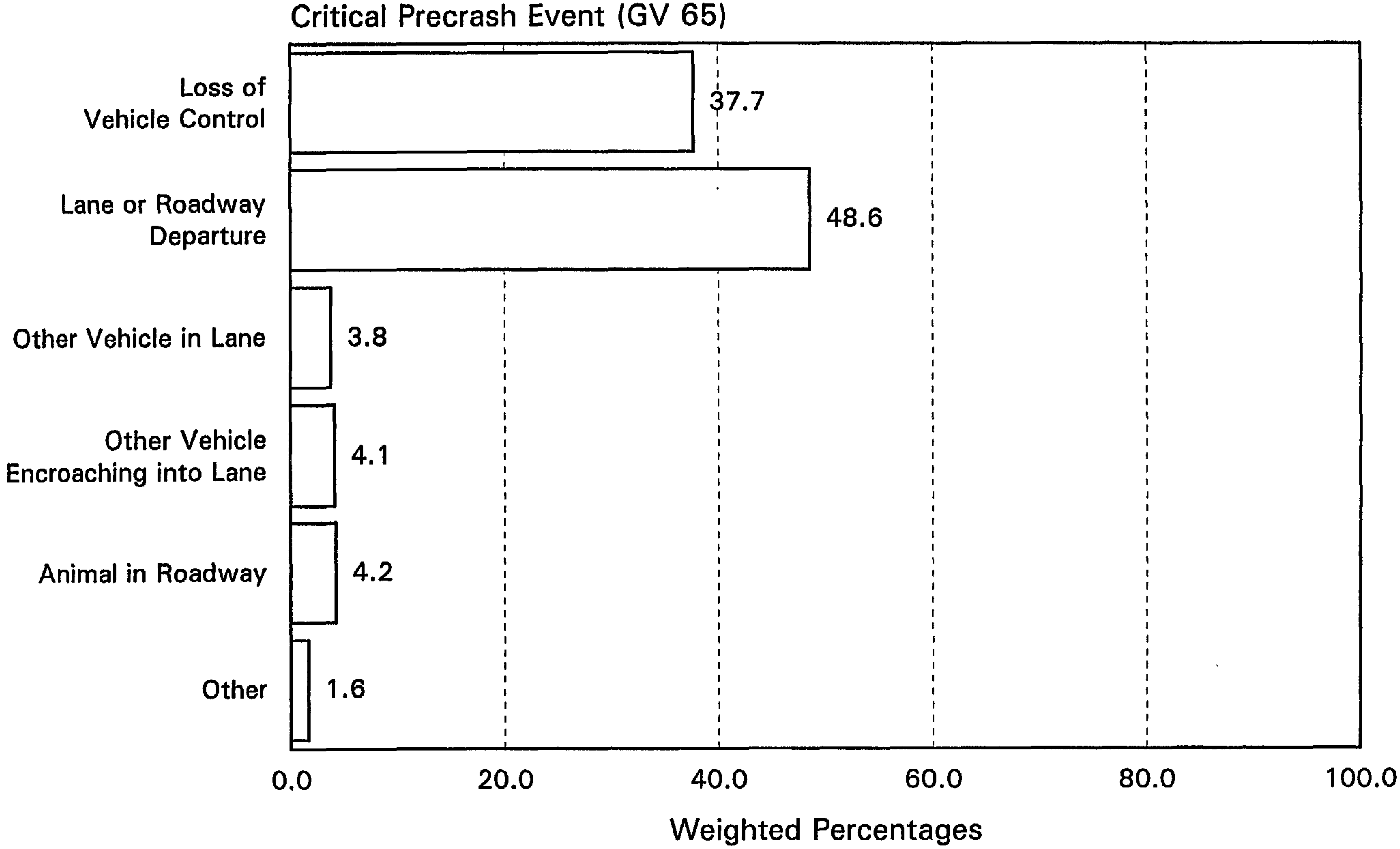


Figure 5-18

Precrash Stability After Avoidance Maneuver in Run-Off-Road Crashes

Weighted Percentages

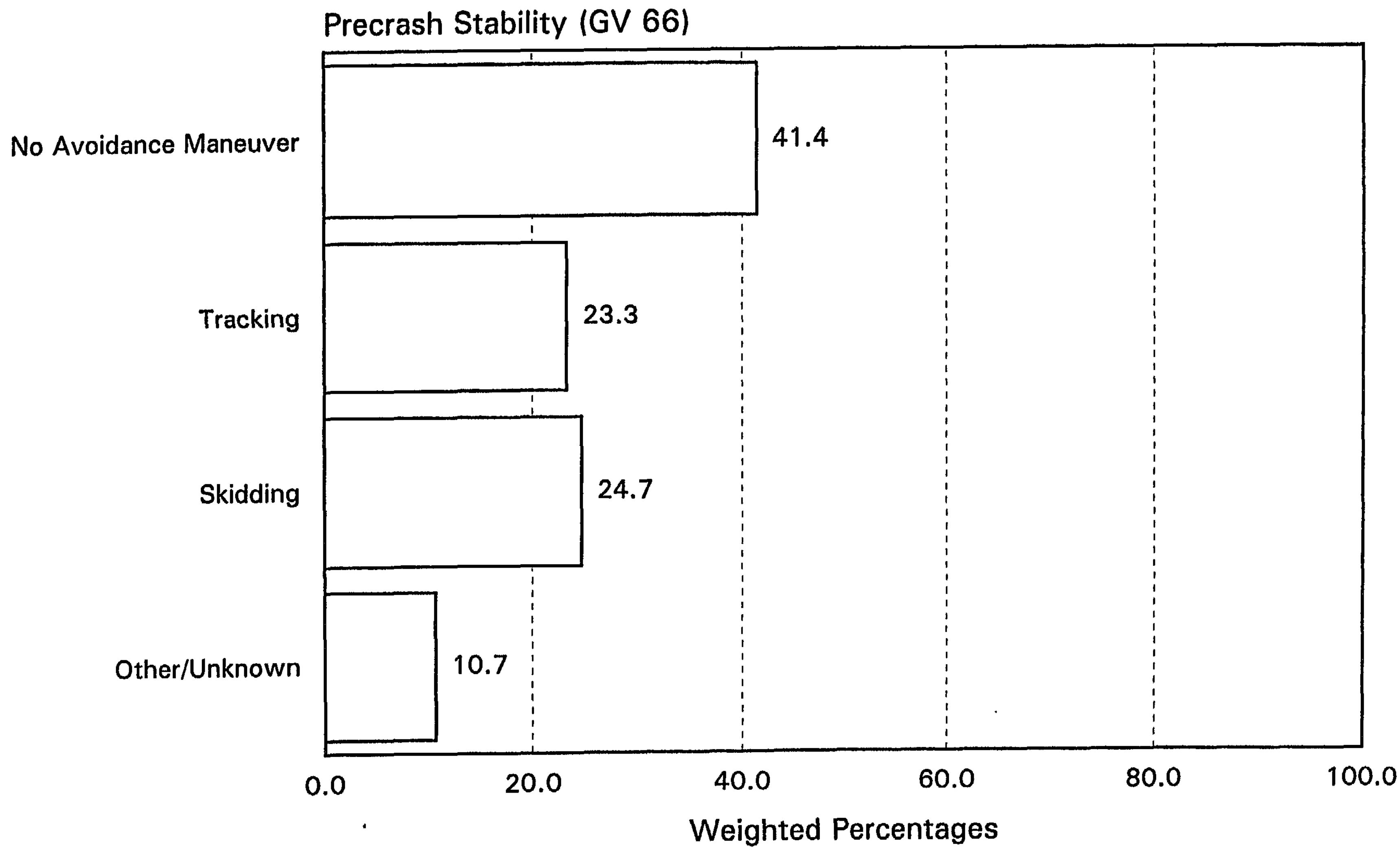


Figure 5-19

Precrash Directional Consequences of Avoidance Maneuver in Run-Off-Road Crashes

Weighted Percentages

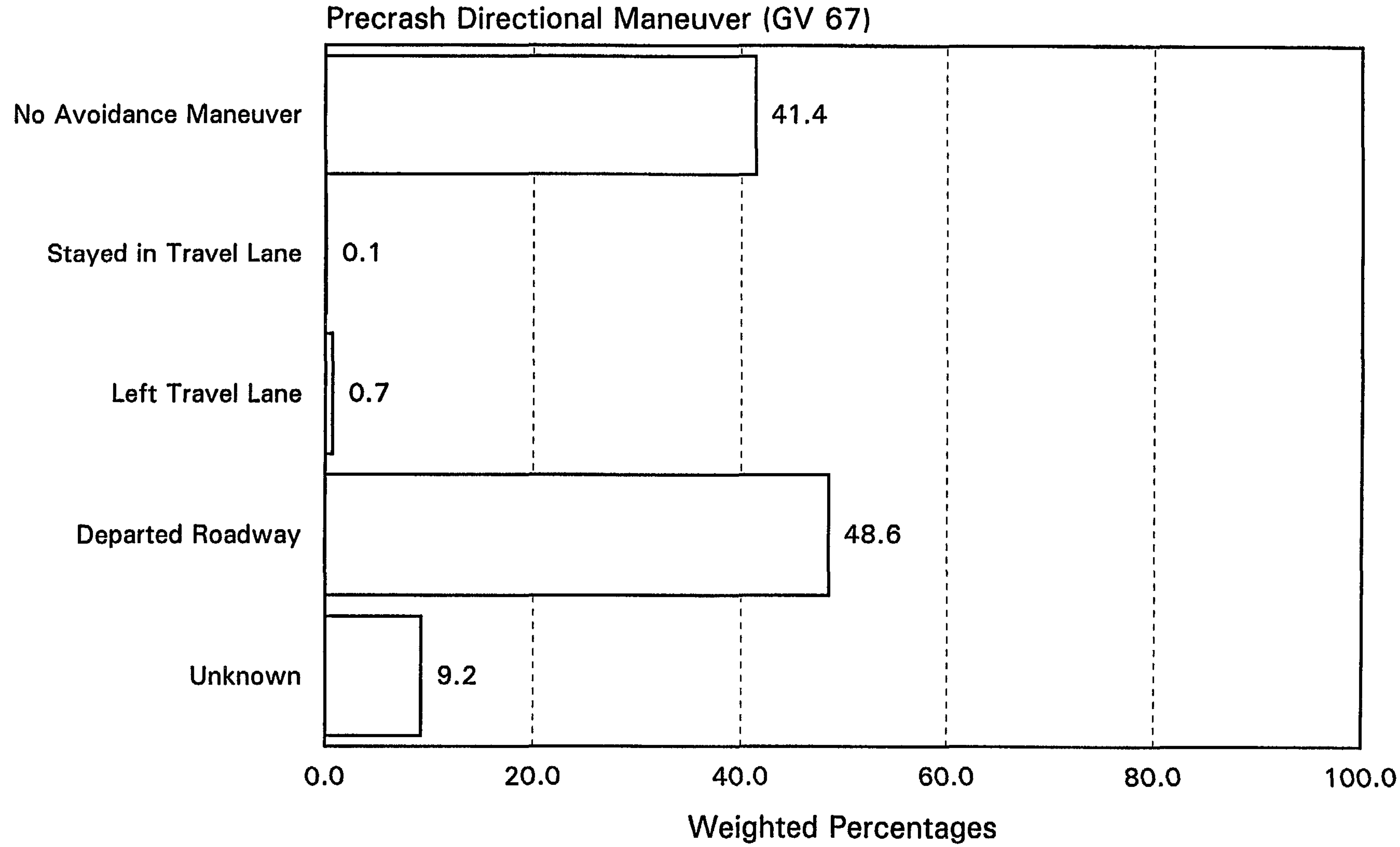


Figure 5-20

Causal Factors in Run-Off-Road Crashes

Weighted Percentages

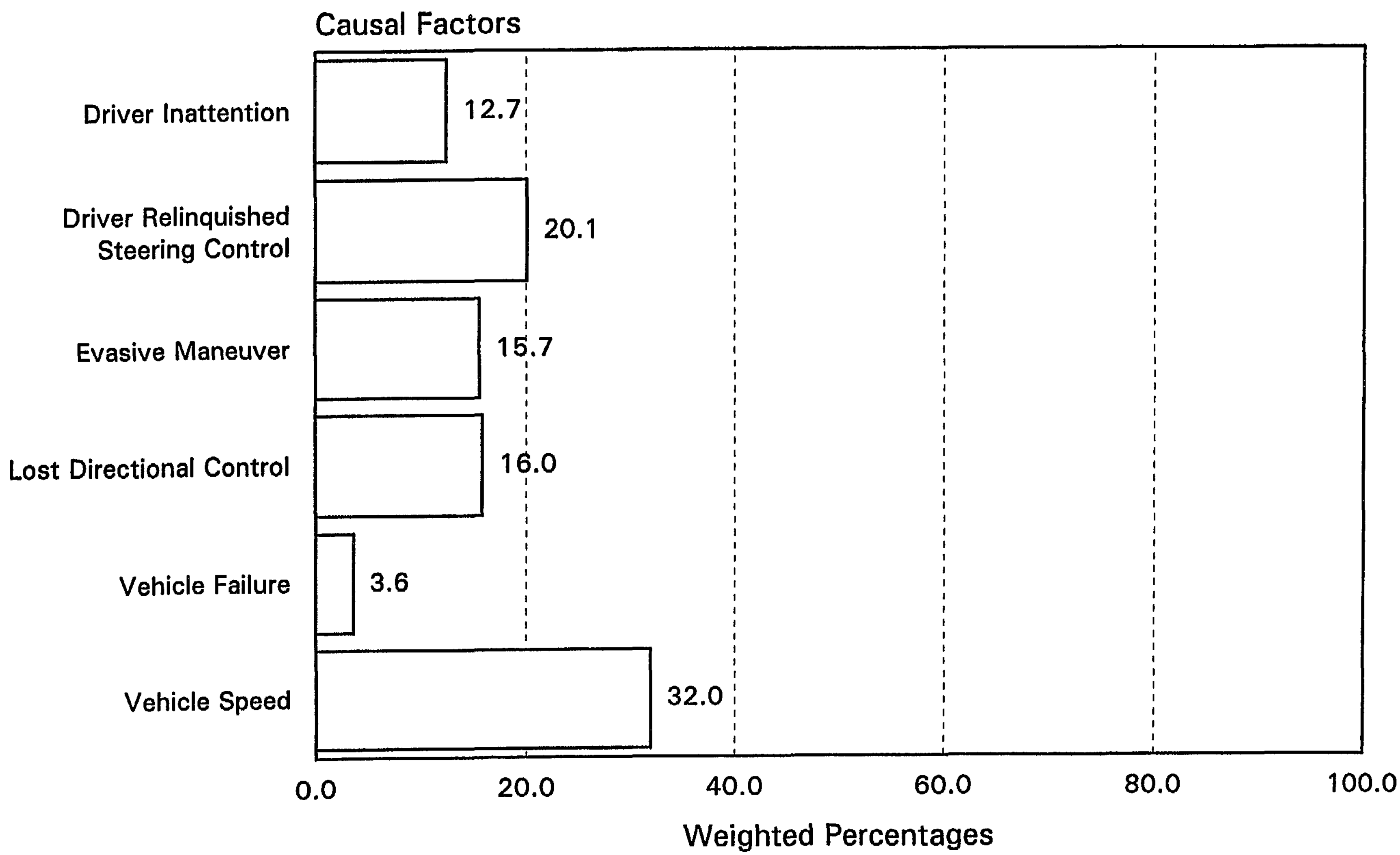


Figure 5-21

Table 5-22
Causal Factor Distribution

Causal Factor	Weighted Percent	
Driver Inattention		
Drifted Off Roadway/Travel Lane	9.96	
Steered Off Roadway Retrieving Object	1.64	
Other	1.06	
Subtotal		12.66
Driver Relinquished Steering Control		
Fell Asleep	6.93	
Intoxicated	10.94	
Physical (seizure, passed out)	1.47	
Other	0.73	
Subtotal		20.07
Evasive Maneuver		
Avoid Animal or Pedestrian	5.37	
Veh. Encroaching into Lane - Opp. dir.	1.55	
Veh. Encroaching into Lane - Same dir.	7.96	
Veh. Encroaching into Lane - Other	0.80	
Subtotal		15.68
Lost Directional Control		
Wet	6.27	
Snow/Ice	4.39	
Other	5.30	
Subtotal		15.96
Vehicle Failure		
Engine	1.47	
Tire Blowout	0.80	
Other	1.37	
Subtotal		3.64
Vehicle Speed		
Excessive	8.23	
Speed and Alcohol	11.96	
Speed and Driver Inexperience	3.66	
Unsafe Driving Act	4.56	
Other	3.59	
Subtotal		31.99
Total	100.00	

The collision avoidance cluster variables reported in Figures 5-16 to 5-20 were recoded by the project staff due to a relatively high error rate detected in the original case reports submitted by the NASS PSU teams. In addition to correcting errors, the project staff also recoded these variables to suit an internal project definition. Specifically, these variables were recoded in relation to the point of initial roadway departure as opposed the area where the crash occurred. The complete set of recoded cluster variables is provided in Volume II. The variables applicable to each case are summarized on the coded variable cover sheet provided for each case.

As reported in Figures 5-16 to 5-20, the proportion of drivers initiating avoidance maneuvers in the clinical sample is significantly higher than corresponding proportion in the GES database. As a result, the proportions for specific actions initiated by drivers also differ significantly between the clinical sample and GES database. We do not believe that any significance should be placed on these differences since the GES database may contain error patterns similar to those detected in the initial coding sequences submitted with the CDS case reports. We also firmly believe that the revised clinical coding schemes as indicated in Figure 5-16 to 5-20 are correct.

The clinical analysis team reviewed the sample of NASS CDS hard copy case reports to determine the causal factors associated with each crash. The case elements most essential to the analysis procedure were:

- Police Accident Reports (PARS)
- Driver statements
- Witness statements (when available)
- Scaled schematics depicting crash events and physical evidence generated during the crash sequence
- Case slides documenting the physical plant, physical evidence, and damage sustained by case vehicles

Each of the case elements shown in the above listing had approximately the same degree of importance or relevance in the causal factor analysis process. Specifically, no one case element was more or less germane to the causal determination than other listed elements. Information was typically extracted from each case element and then weighed against or compared to the information content of other case elements. The final causal factor determination most commonly represented a consensus of the information extracted from each case element.

The causal factor analysis conducted for this effort was also an independent assessment of available information. Analysts did not merely accept and document police reported information and driver statements. These data inputs were evaluated against the physical evidence generated by crash events and in the total context of the crash environment. In a number of instances, the analyst's interpretation of crash events and contributory causal factors diiered with police reported information. While these clinical assessments were subjective in nature, the degree of subjectivity was less than the levels associated with the often biased description provided by crash involved drivers.

5.3.4 Summary of Bivariate Distributions

Bivariate distributions produced during this analysis effort are presented as tabular formats in Table 5-23 to 5-39. Major points indicated by these distributions may be summarized as follows:

- Tables 5-23 to 5-26 examine the relationship between horizontal alignment, surface condition, accident type, and causal factors with respect to injury severity. An explanation of table formats is essential at this point. These formats are exactly reversed from the anticipated or most informative layouts. For example, in Table 5-23 it would be more informative is to examine maximum injury severity by horizontal alignment. This type of format would allow injury patterns to be examined within crashes occurring on straight and curved segments and would allow subsequent comparison of patterns between these alignment categories. Unfortunately, the weighting scheme applied to the clinical sample is based on and derived from injury severity. Therefore, any format where injury severity is in the left vertical portion of the table, results in distributions which are identical to the weighting scheme (e.g., injury data is being weighted by injury data). Due to this problem, table formats must be reversed as shown in Tables 5-23 to 5-26. The project team recognizes that the formats, as presented, provide less insight than might be anticipated.

  The net effect of the weighting scheme, when applied to the clinical sample, is to reduce the severity bias associated with crashes occurring on dry surfaced curves. This severity bias was one of the findings of the statistical analysis discussed in Section 5.2. In view of this circumstance, Tables 5-23 to 5-26 are presented without comment. Raw data tables, constructed with unweighted data frequencies are presented and discussed in Appendix A The weighting schemes applied to clinical analysis outputs are provided in Appendix B.

- In the horizontal alignment by accident type distribution, there is considerable variability between left and right roadside departure crashes, Most left roadside departure crashes occur on curves (58.3 percent) and most right roadside departure crashes occur on straight segments (60.5 percent). This pattern differs significantly from the GES data (Table 5-5) where both configurations demonstrated similar distributions and where crashes occurring on straight segments dominated both configurations (Table 5-27).

  This same variability is evident in Table 5-27A which provides an expanded version of the accident type categories. The incidence rates for crashes occurring on straight roadway segments peak in the Avoid Collision type (65.3 percent) for left roadside departure crashes and in the Drive Off Road type (69.8 percent) for right roadside departure crashes. Similarly, incidence rates for crashes occurring on curved roadway segments peak in the Control/Traction Loss type (64.6 percent) for left roadside departure crashes and in the Avoid Collision type (47.8 percent) for right roadside departure crashes.

  A horizontal tabulation format for this distribution is provided in Table 5-27B. The pattern evident in Table 5-27 is also evident here. Specifically, the largest proportion of crashes occurring on straight segments (60.6 percent) is associated with the right roadside departure accident type. The largest proportion of crashes occurring on curved segments (54.4 percent) is associated with the left roadside departure accident type.

- Significant differences are again noted in the surface condition by accident type distribution. Incidence rates for dry surface conditions dominate the distributions for both left (55.3 percent) and right (67.2 percent) roadside departure crashes. There is, however, a relatively large diierence between these proportions. Similarly, the incidence rate for wet road surface conditions in left roadside departure crashes (33.7 percent) is nearly double the rate (17.2 percent) noted for right roadside departure crashes (Table 5-28).

  Table 5-28A provides an expanded version of the accident type categories for this same distribution. Incidence rates for dry surface conditions peak in the Avoid Collision type (100.0 percent) for left roadside departure crashes and in the Drive Off Road type (72.0 percent) for right roadside departure crashes. Incidence rates for wet road surface conditions peak in the Drive Off Road type (51.6 percent) for left roadside departure crashes and in the Avoid Collision type for right roadside departure crashes. The very high incidence rates for dry surface conditions in the Control/Traction Loss type for both left (52.2 percent) and right (63.3 percent) roadside departure crashes is symptomatic of the involvement of relatively high travel velocities.

  A horizontal tabulation format for this distribution is provided in Table 5-28B. The patterns evident in Table 5-28 are also evident here. Specifically, the highest proportion of crashes occurring on dry surface conditions (58.0 percent) and the highest proportion of crashes occurring on snow (slush/ice) covered surface conditions (66.7 percent) are associated with the right roadside departure accident type. The highest proportion of crashes occurring on wet surface conditions (60.5 percent) is associated with the left roadside departure accident type.

- Significant differences are also apparent between left and right roadside departure crashes in the attempted avoidance maneuver by accident type distribution. The incidence rate for no attempted avoidance maneuver for right roadside departure crashes (54.8 percent) is more than double the rate noted for left roadside departure crashes (22.9 percent). In left roadside departure crashes, 69.1 percent of the subject drivers braked, steered, or braked and steered. This proportion is more than double the rate noted for drivers in right (34.4 percent) roadside departure crashes (Table 5-29).

- In the time by accident type distribution, the proportion of crashes occurring peaks in the 3 PM to 6 PM time frame (17.9 percent-left and 19.1 percent-right). The remainder of the pattern is less consistent than was noted in the GES data (Table 5-30).

- In the light condition by accident type distribution, the profiles for left and right roadside departure crashes are reasonably similar. In both profiles, the incidence rates for no artificial lighting (31.0 percent-left and 28.9 percent-right) exceed the incidence rates for artificial lighting (18.1 percent-left and 22.7 percent-right) during periods of darkness.

This implies that a substantial proportion of the crashes in the clinical sample are occurring in rural environments (Table 5-31).

- In the causal factor by accident type distribution, there are significant differences between the profiles for left and right roadside departure crashes. The most frequently occurring causal factors for left roadside departure crashes are vehicle speed (43.6 percent) followed by evasive maneuvers (22.0 percent) and lost directional control (15.9 percent). This same profile for right roadside departure crashes is driver relinquished steering control (27.7 percent) followed by vehicle speed (22.8 percent) and driver inattention (18.1 percent). These differences between the causal factor profiles for the left and right roadside departure crashes are very important. Previous work performed by the project staff indicates that each causal factor type has an associated set of vehicle states, driver states, and driver actions and that these subsets of factors differ between causal factor types. Therefore, the differences noted between the profiles discussed here imply that there will be significant differences between these crash configurations with respect to dynamic situation factors. This issue will be explored and resolved in the engineering analysis section (Table 5-32).

  A horizontal tabulation format for this distribution is provided in Table 5-32A. The largest proportion of crashes in the evasive maneuver (63.8 percent), vehicle failure (83.7 percent), and vehicle speed (60.0 percent) causal factor categories are associated with the left roadside departure accident type. The largest proportions of crashes in the driver inattention (77.1 percent), driver relinquished steering control (75.5 percent), and lost directional control (61.5 percent) causal factor categories are associated with the right roadside departure accident type.

- The variability noted in the preceding table is also apparent in the causal factor by horizontal alignment distribution. The primary causal factor for crashes occurring on curved and straight segments is vehicle speed (38.7 percent-curve and 26.1 percent-straight). The difference in magnitude between these incidence rates, however, is relatively large. The second most frequently occurring causal factor for crashes on straight segments is evasive maneuver (20.0 percent) and the incidence rate for this causal factor is nearly double the rate noted for crashes on curved segments (10.8 percent). Similarly, the second most frequently occurring causal factor for crashes on curved segments is driver relinquishes steering control (24.8 percent) and this incidence rate is substantially larger than the rate (16.0 percent) associated with crashes on straight segments (Table 5-33).

  A horizontal tabulation format for this distribution is provided in Table 5-33A. The largest proportions in the driver relinquished steering control (62.5 percent), vehicle failure (64.2 percent), and vehicle speed (56.7 percent) causal factor categories are associated with crashes that occur on straight roadway segments. The largest proportions in the driver inattention (65.7 percent), evasive maneuver (66.8 percent), and lost directional control (61.9 percent) causal factor categories are associated with crashes that occur on curved roadway segments.

- Similar order of magnitude differences are noted in the causal factor by surface condition distribution. The most frequently occurring causal factor for dry and wet surface conditions is vehicle speed (32.6 percent-dry and 33.1 percent-wet). For snow/ice covered surfaces, the most frequently occurring causal factor is lost directional control (62.7 percent). The second highest incidence rate for this same surface condition is vehicle speed (23.8 percent) and the incidence rate of this factor is lower than the rates associated with dry or wet surfaces. Similarly, the second most frequently occurring factor for dry surfaces is driver relinquished steering control (24.3 percent) and this incidence rate is substantially higher than corresponding rates associated with wet (15.3 percent) or snow/ice (10.5 percent) covered surfaces. Finally, the second most frequently occurring factor for wet surfaces is evasive maneuver (25.9 percent) and this incidence rate is substantially higher than corresponding rates associated with dry (13.5 percent) or snow/ice (3.0 percent) covered surfaces (Table 5-34).

  A horizontal tabulation format for this distribution is provided in Table 5-34A. Dry surfaces predominate the distributions for the driver inattention (100.0 percent), driver relinquished steering control (78.5 percent), evasive maneuver (56.1 percent), vehicle failure (100.0 percent), and vehicle speed (64.6 percent) causal factor categories. Wet surfaces (41.0 percent) comprise a significant proportion of the distribution for the evasive maneuver category. Snow (slush/ice) covered surfaces (56.6 percent) predominant the distribution for the lost directional control category. Wet surfaces (34.8 percent) also comprise a significant proportion of this distribution.

