Identification of Driver Errors: Overview and Recommendations

FHWA-RD-02-003

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Foreword

In the United States, more than 41,000 people are killed in motor vehicle crashes. Furthermore, there are an estimated 6 million police reported motor vehicle traffic crashes, in which 3 million people are injured. Though estimates of the contribution of driver error to crashes vary, it is generally agreed that close to 90 percent of all crashes involve driver error as a contributing factor, and driver error is considered the primary causal factor in close to half of all crashes. Clearly, countermeasures that would reduce the probability of driver errors would contribute greatly to our efforts to reduce the number of motor vehicle crashes and fatalities.

The research project that produced this report was intended to contribute to the reduction in driver errors by identifying methods of categorizing errors, identifying causal factors within categories, recommending methods of improving crash databases, and empirically identifying infrastructure related causes of driver errors at high crash locations. The report should be of interest to agencies responsible for reporting on crashes, individuals responsible for maintaining crash databases, and to engineers responsible for design and safety evaluation of roadways.

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Research and Development

NOTICE

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16. Abstract

Driver error is cited as a contributing factor in most automobile crashes, and although estimates vary by source, driver error is cited as the principal cause of from 45 to 75 percent of crashes. However, the specific errors that lead to crashes, and the nature of driver error contributions to crash circumstances often cannot be specified. Rather, driver error has been used as a catchall category when machine failures have been ruled out. This report describes an effort to gather more specific information about the driver errors that lead to crashes, the relative influences that various driver errors have in causing crashes, and the degree to which current infrastructure features may contribute driver errors.

This project's objectives were to: (1) develop driver error taxonomies, (2) identify the causes of errors within taxonomic categories, (3) gather data to further develop these taxonomies, and (4) provide recommendations for improvements to traffic control devices, roadway delineations, and accident reporting forms. This report summarizes the tasks that were conducted in support of these project objectives. One highlight of the project was a site surveillance effort in which video cameras recorded over 1,200 traffic events caused by driver error. Analysis of these events included the development of infrastructure-based countermeasures to reduce the number of incidents caused by driver error.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

EXECUTIVE SUMMARY

PROJECT OVERVIEW

Depending on the source, driver error is cited as the cause of 45 to 75 percent of roadway crashes and as a contributing factor in the majority of crashes (Hankey, et al, 1999). However, which driver errors lead to a crash, and the degree to which these errors contribute to the crash, often cannot be specified. Instead, driver error is used as a general catchall category that is invoked when environmental and mechanical causes are no longer considered.

The objectives of the *Identification and Evaluation of Driver Errors* project included:

1. Development of driver error taxonomies.
2. Determination of the causes of the identified errors.
3. Collection of data to support the use of these taxonomies in the study of incidents and accidents.
4. Development of recommendations for improvements in traffic control devices, roadway delineations, and accident reporting forms based on the study findings.

The remainder of this executive summary highlights the work that was conducted and the major project results.

LITERATURE REVIEW AND PRELIMINARY DATABASE EXAMINATION

The first project task was to gather and review relevant information. Three areas were reviewed. The first area reviewed was standards documents that are typically used by roadway and traffic engineers: the *Manual on Uniform Traffic Control Devices* (MUTCD: U.S. Department of Transportation 1988) and *A Policy on Geometric Design of Highways and Streets* [American Association of State and Highway Transportation Officials (AASHTO), 1994]. (The 2000 version of the MUTCD was not yet available.) This review showed traffic engineers that use relatively straightforward design principles to integrate driver performance and driver-vehicle system performance into the design of roadway delineation and traffic control devices. The principles are intended to ensure that drivers have the information they need to in time to take the correct action: Violation of these principles increases crash risk. The review suggested that one countermeasure to crashes is to comply with the design principles, and that driver errors are often caused by failures to follow the principles.

The second area of reviewed was how error has been defined and characterized in previous research and how researchers have used taxonomies to classify errors. This review was to: (1) provide insight into driver error from experts in the field, (2) evaluate driver error classification methods used in the past, and (3) investigate how human error is classified outside of the driving domain and how they are related to causal or contributing factors. Three primary conclusions were drawn from this literature review: (1) complex diagrams of cognitively developed modeling are of limited value; (2) the underlying causes of a crash may be complex and involve multiple contributing factors or interactions between factors; (3) several models of human/driver error classification could be merged to form a suitable taxonomy to facilitate the current project.