- In the causal factor by lighting condition distribution, the highest incidence rates in the daylight condition are vehicle speed (32.4 percent) followed by evasive maneuver (22.3 percent). The highest incidence rates for the artificial lighting condition are vehicle speed (33.6 percent) followed by driver relinquished steering control (24.8 percent). Corresponding rates for the no artificial lighting condition are driver relinquishes steering control (42.8 percent) followed by vehicle speed (29.3 percent). The very low incidence rate of driver relinquished steering control (6.1 percent) in the daylight condition reflects the lower incidence of gross intoxication during this time frame (Table 5-35).

  A horizontal tabulation format for this distribution is provided in Table 5-3 5A. Daylight conditions predominate the distributions for five of the six causal factor categories (i.e., driver inattention - 53.3 percent evasive maneuver - 73.1 percent, lost directional control - 65.0 percent, vehicle failure - 93.9 percent, and vehicle speed - 49.9 percent). The no artificial lighting condition (65.7 percent) predominates the distribution for the driver relinquished steering control category.

- In the causal factor by attempted avoidance maneuver distribution, major variances are again noted between causal factors within the attempted avoidance maneuver categories. In the no avoidance maneuver attempted category, the highest incidence rates are associated with driver relinquished steering control (42.1 percent) and driver inattention (23.5 percent). Corresponding rates in the braking category are associated with vehicle the highest incidence rates are associated with vehicle speed (46.3 percent) and evasive maneuver (27.0 percent). Corresponding rates in the braking and steering category are associated with evasive maneuver (58.2 percent) and vehicle speed (22.3 percent). Rates in the accelerating category reflect the very small number of drivers initiating this maneuver (Table 5-36).

A horizontal tabulation format for this distribution is provided in Table 5-36A. The largest proportion of crashes for the driver inattention (76.7 percent), driver relinquished steering control (88.6 percent), and vehicle failure (66.2 percent) causal factor categories are associated with the no attempted avoidance maneuver designation. The largest proportion of crashes in the evasive maneuver category are associated with braking and steering (5 1.9 percent) and steering (45.6 percent) actions. There are no predominant actions for the lost directional control and vehicle speed categories are, however, the largest proportions in these categories associated with steering (32.5 percent and 30.9 percent, respectively) actions.

- Incidence rates for attempted avoidance maneuvers initiated in crashes occurring on straight and curved segments again differ appreciably. The highest incidence rate within both alignment types is associated with steering actions (18.6 percent-straight and 28.3 percent-curve). The second highest incidence rate for straight segments (18.1 percent) is associated with braking and steering actions and the second highest incidence rate for curved segments (14.9 percent) is associated with braking actions. All of these proportions are considerably higher than comparable proportions observed in the GES database (Table 5-37).

- The variability noted in the preceding table is again evident in the attempted avoidance maneuver by surface condition distribution. The highest incidence rates of attempted avoidance maneuvers within the dry and wet surface condition categories are associated with steering actions (20.5 percent-dry and 35.8 percent-wet). For snow/ice covered surfaces, the highest incidence rate is associated with braking (14.9 percent). The second highest rate is associated with braking (15.0 percent) for dry surfaces and with braking and steering (18.3 percent-wet and 12.0 percent-snow/ice) for wet and snow/ice covered surfaces (Table 5-38).

- The pattern evident in the attempted avoidance maneuver by lighting condition again demonstrates variability across the lighting condition categories. The highest incidence rates in all three conditions are associated with steering actions (28.8 percent-daylight, 20.2 percent-artificial lighting, and 17.3 percent-no artificial lighting). The second highest rate in the daylight condition is associated with braking and steering actions (23.5 percent) and corresponding rates within the artificial lighting (20.1 percent) and no artificial lighting (13.5 percent) categories are associated with braking actions (Table 5-39).

Table 5-23
Horizontal Alignment by Maximum Injury Severity

Horizontal Alignment	Maximum Injury Severity				
	No Injury	Possible Injury	Non-incapacitating Injury	Incapacitating Injury	Fatal Injury
Straight	53.5	52.6	51.9	58.1	52.6
Curve	46.5	47.4	48.2	41.9	47.4
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 5-24
Surface Condition by Maximum Injury Severity

Surface Condition	Maximum Injury Severity				
	No Injury	Possible Injury	Non-incapacitating Injury	Incapacitating Injury	Fatal Injury
Dry	62.8	42.1	74.1	72.0	84.2
Wet	23.3	36.8	18.5	20.4	10.5
Snow (slush/ice)	14.0	21.1	7.4	6.5	5.3
Unknown	0.0	0.0	0.0	1.1	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 5-25
Accident Type by Maximum Injury Severity

Accident Type	Maximum Injury Severity				
	No Injury	Possible Injury	Non-incapacitating Injury	Incapacitating Injury	Fatal Injury
Left Roadside Departure	41.9	47.4	48.2	41.9	47.4
Right Roadside Departure	55.8	52.6	44.4	54.8	47.4
Forward Impact	2.3	0.0	7.4	3.2	5.3
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 5-26
Causal Factor by Maximum Injury Severity

Causal Factor	Maximum Injury Severity				
	No Injury	*Possible Injury*	*Non-incapacitating Injury*	*Incapacitating Injury*	*Fatal Injury*
Driver Inattention	14.0	10.5	7.4	14.0	21.1
Driver Relinquished Steering Control	18.6	10.5	29.6	31.2	5.3
Evasive Maneuver	14.0	21.1	22.2	10.8	5.3
Lost Directional Control	18.6	21.1	3.7	11.8	10.5
Vehicle Failure	2.3	10.5	3.7	4.3	0.0
Vehicle Speed	32.6	26.3	33.3	28.0	57.9
Total	100.0	100.0	100.0	100.0	100.0

Table 5-27
Horizontal Alignment by Accident Type

Horizontal Alignment	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
Straight	41.7	60.5	97.0
Curve	58.3	39.5	3.0
Total	**100.0**	**100.0**	**100.0**

Table 5-27A
Horizontal Alignment by Accident Type

Horizontal Alignment	Accident Type								
	Left Roadside Departure			*Right Roadside Departure*			*Forward Impact*		
	Drive Off Road	*Control/ Traction Loss*	*Avoid Collision*	*Drive Off Road*	*Control/ Traction Loss*	*Avoid Collision*	*Parked Vehicle*	*Stationary Object*	*End Departure*
Straight	44.5	35.4	65.3	69.8	57.1	52.2	100.0	0.0	100.0
Curve	55.5	64.6	34.7	30.3	42.9	47.8	0.0	100.0	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 5-27B
Horizontal Alignment by Accident Type

Horizontal Alignment	Accident Type			Total
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*	
Straight	34.0	60.6	5.4	**100.0**
Curve	54.4	45.4	0.2	**100.0**

Table 5-28
Surface Condition by Accident Type

Surface Condition	Accident Type: Left Roadside Departure	Right Roadside Departure	Forward Impact
Dry	55.3	67.2	94.1
Wet	33.7	17.2	5.9
Snow (slush/ice)	10.9	15.6	0.0
Unknown	0.2	0.0	0.0
Totall	100.0	100.0	100.0

Table 5-28A
Surface Condition by Accident Type

	Accident Type								
	Left Roadside Departure			Right Roadside Departure			Forward Impact		
Surface Condition	Drive Off Road	Control/ Traction Loss	A void Collision	Drive Off Road	Control/ Traction Loss	Avoid Collision	Parked Vehicle	Stationary Object	End Departure
Dry	47.5	52.2	100.0	72.0	63.3	54.8	100.0	0.0	83.1
Wet	51.6	31.7	0.0	28.0	7.4	45.2	0.0	100.0	16.9
Snow (slush/ice)	0.9	15.6	0.0	0.0	29.3	0.0	0.0	0.0	0.0
Unknown	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5-28B
Surface Condition by Accident Type

Surface Condition	Accident Type: Left Roadside Departure	Right Roadside Departure	Forward impact	Total
Dry	37.9	58.0	4.1	100.0
Wet	60.5	38.7	0.8	100.0
Snow (slush/ice)	33.3	66.7	0.0	100.0
Unknown	100.0.	0.0.	0.0.	100.0

Table 5-29
Attempted Avoidance Maneuver by Accident Type

Attempted Avoidance Maneuver	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
None	*22.9*	54.8	82.4
Braked	21.0	4.0	11.7
Steered	33.3	16.4	3.0
Braked & Steered	14.8	14.0	3.0
Accelerated	0.0	0.2	0.0
Unknown	8.0	10.6	0.0
Total	100.0	100.0	100.0

Table 5-30
Time of Day by Accident Type

Time of Day	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward impact*
12am - 3am	8.8	17.8	11.7
3am - 6am	10.1	12.5	1.9
6am - 9am	18.5	5.6	3.0
9am - 12pm	7.6	14.9	0.0
12pm - 3pm	15.0	5.0	0.0
3pm - 6pm	*17.9*	*19.1*	11.7
6pm - 9pm	7.2	9.3	0.0
9pm - 12am	11.3	16.0	71.8
Unknown	3.5	0.0	0.0
Total	100.0	100.0	100.0

Table 5-31
Light Condition by Accident Type

Light Condition	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
Daylight	50.9	48.2	14.6
Artificial Lighting	18.1	22.7	4.9
No Artificial Lighting	31.0	28.9	80.5
Unknown	0.0	0.2	0.0
Total	100.0	100.0	100.0

Table 5-32
Causal Factor by Accident Type

Causal Factor	Accident Type		
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*
Driver Inattention	6.3	18.1	1.9
Driver Relinquished Steering Control	7.1	27.7	80.5
Evasive Maneuver	22.0	12.5	0.0
Lost Directional Control	15.9	16.4	3.0
Vehicle Failure	5.1	2.6	3.0
Vehicle Speed	43.6	22.8	11.7
Total	**100.0**	**100.0**	**100.0**

Table 5-32A
Causal Factor by Accident Type

Causal Factor	Accident Type			Total
	Left Roadside Departure	*Right Roadside Departure*	*Forward Impact*	
Driver Inattention	22.4	77.1	0.4	**99.9**
Driver Relinquished Steering Control	14.8	75.5	9.8	**100.1**
Evasive Maneuver	63.8	36.2	0.0	**100.0**
Lost Directional Control	37.8	61.5	0.7	**100.0**
Vehicle Failure	83.7	14.3	2.0	**100.0**
Vehicle Speed	60.0	38.0	2.0	**100.0**

Table 5-33
Causal Factor by Horizontal Alignment

Causal Factor	Horizontal Alignment	
	Straight	*Curve*
Driver Inattention	16.9	7.7
Driver Relinquished Steering Control	16.0	24.8
Evasive Maneuver	20.0	10.8
Lost Directional Control	16.9	15.0
Vehicle Failure	4.1	3.2
Vehicle Speed	26.1	38.7
Total	100.01	100.0

Table 5-33A
Causal Factor by Horizontal Alignment

Causal Factor	Horizontal Alignment		Total
	Straight	*Curve*	
Driver Inattention	34.3	65.7	100.0
Driver Relinquished Steering Control	62.5	37.5	100.0
Evasive Maneuver	33.2	66.8	100.0
Lost Directional Control	38.1	61.9	100.0
Vehicle Failure	64.2	35.8	100.0
Vehicle Speed	56.7	43.3	100.0

Table 5-34
Causal Factor by Surface Condition

Causal Factor	Surface Condition: Dry	Wet	Snow (slush/ice)
Driver Inattention	20.5	0.0	0.0
Driver Relinquished Steering Control	24.3	15.3	10.5
Evasive Maneuver	13.5	25.9	3.0
Lost Directional Control	2.5	25.7	62.7
Vehicle Failure	6.6	0.0	0.0
Vehicle Speed	32.6	33.1	23.8
Total	100.0	100.0	100.0

Table 5-34A
Causal Factor by Surface Condition

Causal Factor	Surface Condition: Dry	Wet	Snow (slush/ice)	Unknown	Total
Driver Inattention	100.0	0.0	0.0	0.0	100.0
Driver Relinquished Steering Control	78.5	13.6	7.9	0.0	100.0
Evasive Maneuver	56.1	41.0	3.0	0.0	100.1
Lost Directional Control	8.6	34.8	56.6	0.0	100.0
Vehicle Failure	100.0	0.0	0.0	0.0	100.0
Vehicle Speed	64.6	25.8	9.2	0.3	99.9

Table 5-35
Causal Factor by Lighting Condition

Causal Factor	Lighting Condition		
	Daylight	*Artificial Lighting*	*No Artificial Lighting*
Driver Inattention	13.7	11.3	12.0
Driver Relinquished Steering Control	6.1	24.8	42.8
Evasive Maneuver	22.3	9.0	9.2
Lost Directional Control	19.3	19.0	6.6
Vehicle Failure	6.2	2.4	0.0
Vehicle Speed	32.4	33.6	29.3
Total	**100.0**	**100.0**	**100.0**

Table 5-35A
Causal Factor by Lighting Condition

Causal Factor	Lighting Condition				Total
	Daylight	*Artificial Lighting*	*No Artificial Lighting*	*Unknown*	
Driver Inattention	53.3	18.2	28.5	0.0	100.0
Driver Relinquished Steering Control	12.8	21.5	65.7	0.0	100.0
Evasive Maneuver	73.1	8.9	17.2	0.8	100.0
Lost Directional Control	65.0	21.2	13.8	0.0	100.0
Vehicle Failure	93.9	6.2	0.0	0.0	100.1
Vehicle Speed	49.9	21.0	29.1	0.0	100.0

Table 5-36
Causal Factor by Attempted Avoidance Maneuver

Causal Factor	Attempted Avoidance Maneuver				
	None	*Braking*	*Steering*	*Braking & Steering*	*Accelerating*
Driver Inattention	23.5	0.0	6.2	1.7	0.0
Driver Relinquished Steering Control	42.1	0.0	3.2	1.0	0.0
Evasive Maneuver	0.0	3.1	27.0	58.2	0.0
Lost Directional Control	10.2	21.4	14.6	16.2	100.0
Vehicle Failure	3.7	7.3	2.7	0.5	0.0
Vehicle Speed	20.5	68.2	46.3	22.3	0.0
Total	100.0	100.0	100.0	100.0	100.0

Table 5-36A
Causal Factor by Attempted Avoidance Maneuver

Causal Factor	Attempted Avoidance Maneuver						Total
	None	*Braking*	*Steering*	*Braking & Steering*	*Accel.*	*Unknown*	
Driver inattention	76.7	0.0	11.1	0.4	0.0	11.7	99.9
Driver Relinquished Steering Control	88.6	0.0	2.5	0.5	0.0	8.4	100.0
Evasive Maneuver	0.0	2.6	45.6	51.9	0.0	0.0	100.1
Lost Directional Control	22.6	12.3	32.5	13.0	0.7	18.8	99.9
Vehicle Failure	66.2	14.3	17.6	2.0	0.0	0.0	100.1
Vehicle Speed	27.5	23.9	30.9	10.1	0.0	7.5	99.9

Table 5-37
Attempted Avoidance Maneuver by Horizontal Alignment

	Horizontal Alignment	
Attempted Avoidance Maneuver	*Straight*	*Curve*
None	44.0	38.7
Braked	9.1	14.9
Steered	18.6	28.3
Braked & Steered	18.1	9.8
Accelerated	0.1	0.0
Unknown	10.1	8.3
Total	**100.0**	**100.0**

Table 5-38
Attempted Avoidance Maneuver by Surface Condition

	Surface Condition		
Attempted Avoidance Maneuver	*Dry*	*Wet*	*Snow (slush/ice)*
None	*47.7*	*33.9*	*37.5*
Braked	*15.0*	*3.9*	*14.9*
Steered	*20.5*	*35.8*	*10.2*
Braked & Steered	11.3	*18.3*	*12.0*
Accelerated	*0.0*	*0.0*	1.5
Unknown	*5.5*	*8.0*	*23.9*
Total	100.0	100.0	100.0

Table 5-39
Attempted Avoidance Maneuver by Lighting Condition

	Lighting Condition		
Attempted Avoidance Maneuver	*Daylight*	*Artificial Lighting*	*No Artificial Lighting*
None	29.1	52.6	54.7
Braked	7.1	20.1	13.5
Steered	28.8	20.2	17.3
Braked & Steered	23.5	6.3	3.0
Accelerated	0.2	0.0	0.0
Unknown	11.4	0.8	11.6
Total	**100.0**	**100.0**	**100.0**

5.3.5 Interpretation of Bivariate Results

The injury severity weighting scheme problem associated with Tables 5-23 to 5-26 is real, but should not be overemphasized. As indicated in the discussion and comparable unweighted tables presented in Appendix A, the clinical sample is unquestionably comprised of severe crashes. Since NASS oversamples this severity level, even the crashes occurring on straight roadway segments tend to result in severe injury consequences. As a result, many of the injury related patterns established in the statistical analysis sequence are masked in the clinical sample. The statistical profile is correct as presented.

A more germane question at this point is whether or not the clinical sample is representative with respect to the statistical profile and the national crash population. The clinical sample is certainly not representative in terms of crash severity, however, we believe that the sample is representative in all other major respects. Lower severity level crashes are included in the sample and a careful review of crash circumstances/characteristics indicates that the full range of these parameters is included in available case material.

The variability demonstrated in Tables 5-27 to 5-39 indicates that there are substantial differences between subgroups of crashes within the run-off-road crash population. This is particularly evident in those distributions addressing relationships between causal factors and crash characteristics and again in distributions addressing relationships between attempted avoidance maneuvers and crash characteristics. One of the primary objectives of the engineering analysis will be to examine situational circumstances within groups of similar crashes to more precisely delineate the relationships indicated by the clinical analysis effort.

5.3.6 Summary of Trivariate Distributions

Trivariate distributions produced during this analysis effort are presented as tabular formats in Tables 5-40 to 5-45. Major points indicated by the distributions may be summarized as follows:

- The patterns evident in the accident type by causal factor by attempted avoidance maneuver distribution are very distinctive. When no avoidance maneuver is attempted by the driver, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (48.6 percent), vehicle failure (21.4 percent), and driver relinquished steering control (16.7 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are driver relinquished steering control (44.3 percent), driver inattention (30.2 percent), and vehicle speed (16.2 percent).

  When the driver initiates a braking action, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (75.8 percent) and lost directional control (24.2 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are vehicle failure (45.5 percent) and evasive maneuver (43.5 percent).

When the driver initiates a steering action, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (37.2 percent) and evasive maneuver (34.0 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are vehicle speed (57.8 percent) and lost directional control (23.8 percent).

When the driver initiates braking and steering actions, the most frequently occurring causal factors in left roadside departure crashes are evasive maneuver (77.4 percent) and vehicle speed (13.0 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are evasive maneuver (5 1.3 percent), vehicle speed (25.4 percent), and lost directional control (23.4 percent).

Due to the very small number of cases associated with the acceleration evasive maneuver, this category is not addressed (Table 5-40).

- Patterns in the accident type by causal factor by horizontal alignment distribution are again very distinctive. When crashes occur on straight roadway segments, the most frequently occurring causal factors in left roadside departure crashes are evasive maneuver (37.5 percent), vehicle speed (26.3 percent), and lost directional control (25.3 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are vehicle speed (26.0 percent), driver inattention (24.7 percent), and driver relinquished steering control (17.5 percent).

  When crashes occur on curved segments, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (56.1 percent) and evasive maneuver (11.5 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are driver relinquished steering control (44.5 percent), lost directional control (21.4 percent), and vehicle speed (16.9 percent). Due to the very small number cases associated with forward impacts, this accident type is not addressed (Table 5-41).

- Patterns in the accident type by causal factor by surface condition distribution are also distinctive. When crashes occur on dry surfaces, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (47.9 percent) and evasive maneuver (22.0 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are driver relinquished steering control (28.6 percent), driver inattention (27.2 percent), and vehicle speed (24.0 percent).

  When crashes occur on wet surfaces, the most frequently occurring causal factors in left roadside departure crashes are vehicle speed (44.1 percent), evasive maneuver (27.0 percent), and lost directional control (23.7 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are driver relinquished steering control (33.4 percent), lost directional control (28.9 percent), and vehicle speed (23.9 percent).

When crashes occur on snow/ice covered surfaces, the most frequently occurring causal factors in left roadside departure crashes are lost directional control (59.l percent) and vehicle speed (40.9 percent). For right roadside departure crashes, the most frequently occurring causal factors in this same circumstance are lost directional control (63.9 percent), driver relinquished steering control (16.1 percent), and vehicle speed (13.9 percent).

Note that virtually no crashes associated with the driver inattention causal factor occur on wet or snow/ice covered surfaces (Table 5-42).

- The patterns within the causal factor by surface condition by horizontal alignment distribution are very evident. For crashes occurring on straight or curved segments, the only surface condition associated with the driver inattention causal factor is the dry surface condition.

  For crashes associated with the driver relinquishes steering control causal factor, the dry surface condition (70.9 percent-straight and 79.3 percent-curve) dominates the distributions for straight and curved segments. For crashes occurring on straight segments, wet surface conditions also occur in a significant proportion of the cases (29.1 percent). For crashes occurring on curved segments, wet (8.1 percent) and snow/ice covered (12.6 percent) surfaces comprise the remainder of the distribution.

  For crashes associated with the evasive maneuver causal factor, the dry and wet surface conditions apply to crashes occurring on both straight and curved segments. For example, for straight segments the proportion of crashes occurring on dry surfaces is 54.7 percent and the proportion occurring on wet surfaces is 41.2 percent. Corresponding proportions for curved segments are 56.4 percent and 43.7 percent, respectively.

  For crashes associated with the lost directional control causal factor, the most prevalent surface conditions are wet and snow/ice covered. For crashes occurring on straight segments, incidence rates peak for the wet surface condition (45.7 percent) with snow/ice covered conditions (37.3 percent) and dry surface conditions (17.1 percent) also contributing to the profile. For crashes occurring on curved segments, incidence rates peak for the snow/ice-covered condition (77.2 percent) with wet conditions (22.8 percent) also contributing to the profile.

  All crashes associated with the vehicle failure causal factor occurred on segments where the road surface was dry. Due to the very small number of cases in the vehicle failure category, no significance should be placed on this finding.

  For crashes associated with the vehicle speed causal factor, dry surface conditions dominate the distributions for both alignment types. In crashes occurring on straight segments, the proportions for dry, wet, and snow/ice-covered conditions are 66.7 percent, 26.9 percent, and 5.8 percent, respectively. Corresponding proportions for curved segments are 58.3 percent, 29.1 percent, and 12.6 percent, respectively (Table 5-43).

- Patterns within the causal factor by attempted avoidance maneuver by horizontal alignment distribution are again very clear. For crashes associated with the driver inattention causal factor, the incidence rate for no attempted avoidance maneuver (82.6 percent) dominates the distribution applicable to crashes occurring on straight segments. The distribution applicable to crashes occurring on curves is dominated by steering actions (64.2 percent). It should be noted, however, that these steering actions are associated with curve traversal as opposed to the inattention causal factor. In a typical case, the driver initiates steering input to track the curve, but due to subsequent inattention fails to notice that the steer input is insufficient.

  For crashes associated with the driver relinquishes steering control causal factor, the distributions applicable to straight and curved segments are dominated by incidence rates for no attempted avoidance maneuver (97.7 percent-straight and 8 1.1 percent-curve).

  For crashes associated with the evasive maneuver causal factor, the distributions applicable to straight and curved segments are dominated by steering a braking/steering action. For straight segments the relevant proportions are 39.4 percent steering and 56.7 percent braking and steering. Corresponding proportions for curved segments are 56.4 percent steering and 43.7 percent braking and steering. Note that the incidence rates are reversed between straight and curved segments. This reversal is associated with natural steering actions applicable to curved segments.

  For crashes associated with the lost directional control causal factor, the distribution applicable to straight segments is dominated by no attempted avoidance maneuver (35.9 percent) and steering actions (32.4 percent). The distribution applicable to curved segments is comprised of braking and steering actions (22.8 percent), steering actions (20.9 percent), braking actions (20.9 percent), and no attempted avoidance maneuver (16.5 percent).

  The distributions applicable to the vehicle failure causal factor are not addressed due to the small number of cases associated with this category.

  For crashes associated with the vehicle speed causal factor, the distributions associated with straight and curved segments are comprised of the full range of avoidance maneuvers. The highest incidence rate for straight segments is no attempted avoidance maneuver (3 1.9 percent) and the highest incidence rate for curved segments is steering action (37.5 percent). Proportions associated with other actions in the distribution decrease from these levels (Table 5-44).

- Variations in patterns associated with the causal factor by attempted avoidance maneuver by surface condition distribution are similar in nature to the preceding table. Major points are as follows:

  + Distributions within the driver inattention and driver relinquishes steering control causal factors are dominated by the no attempted avoidance maneuver categories.

+ Distributions within the evasive maneuver causal factor are dominated by steering and braking/steering actions.

+ Distributions within the lost directional control and vehicle speed causal factors are comprised of the full range of attempted avoidance maneuvers. There are, however, significant differences between the profiles associated with each surface condition in these causal factors (Table 5-45).

Table 5-40
Accident Type by Causal Factor by Attempted Avoidance Maneuver

Accident Type	Causal Factor	Attempted Avoidance Maneuver				
		None	*Braked*	*Steered*	*Braked & Steered*	*Accel.*
Left Roadside Departure	*Driver Inattention*	5.8	0.0	9.0	1.7	0.0
	Driver Relinquished Steering Control	16.7	0.0	3.8	2.6	0.0
	Evasive Maneuver	0.0	0.0	34.0	77.4	0.0
	Lost Directional Control	7.6	24.2	12.1	4.0	0.0
	Vehicle Failure	21.4	0.0	3.8	1.3	0.0
	Vehicle Speed	48.6	75.8	37.2	13.0	0.0
	Total	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**
Right Roadside Departure	*Driver Inattention*	30.2	0.0	0.9	0.0	0.0
	Driver Relinquished Steering Control	44.3	0.0	1.8	0.0	0.0
	Evasive Maneuver	0.0	43.5	15.8	51.3	0.0
	Lost Directional Control	9.3	11.1	23.8	23.4	100.0
	Vehicle Failure	0.0	45.5	0.0	0.0	0.0
	Vehicle Speed	16.2	0.0	57.8	25.4	0.0
	Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Forward Impact	*Driver Inattention*	2.1	0.0	0.0	0.0	0.0
	Driver Relinquished Steering Control	97.9	0.0	0.0	0.0	0.0
	Evasive Maneuver	0.0	0.0	0.0	0.0	0.0
	Lost Directional Control	*0.0*	*0.0*	*0.0*	*100.0*	0.0
	Vehicle Failure	*0.0*	*0.0*	100.0	0.0	0.0
	Vehicle Speed	*0.0*	100.0	0.0	0.0	0.0
	Total	100.0	100.0	100.0	100.0	[illegible]

Table 541
Accident Type by Causal Factor by Horizontal Alignment

Accident Type	Causal Factor	Horizontal Alignment	
		Straight	Curve
left Roadside Departure	Driver Inattention	1.8	8.7
	Driver Relinquished Steering Control	5.3	8.3
	Evasive Maneuver	37.5	11.5
	Lost Directional Control	25.3	9.7
	Vehicle Failure	3.7	5.7
	Vehicle Speed	26.3	56.1
	Tot;al	100.0	100.0
Right Roadside Departure	Driver Inattention	24.7	6.8
	Driver Relinquished Steering Control	17.5	44.5
	Evasive Maneuver	13.5	10.5
	Lost Directional Control	14.0	21.4
	Vehicle Failure	4.3	0.0
	Vehicle Speed	26.0	16.9
	Total	100.0	100.0
Forward Impact	Driver Jnattention	1.9	0.0
	Driver Relinquished Steering Control	80.5	0.0
	Evasive Maneuver	0.0	0.0
	Lost Directional Control	0.0	100.0
	Vehicle Failure	4.4	0.0
	Vehicle Speed	13.1	0.0
	Total	100.0	100.0

Table 542
Accident Type by Causal Factor by Surface Condition

Accident Type	Causal Factor	Surface Condition: Dry	Wet	Snow (slush/ice)
Left Roadside Departure	*Driver Inattention*	10.6	0.0	0.0
	Driver Relinquished Steering Control	10.2	5.2	0.0
	Evasive Maneuver	22.0	27.0	0.0
	Lost Directional Control	0.3	23.7	59.1
	Vehicle Failure	9.0	0.0	0.0
	Vehicle Speed	47.9	44.1	40.9
	Total	**100.0**	**100.0**	**100.0**
Right Roadside Departure	*Driver Inattention*	27.2	0.0	0.0
	Driver Relinquished Steering Control	28.6	33.4	16.1
	Evasive Maneuver	11.5	13.9	6.2
	Lost Directional Control	3.7	28.9	63.9
	Vehicle Failure	5.0	0.0	0.0
	Vehicle Speed	24.0	23.9	13.9
	Total	**100.0**	**100.0**	**100.0**
Forward Impact	*Driver Inattention*	1.9	0.0	0.0
	Driver Relinquished Steering Control	80.5	50.0	0.0
	Evasive Maneuver	0.0	50.0	0.0
	Lost Directional Control	0.0	0.0	0.0
	Vehicle Failure	8.9	0.0	0.0
	Vehicle Speed	8.7	0.0	0.0
	Total	**100.0**	**100.0**	**0.0**

Table 543
Causal Factor by Surface Condition by Horizontal Alignment

Causal Factor	Surface Condition	Horizontal Alignment	
		Straight	*Curve*
Driver Inattention	*Dry*	100.0	100.0
	Wet	0.0	0.0
	Snow (slush/ice)	0.0	0.0
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Driver Relinquishes Steering Control	*Dry*	70.9	79.3
	Wet	29.1	8.1
	Snow (slush/ice)	0.0	12.6
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Evasive Maneuver	*Dry*	54.7	56.4
	Wet	41.2	43.7
	Snow (slush/ice)	4.1	0.0
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Lost Directional Control	*Dry*	17.1	0.0
	Wet	45.7	22.8
	Snow (slush/ice)	37.3	77.2
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Vehicle Failure	*Dry*	100.0	100.0
	Wet	0.0	0.0
	Snow (slush/ice)	0.0	0.0
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Vehicle Speed	*Dry*	66.7	58.3
	Wet	26.9	29.1
	Snow (slush/ice)	5.8	12.6
	Unknown	0.7	0.0
	Total	**100.0**	**100.0**

Table 5-44
Causal Factor by Attempted Avoidance Maneuver by Horizontal Alignment

Causal Factor	Attempted Avoidance Maneuver	Horizontal Alignment	
		Straight	*Curve*
Driver Inattention	*None*	82.6	33.8
	Braked	0.0	0.0
	Steered	1.0	64.2
	Braked & Steered	0.5	0.0
	Accelerated	0.0	0.0
	Unknown	15.9	2.0
	Total	**100.0**	**100.0**
Driver Relinquishes Steering Control	*None*	97.7	81.1
	Braked	0.0	0.0
	Steered	1.1	5.1
	Braked & Steered	0.6	0.6
	Accelerated	0.0	0.0
	Unknown	0.6	13.2
	Total	**100.0**	**100.0**
Evasive Maneuver	*None*	0.0	0.0
	Braked	3.9	0.0
	Steered	39.4	56.4
	Braked & Steered	56.7	43.7
	Accelerated	0.0	0.0
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Lost Directional Control	*None*	35.9	16.5
	Braked	5.3	20.9
	Steered	32.4	20.9
	Braked & Steered	5.3	22.8
	Accelerated	1.3	0.0
	Unknown	19.8	19.0
	Total	**100.0**	**100.0**
Vehicle Failure	*None*	5.5	100.0
	Braked	39.9	0.0
	Steered	49.0	0.0
	Braked & Steered	5.5	0.0
	Accelerated	0.0	0.0
	Unknown	0.0	0.0
	Total	**100.0**	**100.0**
Vehicle Speed	*None*	31.9	25.5
	Braked	15.4	29.8
	Steered	19.8	37.5
	Braked & Steered	23.1	3.7
	Accelerated	0.0	3.6
	Unknown	9.9	0.0
	Total	**100.0**	**100.0**

Table 5-45
Causal Factor by Attempted Avoidance Maneuver by Surface Condition

Causal Factor	Attempted Avoidance Maneuver	Surface Condition *Dry*	*Wet*	*Snow (slush/ice)*
Driver Inattention	*None*	76.7	0.0	0.0
	Braked	0.0	0.0	0.0
	Steered	11.1	0.0	0.0
	Braked & Steered	0.4	0.0	0.0
	Accelerated	0.0	0.0	0.0
	Unknown	11.7	0.0	0.0
	Total	**100.0**	**0.0**	**0.0**
Driver Relinquishes Steering Control	*None*	95.3	100.0	0.0
	Braked	0.0	0.0	0.0
	Steered	3.3	0.0	0.0
	Braked & Steered	0.7	0.0	0.0
	Accelerated	0.0	0.0	0.0
	Unknown	0.7	0.0	100.0
	Total	**100.0**	**100.0**	**100.0**
Evasive Maneuver	*None*	0.0	0.0	0.0
	Braked	3.1	0.0	0.0
	Steered	37.1	42.8	0.0
	Braked & Steered	59.8	57.2	100.0
	Accelerated	0.0	0.0	0.0
	Unknown	0.0	0.0	0.0
	Total	**100.0**	**100.0**	**100.0**
Lost Directional Control	*None*	89.0	5.1	25.5
	Braked	0.0	1.5	23.8
	Steered	11.0	49.7	17.3
	Braked & Steered	0.0	11.8	15.8
	Accelerated	0.0	0.0	2.0
	Unknown	0.0	32.0	15.8
	Total	**100.0**	**100.0**	**100.0**
Vehicle Failure	*None*	66.2	0.0	0.0
	Braked	14.3	0.0	0.0
	Steered	17.6	0.0	0.0
	Braked & Steered	2.0	0.0	0.0
	Accelerated	0.0	0.0	0.0
	Unknown	0.0	0.0	0.0
	Total	**100.0**	**0.0**	**0.0**
Vehicle Speed	*None*	13.9	53.0	83.7
	Braked	39.6	9.2	4.0
	Steered	28.9	32.2	0.0
	Braked & Steered	10.6	5.6	0.0
	Accelerated	0.0	0.0	0.0
	Unknown	7.1	0.0	12.3
	Total	**100.0**	**100.0**	**100.0**

5.3.7 Interpretation of Trivariate Results

The clinical analyses described in this **section,** in effect, function as a bridge between the statistical analysis described in Section 5.2 and the engineering analysis described in Section 5.4. The Trivariate analyses, in particular, demonstrate that there are substantial differences between subgroups contained within the run-off-road clinical sample. Highlights of these analyses may be summarized as follows:

- Table 5-40 - There are substantial differences between causal factor distributions for left and right roadside departure crashes when these distributions are grouped by attempted avoidance maneuver.

- Table 5-41- There is substantial differences between causal factor distributions for left and right roadside departure crashes when these distributions are grouped by horizontal alignment.

- Table 5-42 - There are substantial differences between causal factor distributions for left and right roadside departure crashes when these distributions are grouped by surface condition.

- Table 5-43 - There are substantial differences between surface condition distributions for causal factor designations when these distributions are grouped by horizontal alignment.

- Table 5-44 - There are substantial differences between attempted avoidance maneuver distributions for causal factor designations when these distributions are grouped by horizontal alignment.

- Table 5-45 - There are substantial differences between attempted avoidance maneuver distributions for causal factor designations when these distributions are grouped by surface condition.

A deficiency of this analysis sequence is that it lacks a defined focus or basis of comparison. One of the primary objectives of the engineering analysis will be establishment of this basis for grouping crashes with similar characteristics. These characteristics can then be described within the defined groups and subsequently compared across the groups.

5.4 Engineering Analysis

As indicated in the discussion in Section 4.1, dynamic scenario descriptions delineate existing conditions related to crash occurrence (driver state, vehicle state, environmental conditions), driver/vehicle actions or events, driver corrective actions initiated to avoid the crash, and vehicle responses to these corrective actions. These descriptions may be represented as situation trees. The specific situation tree/data reduction format developed for this effort was illustrated in Figure 4-1.

Situation trees were developed for each case in the clinical sample. Individual copies of the trees are provided in Volume 2 of this report series. These trees were subsequently analyzed to determine characteristics associated with groups of similar trees and to determine similarities/differences between these groups. A top-level evaluation of analytical parameters (velocity, steer inputs, and braking inputs) was also conducted. , This section documents the results of the analysis sequence. Grouping of similar scenarios/trees is discussed in the subsection which follows. That discussion is then followed by a presentation of findings associated with the top-level evaluation of analytical parameters and the comparison of similar groups.

5.4.1 Grouping of Similar Situation Trees

Several approaches to categorizing/grouping similar situation trees were explored and subsequently dropped. For example, groupings based on roadway alignment, roadway state, and on-road dynamic state were examined. Variations within groups established on this basis were substantial and these attempts to superimpose a distinct structure to the grouping process were abandoned.

When situation trees were grouped solely on the basis of having similar responses in each of the branches contained in the data reduction formats, it was noted that the resulting groups or subsets of formats very closely paralleled causal factor designations. At that point, a decision was made to group the trees by causal factor designation and to examine similarities and variances within these groupings. Findings associated with this effort are described in the subsections below. Each subsection describes characteristics within a single defined causal factor.

5.4.1.1 Situation Trees for Driver Inattention

Responses for the individual branches of situation trees associated with the driver inattention causal factor are provided in Figure 5-22. Major points with respect to these responses may be summarized as follows:

- Driver State - All drivers in this causal factor group are inattentive to the driving task.
- Vehicle State - The predominant vehicle state is operating normally (91.8 percent), however, a relatively small incidence rate of excessive speed (8.3 percent) is noted.
- Roadway Alignment - Most crashes occur on straight segments (66.3 percent), however, the proportion occurring on curves (33.7 percent) is significant.
- Roadway State - All crashes in this causal factor group occur on dry surfaces.
- Obstacles - There are no obstacles in the driver's intended path of travel.
- Shoulder - The proportions of crashes occurring on roadways with (51.1 percent) and without (48.9 percent) shoulders are approximately equal.

- On-Road Driver Response - The predominant driver response is not to initiate a pre-departure evasive maneuver (49.7 percent). A significant proportion of drivers, however, do initiate inadvertent steering input (39.8 percent). These types of steering inputs typically occur when the driver is reaching for something inside the vehicle and inadvertently moves the steering wheel (i.e., the steering wheel movement is associated with the reaching action). The incidence rate for deliberate steering actions (10.5 percent) reflects circumstances where the driver returns attention to the driving task, recognizes the imminent roadway departure, and then initiates an evasive maneuver with respect to the imminent departure.

- On-Road Vehicle Response - There is virtually a one-to-one correspondence between driver response and vehicle response. The 49.7 percent incidence rate for no driver response corresponds directly to the 49.7 percent incidence rate for the vehicle drifting off the road. Departure angles in this circumstance are typically very small (e.g., l-3 degree range). The 39.8 percent incidence rate for inadvertent steering corresponds directly to the 39.8 percent rate noted for vehicles departing the roadway in a tracking attitude. Departure angles in this circumstance exceed those associated with drift movements. The 10.5 percent incidence rate for deliberate steering actions corresponds directly to the 10.5 percent rate noted for uncontrolled vehicle yawing actions (i.e., the typical surprisal driver steering response involves overcorrection which induces a yawing action.).

- Off-Road Driver Response - The off-road driver response is approximately evenly divided between drivers not initiating corrective action (50.9 percent) and drivers initiating corrective action (49.1 percent). The predominant corrective actions are steering (37.0 percent) and steering/braking combinations (12.1 percent).

- Off-Road Vehicle Response - There is again a direct correlation between driver response and vehicle response. Those drivers who do not initiate correction actions (50.9 percent) are distributed between the drift (38.6 percent) and tracking (11.8 percent) vehicle responses. A very small proportion is also contained in the yaw movement category. This proportion results from terrain induced yawing actions. Drivers initiating steering actions (37.0 percent) are associated with the yaw movement (39.1 percent). The tendency here is for the driver to overcorrect, inducing the yawing action. Drivers initiating steering and braking actions (12.1 percent) are associated with longitudinal skid patterns (10.5 percent) and yawing movement (39.1 percent). The specific result for the steering and braking actions in these cases is primarily a timing issue. In those cases where the steering and braking actions are simultaneous or very closely spaced, the vehicle enters a longitudinal skid pattern. In those cases where the braking action is delayed with respect to the steering action, the vehicle typically spins out (e.g., yaws).

- Roadway Departure Crash Type - The predominant crash type associated with this causal factor is the frontal impact configuration (59.6 percent). The remainder of the profile is comprised of rollover events (25.8 percent) and side impacts (13.9 percent).

A composite situation tree, derived ‘from frequency responses shown in Figure 5-22, is provided as Figure 5-23. An exemplar case description, abstracted Corn the clinical database, is provided below. The schematic for this case is provided as Figure 5-24 and the situation tree coded for this case is provided as Figure 5-24A.

Exemplar Case Description (13-149J)

The subject vehicle was southbound on a divided interstate roadway with a posted speed limit of 105 kph. The roadway consisted of two travel lanes in each direction separated by a depressed grass median. Paved shoulders bordered both edges of the divided travel lanes. The crash occurred during daylight hours, on a dry surface. The subject driver was traveling at a police and witness reported high rate of speed. She became inattentive to the driving task and allowed her vehicle to drift off the left road edge, onto the grass median. The driver steered in a clockwise direction, which induced a slight CW yaw. She then applied a rapid CCW steering input which reversed the vehicle’s rotation to CCW. The vehicle crossed the depressed grass median in a broadside orientation and rolled over into an unprotected from SB traffic) signpost. The vehicle continued to roll before coming to rest in an upright orientation. The driver was inattentive to the driving task, which was the primary causal factor. Vehicle speed contributed to the severity of the crash, but was not a primary factor in causation.

Causal Factor: ***Driver Inattention***

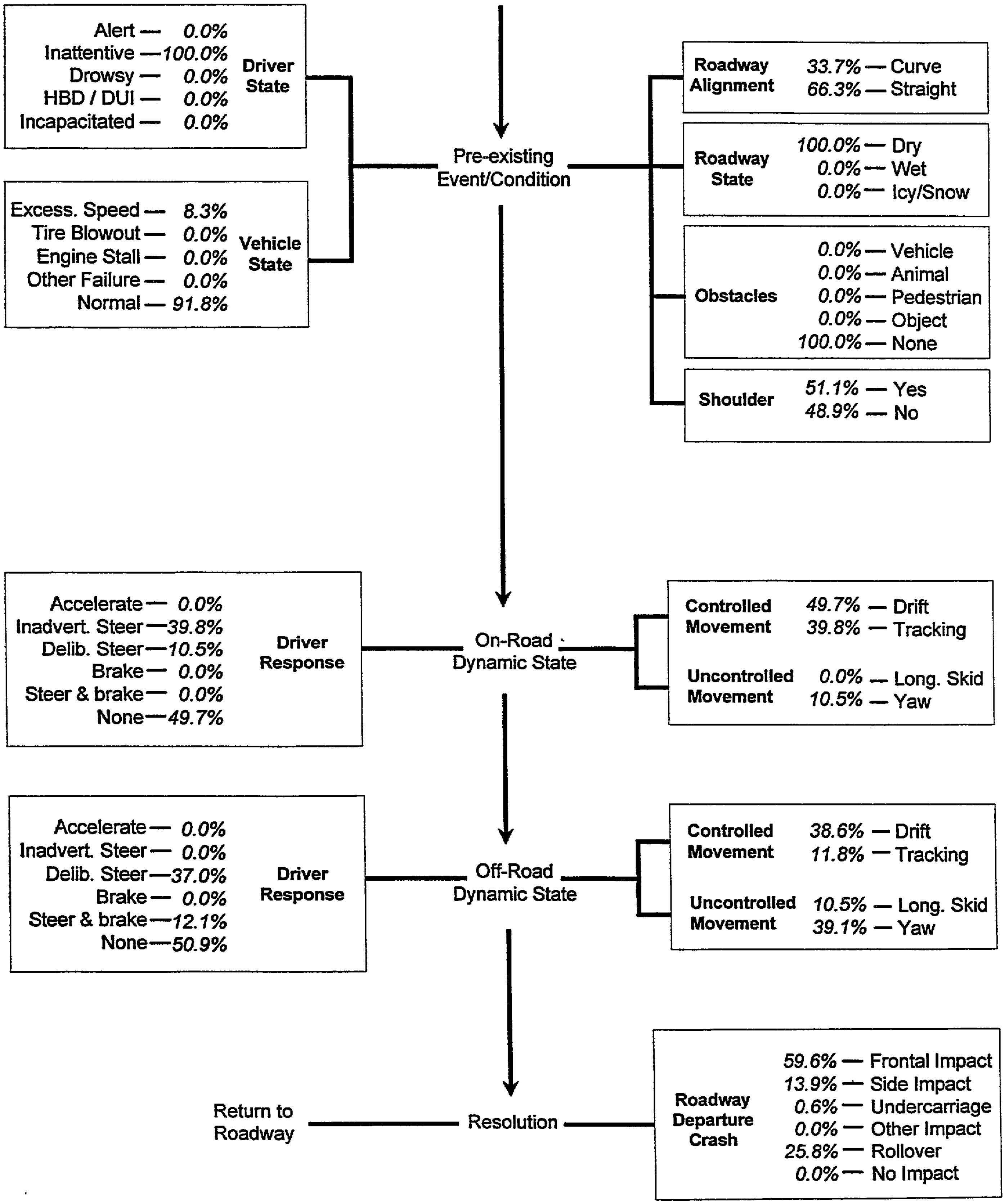


Figure 5-22 Vehicle Dynamic Scenario Analysis - Driver Inattention

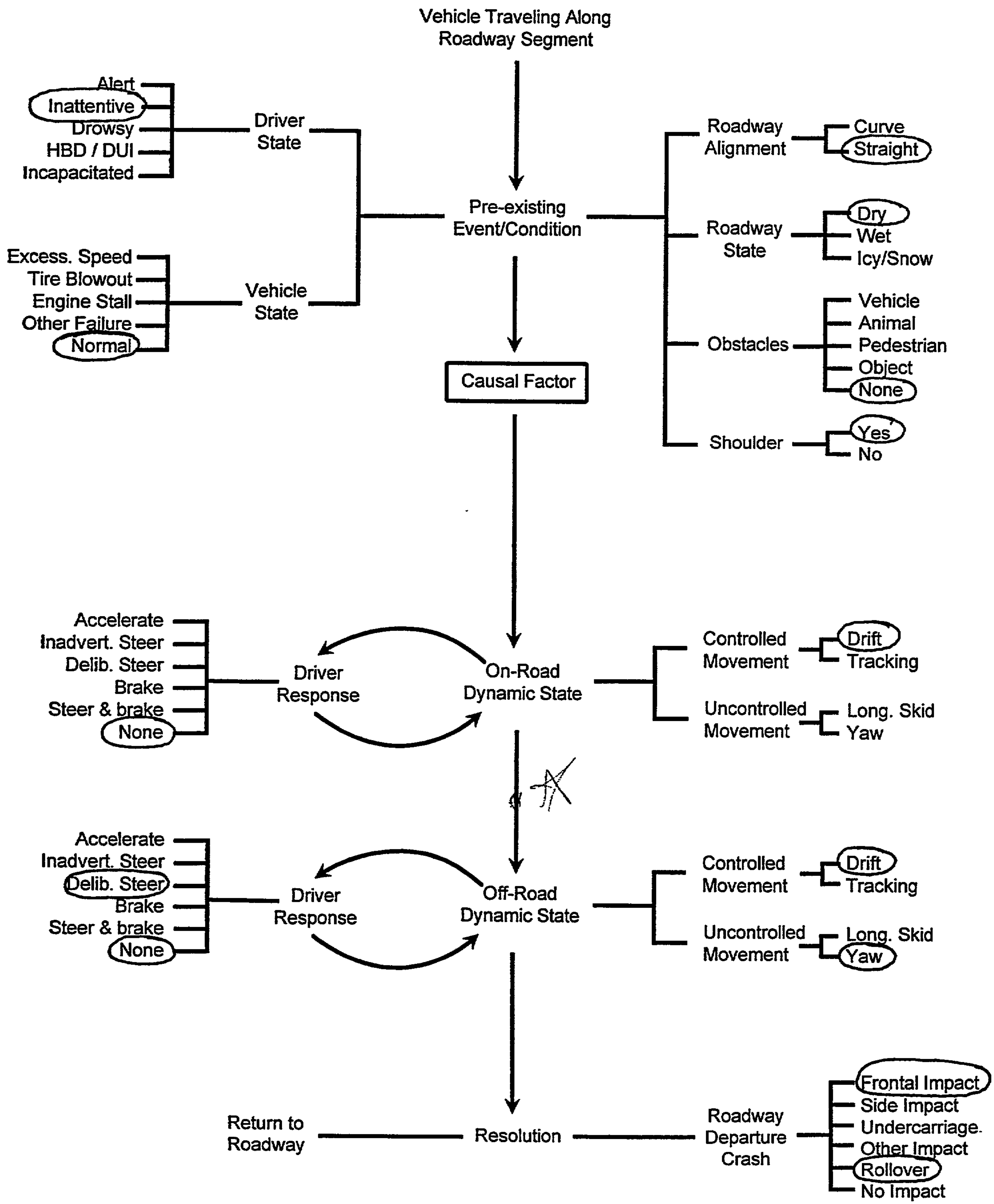


Figure 5-23 Vehicle Dynamic Scenario Example - Driver Inattention

ACCIDENT COLLISION DIAGRAM

PSU No. 13 Case Number – Stratum 149J Indicate North

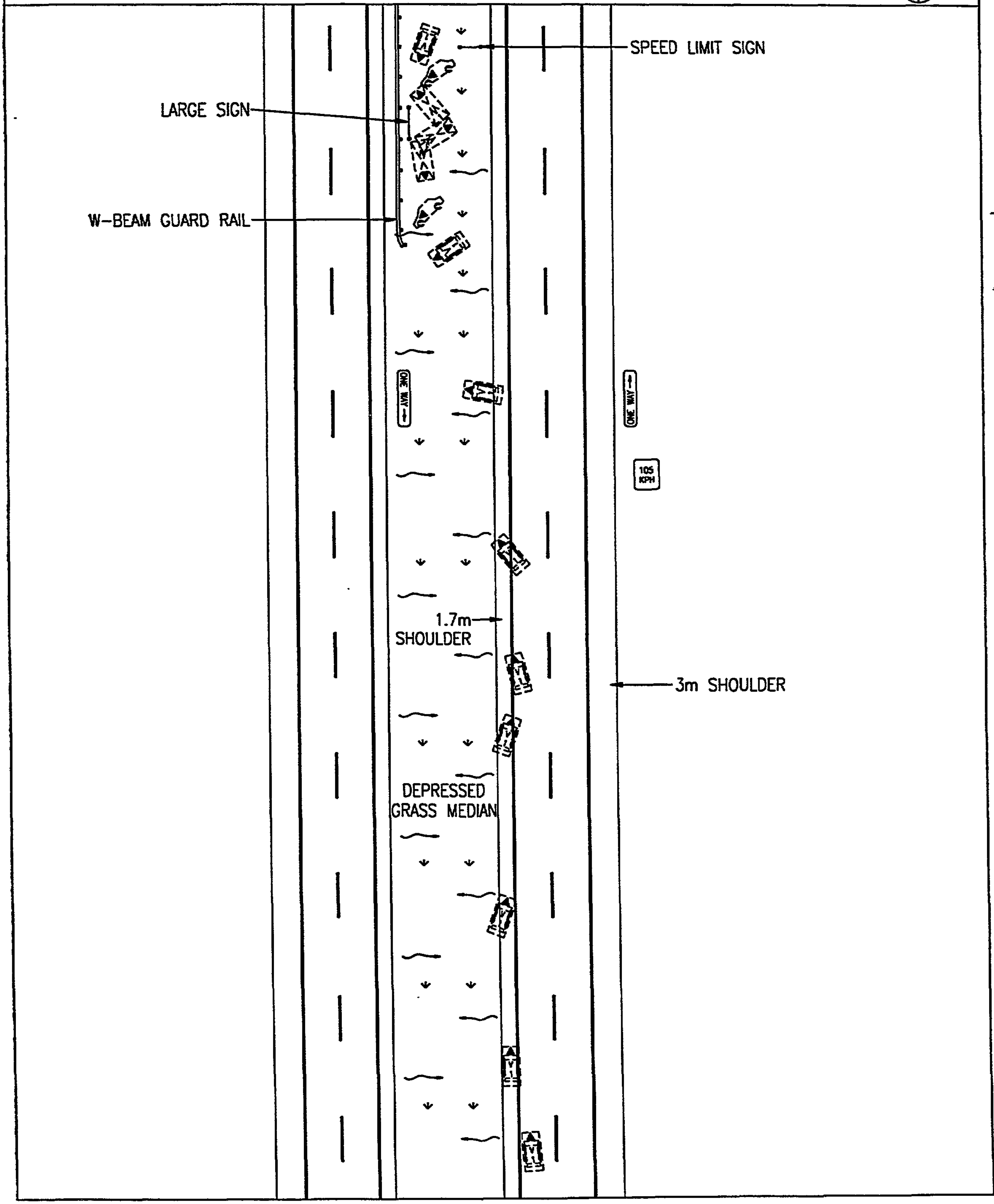


Figure 5-24

Scale: 1/250

13-149J

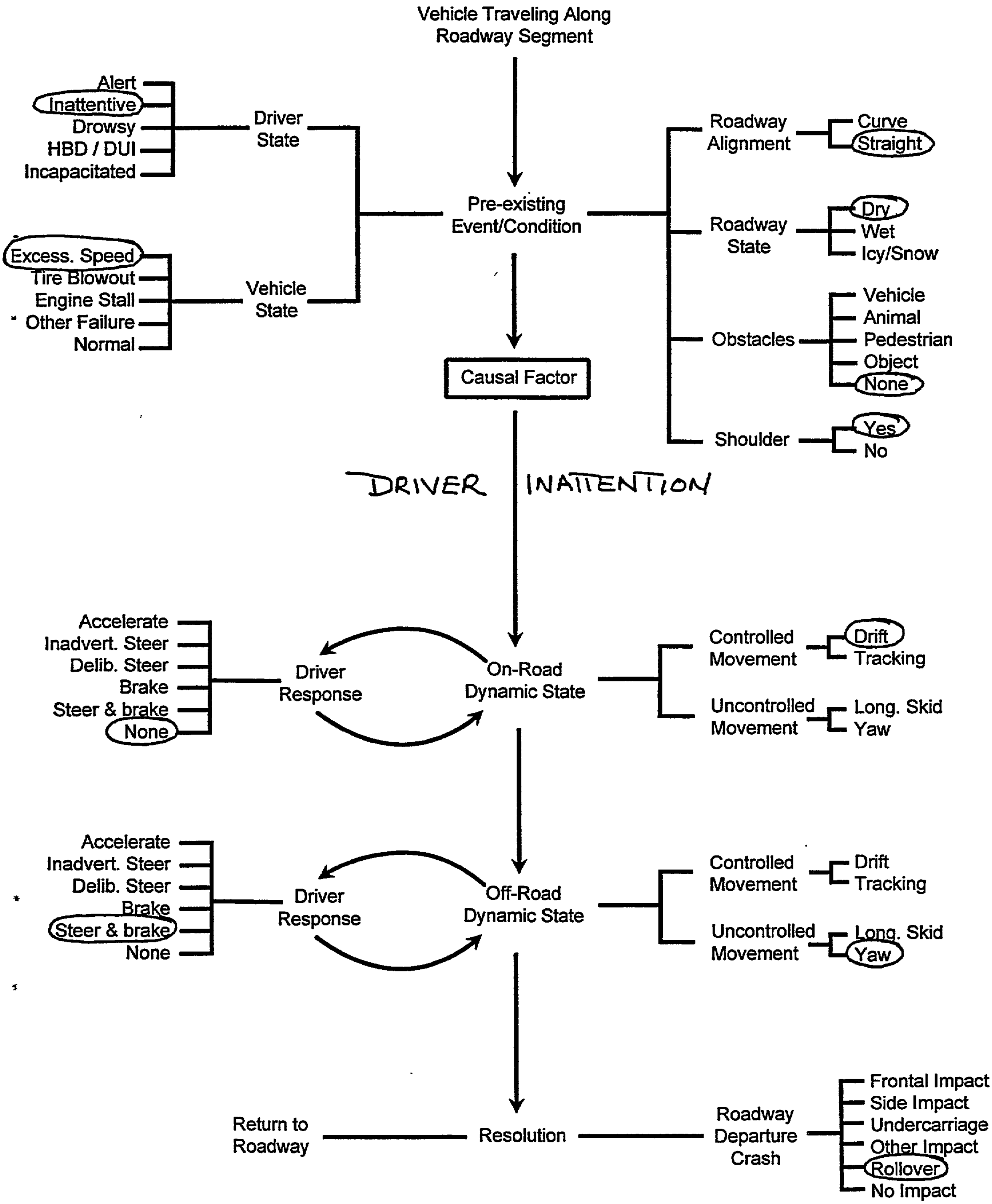


Figure 5-24A Vehicle Dynamic Scenario

5.4.1.2 Situation Trees for Driver Relinquished Steering Control

Responses for the individual branches of situation trees associated with the driver relinquished steering control causal factor are provided in Figure 5-25. Major points with respect to these responses may be summarized as follows:

Driver State - The predominant driver state associated with this causal factor is had been drinking/driving under the influence (58.9 percent). This category generally reflects drivers who are grossly intoxicated (e.g., BAC > 0.10 with typical values in the 0.15 to 0.30 range). Drowsy drivers (36.0 percent) and drivers who are incapacitated (5.2 percent) comprise the remainder of the profile. Drowsy drivers typically fall asleep during the immediate pre-departure sequence and incapacitated drivers sustain a variety of physical problems (e.g., heart attack, seizure, etc.).