The third area was an examination of several accident databases, with emphasis on driver error extraction and categorization, to support later project phases.

DRIVER ERROR TAXONOMY DEVELOPMENT

Tasks that supported development of driver error taxonomies were: (1) analyses of national and State accident databases, (2) conduct of focus groups with investigating officers, and (3) interviews with drivers about critical incidents in which they were involved.

The Fatality Analysis and Reporting System (FARS), the Highway Safety Information System (HSIS), the State Data Program (SDP), and the North Carolina Narrative Accident Database were analyzed. Searches of narrative fields in the North Carolina database proved to be more enlightening as to the causes of crashes, i.e., why crashes happened, whereas the non-narrative fields in the other databases were primarily useful for determining what happened, but not why.

A number of taxonomies were developed. For example, taxonomies were developed that detailed characteristics of the roadway (e.g., infrastructure elements) and the characteristics of the driver (e.g., driver age). A taxonomy format that was useful in detailing why the crash occurred was the tree diagram. An example of a tree diagram taxonomy is shown in figure 9B in the main body of this report. Each successive branch of a tree provides more detailed information than the previous branch.

Five investigating officer focus groups were conducted. Police departments from Blacksburg, Roanoke, and Arlington (Virginia) represented small, medium, and large municipalities, respectively. Two divisions of the Virginia State Police were also included. The officers indicated which driver errors they believe are most frequent, what they thought were the underlying causes of the errors, and what infrastructure changes might reduce the frequency of those errors.

Fifty-four drivers from three age groups and from three driving environments (rural/small town, medium-sized city, and large city/metropolitan area) were interviewed about crashes and "close-calls" they had experienced. The drivers provided candid responses that resulted in a multitude of crash contributing factors. These factors were organized into a collision taxonomy and a close-call taxonomy that emphasized the multi-contributing factor nature of crashes. A model of contributing factors that affect driving performance was developed. That model reflects the multiple contributing factors and factor interactions that characterize most crashes.

CRITICAL INCIDENT INVESTIGATION

A critical incident is a traffic event in which a conflict occurs between two or more vehicles or between a vehicle and a pedestrian. A conflict requires at least one of the participants involved take evasive action to avoid a collision. Site surveillance was carried out at 31 roadway sites. The sites represented a variety of geometric features, and traffic control devices. Over 200 hours of video recordings were made. Data were collected at the peak traffic periods. Trained video analysts reviewed the recordings. Over 1,200 critical incidents were captured and analyzed. Each critical incident was characterized with regard to: site geometry, traffic count, location, and time of day.

Four analyses were conducted on the critical incident data: (1) generalized infrastructure analysis, (1) specific site analysis, (3) time-of-day/day-of-week analysis, and (4) most serious incident evaluation.

The generalized infrastructure analysis resulted in "Event Occurrence Taxonomies." These taxonomies were hierarchically structured. The highest taxonomy level was the the roadway geometry of the roadway site. The second level described the event (e.g., right turn). The third level described the interaction that occurred between the vehicles, or the vehicle and the pedestrian. The fourth level defined the precipitating element that affected the path of the primary vehicle. Probability models that might be incorporated into traffic simulation models were also developed.

The specific site analysis produced a list of incident clusters. This analysis was conducted only two sites: one of moderate complexity, and one of high complexity. The specific site analysis proved useful for identifying contributing factors, identifying clusters of incidents with common causal factors, and exploring countermeasures to mitigate the identified causal factors.

The time-of-day/day-of-week analysis indicated that: (1) the presence of traffic control officers has a dramatic effect on reducing the number of critical incidents, (2) critical incidents were more prevalent at the town site, (3) and critical incidents were more prevalent earlier in the week, and higher severity incidents occurred more frequently later in the day.

The most serious incident evaluation revealed that there is a similarity between critical incidents and the crash taxonomies developed earlier in the study. "Willful inappropriate behavior" was the principal contributor in 57 percent of all the critical incidents. "Inadequate knowledge" and "infrastructure" were principal contributing factors in 23 and 20 percent of the incidents, respectively.