- Vehicle State - The predominant vehicle state is normal operation.

- Roadway Alignment - Crashes occur on both curved (55.7 percent) and straight (44.3 percent) segments.

- Roadway State - The predominant surface condition is dry (86.4 percent) with a relatively small proportion of crashes occurring on ice/snow covered (7.9 percent) or wet (5.7 percent) surfaces.

- Obstacles - There are no obstacles in the driver's intended path of travel.

- Shoulder - Most crashes occur on roadways that do not have an adjacent shoulder (76.3 percent).

- On-Road Driver Response - Most drivers do not initiate corrective action (85.3 percent) prior to roadway departure. There is, however, a significant contribution from inadvertent steering input (14.5 percent). These inadvertent inputs are typically associated with drivers who slump to the left or right as they fall asleep, pass out, or are incapacitated.

- On-Road Vehicle Response - There is, obviously, a very strong correlation between driver action and vehicle response. Drivers not initiating corrective action (85.3 percent) translate to the vehicle drift category (85.3 percent). The inadvertent steering input category (14.5 percent) translates to the vehicle tracking category (14.2 percent) and to one terrain induced yaw action (0.3 percent).

- Off-Road Driver Response - The dominant off-road corrective action is again no corrective action (80.9 percent). The deliberate steer (17.2 percent) and steering/braking (1.9 percent) proportions are typically associated with drivers who fall asleep on the roadway and then wake up as the vehicle traverses off-road terrain.

- Off-Road Vehicle Response - In this case, drivers not initiating corrective action (80.9 percent) translate to the vehicle drift (65.9 percent) and vehicle tracking (14.2 percent) categories. The deliberate steer (17.2 percent) and steer/brake (1.9 percent) categories translate to vehicle yaw (19.9 percent) movement.

- Roadway Departure Crash Type - The predominant crash type is the frontal impact configuration (77.2 percent) with side impacts (19.6 percent) and rollovers (3.3 percent) also contributing to the profile. It is important to note that for this causal factor, the correlation between driver response and vehicle response also extends to crash type. The specific patterns may be summarized as follows:

  + No corrective action --) vehicle drift/tracking + frontal impact
  + Steer/brake + vehicle yaw + side impact/rollover

A composite situation tree, derived from frequency responses shown in Figure 5-25, is provided as Figure 5-26. An exemplar case description, abstracted from the clinical database, is provided below. The schematic for this case is provided as Figure 5-27 and the situation tree coded for this case is provided as Figure 5-27A.

Exemplar Case Description (13-017J)

The vehicle was traveling north in the right lane of a divided dry level asphalt roadway when it departed the right side of a left curved section of the interstate. The vehicle traveled in a straight trajectory approximately 45 meters across the asphalt shoulder and snow covered adjacent grass area and struck a tree with its frontal plane. A witness noted that the subject driver passed their vehicle and returned to the right travel lane. After some distance the subject driver appeared to fall asleep and drift off the roadway. The causal factor was driver relinquished control as a result of falling asleep. There were no adverse weather conditions. The accident occurred during the early morning daylight hours.

Causal Factor: ***Driver Relinquished Steering Control***

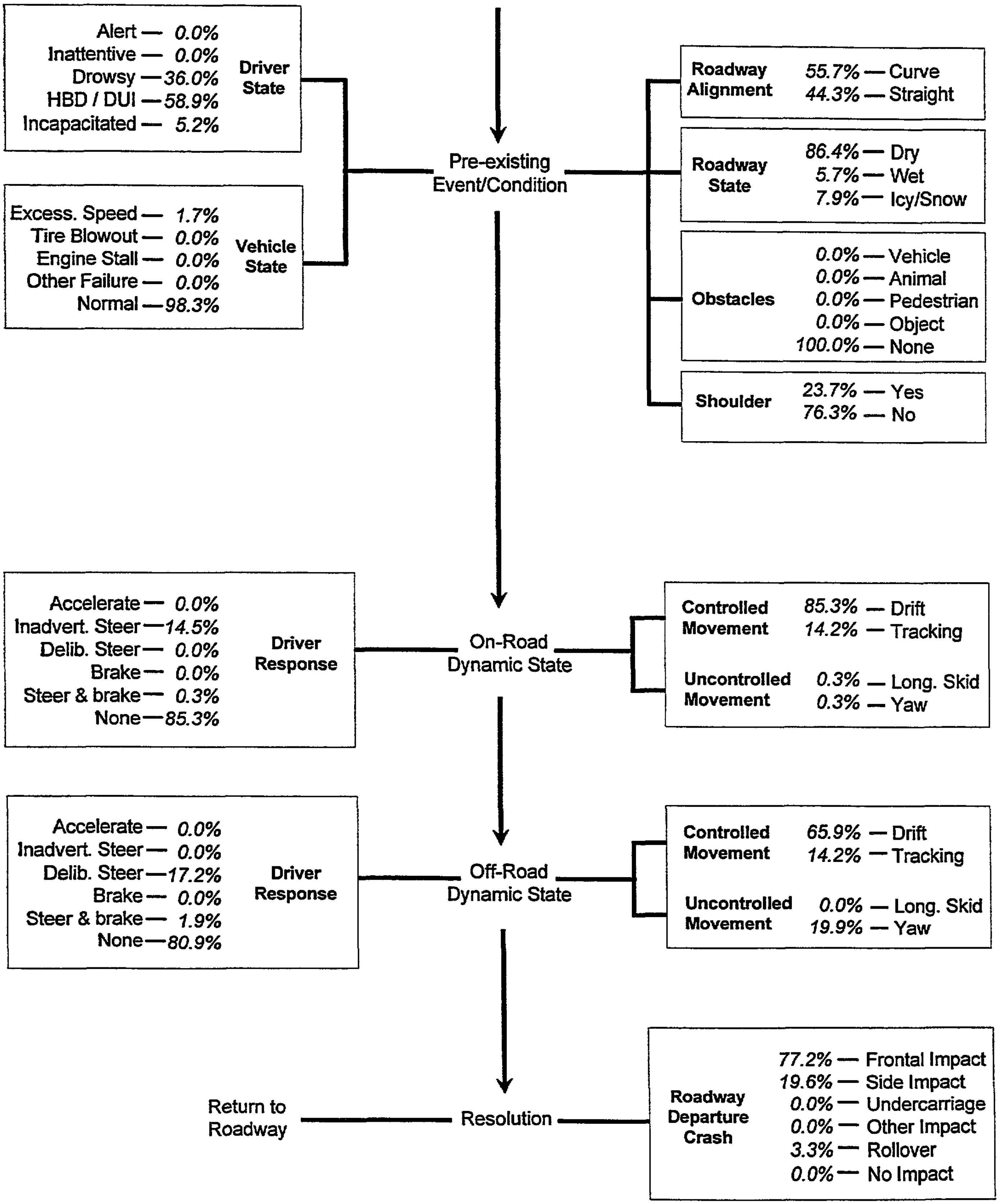


Figure 5-25 Vehicle Dynamic Scenario Analysis - Driver Relinquished Steering Control

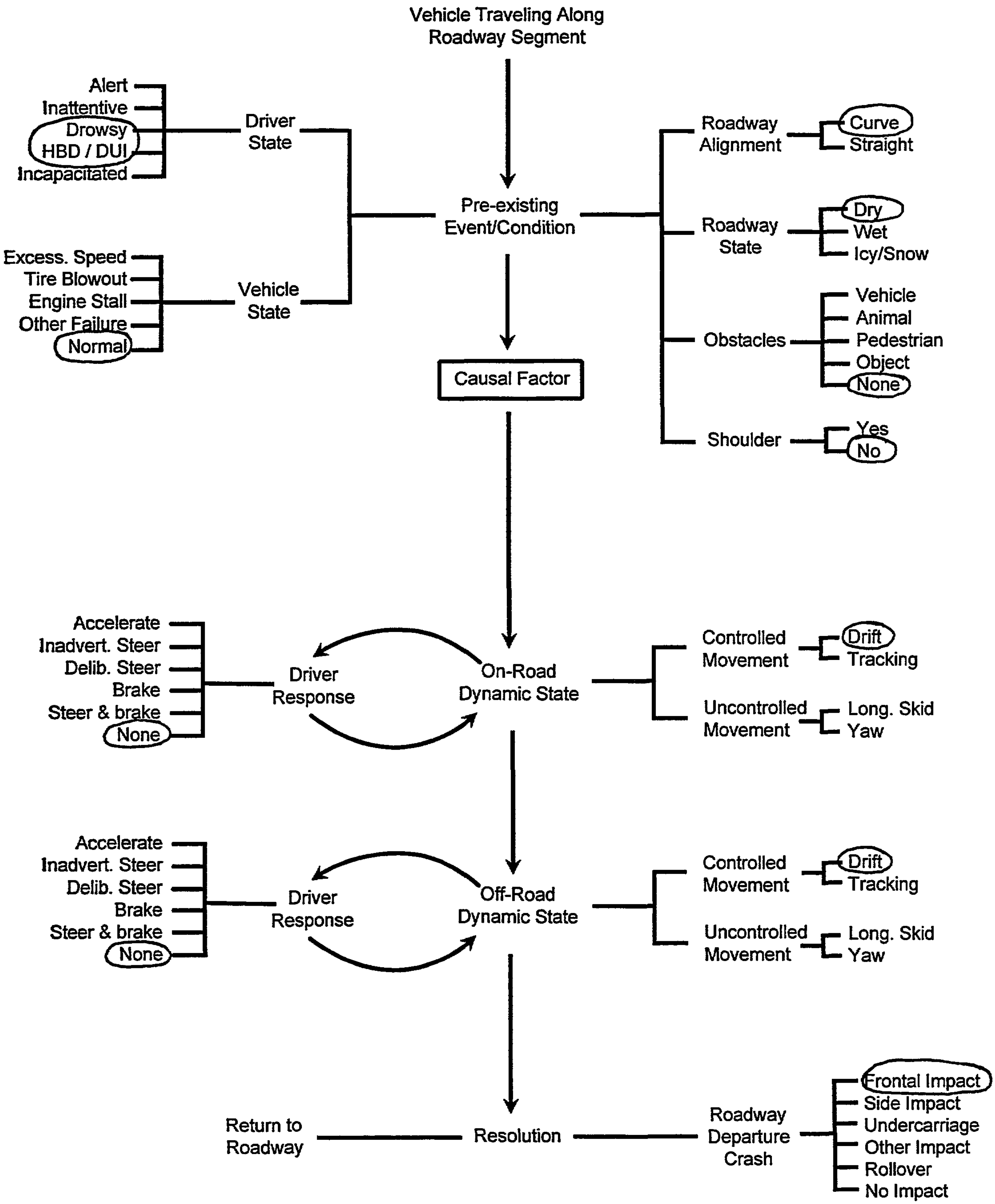


Figure 5-26 Vehicle Dynamic Scenario Example - Driver Relinquished Steering Control

ACCIDENT COLLISION DIAGRAM

PSU No. 13 Case Number – Stratum 017J Indicate North

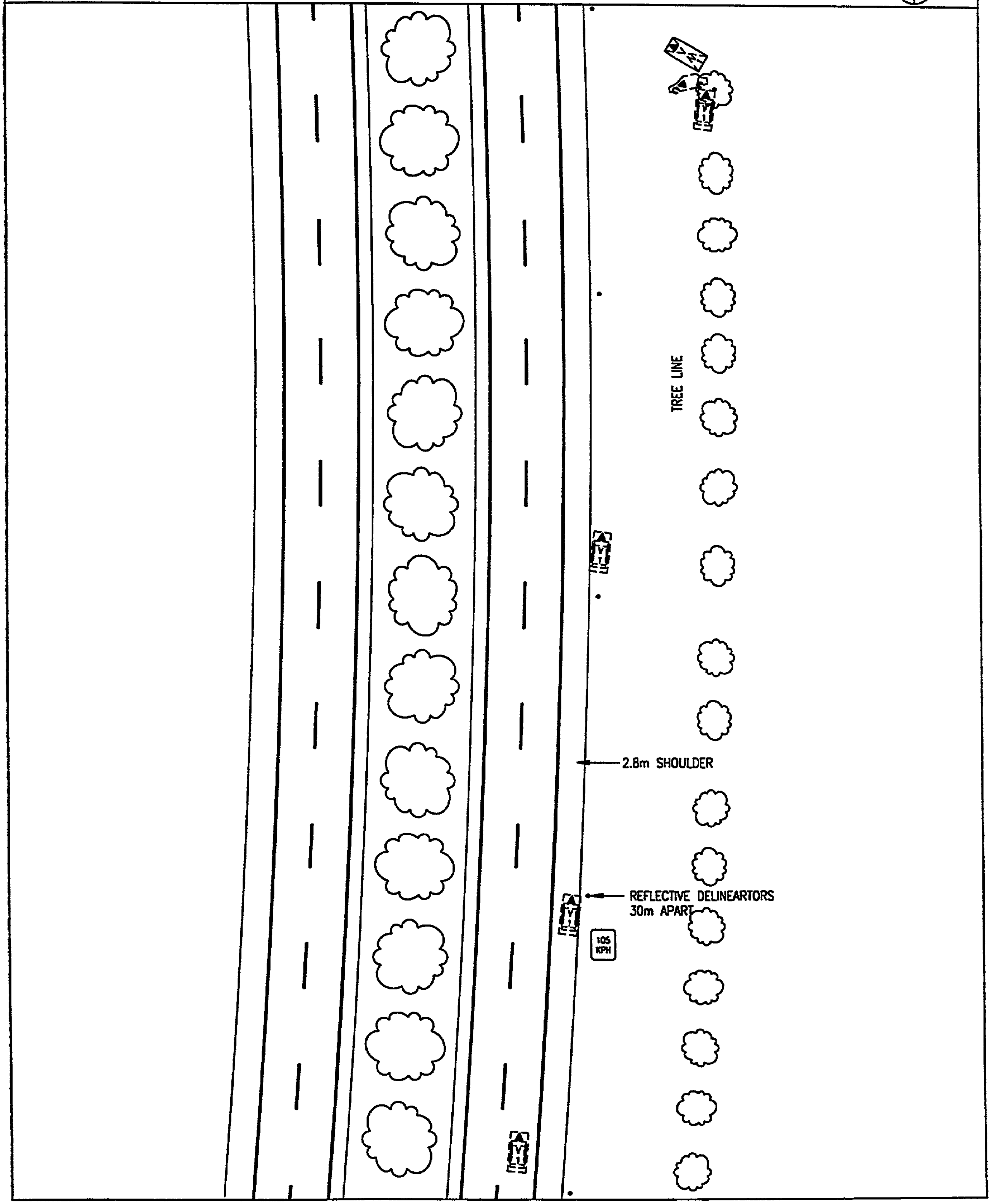


Figure 5-27

Scale: 1/500

13-017J

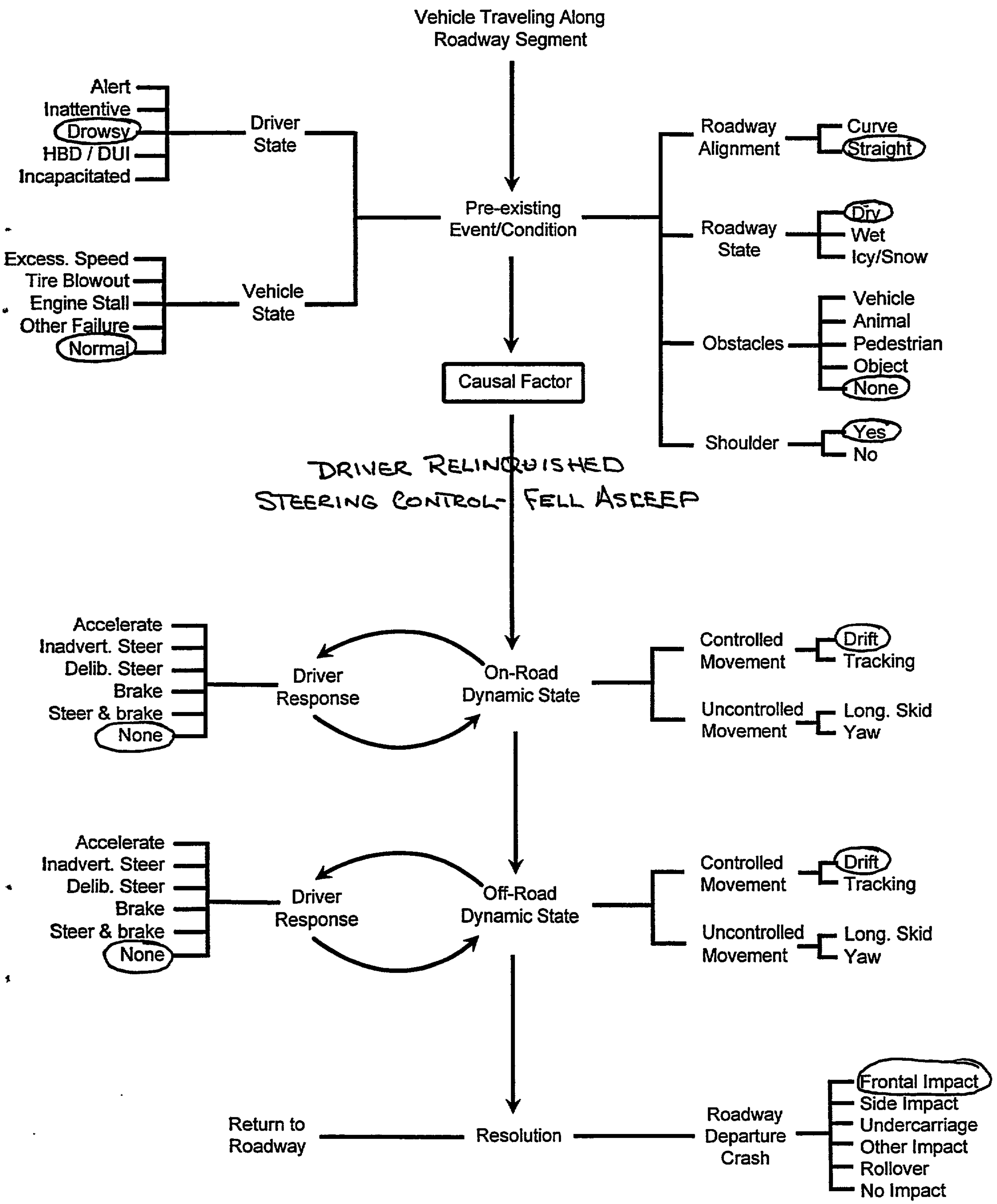


Figure 5-27A Vehicle Dynamic Scenario

5.4.1.3 ***Situation Trees for Evasive Maneuver***

Responses for the individual branches of situation trees associated with the evasive maneuver causal factor are provided in Figure 5-28. Major points with respect to these responses may be summarized as follows:

Driver State - The predominant driver state is alert (84.5 percent). The proportion associated with inattention (10.5 percent) reflects circumstances where the driver is initially inattentive and, therefore, drives up on (or approaches) a vehicle that is stopped in the subject vehicle's travel lane. The subject driver then initiates an evasive maneuver to avoid the stopped vehicle. In circumstances where the driver is alert, the principal other vehicle (POV) encroaches into the subject vehicle's lane, prompting the evasive maneuver.

- Vehicle State - The predominant vehicle state is normal (89.5 percent). The other failure category (10.5 percent) represents a single case where a driver could not stop, after initiating an evasive maneuver, as a result of a faulty braking system.

- Roadway Alignment - The predominant alignment type is straight (66.8 percent) with curved segments (33.2 percent) also contributing to the profile.

- Roadway State - Most crashes occur on surfaces that are dry (60.0 percent), however, the proportion of wet surfaces (37.9 percent) is also significant.

- Obstacles - All crashes in this causal factor group involve a vehicle (67.2 percent) or animal (32.8 percent) in the subject vehicle's intended travel path.

- Shoulder - Most crashes of this type occur on roadways where an adjacent shoulder area is present (69.6 percent).

- On-Road Driver Response - All crashes in this causal factor group involve on-road driver corrective action. The primary responses are steering (56.1 percent) and steering/braking combinations (4 1.4 percent).

- On-Road Vehicle Response - The predominant vehicle response to corrective inputs is to continue in a tracking attitude (77.6 percent). The remainder of the profile is comprised of yaw (16.1 percent) and longitudinal skid (6.4 percent) movements.

- Off-Road Driver Response - The proportion of drivers initiating off-road corrections is very high (89.5 percent). Steering (47.8 percent) and steering/braking combinations (39.1 percent) dominate the corrective actions initiated.

- Off-Road Vehicle Response - The dominant off-road vehicle response to corrective input is yaw movement (55.6 percent). In this circumstance, the difference between the off-road yaw proportion (55.6 percent) and the on-road proportion (16.1 percent) noted above, partially reflects differences between friction values of on-and off-road surfaces. Proportionately larger steering corrections are required on road surfaces (high friction value) to induce yaw actions in comparison to off-road surfaces (low friction value), assuming similar travel velocities. The difference also reflects the more intense steering corrections initiated off-road.

- Roadway Departure Crash Type - The most frequent configurations are frontal impacts (38.1 percent) followed by rollovers (24.3 percent), undercarriage impacts (2 1.0 percent), and side impacts (16.1 percent). This wide range of impact types, in comparison to preceding causal factors, reflects the increased incidence of off-road yaw movements.

A composite situation tree, derived from the frequency responses shown in Figure 5-28, is provided as Figure 5-29. An exemplar case description, abstracted fi-om the clinical database, is provided below. The schematic for this case is provided as Figure 5-30 and the situation tree coded for this case is provided as Figure 5-30A.

Exemplar Case Description (48-108K)

The subject vehicle (1976 Olds Cutlass) was proceeding in an easterly direction on a two lane rural roadway (asphalt, dry, straight, no surface markings) at a police estimated speed of 45mph A dog entered the roadway, forward of the vehicle, and began crossing the road proceeding from the driver’s right to the driver’s left. The subject driver steered sharply to the right in an evasive maneuver. The subject vehicle rotated clockwise and entered a broadside skid to the left (left side leading). The vehicle exited the right edge of the roadway, entered a drainage ditch, struck the far wall of the ditch with its frontal structure, and then rolled side-over-side to the left. The vehicle rolled one complete roll and then came to rest on its wheels, facing in an east southeasterly direction.

Causal Factor: *Evasive Maneuver*

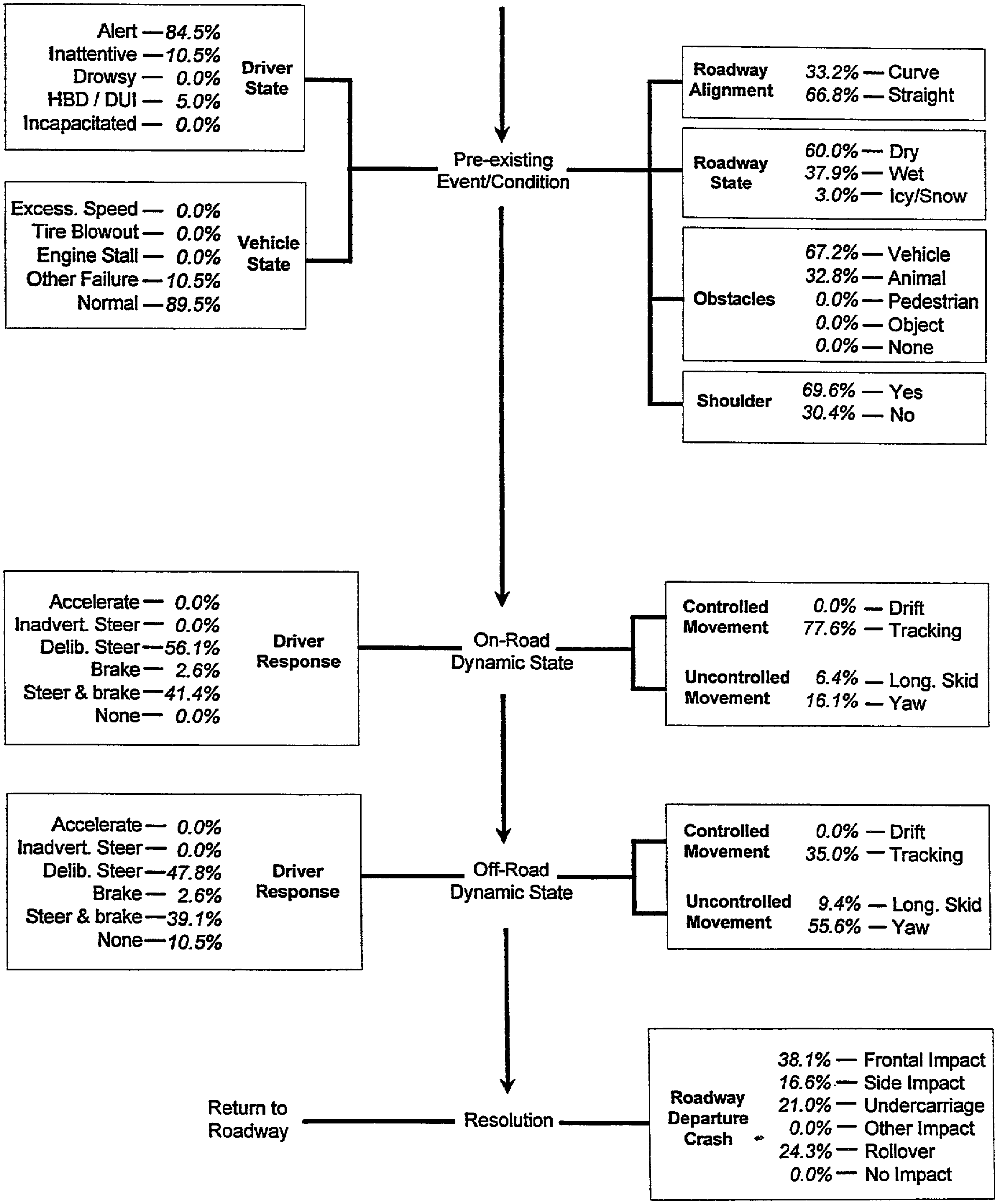


Figure 5-28 Vehicle Dynamic Scenario Analysis - Evasive Maneuver

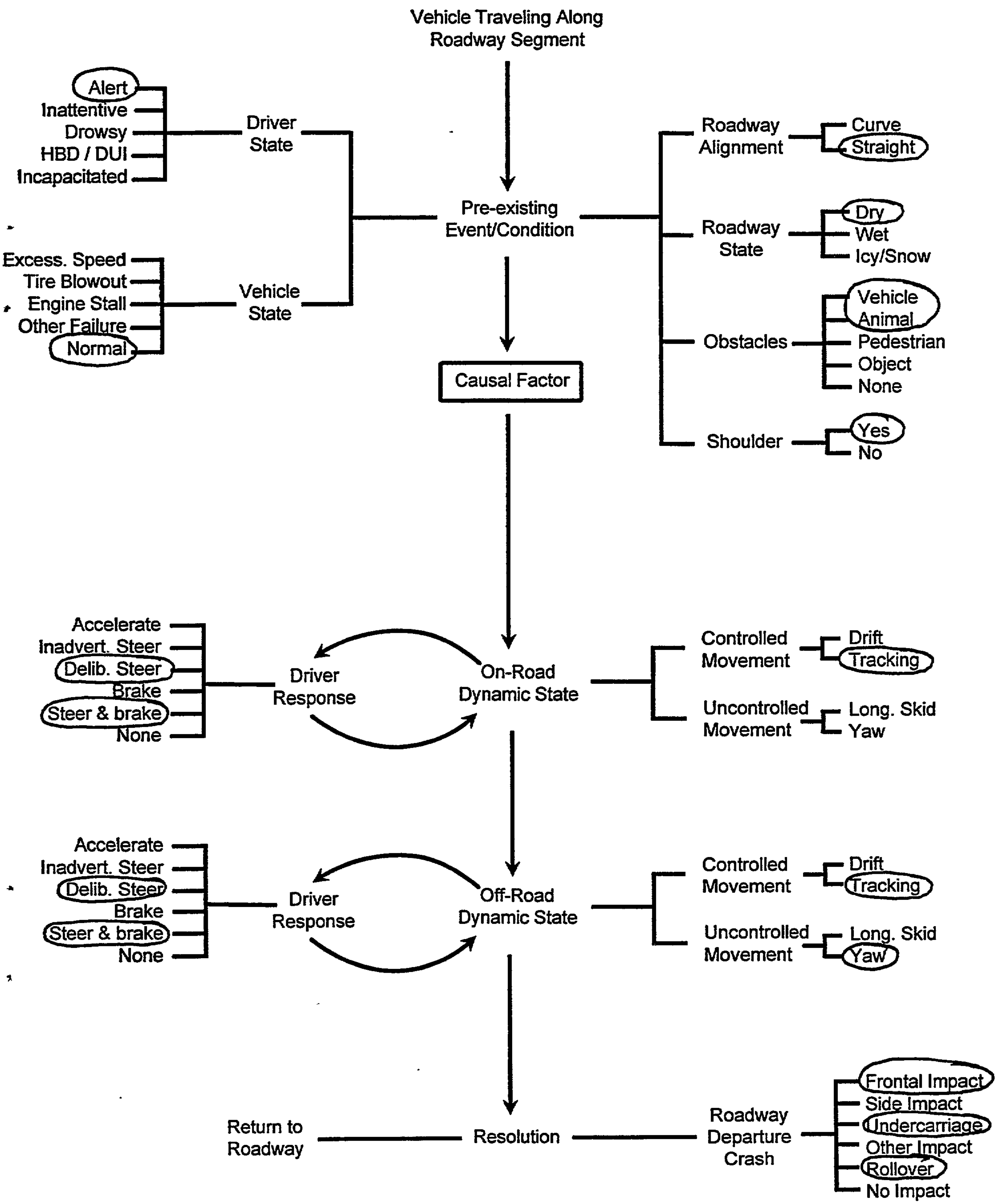


Figure 5-29 Vehicle Dynamic Scenario Example - Evasive Maneuver

ACCIDENT COLLISION DIAGRAM

PSU No. 48 Case Number – Stratum 108K Indicate North

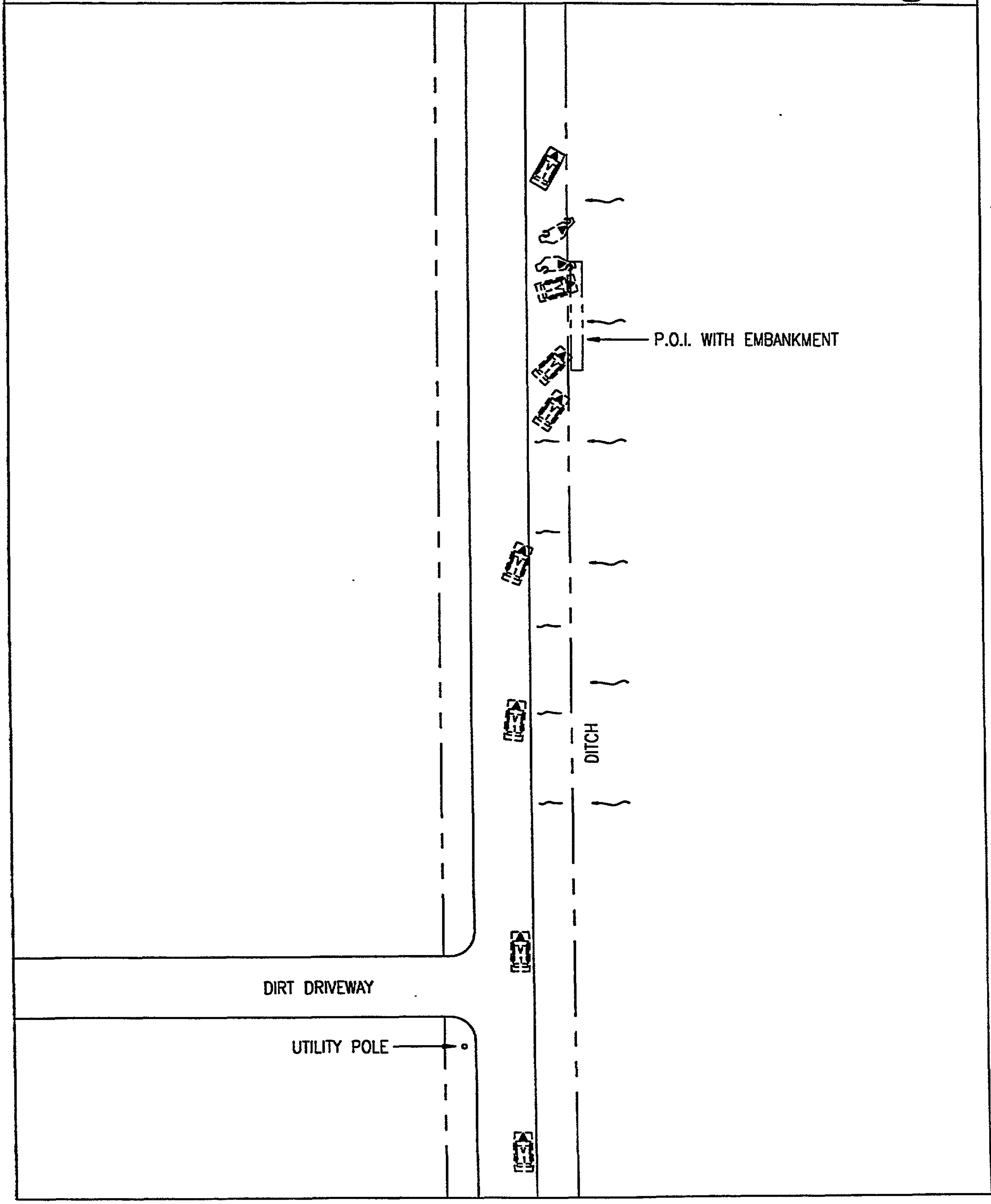


Figure 5-30

Scale: 1/500

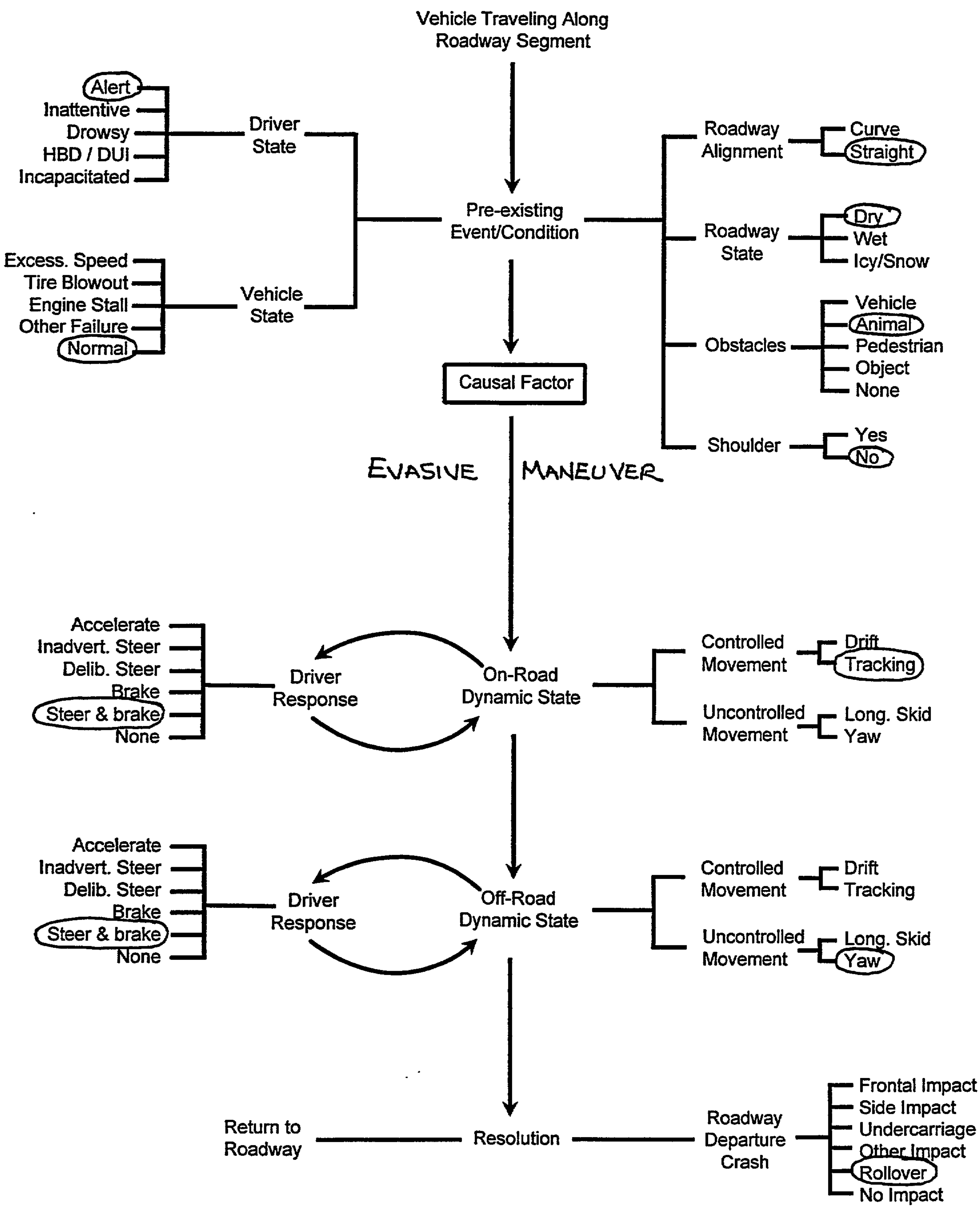


Figure 5-30A Vehicle Dynamic Scenario

5.4.1.4 *Situation Trees for Lost Directional Control*

Responses for the individual branches of situation trees associated with the lost directional control causal factor are provided in Figure 5-3 1. Major points with respect to these responses may be summarized as follows:

- Driver State - The predominant driver state is alert (99.2 percent).

- Vehicle State - The predominant vehicle state is normal (96.1 percent),

- Roadway Alignment - Alignment types are distributed between straight (53.3 percent) and curved (46.7 percent) segments.

- Roadway State - Ice/snow covered (56.6 percent) and wet (34.8 percent) surface conditions occur most frequently. Crashes associated with the dry condition (8.6 percent) involve unusual circumstances (e.g., loss of control associated with traversal of an irregular wash board surface).

- Obstacles - No crashes in this causal factor group involve obstacles in the drivers intended path of travel.

- Shoulder - Most crashes occur on roadways with an adjacent shoulder area (65.5 percent), however, the proportion of crash site locations without shoulders (34.5 percent) is significant.

- On-Road Driver Response - The range of driver responses covers the full spectrum of intended actions. The most frequently occurring corrections are steering actions (40.4 percent) followed by steering/braking combinations (13.0 percent) and braking actions (12.3 percent). The incidence rate for no corrective action (33.5 percent) is also significant.

- On-Road Vehicle Response - The most frequent vehicle response to corrective inputs is yaw movement (69.5 percent). Longitudinal skid patterns (28.1 percent) also comprise a significant proportion of the profile. The increased incidence rates of these uncontrolled movements, as compared to preceding causal factor groups, is associated with the reduced friction levels of the surfaces associated with this specific group of crashes. The incidence rate of ice/snow covered surfaces is elevated and differences are evident between the wet surfaces in this group as compared to preceding groups. Specifically, this group of crashes involves a significant proportion of hydroplaning actions as a result of vehicles traversing through water accumulations in the roadway.

- Off-Road Driver Response - The incidence rates for off-road corrective actions are again substantial. The most frequent corrective inputs are steering actions (24.1 percent) followed by braking actions (17.9 percent) and steering/braking combinations (13.0 percent). The incidence rate of no corrective action (45.0 percent) is also substantial.

- Off-Road Vehicle Response - Yaw movements (61.1 percent) and longitudinal skid patterns (28.1 percent) again dominate the distribution. In this circumstance, these movements tend to reflect a continuation of the movement patterns initiated on the roadway.

- Roadway Departure Crash Types - Due to the high incidence rates associated with yaw movements, the proportion of frontal impacts in this causal factor group is again depressed. The most frequently occurring impact configurations are side impacts (42.4 percent) followed by frontal impacts (39.7 percent), rollovers (10.0 percent), and undercarriage impacts (7.9 percent).

A composite situation tree, derived from the frequency responses shown in Figure 5-3 1, is provided as Figure 5-32. An exemplar case description, abstracted from the clinical database, is provided below. The schematic for this case is provided as Figure 5-33 and the situation tree coded for this case is provided as Figure 5-33A.

Exemplar Case Description (13-034H)

This accident involved a left side road departure. The vehicle was traveling south on a two lane, level, icy, asphalt roadway when the driver lost control. The vehicle crossed the oncoming lane of traveI and departed the left roadside in a counterclockwise rotation and struck a tree on the grass area adjacent to the curb with its right side leading. The causal factor was driver lost directional control as the result of the icy roadway condition. There were no adverse ambient weather conditions. The roadway was illuminated by overhead street lights. The roadway was delineated by a broken yellow center line which was in good condition. The driver attempted to regain control of the vehicle by counter-steering and applying the brakes with lock-up.

Causal Factor: *Lost Directional Control*

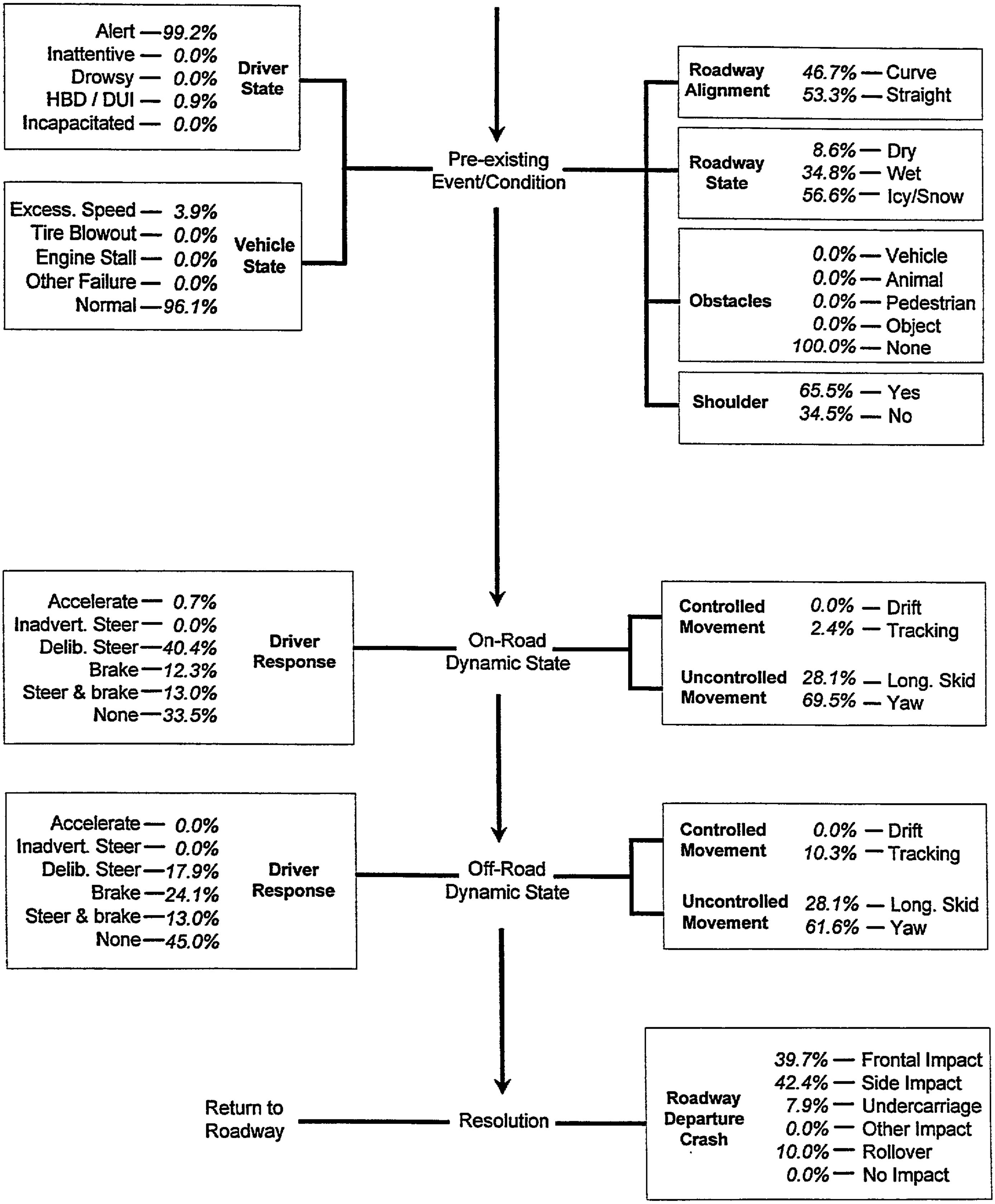


Figure 5-31 Vehicle Dynamic Scenario Analysis - Lost Directional Control

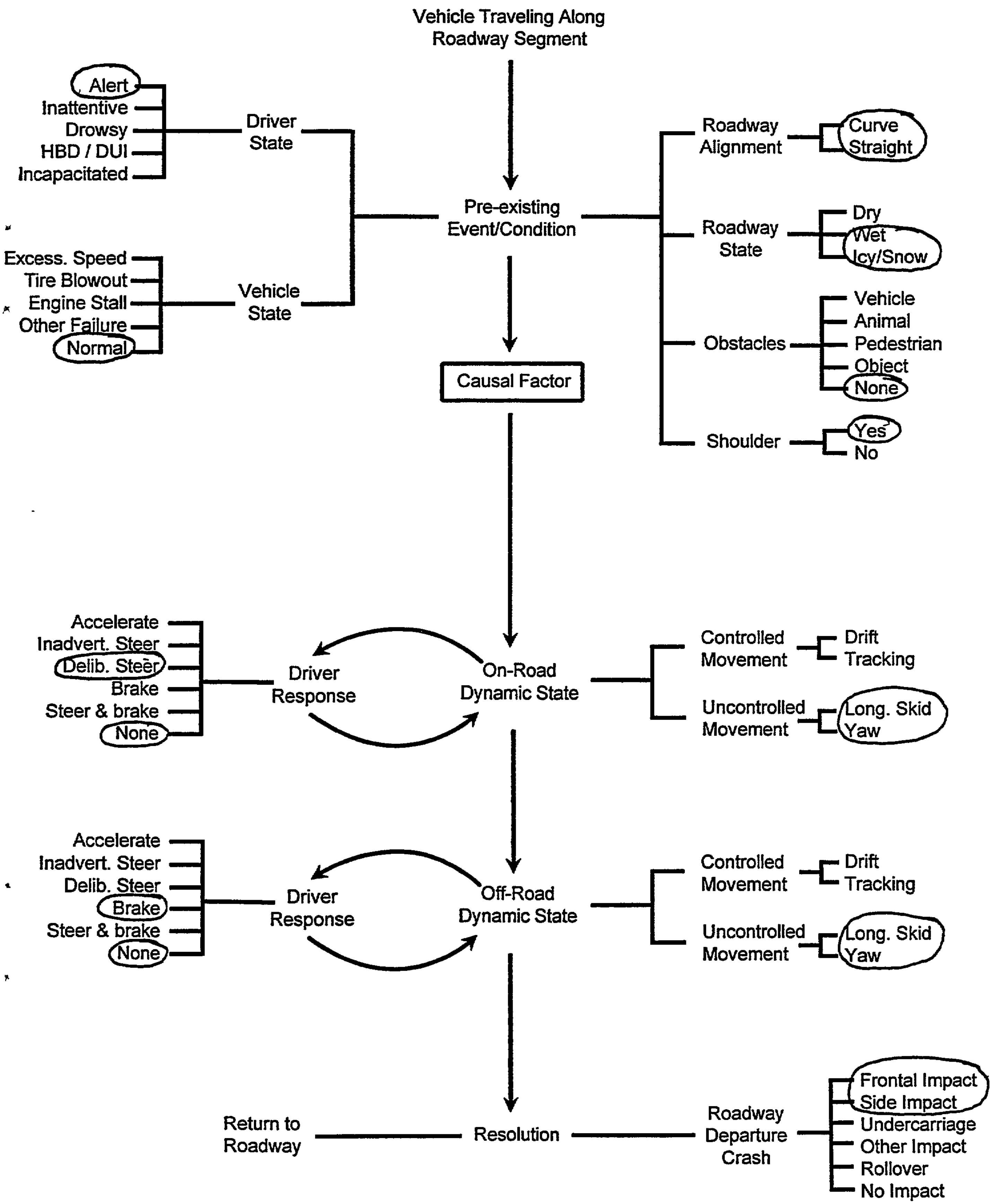


Figure 5-32 Vehicle Dynamic Scenario Example - Lost Directional Control

ACCIDENT COLLISION DIAGRAM

PSU No. 13 Case Number - Stratum 034H Indicate North

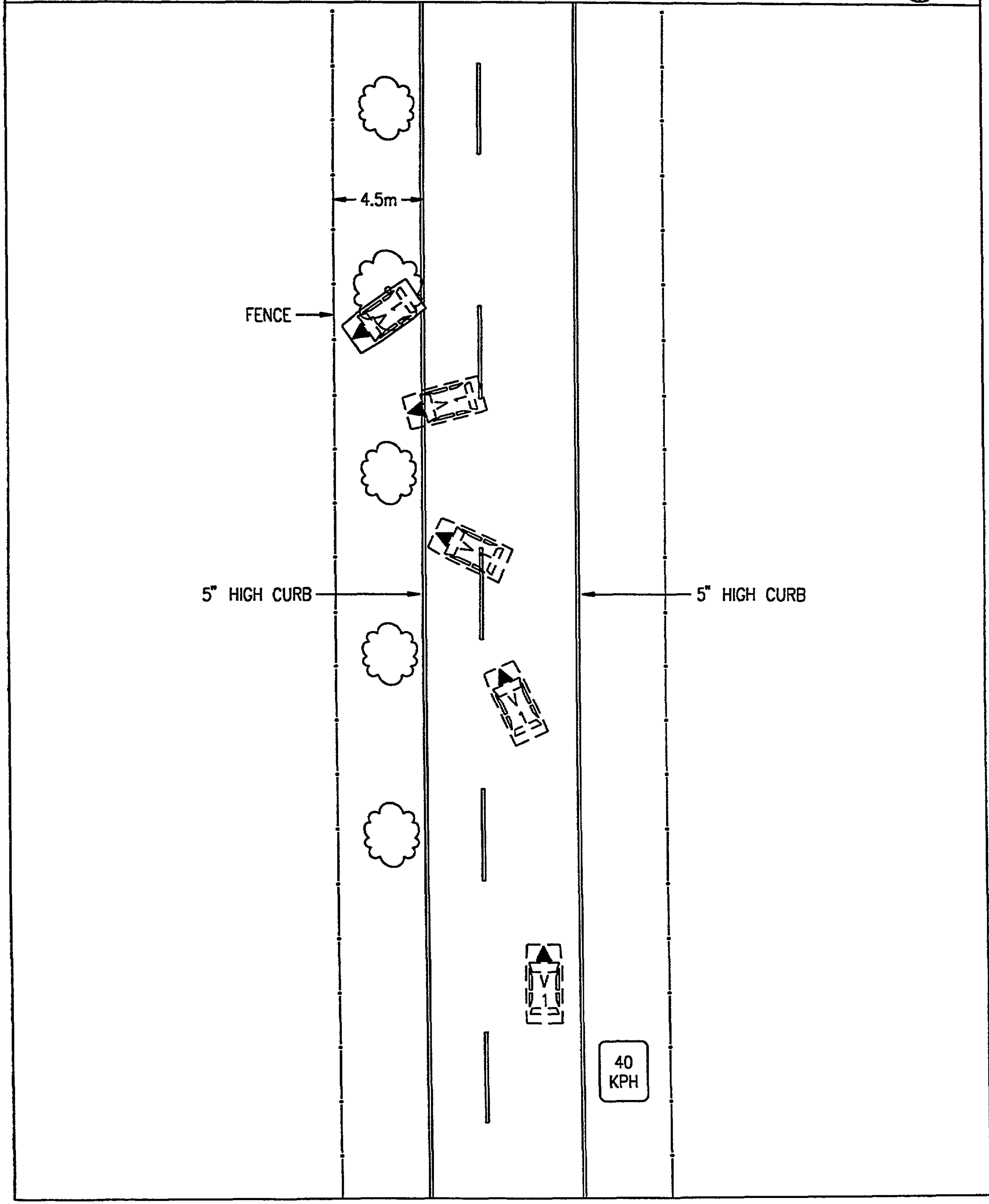


Figure 5-33

Scale: 1/250

13-034 H

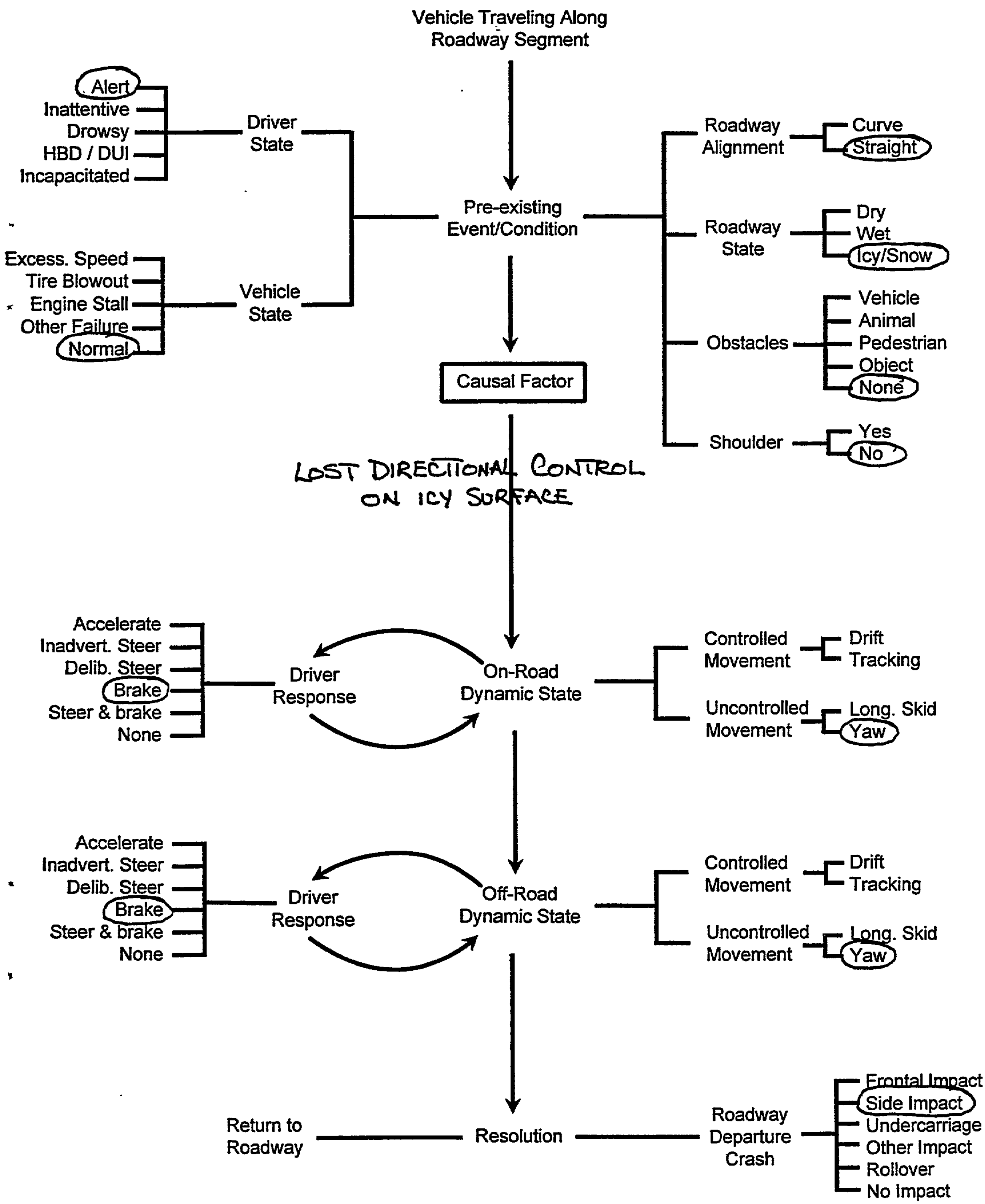


Figure 5-33A Vehicle Dynamic Scenario

5.4.1.5 Situation Trees for Vehicle Failure

Responses for the individual branches of situation trees associated with the vehicle failure causal factor are provided in Figure 5-34. Major points with respect to these responses may be summarized as follows:

- NOTE: Due to the small number of cases associated with this causal factor (i.e., eight cases), specific trends should be interpreted cautiously.