Three primary products were delivered: (1) the probability models that predict the likelihood of a critical incident, given a certain set of characteristics; (2) a recommended methodology for analyzing sites for high frequency or severity of critical incidents; (3) and validated taxonomies that categorize critical incidents into a structured, hierarchical format.

DEVELOPMENT OF INFRASTRUCTURE-RELATED COUNTERMEASURES

To further characterize the infrastructure contribution, this analysis focused on those critical incidents for which infrastructure was a contributing factor.

Forty-three instances of infrastructure contributions were identified and described. The descriptions included diagrams that accurately and concisely the relation between the incident and the infrastructure. Candidate countermeasures were developed for each of the forty-three instances. These countermeasures provide the logical concepts for solving the problems. Many of the solutions were to modify the sites to conform to standard engineering practice, whereas others involved introduction of novel traffic control devices. Alternatives to the recommended countermeasures were also suggested. The cost of each recommendation was approximated.

The forty-three critical incidents were characterized by eight commonly recurring factors: (1) visibility blockage caused by large vehicles; (2) pedestrian right-of-way violations; (3) left turns at signalized intersections; (4) right of way confusion at two-way stop-controlled intersections; (5) entrance and exit lane inadequacies; (6) driveways near or in an intersections; (7) intersections in close proximity to one another; and (8) time-of-day dependent lane control.

Each commonly recurring factor is described, the probable cause of the driver errors is identified, potential countermeasures are proposed, and additional research recommendations are made.

DEVELOPMENT OF RECOMMENDATIONS

Three specific sets of recommendations are proposed: (1) guidelines for coding of crash data, (2) guidelines for including critical incident risk in traffic simulation models, and (3) revisions to highway design guidelines.

To improve the utility of crash databases for the analysis of the causes of driver errors it is recommended that: (1) a national uniform coding scheme be developed that meets the needs of all stakeholders be developed; (2) human factors principles be applied to the design of paper based and computerized reporting forms; (3) a section listing principal contributing factors and driving performance be included on police accident reporting forms; (4) that re-transcription of police reports be eliminated; (5) that in the development of reporting forms, police officers be included in the requirements analysis, test, and evaluation; and (6) safety evaluations of roadways include interviews with the police responsible for those roadways.

The probability models developed in this project are for critical incidents, not crashes. A linear relationship between critical incident probability and crash probability was assumed.

Because most of the critical incidents that were observed were related to deviations from current FHWA approved guidelines, it was concluded additional emphasis on the consequences of deviating from design guidelines be added and eight guideline statements were proposed.

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CHAPTER I. INTRODUCTION

DEFINITIONS OF DRIVER ERROR

The fundamental concept investigated in this project is "driver error." A search of the literature reveals that "error" (in general), driver error, and other factors contributing to vehicle crashes have been explored and defined in a number of different studies (e.g., Rasmussen, 1980; Reason, 1990; Treat, 1980; Wierwille and Tijerina, 1996). This brief review of driver error will begin with an overview of the general notion of human error. For a more detailed review of human error and driver error, the reader is directed to the Task C report from this project (Hankey et al., 1999).

Perhaps the most thorough exploration and discussion of "error" was conducted by Reason (1990). For the current effort, definitions from Reason were used as a baseline for defining errors, slips, lapses, and mistakes. Reason generically defines errors as "…all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency" (p. 9). For the purpose of this project, an error has been loosely defined through Reason's definition as the failure to achieve a sequence of mental or physical activities through a thought-out plan-of-action. For example, within the driving environment, an error is committed when a driver does not successfully stop for a red traffic light because he or she depresses the accelerator instead of the brake pedal.

Under the umbrella of errors, Reason (1990) also defines and differentiates slips, lapses, and mistakes. Slips and lapses are "errors which result from some failure in the execution and/or storage stage of an action sequence…" regardless of how well planned an action is. However, the difference between a slip and a lapse is that a slip is "potentially observable as externalized actions-not-as-planned," while a lapse is "a more covert error, largely involving failures of memory…" that are not necessarily externalized and often are "only apparent to the person who experiences them" (p. 9). Mistakes, however, are defined as "deficiencies or failures in the judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan" (p. 9). Slips and mistakes, as defined by Reason, would be the two primary factors involved in errors committed by drivers because they concentrate on exhibited behaviors.

Although it is good to have a baseline to differentiate and categorize general errors, driver errors can be classified into more than two categories. This was done by researchers involved in the *Tri-level Study of the Causes of Traffic Accidents* (Indiana University Institute for Research in Public Safety, 1977). Table 1 illustrates the classification hierarchy used in the Indiana Tri-level Study (1977).

Table 1. Overview of driver error and incident causation factors.

I. Human Conditions and States		
A) Physical/Physiological	**B) Mental/Emotional**	**C) Experience/Exposure**
• Alcohol impairment • Other drug impairment • Reduced vision • Critical non-performance	• Emotionally upset • Pressure or strain • In hurry	• Driver inexperience • Vehicle unfamiliarity • Road over-familiarity • Road/area unfamiliarity
II. Human Direct Causes		
A) Recognition Errors	**B) Decision Errors**	**C) Performance Errors**
• Failure to observe • Inattention • Internal distraction • External distraction • Improper lookout • Delay in recognition for other or unknown reasons	• Misjudgment • False assumption • Improper maneuver • Improper driving technique or practice • Inadequately defensive driving technique • Excessive speed • Tailgating • Excessive acceleration • Pedestrian ran into traffic	• Panic or freezing • Inadequate directional control
III. Environmental Factors		
A) Highway-Related	**B) Ambient Condition**	
• Control hindrance • Inadequate signs and signals • View obstructions • Design problems • Maintenance problems	• Slick roads • Special/transient hazards • Ambient vision limitations • Rapid weather change	
IV. Vehicular Factors		
• Tire and wheel problems • Brake problems • Engine system failures	• Vision obscured • Vehicle lighting problems • Total steering failure	

Errors and factors were categorized under four primary groups: (I) Human Conditions and States, (II) Human Direct Causes, (III) Environmental Factors, and (IV) Vehicular Factors. It must be noted that as a result of Reason's definitions of slips, lapses, and mistakes, one sub-category from the original Tri-Level Study classification hierarchy (Critical non-performance) was moved from Human Direct Causes to Human Conditions and States.

As defined by the Indiana Tri-Level Study (1977), human conditions and states are factors "which adversely affect the ability of the driver to perform the information processing functions necessary for safe performance of the driving task" (p. 212). Included under this heading are:

- Physical/physiological conditions such as alcohol impairment, other drug impairment, reduced vision, and critical non-performance (e.g., a form of unconsciousness);
- Mental/emotional conditions such as being emotionally upset, feeling pressure or strain caused by another driver or traffic conditions, or being in a hurry; and
- Experience/exposure conditions such as driver experience, not being familiar with the vehicle, being over-familiar with the road or path, or being unfamiliar with the road, path, or area.

Human direct causes, as defined by the Indiana Tri-Level Study (1977), are "human acts and failures to act in the minutes immediately preceding an *incident,* which increase the risk of collision beyond that which would have existed for a conscious driver driving at a high but reasonable standard of good defensive driving practice" (p. 201). Included under this heading are:

- Recognition errors such as driver inattention, an internal distraction, an external distraction, performing an improper or inadequate lookout or visual search, and other delays in perception, comprehension, or reaction due to unknown reasons;
- Decision errors such as a misjudgment, a false assumption, an improper maneuver (which is primarily used here as a willful violation), an improper driving technique or practice, an inadequate defensive driving technique, excessive speed, tailgating or following too closely, excessive acceleration, a pedestrian running into traffic in an area not designated for pedestrian traffic, and an improper evasive action used to avoid a collision; and

- Performance errors such as over-compensation during a driving maneuver, the driver panicking or freezing, and inadequate directional control.

The Indiana Tri-Level Study (1977) defines environmental factors as "those factors external to the driver or vehicle which increase the risk of accident involvement unnecessarily or to an excessive extent" (p. 230). Included under this heading are:

- Highway-related factors such as inadequate signs or signals, stationary view obstructions, roadway design problems, and roadway maintenance problems; and,
- Ambient-condition factors such as temporarily slick roads, a special or transient hazard, vision limitations because of temporary ambient conditions, avoidance obstructions, and a rapid change in weather conditions.

Vehicular factors, as defined by the Indiana Tri-Level Study (1977), are "all vehicle-related deficiencies which result in an accident, or increase the severity of vehicle impact which results" (p. 224). Included under this heading are: tire and wheel problems, vision obscured, brake problems, vehicle lighting problems, engine system failures, and total steering failure. Note that the Indiana Study separated vehicular factors in much greater detail, but this level of detail was not required for the present research.