- Driver State - All drivers in this causal factor group are categorized as alert.

- Vehicle State - The predominant vehicle failure is engine stall (64.2 percent) followed by other failure (25.7 percent) and tire blowout (10.1 percent). The other failure category is comprised of a transmission failure, a wheel which separated from the vehicle, a failure of the accelerator linkage, and degraded performance of a steering system.

- Roadway Alignment - The predominant roadway alignment type is curve (79.8 percent).

- Roadway State - All of the crashes in this group occur on dry surfaces.

- Obstacles -No crashes in this group involved an obstacle in the driver's intended path of travel.

- Shoulder - Most crashes occur at locations that do not have an adjacent shoulder area (66.2 percent).

- On-Road Driver Response - The predominant driver response is to initiate no corrective action (66.2 percent). Corrective actions initiated include steering actions (17.6 percent) and braking actions (14.3 percent).

- On-Road Vehicle Response - The proportion of no corrective action initiated (66.2 percent) translates to the proportion of vehicle drift movements (64.2 percent). The steer and brake actions translate to yaw movements (23.7 percent) and longitudmal skid patterns (8.1 percent).

- Off-Road Driver Response - Off-road driver responses tend to reflect a continuation of on-road actions. The predominant driver response is again no corrective action (66.2 percent) with steering (15.6 percent) and braking (14.3 percent) actions also contributing to the profile.

- O&Road Vehicle Response - The vehicle response pattern also reflects a continuation of on-road movements. The predominant response is again drift movement (64.2 percent) which reflects a continuation of on-road drift movement (64.2 percent). Off-road driver corrective actions translate almost exclusively to yaw movements (33.8 percent).

- Roadway Departure Crash Type - The high incidence rate of drift movements in this group translates to an elevated rate for the frontal impact (74.3 percent) configurations. Similarly, the off-road incidence rate for yaw movements translates directly to the rollover (23.7 percent) category.

A composite situation tree, derived from frequency responses shown in Figure 5-34, is provided as Figure 5-35. An exemplar case description, abstracted from the clinical database, is provided below. The schematic for this case is provided as Figure 5-36 and the situation tree coded for this case is provided as Figure 5-36A.

Exemplar Case Description (04-116H)

The subject driver was attempting to negotiate a right curve on a four lane, one-way road that separated into a Y-configuration As she approached the junction, the engine stalled and the driver was unable to steer the vehicle through the curve. The vehicle impacted the barrier curb at the island area with the right front tire and skidded to a stop on the grassy surface. There was no evidence of pre-impact braking, however, the driver braked at or post-impact. The asphalt road surface was dry and open and afforded the driver a clear line of sight. She claimed the engine stalled, therefore, environmental conditions were not a clear factor. All road markings were in good condition and there were no roadside reflective markers/delineators.

Causal Factor: ***Vehicle Failure***

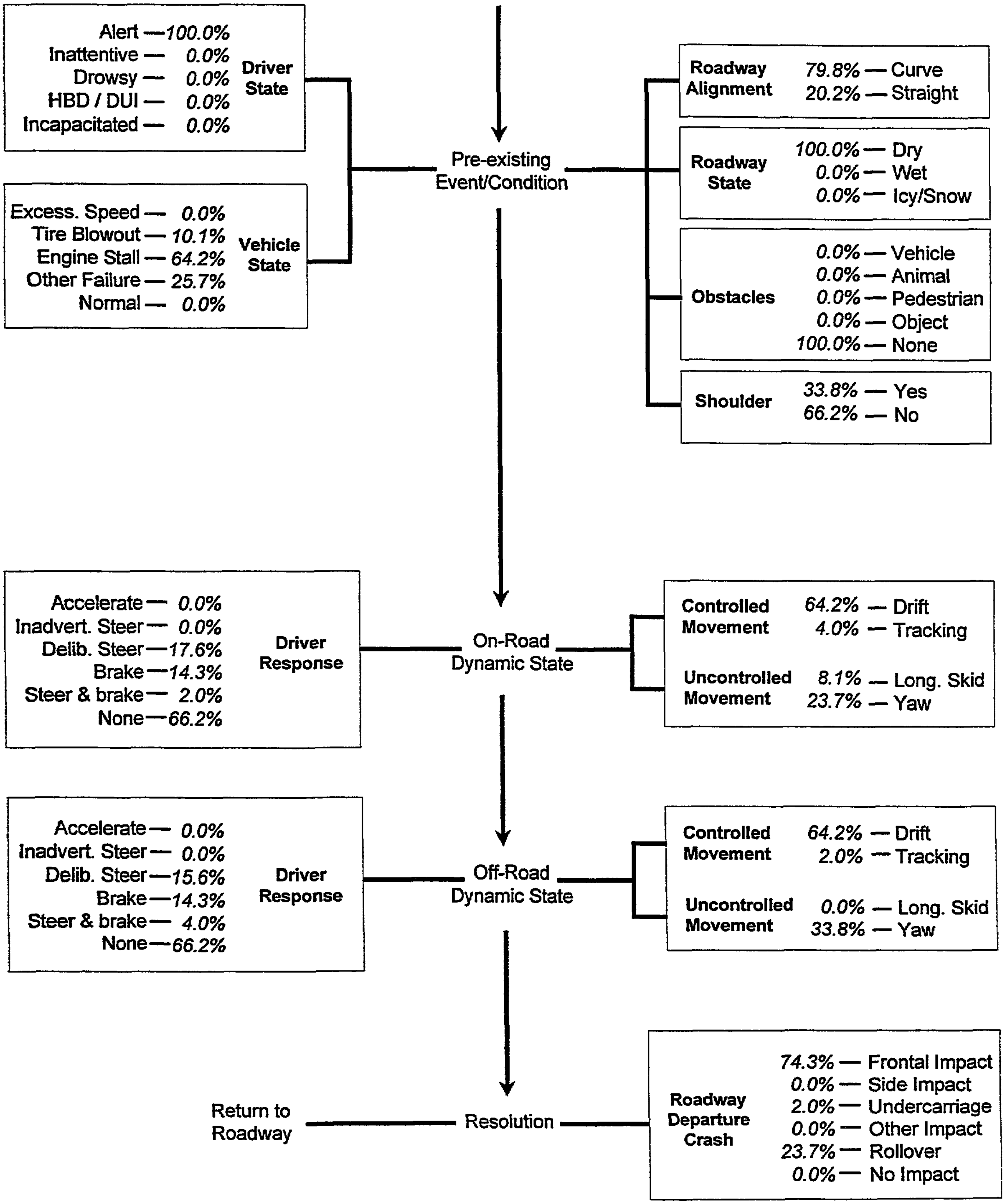


Figure 5-34 Vehicle Dynamic Scenario Analysis - Vehicle Failure

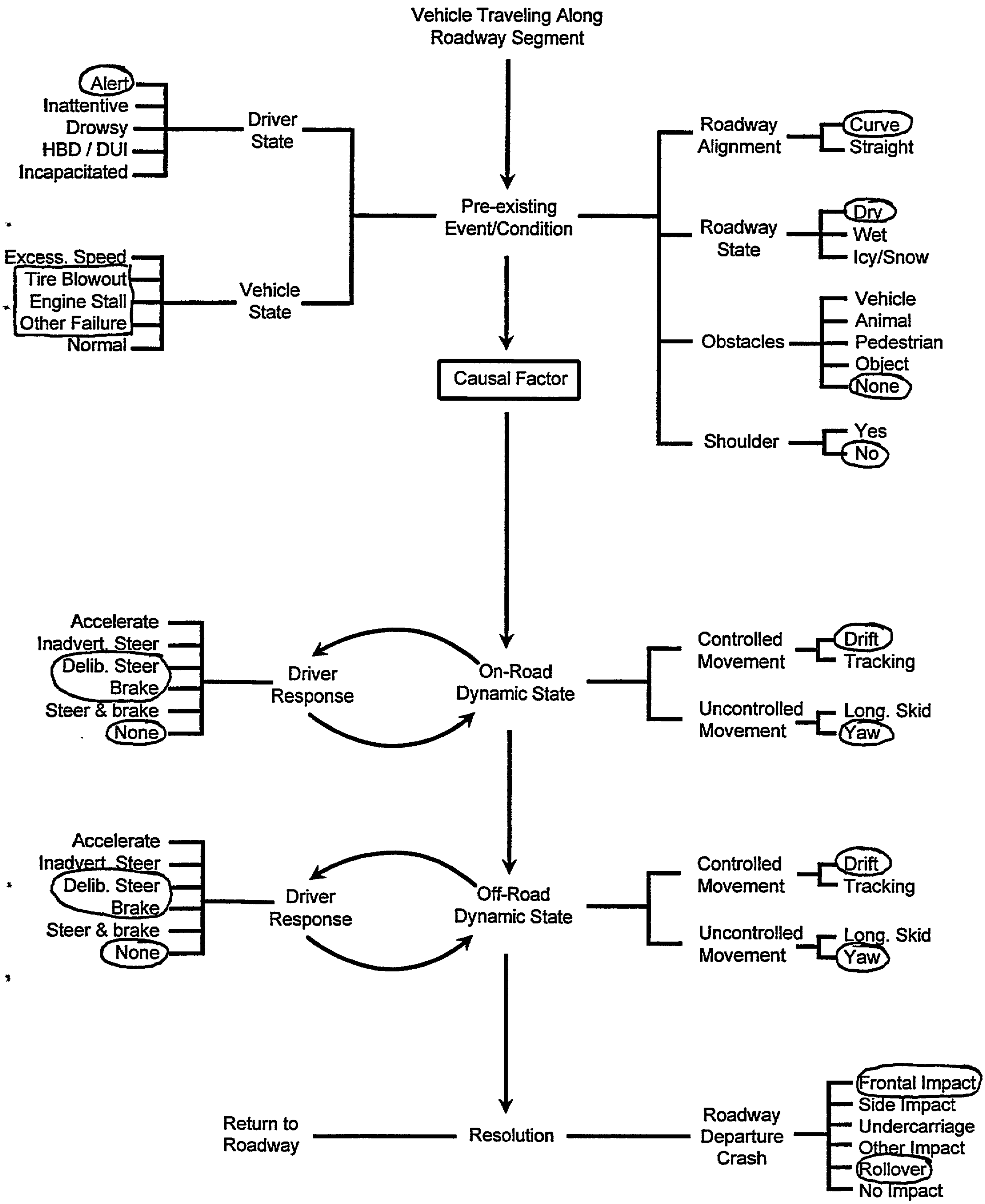


Figure 5-35 Vehicle Dynamic Scenario Example - Vehicle Failure

ACCIDENT COLLISION DIAGRAM

PSU No. 04 Case Number – Stratum 116H Indicate North

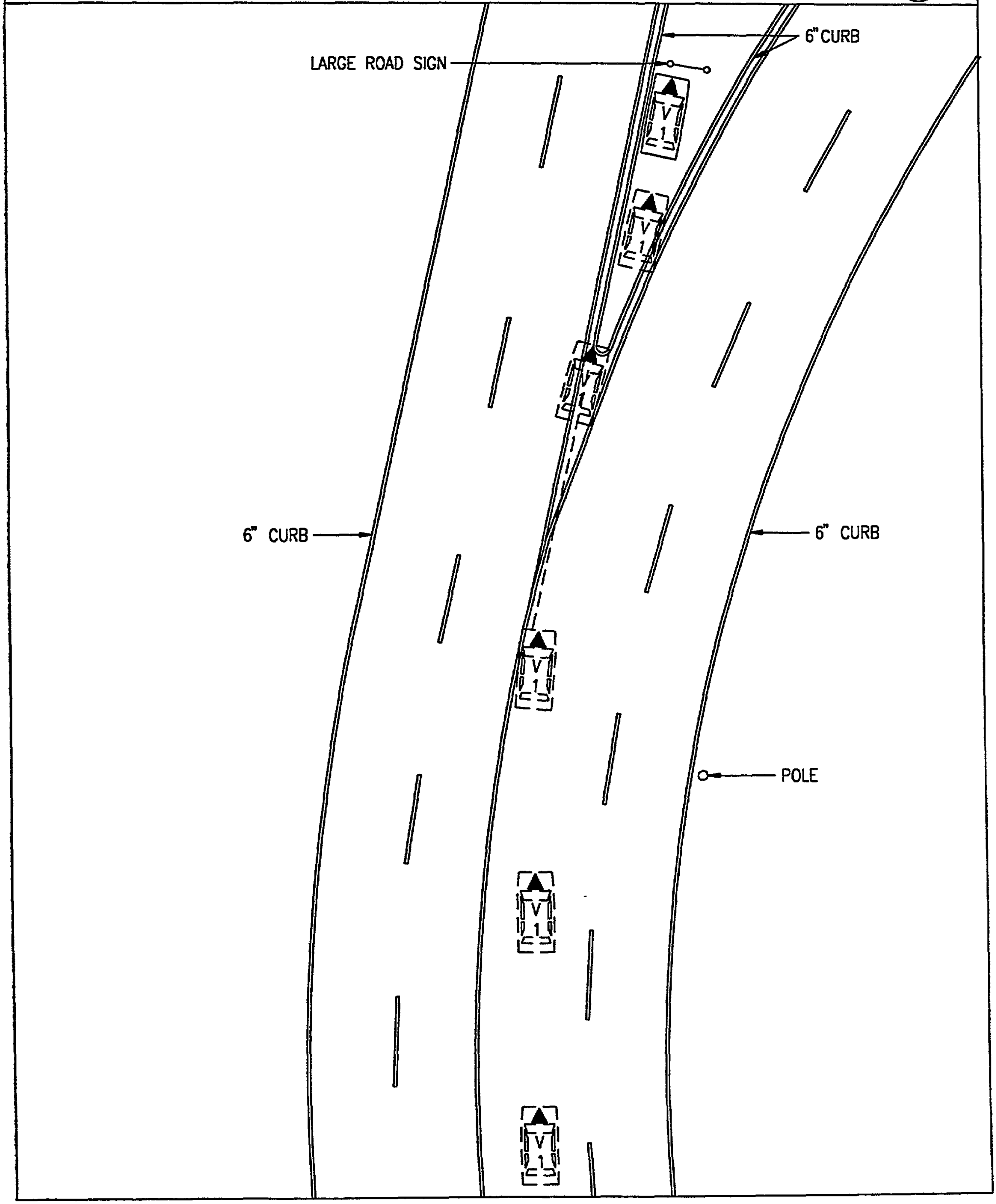


Figure 5-36

Scale: 1/250

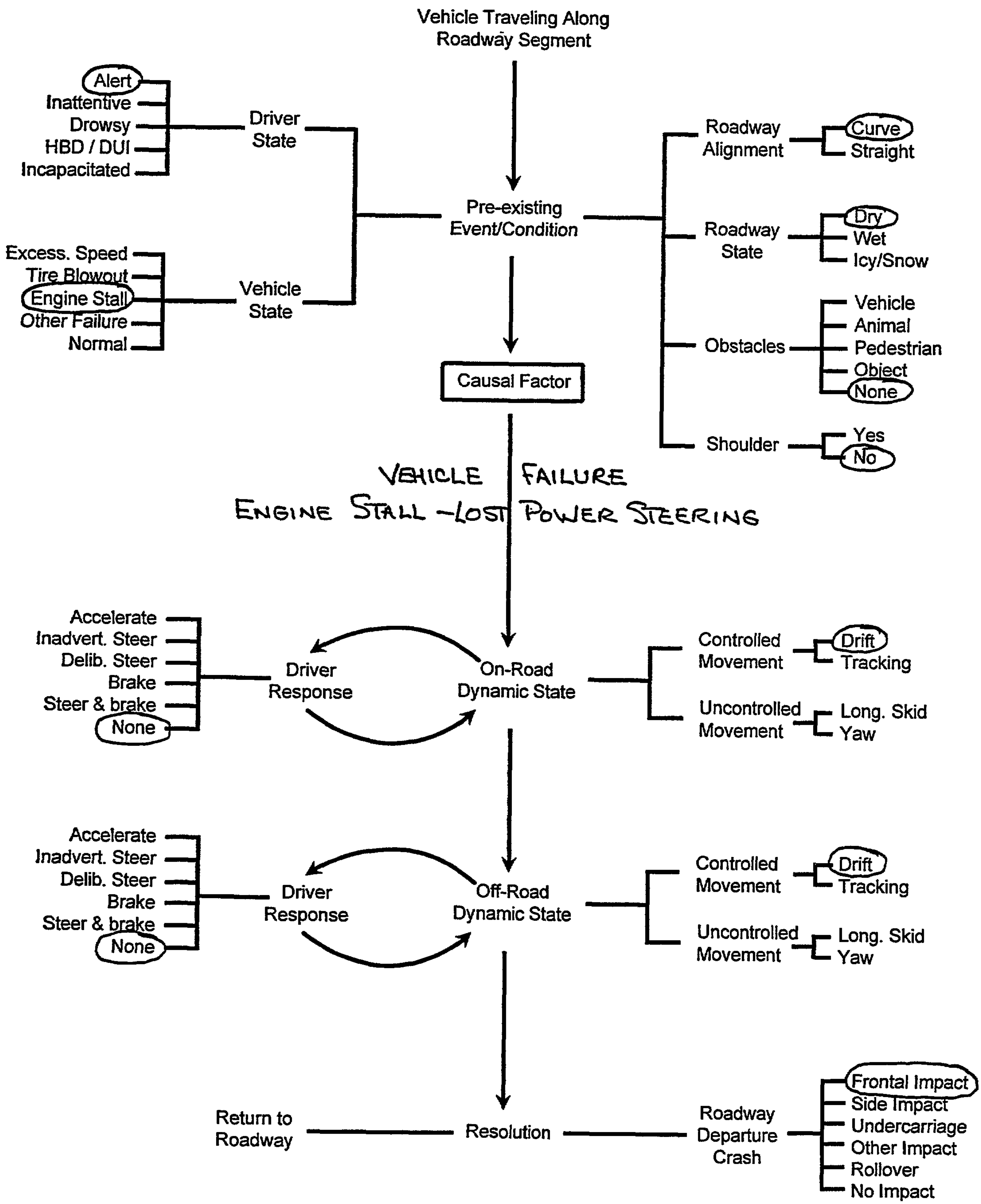


Figure 5-36A Vehicle Dynamic Scenario

5.4.1.6 Situation Trees for Vehicle Speed

Responses for the individual branches of situation trees associated with the vehicle speed causal factor are provided in Figure 5-37. Major points with respect to these responses may be summarized as follows:

- Driver State - Most drivers are classified as alert (59.5 percent), however, the proportion of drivers who had been drinking (40.3 percent) is also substantial.

- Vehicle State - All crashes in this causal factor group involve excessive vehicle speed.

- Roadway Alignment - The predominant alignment type is curve (58.4 percent), however, the proportion of straight segments (41.6 percent) is also substantial.

- Roadway State - The predominant surface condition is dry (64.9 percent) with wet surfaces (21.3 percent) and ice/snow covered surfaces (13.7 percent) also contributing to the profile.

- Obstacles - Most crashes are unrelated to the presence of an obstacle in the driver's intended travel path (95.5 percent). In a small proportion of crashes, however, another vehicle (4.5 percent) does function as an obstacle.

- Shoulder - Most crashes occur at locations where an adjacent shoulder area is present (72.4 percent). .

- On-Road Driver Response - Most drivers initiate pre-departure corrective action (63 .O percent). The specific actions initiated include steering (26.8 percent), braking (23.6 percent), and steering/braking combinations (12.6 percent). The proportion of drivers not initiating corrective action (27.5 percent) is relatively small as is the proportion of drivers initiating inadvertent steering inputs (9.6 percent).

- On-Road Vehicle Response - Given the proportion of drivers initiating corrective action (63 .0 percent), the proportion of vehicles in a tracking attitude (41.8 percent) is high. This circumstance results from the higher friction values found on the dry surfaces (64.9 percent) associated with this group. The proportions of longitudinal skid patterns (23.9 percent) and yaw movements (29.9 percent) are very substantial and reflect the high incidence rate noted for excessive vehicle speed (100.0 percent).

- Off-Road Driver Response - The proportion of drivers with corrective action off-road (74.9 percent) parallels the rate noted for on-road correction (63 .O percent) and reflects the continuation of on-road activities with the addition of a smaller proportion of drivers initiating corrective action off road. Braking (33.9 percent) is the most frequently occurring action followed by steering actions (29.0 percent) and steering/braking combinations (12.0 percent).

- Off-Road Vehicle Response - During off-road movement, the incidence rate for yaw actions (40.6 percent) increases in comparison to on-road movement (29.0 percent). Similarly, the incidence rates for tracking movements (37.4 percent) and longitudinal skid patterns (21.4 percent) decline.

- Roadway Departure Crash Type - The predominant crash types are frontal impacts (58.8 percent) followed by rollovers (16.3 percent), side impacts (15.9 percent), and undercarriage impacts (9.0 percent).

A composite situation tree, derived from the frequency responses shown in Figure 5-37, is provided as Figure 5-38. An exemplar case description, abstracted from the clinical database, is provided below. The schematic for this case is provided as Figure 5-39 and the situation tree coded for this case is provided as Figure 5-39A.

Exemplar Case Description (12-079E)

The subject vehicle was traveling west on a ramp connecting two interstate roadways during the evening hours with no overhead illumination. The positive 2.1 percent sloped, dry, concrete, single lane roadway curved to the right and was not superelevated. The driver had consumed alcohol prior to the crash and lost control of the vehicle, departing the left side of the roadway, traveling down an embankment (8.0 percent negative grade), striking a ditch and rolling over. The causal factor was excessive speed for the ramp and alcohol consumption. There were no sight line or roadway restrictions. The off road terrain was open with no obstacles in the grassy area.

Causal Factor: *Vehicle Speed*

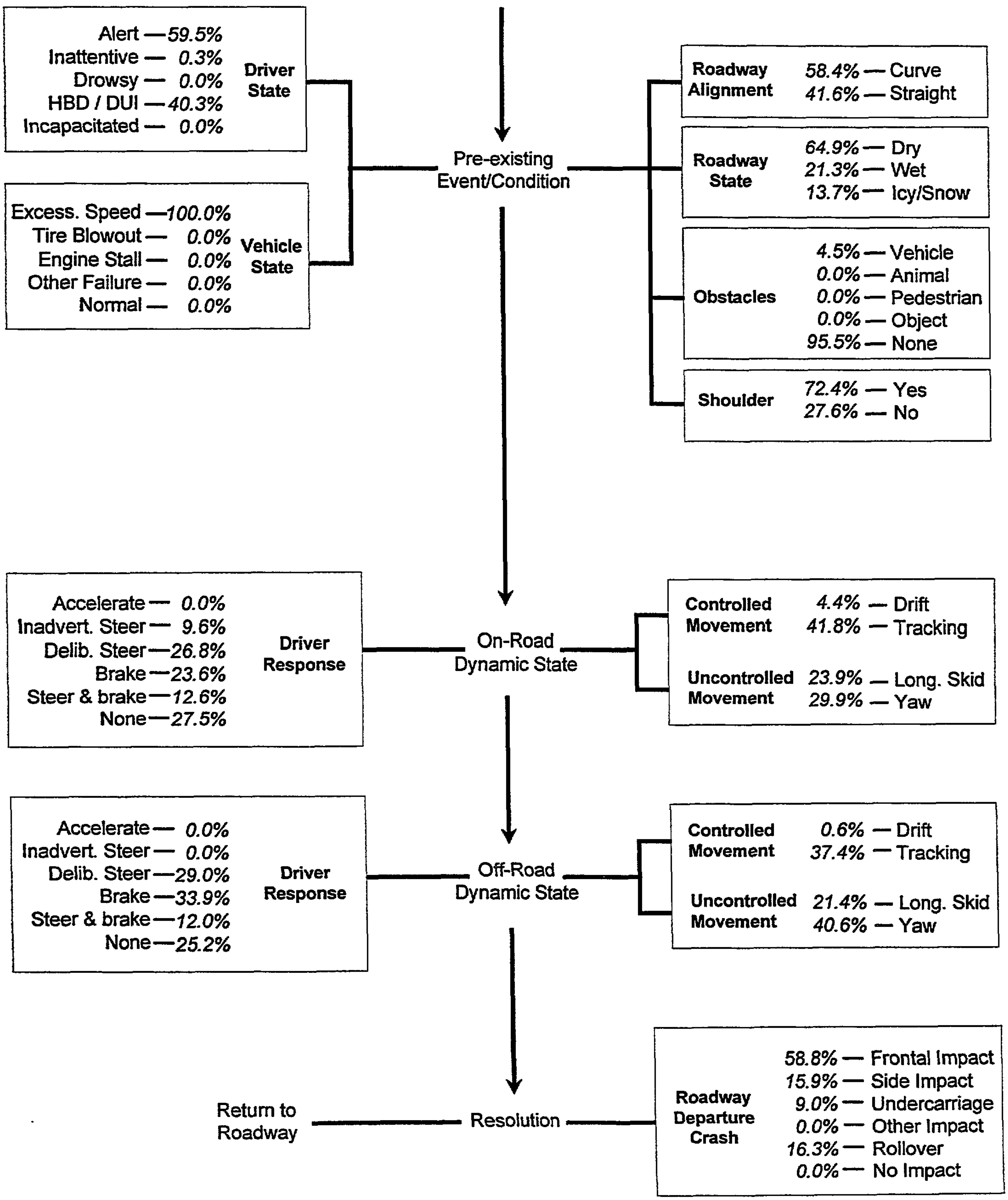


Figure 5-37 Vehicle Dynamic Scenario Analysis - Vehicle Speed

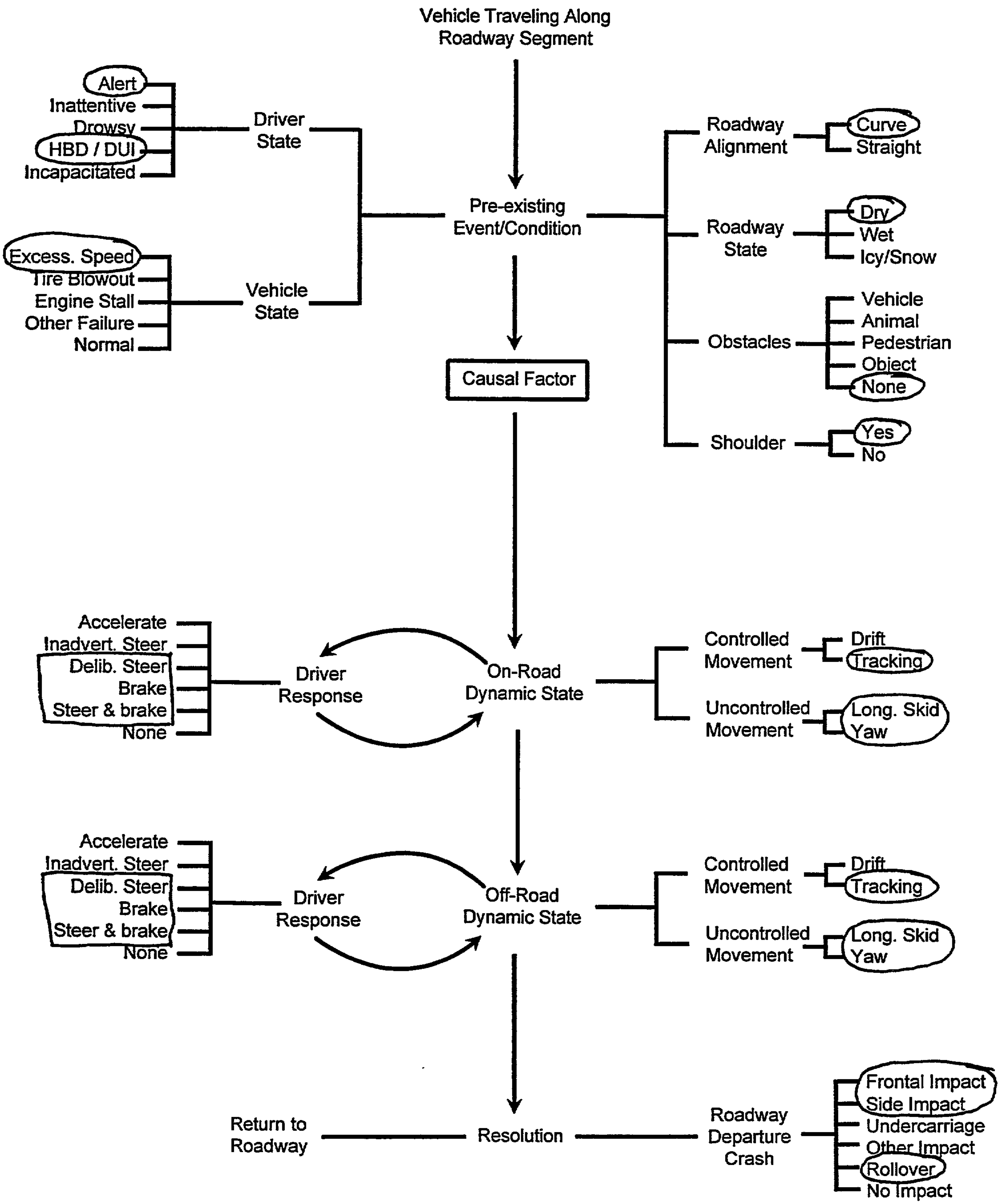


Figure 5-38 Vehicle Dynamic Scenario Example - Vehicle Speed

ACCIDENT COLLISION DIAGRAM

PSU No. 12 Case Number - Stratum 079E Indicate North

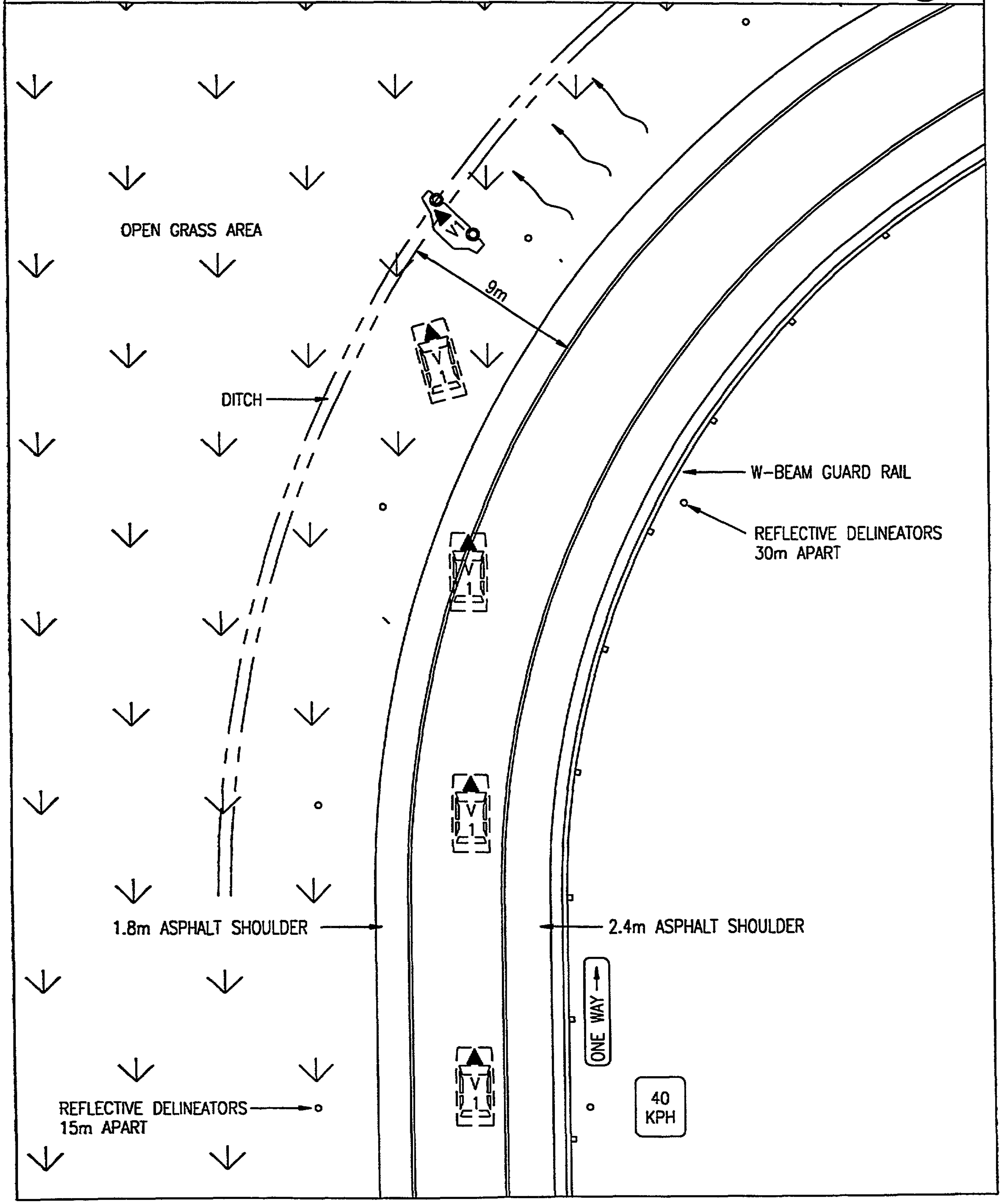


Figure 5-39

Scale: 1/250

12-079E

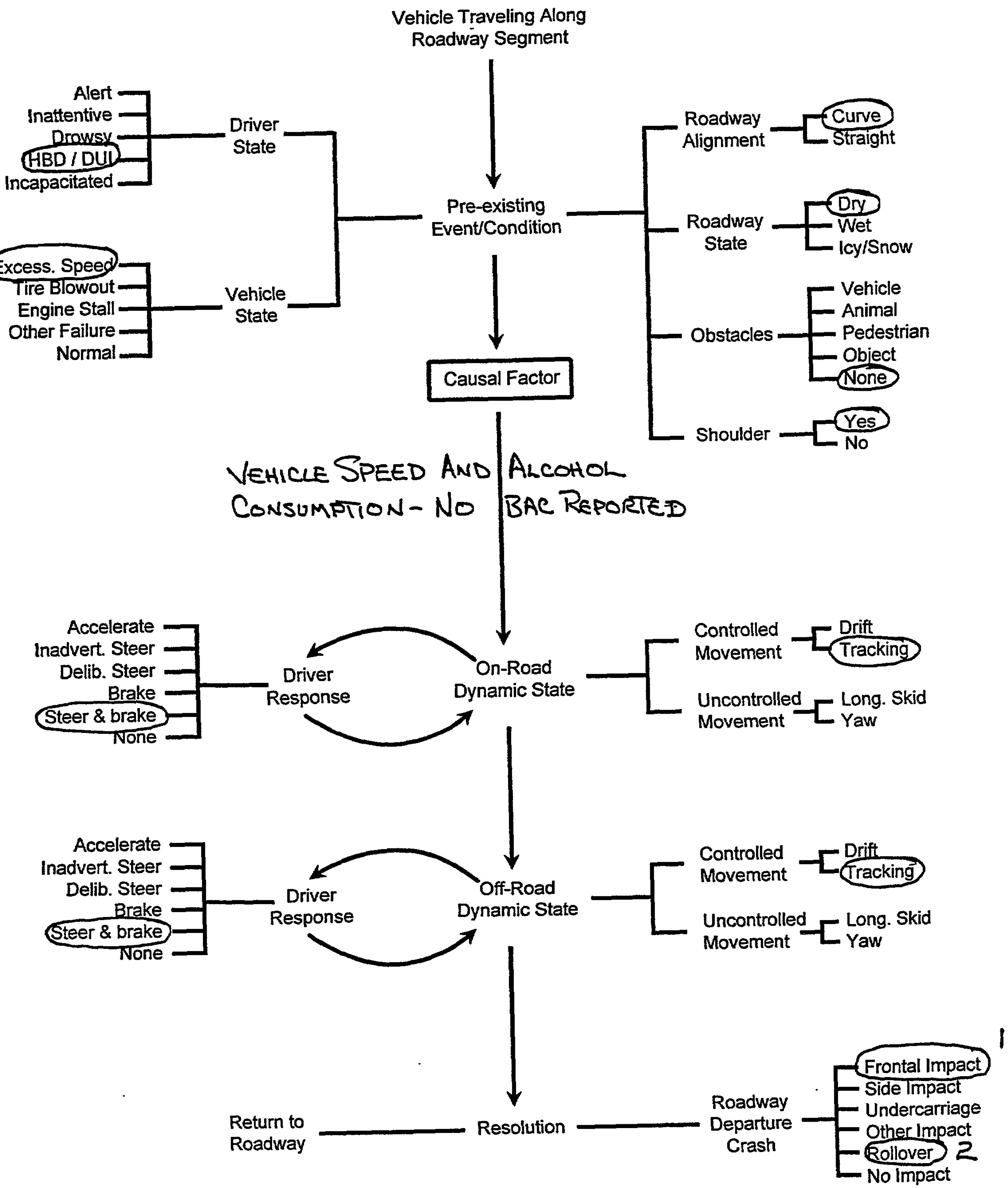


Figure 5-39A Vehicle Dynamic Scenario

5.4.2 Top-Level Evaluation of Analytical Parameters

As part of the case review process, the project staff completed a qualitative assessment of analytical parameter characteristics associated with run-off-road crashes. The evaluation was performed for the interval between event initiation and roadway departure and focused on subject vehicle velocity characteristics, driver steering input characteristics, and driver braking input characteristics.

Results of this evaluation effort are provided in Table 5-46. It should be noted that characteristic values in the table reflect the most frequently occurring values within each causal factor group in circumstances where the parameter is applicable. For example, within the driver inattention causal factor group, steer inputs are classified as none or minimal (<3 degrees). These classifications are representative of typical values found within this group. There are, however, individual cases where steer inputs are more appropriately classified as moderate (3-6 degrees) or large (> 6 degrees). The latter cases may be considered "Outliers" and are not representative of the driver inattention group. Steer inputs in the evasive maneuver (moderate to large) and lost directional control (minimal to moderate) again reflect the typical values associated with these groups. The responses indicated for the vehicle failure (minimal) and vehicle speed (minimal to moderate) groups, however, are not typical values since most drivers in these groups do not initiate corrective steering inputs prior to the point of departure. For these two groups, the responses indicate that when a steering correction is initiated, the most frequent steer inputs are in this range.

Major trends within Table 5-46 may be summarized as follows:

- Velocity - In the driver inattention and driver relinquished steering control groups the velocity parameter is characterized as being constant at the point of roadway departure. In the four other causal factor groups, the velocity parameter is typically decreasing in value at this same point This characteristic value for these groups is typically associated with engine drag as opposed to braking activity (i.e., driver is no longer applying accelerator input).

- Steer Input - These inputs are characterized as none or minimal (<3 degrees) in the driver inattention and driver relinquished steering control groups. Within these groups, many of the minimal inputs are associated with inadvertent steering. Steer inputs in the evasive maneuver group are characterized as moderate (3-6 degrees) to large (> 6 degrees). Corresponding inputs in the lost directional control, vehicle failure, and vehicle speed groups are characterized as minimal (<3 degrees) to moderate (3-6 degrees) when these inputs occur.

- Brake Input - In typical cases in the driver inattention and driver relinquished steering control groups, the subject driver does not initiate braking effort prior to the point of roadway departure. In the other four causal factor groups this parameter is again characterized by typical values noted when braking is initiated. Braking inputs in the evasive maneuver group are characterized as moderate (0.25-0.50 Gs) to heavy (> 0.50 Gs) as are inputs in the vehicle speed group. Corresponding inputs in the lost directional control and vehicle failure groups are characterized as minimal (< 0.25Gs) to moderate (0.25-0.50Gs) This characterization for the lost directional control group is closely associated with surface conditions in this group (wet and ice/snow covered) as opposed to the level of effort initiated by the driver. Specifically, drivers in this group tend to apply heavy brake pedal pressure. The vehicle, however, cannot generate braking levels which exceed the friction values of the involved surfaces.

A more complete evaluation of these analytical parameters will be conducted as part of the Task 2 effort. The project staff is generating timeline histories for the clinical sample in Task 2. Therefore, "hard data" relating to the velocity and braking parameters will be available for review.

Table 5-46
Analytical Parameter Characteristics Within Causal Factor Groups

Parameter Characteristics	Causal Factors					
	Driver Inattention	Relinquished St. Control	Evasive Maneuver	Lost Directional Control	Vehicle Failure	Vehicle Speed
Velocity						
Constant	X	X				
Increasing						
Decreasing			X	X	X	X
Steer Input						
None	X	X				
Minimal (<3°)	X	X		X	X	X
Moderate (3-6°)			X	X		X
Large (> 6°)			X			
Brake Input						
None	X	X				
Minimal (< 0.25Gs)				X	X	
Moderate (0.25-05Gs)			X	X	X	X
Heavy (>0.5Gs)			X			X

NOTES:

1. The parameter evaluation applies to the interval between event initiation and roadway departure.

2. The range in values shown for specific parameters are typical and the most frequently occurring values in circumstances where the parameter is applicable. Within any given causal factor group there are likely to be combinations of cases which demonstrate the full range of the characteristics evaluated.

5.4.3 Comparison of Situation Tree Groups

Tabulations of the most frequently occurring variables within each causal factor group are provided in Tables 5-47 and 5-48. Table 5-47 describes pre-existing conditions within each causal factor group. Table 5-48 describes dynamics states and the result of these states (e.g. impact type) within each causal factor group. Major points derived from these tables may be summarized as follows:

Table 5-47

- Driver State - In three of the causal factor groups, the predominant driver state is alert. These groups are evasive maneuver (84.5 percent), lost direction control (99.2 percent), and vehicle failure (100.0 percent). The predominant state for the driver inattention group is inattention (100.0 percent). In the driver relinquished steering control group, there are two primary states (HBD/DUI -58.9 percent and Drowsy -36.0 percent). The vehicle speed group also has two primary states (Alert -59.5 percent and HBD/DUI -40.3 percent).

- Vehicle State - In four of the causal factor groups, the predominant vehicle state is normal. These groups are driver inattention (91.8 percent), driver relinquished steering control (98.3 percent), evasive maneuver (100.0 percent), and lost directional control (96.1 percent). A variety of vehicles failures dominate the distribution for the vehicle failure group and virtually all crashes in the vehicle speed group involve excessive speed.

- Roadway Alignment - The causal factor groups are evenly split between straight and curved segments. Curved segment locations dominate the distribution for the driver relinquished steering control (55.7 percent), vehicle failure (79.8 percent), and vehicle speed (58.4 percent) groups. Straight segment locations dominate the distributions for the driver inattention (66.3 percent), evasive maneuver (66.8 percent), and lost directional control (53.3 percent) groups.

- Roadway State - The dry surface condition is the most prevalent condition in five of the causal factor groups. Icy/snow conditions (56.6 percent) and wet surfaces (34.8 percent) dominate the distribution for the lost directional control group.

- Obstacles - Obstacles are typically not involved in the crash sequences associated with five of the causal factor groups. The presence of vehicles (67.2 percent) and animals (32.8 percent) in the driver's intended path of travel dominates the distribution for the evasive maneuver group.

- Shoulder - Most crashes occur in locations that have an adjacent shoulder for the driver inattention (5 1.1 percent), evasive maneuver (69.6 percent), lost directional control (65.5 percent), and vehicle speed (72.4 percent) groups. The no shoulder circumstance dominates distributions for the driver relinquished steering control (76.3 percent) and vehicle failure (66.2 percent) groups.

Table 5-48

- On-Road Driver Response - In four of the six groups the most frequent driver response involves no corrective action. These groups are the driver inattention (49.7 percent), driver relinquished steering control (85.3 percent), vehicle failure (66.2 percent), and vehicle speed (27.5 percent) groups. In the evasive maneuver and lost directional groups, deliberate steering actions (56.1 and 40.4 percent, respectively) are the most frequent response.

- On-Road Vehicle Response - Drift movements are the most frequent responses in three groups; driver inattention (49.7 percent), driver relinquished steering control (85.3 percent), and vehicle failure (64.2 percent). Tracking movements are the most frequent responses in the evasive maneuver (77.6 percent) and vehicle speed (41.8 percent) groups. Yaw movements dominate the distribution for the lost directional control (69.5 percent) group.

- Off-Road Driver Response - The most frequent off-road driver response is to initiate no corrective action in four of the causal factor groups; driver inattention (50.9 percent), driver relinquished steering control (80.9 percent), lost directional control (45.0 percent), and vehicle failure (66.2 percent). Deliberate steering actions dominate the distribution for evasive maneuver (47.8 percent) and braking actions dominate the distribution for vehicle speed (33.9 percent).

- Off-Road Vehicle Response - Yaw movements are the most frequent responses in four groups; driver inattention (39.1 percent), evasive maneuver (55.6 percent), lost directional control (61.6 percent), and vehicle speed (40.6 percent). Drift movements are the most frequent responses in two groups; driver relinquished steering control (65.9 percent) and vehicle failure (64.2 percent).

- Roadway Departure Crash Type - The frontal impact configuration is the most frequent impact type in five of the six groups; driver inattention (59.6 percent), driver relinquished steering control (77.2 percent), evasive maneuver (38.1 percent), vehicle failure (74.3 percent), and vehicle speed (58.8 percent). Rollovers are the second most frequent configuration in four of these groups; driver inattention (25.8 percent), evasive maneuver (24.3 percent), vehicle failure (23.7 percent), and vehicle speed (16.3 percent). Side impacts are the most frequent configuration in the lost directional control (42.7 percent) group.

Additional distinction between these groups may be obtained by incorporating the discussion generated for Table 5-46 in Section 5.4.2.

Table 5-47
Pm-existing Conditions Within Causal Factor Groups

Crash Characteristics	Causal Factor Groups					
	Driver Inattention	Driver Relinquished Steering Control	Evasive Maneuver	Lost Directional Control	Vehicle Failure	Vehicle Speed
Driver State						
Alert			84.5	99.2	100.0	59.5
Inattentive	100.0					
Drowsy		36.0				
HBD/DUI		58.9				40.3
Incapacitated						
Vehicle State						
Excess Speed						100.0
Tire Blowout						
Engine Stall					64.2	
Other Failure					25.7	
Normal	91.8	98.3	100.0	96.1		
Roadway Align.						
Curve		55.7			79.8	58.4
Straight	66.3		66.8	53.3		
Roadway State						
Dry	100.0	86.4	60.0		100.0	64.9
Wet				34.8		
Icy/snow				56.6		
Obstacles						
Vehicle			67.2			
Animal			32.8			
Pedestrian						
Object						
None	100.0	100.0		100.0	100.0	95.5
Shoulder						
Yes	51.1		69.6	65.5		72.4
No		76.3			66.2	

Table 5-48
Dynamic State Within Causal Factor Groups

Crash Characteristics	Causal Factor Groups					
	Driver Inattention	Relinquished Steering Control	Evasive Maneuver	Lost Directional Control	Vehicle Failure	Vehicle Speed
On-Road Dr. Response						
Accelerate						
Inadvert. steer	39.8					
Delib steer			56.1	40.4	17.6	26.8
Brake						
Steer+Brake			41.1			
None	49.7	85.3		33.5	66.2	27.5
On-Road Veh. Response						
Drift	49.7	85.3			64.2	
Tracking	39.8		77.6			41.8
Long Skid				28.1		
Yaw				69.5	23.7	29.9
Off-Road Dr. Response						
Accelerate						
Inadvert. Steer						
Delib. Steer	37.0	17.2	47.8		15.6	29.0
Brake				24.1		33.9
Steer+Brake			39.1			
None	50.9	80.9		45.0	66.2	
Off-Road Veh. Response						
Drift	38.6	65.9			64.2	
Tracking			35.0			37.4
Long. Skid				28.1		
Yaw	39.1	19.9	55.6	61.6	33.8	40.6
Roadway Departure Crash Type						
Frontal Impact	59.6	77.2	38.1	39.7	74.3	58.8
Side Impact		19.6		42.7		
Undercarriage						
Other Impact						
Rollover	25.8		24.3		23.7	16.3
No Impact						

5.4.4 Interpretation Of Engineering Analysis Results

Similar to the two preceding analyses (e.g., statistical and clinical), the engineering analysis sequence demonstrates that there are distinctive subgroups within the run-off-road crash population. The engineering analysis described in the preceding subsections crystallizes these subgroups on the basis of causal factor designation, defines characteristics of each causal factor group, and then compares the groups to isolate major differences.

A major fmding of this effort is that in a substantial proportion of run-off-road crashes, the subject driver does not initiate corrective action prior to the point of roadway departure. Countermeasure application in this circumstance has a potentially large positive benefit assuming that the specific countermeasure(s) either elicit appropriate driver responses or assume control of the vehicle to execute appropriate responses. Initiating corrective action on the roadway will be critical to successful application since the vehicle is relatively more controllable in this environment as compared to the off-road environment.

One of the more disconcerting findings of the analysis sequence is the relatively high proportion of yaw movements associated with off-road vehicle movement in virtually all of the causal factor groups. These movements are typically associated with driver steering corrections and could potentially have serious negative implications with respect to countermeasure design. Specifically, it would appear that the driver overreacts in these off-road traversals and as a result, creates a non-recoverable vehicle movement pattern. There are, however, other factors which must be considered before a complete evaluation can-be performed. These factors may be summarized as follows:

- This analysis only examines driver failures (e.g., circumstances which result in a crash). A complete evaluation of likely driver response patterns must include incidents where the driver is successful (e.g., drives off road and then successfully returns to the road). These near miss events are not available in the data tiles examined for this effort. Data of this type, however, should be included in human factors evaluations of likely response patterns to system warnings.

- It may be possible to improve driver performance by providing warnings at a point that is further removed from the rather intense corrections required during off-road terrain traversal. Specifically, it appears that driver performance is better in the on-road environment in terms of inducing fewer yaw actions. Therefore, one of the goals of the countermeasure design phase might be to issue warnings prior to roadway departure and if feasible, even further removed from this point.

This issue will be examined in greater depth in subsequent Phase I tasks. For example, in Task 3, driver simulator experiments will be conducted to determine if driver's accept and respond appropriately to systems providing early warning of impending roadway departure. In Task 4, the critical driver, vehicle, countermeasure, and environmental factors/characteristics will be modelled to evaluate the potential effectiveness of countermeasure concepts. The project staff does not believe that the problem will significantly impede countermeasure development or performance.

6.0 Comparison Of OMNI And Run-Off-Road Analysis Results

The OMNI IVHS program, sponsored by NHTSA and administered by VNTSC, preceded the current countermeasure specification programs. This program provided crash problem size estimates, causal factor assessments, and associated crash characteristics/circumstances for a number of crash types within the national crash population. The second crash type addressed, within the topical report sequence issued for the OMNI program, was the single vehicle roadway departure (run-off-road) crash. In the clinical analysis sequence conducted for that effort, a total of 100 NASS CDS hard copy case reports selected from the 1991 data file were examined to determine causal factors associated with this crash type.

Since the case reports used in the OMNI program were selected from the 1991 file and case reports used in the current effort were selected from the 1993 file, it would be informative to compare analysis results. This comparison will allow an evaluation of the consistency of causal factor determinations over time.

Figure 5-21 from Section 5.32 is reproduced as Figure 6-l. This figure provides the causal factor profile as determined in the clinical analysis sequence performed for this effort. The relative ranking of each causal factor assessment, in terms of frequency, has been superimposed on the figure. OMNI program results are also superimposed to show the causal factor distribution and the relative ranking of each assessment in that program. Major points with respect to comparing results of these two evaluation efforts may be summarized as follows:

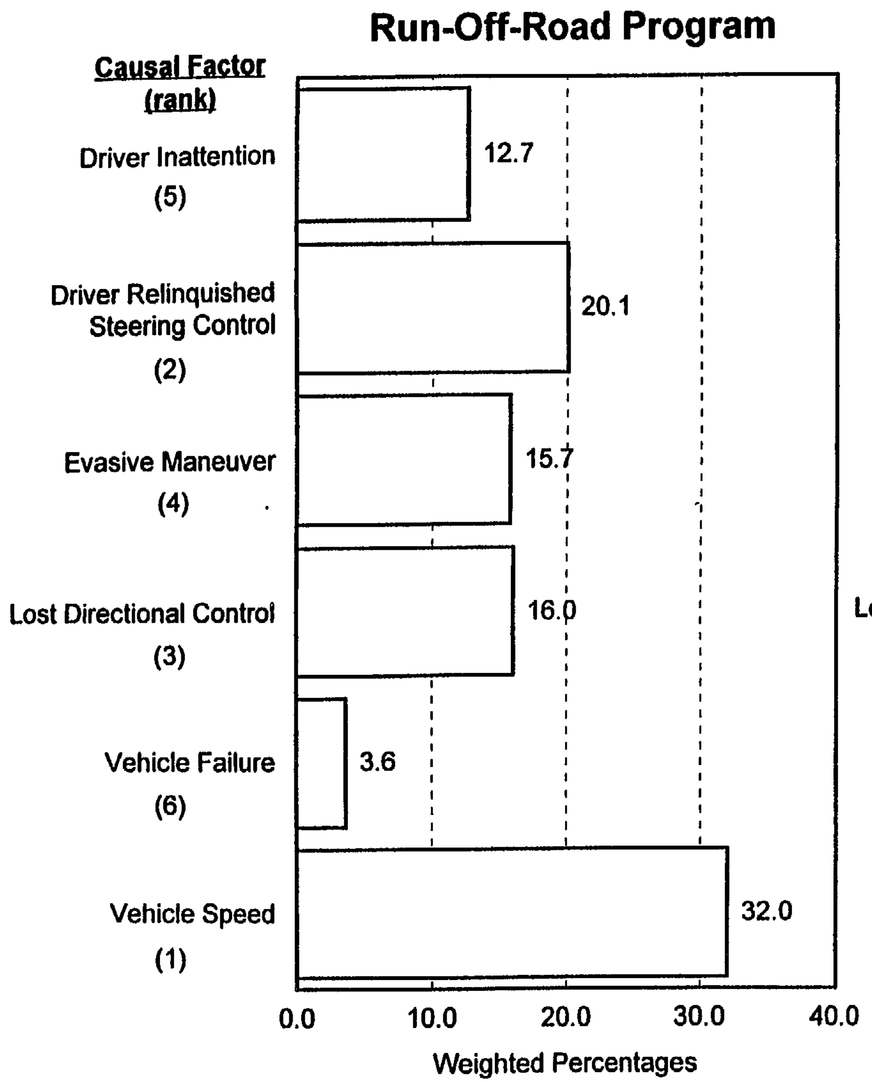
- The same six causal factor categories/groups are identified in both programs.

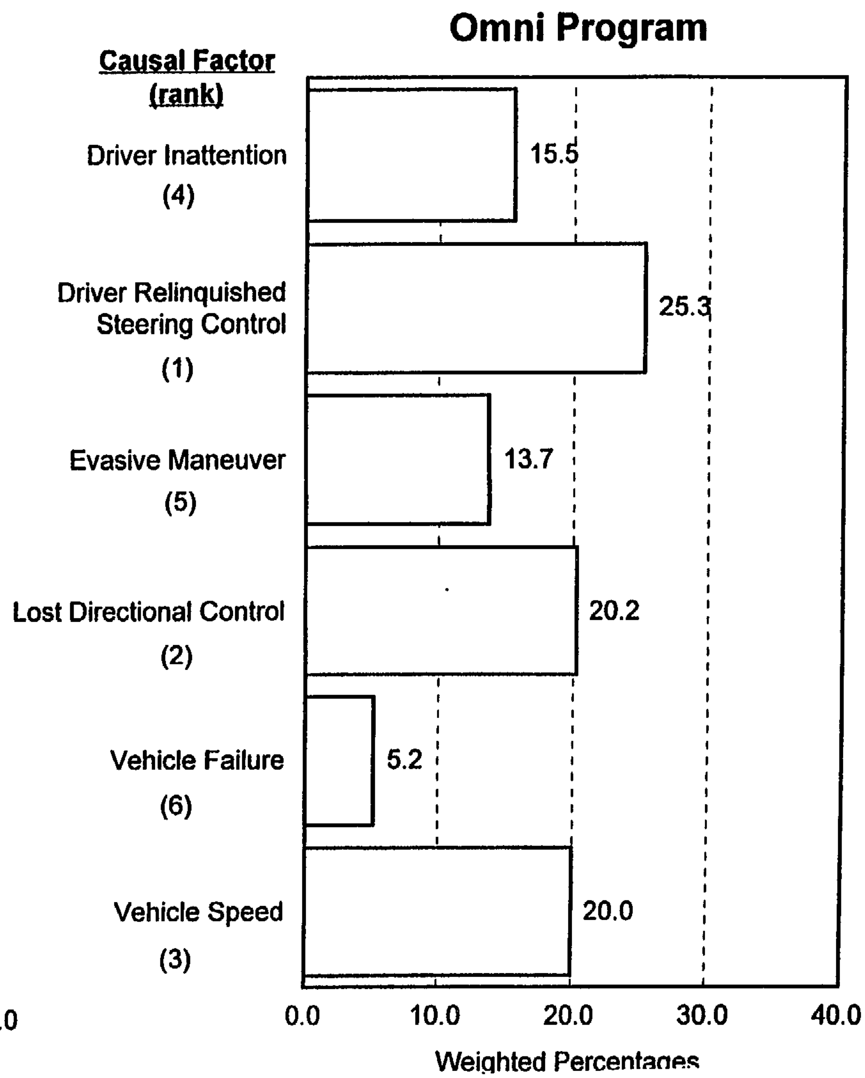
- For the first four causal factors in Figure 6-1, the relative ranking between these programs changes by a factor of one. Specifically, the driver inattention causal factor is ranked fifth in the current effort and fourth in the OMNI program. The driver relinquished steering control causal factor is ranked second in the run-off-road analysis and first in the OMNI program. Corresponding rankings for the evasive maneuver causal factor are fourth in the current effort and fifth in the OMNI program. Similarly, the lost directional control causal factor is ranked third in the current effort and second in the OMNI program.

- The vehicle failure causal factor is ranked sixth in both programs. This ranking is not surprisiig given the very small proportion crashes that are associated with vehicle failure.

- The most pronounced difference between the two programs is associated with the vehicle speed causal factor which is ranked first in the current effort and third in the OMNI program. The difference between the relative proportions of this factor in the two sample profiles is also substantial (e.g., 32.0 percent-run-off-road and 19.97 percent-OMNI program).

Causal Factors in Run-Off-Road Crashes





Since the same analysis procedures and staff were used in both programs, this shifting in rankings between the two efforts is suggestive of sample differences. A quick check of this possibility is provided in table 6-l which tabulates the proportions of crashes occurring on curved and straight segments within the two samples. Note that there are, in fact, substantial differences between the samples in each causal factor designation. We believe that these differences are associated with the more limited nature of the OMNI sample. The OMNI sample is considerably smaller than the run-off-road sample (100 versus 201) and the OMNI sample was selected from the case files available at NASS Zone Center # 1 as opposed to the run-off-road sample which included cases from both NASS Zone Centers.

Table 6-l
Causal Factor by Roadway Alignment
For Run-Off-Road and OMNI Samples

Causal Factor/Sample	Roadway Alignment	
	Curve (%)	Straight (%)
Driver Inattention/Run-Off-Road	33.7	66.3
/OMNI	58.6	41.4
Driver Relinquished Steering Control/Run-Off-Road	55.7	44.3
/OMNI	49.8	50.2
Evasive Maneuver/Run-Off-Road	33.2	66.8
/OMNI	47.7	52.3
Lost Directional Control/Run-Off-Road	46.7	53.5
/OMNI	69.0	31.0
Vehicle Failure/Run-Off-Road	79.8	20.2
/OMNI	57.6	42.4
Vehicle Speed/Run-Off-Road	58.4	41.6
/OMNI	79.4	20.6

Although the causal profiles differ between these samples and there are evident sample differences, the project staff is encouraged by the fact that the same six causal factors were identified in both samples and by the small proportional differences noted for five of the six causal factors. On this basis, we believe that causal factors do remain relatively stable over time.

Since the engineering analysis conducted for the current effort demonstrated a close association between causal factor designations and dynamic scenario characteristics, we also believe that the characteristics of the two samples are in reasonable agreement (i.e., within the order of magnitude noted for causal factor profile differences). It is, however, difficult to assess this belief since dynamic situations for the OMNI sample are not described in detail.

With respect to the statistical analyses conducted for the current effort and presented in Section 5.2, the intent was to supplement and expand upon the findings of OMNI program. Specifically, the current effort focused on examining the relationship between variables available in the GES database. For example, only one of the sixteen bivariate distributions presented in Section 5.2.3 of this report was addressed in the OMNI report and none of the four trivariate distributions presented in Section 5.24 of this report was addressed in the OMNI report.The project staff believes that these additional analyses provide greater insight to the circumstances surrounding run-off-road crashes and the relationships associated with these crashes. One example of this improved insight is the profile established for a subset of the more severe crashes which may be summarized as follows:

- The more severe run-off-road crashes tend to be curve related and the curve related crashes tend to occur in rural/suburban areas.

- These crashes tend to occur on dry surfaces.

- These crashes tend to occur in the evening hours (e.g., 4 PM to 4 AM).

- These crashes tend to be related to increased levels of alcohol consumption and to an increased incidence of speeding.

Other relevant findings associated with these analyses are presented in the discussion developed for Tables 5-l through 5-20. Again, these individual findings and the collective weight of the findings presented as a whole provide a more complete picture of the run-off-road crash problem

In a similar fashion, excluding causal factor analysis results, virtually none of the clinical analyses presented in Section 5.3 was addressed in the OMNI program. Collectively, these analyses verify that the clinical sample is reasonably representative of the national crash population. Specific findings are delineated in the discussions developed for Figures 5-10 through 5-21 and Tables 5-23 through 5-45. Again, these findings add to our understanding of the run-off-road crash problem.

7.0 Definition of Benefit Analysis Sample

A major goal of the Run-Off-Road Collision Avoidance program is development of a countermeasure that either eliminates these crashes or reduces the severity of these crashes. The specific crash types contained in the target crash population were delineated in Section 3.0. It is likely, however, that a countermeasure developed for application to the target crash population will also have success with respect to eliminating crashes which are dynamically similar to the target crash population. This section delineates dynamically siiar crash types and combines them with the target crash population to define the benefit analysis sample (i.e., those crashes that will benefit from countermeasure application). This latter sample will be used to estimate the overall potential effectiveness of countermeasure concepts.

The crash types defined/included in the benefit analysis will be used to develop crash scenarios in Tasks 3 and 4. A simulator will then be used in Task 3 to evaluate the potential effectiveness of existing prototype systems in these scenarios. Computer simulations will be developed in Task 4 to evaluate additional and existing countermeasure concepts in these same scenarios. (NOTE: The crash scenarios developed for Tasks 3 and 4 will focus on run-off-road crash types. However, since additional crash types identified for the benefit analysis sample will be dynamically similar, it should be feasible to use these same scenarios with minimal modification.)

7.1 Determination of Crash Types With Similar Dynamic Scenarios

Run-off-road crashes are characterized by subject vehicle movement. For example, virtually all of the single vehicle crashes considered to this point involve a lane departure movement. There are a number of vehicle-to-vehicle configurations which involve this same movement pattern. The fill range of characteristics of interest may be summarized as follows:

- Vehicle-to-vehicle path orientation - parallel, traveling in opposite directions (parallel paths in the same direction will be resolved in the lane change/merge program)
- Vehicle maneuver - unintended lane departure (drift, loss of control, etc.)
- Vehicle velocity range - 5 mph to 70 mph

The NASS CDS and GES accident type classification scheme was examined to identify additional crash types complying with the specification described above. This examination identified three additional accident types with dynamic situations similar to the target crash population. All three accident types reside in the “Same Trafficway Opposite Direction” category of the classification scheme as follows:

- Head-On, Lateral Move - Codes 50 and 51
- Forward Impact, Control/Traction Loss - Codes 54 through 57
- Sideswipe/Angle, Lateral Move - Codes 64 and 65

Of the three identified accident types, the Forward Impact, Control/Traction Loss type would be expected to involve the largest relative proportion of unintended lane departures. The Head-On, Lateral Move and Sideswipe/Angle Lateral Move types both contain a substantial number of crashes where the subject driver was initiating a passing maneuver. It is likely that intentional lane departures of this type will be culled from the benefit sample prior to evaluation of countermeasure concepts. Crashes, in these types, where the movement is associated with drifting actions or inadvertent steering inputs will be retained.

7.2 Specification of the Benefit Analysis Sample

The benefit analysis sample will be comprised of the target crash population identified in Table 3-3 and the three additional accident types identified in the preceding subsection. The sample composition is summarized in table 7-l.

Table 7-l
Benefit Analysis Sample

		Relation to Roadway	
Category	**Configuration/Type**	**Off Roadway**	**On Roadway**
Single Driver	Roadside Departure		
	Drive Off Road	374,000	
	Control/Traction Loss	398,000	
	Avoid Collision	79,000	
	Forward Impact		
	Parked Vehicle	308,000	
	End Departure	29,000	
	Stationary Object	2,000	
	Other		
	Unknown Specifics	16,000	
Same Trafficway Opposite Direction	Head-On		
	Lateral Move		55,000
	Forward Impact		
	Control/Traction Loss		0
	Sideswipe/Angle		
	Lateral Move		119,000
	Total	1,206,000	174,000

The benefit analysis sample will be comprised of 1,206,000 crashes occurring off the roadway and not more than 174,000 crashes occurring on the roadway. As indicated previously, it is likely that the on road portion of the sample will be further reduced in subsequent tasks to eliminate intentional lane departure movements.

8.0 Summary and Conclusions

The single vehicle run-off-road crash represents a significant highway safety problem. In this crash type, the subject driver either deliberately steers off the roadway as an evasive maneuver or allows the subject vehicle to depart from the roadway due to a variety of crash related events. The subject vehicle is subsequently involved in a broad range of impact configurations and/or non-collision rollover events.

The objective of the Run-Off-Road Collision Avoidance program is to develop practicable performance specifications for run-off-road crash avoidance systems. This program consists of a sequence of nine related tasks to be completed in three distinct program phases. The goal of Task 1 of this effort is to thoroughly analyze the crash problem and, thereby, establish a knowledge base for this crash type which can be utilized to successfully address subsequent tasks.

This report describes and documents the analysis sequence completed for Task 1. The sequence utilized three types of analysis types as follows:

- Statistical Analysis - Mass databases (GES and FARS) were examined to obtain an updated estimate of problem size and to establish characteristics of the national crash population.

- Clinical Analysis - A sample of NASS CDS hard copy case reports was evaluated to determine crash causation factors and to establish the circumstances in which these crashes occurred. This sample was selected to be representative of the national crash population. A comparison of the profile of crash characteristics established for the clinical database and a similar profile established for the statistical database, indicated that the NASS CDS sample was reasonably representative of the national crash population.

- Engineering Analysis - The NASS CDS hard copy case reports were examined to establish the dynamic scenarios associated with each crash contained in the clinical sample. These scenarios were represented as situation trees which delineated the specific combination of driver, vehicle, and environmental factors in each crash and driver/vehicle responses to critical events. Similar groups of situation trees were then compared to establish similarities/differences between groups. Analysts also completed a top-level evaluation of analytical parameters (velocity, steer input, and brake input) during the course of this effort.

Major findings of the analysis sequence are summarized in Section 8.1. Conclusions deriving from these results and the analysis effort are described in Section 8.2.

8.1 Summary of Technical Findings

Technical findings are presented for each of the analysis types conducted for this effort. Implications of these findings are discussed in the subsection that delineates conclusions.

8.1.1 Statistical Analysis

The 1992 NASS GES and 1992 FARS databases were utilized to complete the statistical analysis sequence. Major findings associated with this effort may be summarized as follows:

- The run-off-road target crash population totals approximately 1.2 million crashes. This crash population comprises approximately 20.0 percent of the GES file crashes and accounts for nearly 37.0 percent of the injured occupants in the GES file. The 14,03 1 fatalities sustained in run-off-road crashes account for more than 41.0 percent of the 33,846 in-vehicle fatalities that occurred in 1992 (FARS database). Thus, in terms of both injury frequency and injury severity, the run-off-road target crash population is overrepresented. The specific reasons for this overrepresentation are related to the nature of these crashes. Run-off-road target population crashes tend to occur on two lane roadways in rural and suburban environments. Speed limits and associated travel speeds in these environments are higher than corresponding values for urban environments. Similarly, these crashes tend to occur on dry road surfaces with no adverse weather conditions. Travel speeds in these conditions are again higher than corresponding values associated with adverse weather conditions.

- Most run-off-road crashes occur at locations where the horizontal roadway alignment is classified as straight. In terms of injury severity, however, the highest severity crashes tend to occur at locations where the horizontal roadway alignment is classified as curved.

- The time distributionassociated with these crashes is distinctive. The incidence rate for run-off-road cashes peaks in the 4 PM to 8 PM time frame, declines slightly in each of the next two time blocks (8 PM to 12 AM and 2 AM to 4 AM), bottoms out in the 4 AM to 8 AM time frame, and then begins rising again in the next two time blocks (8 AM to 12 PM and 12 PM to 4 PM) as the peak time frame is once again approached. As implied by this pattern and other analyses, more run-off-road crashes occur during periods of darkness than occur during daylight conditions. Of those crashes occurring during periods of darkness, more crashes occur in dark/unfit conditions than occur in dark/lighted conditions. This finding reflects the rural nature of these crashes.

- The number of right roadway departure crashes in the GES database exceeds the number of left roadway departure crashes by a substantial margin. This difference is related to the nature and events associated with the left roadway departure configuration. First, in departures to the left there is an associated risk of involvement with on-coming traffic. Thus, a number of these departures result in vehicIe-to-vehicle involvement and are classified as head-on or sideswipe crashes. Secondly, in departures to the left, there is greater distance and time in which the driver can initiate corrective action and avoid the impending departure (as compared to right roadside departures).

- Most drivers involved in run-off-road crashes do not initiate corrective action prior to the crash. As will be shown in the clinical and engineering analyses, a portion of this lack of action may be attributed to the driver's lack of awareness of the impending departure.

In a number of cases, however, it is likely that the driver does not initiate corrective action due to the lack of sufficient time (i.e., a number of these crashes are associated with very short time frames between the point of departure and the point of impact).

- The highest incidence rates for violations charged in these crashes are associated with vehicle speed violations, alcohol consumption, and combinations of these factors. There is a relationship between these violations and the time periods when run-off-road crashes occur. Specifically, the highest incidence rates for these crashes are during evening hours when alcohol consumption is most likely to occur. There is also a relationship between alcohol consumption and vehicle speed violations since many of these citations are issued jointly in the same crash.

8.1.2 Clinical Analysis

A sample of 201 NASS CDS hard copy case reports was analyzed to establish causal factors and crash circumstances/characteristics. Major findings associated with this effort may be summarized as follows:

- There is general agreement between the statistical and clinical crash characteristic profiles. Specifically, crashes in the clinical database also tend to occur on rural, dry, two lane roadways without adverse weather conditions. The proportion of crashes occurring on curved segments in the clinical database exceeds the corresponding proportion noted in the GES database. This finding is consistent with the more severe nature of CDS cases as compared to the GES profile (i.e., more severe crashes tend to occur on curved segments).

- The proportion of drivers initiating avoidance maneuvers in the clinical sample is significantly higher than the corresponding proportion noted in the GES database. We do not believe that any significance should be placed on these differences since the CDS variables were recoded by the project staff to correct errors noted in the initial case submissions and it is likely that the GES database contains similar error patterns.

- The causal factor profile established for the clinical sample is as follows:

+ Driver Inattention -	12.7 percent
+ Driver Relinquishes Steering Control -	20.1 percent
+ Evasive Maneuver -	15.7 percent
+ Lost Directional Control -	16.0 percent
+ Vehicle Failure -	3.6 percent
+ Vehicle Speed -	32.0 percent

- The causal factor profile established for this effort was compared to the profile established in the OMNI program. The same six causal factors were identified in both programs. There is, however, variability in the relative rankings between programs of these causal factors within the profiles established for each program. For the first four causal factors shown in the above distribution, the difference in relative rankings was one position (e.g., the driver inattention causal factor is the fifth most frequently occurring factor in the current program and the fourth most frequently occurring factor in the OMNI program). The vehicle failure causal factor is ranked sixth in both programs and the vehicle speed causal factor is ranked first in the current program and third in the OMNI program. We believe that this variability can be traced to the more limited nature of the OMNI program. The OMNI sample is significantly smaller and is limited to cases selected from NASS Zone Center #l.

- A number of interesting trends can be detected by comparing the causal factor profile, noted above and presented in Figure 5-21, with bivariate distribution results reported in Table 5-35 (Causal Factor by Horizontal Alignment) and Table 5-36 (Causal Factor by Surface Condition). For example, based on the distribution profile presented in Figure 5-21, the driver inattention causal factor is over-represented in the straight horizontal alignment category (Table 5-35) and overrepresented again in the dry surface condition category (Table 5-36). Thus, there is a tendency for this causal factor to be associated with straight, dry road segments. Similarly, the driver relinquished steering control causal factor is overrepresented in the curved horizontal alignment category (Table 5-35) and overrepresented again in the dry surface condition category (Table 5-36). Thus, there is a tendency for this causal factor to be associated with curved, dry road segments. Trends of this type were further explored in the engineering analysis effort conducted for this program.

8.1.3 Engineering Analysis

The NASS CDS hard copy case reports were further evaluated to identify dynamic scenarios associated with each case. These scenarios were represented as situation trees which were coded on data entry/reduction formats developed for this effort. Situation trees demonstrating similar responses in the individual branches comprising each tree were subsequently grouped and analyzed to determine trends within each group and similarities/differences between groups. Major findings associated with the analysis may be summarized as follows:

- The highest levels of coherence within groups and the most interesting differences between groups were found when the situation trees were aggregated by causal factor.

- Specific patterns noted for key branches of the situation trees are as follows:

    + Driver State - In three of the causal factor groups, the predominant driver state is alert. These groups are evasive maneuver (84.5 percent), lost directional control (99.2 percent), and vehicle failure (100.0 percent). The predominant state for the driver inattention group is inattention (100.0 percent). In the driver relinquished steering control group, there are two primary states (HBD/DUI-58.9 percent and Drowsy-36.0 percent). The vehicle speed group also has two primary states (Alert-59.5 percent and HBD/DUI-40.3 percent).

    + Roadway Alignment - The causal factor groups are evenly split between straight and curved segments. Curved segment locations dominate the distributions for the driver relinquished steering control (55.7 percent), vehicle failure (79.8 percent), and vehicle speed (58.4 percent) groups. Straight segment locations dominate the distributions for the driver inattention (66.3 percent), evasive maneuver (66.8 percent), and lost directional control (53.3 percent) groups.

+ Roadway State - The dry surface condition is the most prevalent condition in five of the causal factor groups. Icy/snow conditions (56.6 percent) and wet surfaces (34.8 percent) dominate the distribution for lost directional control group.

+ On-Road Driver Response - In four of the six groups the most frequent driver response involves no corrective action. These groups are the driver inattention (49.7 percent), driver relinquished steering control (85.3 percent), vehicle failure (66.2 percent), and vehicle speed (27.5 percent) groups. In the evasive maneuver and lost directional groups, deliberate steering actions (56.1 percent and 40.4 percent, respectively) are the most frequent response.

+ On-Road Vehicle Response - Drift movements are the most frequent responses in three groups; driver inattention (49.7 percent), driver relinquished steering control (85.3 percent), and vehicle failure (64.2 percent). Tracking movements are the most frequent responses in the evasive maneuver (77.6 percent) and vehicle speed (41.8 percent) groups. Yaw movements dominate the distribution for the lost directional control (69.5 percent) group.

+ Off-Road Driver Response - The most frequent off-road driver response is to initiate no corrective action in four of the causal factor groups; driver inattention (50.9 percent), driver relinquished steering control (80.9 percent), lost directional control (45.0 percent), and vehicle failure (66.2 percent). Deliberate steering actions dominate the distribution for evasive maneuver (47.8 percent) and braking actions dominate the distribution for vehicle speed (33.9 percent).

+ Off-Road Vehicle Response - Yaw movements are the most frequent responses in four groups; driver inattention (39.1 percent), evasive maneuver (55.6 percent), lost directional control (61.6 percent), and vehicle speed (40.6 percent). Drift movements are the most frequent responses in two groups; driver relinquished steering control (65.9 percent) and vehicle failure (64.2 percent).

- As indicted in the patterns described above, in a large proportion of these cases, drivers do not initiate corrective actions while on the roadway. A somewhat larger proportion respond off the road, between the point of departure and the impact location.

- The most frequent driver corrective actions involve steering inputs. Many of these inputs may be characterized as overcorrections which result in the loss of vehicle control as evidenced by the relatively high rates reported for off-road yaw movements.

8.2 Conclusions

Major conclusions derived from this effort may be summarized as follows:

- There are substantial differences between groups of situation trees when the groups are aggregated on the basis of causal factor designation. These differences will be used to identify appropriate intervention opportunities and mechanisms. These opportunities will be further evaluated and developed in Task 2.

- A wide range of dynamic situations and causal factors has been identified. The breadth of these factors suggests that no single countermeasure will be effective with respect to preventing, and/or reducing the severity of, the target crash population.

- Roadway conditions are relatively benign from the perspective of sensor based countermeasures (i.e., dry, rural, minimal levels of adverse weather conditions). The technology evaluation tests scheduled in Task 3 will assess the performance of promising sensors and algorithms in these and other common conditions.

- Analysis findings indicate that a substantial proportion of subject drivers do not initiate corrective actions while on the roadway. If countermeasures could elicit appropriate driver responses, or automatically initiate action, the benefit in terms of reduced frequency and severity of crashes, would be substantial. Human factors experiments scheduled for Task 3 will further explore the issue of driver responses.

- Since drivers tend to overcorrect and induce yaw movements in the off-road environment, active braking by the countermeasure prior to roadway departure may be a viable alternative. This concept would provide the driver a longer interval in which to react while on the roadway, possibly resulting in a more controlled vehicle trajectory and a reduced tendency to overcorrect on the part of the driver. This concept will be further evaluated in Tasks 3 and 4.

- The tendency of drivers to oversteer in corrective maneuvers suggests there could be a negative interaction between the steering input from the driver and from an active countermeasure. In particular, it is possible that steering inputs provided by the driver and an active countermeasure will be additive, resulting in severe oversteering and the attendant consequences. This possibility will be examined in the Task 3 effort.

- Driver impairment/incapacitation are significant contributing factors in vehicle speed and driver relinquished steering control crashes. These factors have negative design implications since the driver will be less likely to respond appropriately to system warnings than an unimpaired driver. Therefore, active control intervention may be required to prevent crashes involving these factors.

- Evaluations completed during this analysis sequence indicate that the time available to initiate avoidance actions may be a major design consideration. This issue will be examined in a more detailed manner in Task 2 as part of the timeline analysis effort. The timeline analysis will establish the range of times available. Human factors evaluations scheduled for Task 3 and mathematical modelling conducted in Task 4 will address the issue of whether these time frames are sufficient to achieve successful crash avoidance.