Although the Indiana Tri-Level Study (1977) was used in the formation of the taxonomies developed in the current effort, a data-driven approach was the primary factor that was used to develop the driver error taxonomies. That is, categories and hierarchies in the taxonomies were defined based on the data that were collected. These taxonomies are presented later in this final report.

PREVALENCE OF DRIVER ERROR AS A CAUSE OR FACTOR IN CRASHES

The previous section should have provided the reader with a basic understanding of the concept of "error," in general, and "driver error," in particular. Building upon this understanding, it is now worthwhile to consider the role that driver error has in vehicle crashes. The prevalence of driver error as a cause or factor in crashes will be examined in two parts. First, consideration will be given to the driving process, and statistics abstracted from the literature will be presented.

Second, the results from a focus group effort conducted for this project, which was directed at understanding the impact of driver error, will be highlighted.

Analysis of the Driving Process and Relevant Driver Error Statistics From the Literature

The driving environment consists of three key elements: (1) human drivers, (2) vehicles, and (3) the roadway and roadside environment. Vehicle response is a function of the roadway and roadside geometry, vehicle attributes, and driver action. In turn, driver action is a result of a complex perception-reaction process in which the driver obtains information through a number of sensory inputs. This information is processed in order to decide upon a course of action, and the driver then initiates a physical response. The perception-reaction process is influenced by many factors, which have been loosely grouped under the heading *Driver Personality* in figure 1. As illustrated in figure 1, the characteristics of the driver, vehicle, and roadway combine to determine the operating characteristics of the roadway system as a whole.

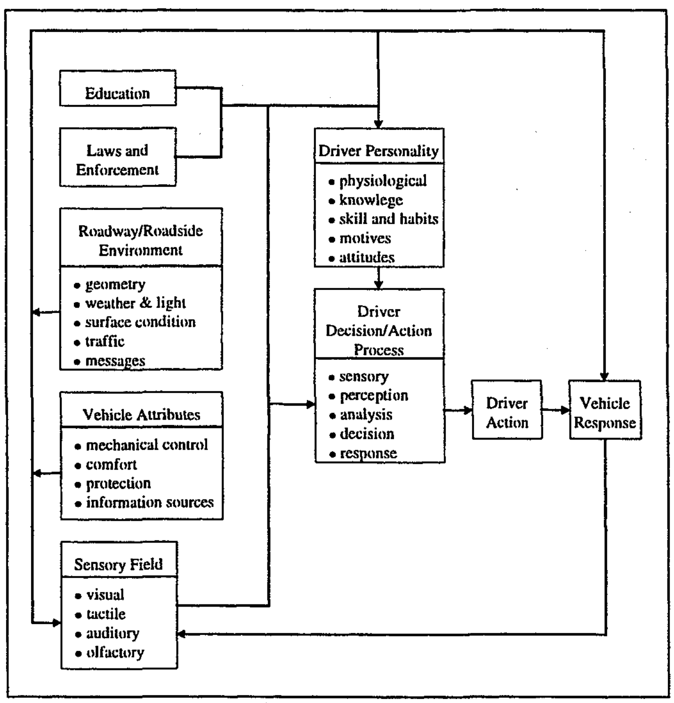


Figure 1.

A primary goal of the transportation system is to provide safe and efficient travel. As a result, elements of the system are designed (e.g. roadways and vehicles) and/or regulated (e.g. driver behavior through enforcement of laws) to reduce the likelihood of traffic accidents. Despite these efforts to reduce accident likelihood, in recent years there have been 40,000 to 55,000 traffic-related fatalities per year in the United States. In order to reduce the number of traffic accidents and fatalities, the elements of the road transportation system that are the largest causal factors in these accidents must be identified.

Although much variation exists, and depending on the source, it is generally agreed that "driver error" is the primary cause of the majority of traffic accidents. The relative distribution of causal factors from a study conducted by Sabey (1980), presented in table 2, indicates that human error (or, at least, human behavior) is a causal factor, though not necessarily the only causal factor, in greater than 95 percent of all accidents. Unfortunately, though we know that driver error is prevalent in crashes, little is known about the specific driver errors that lead to crashes, the relative influences that various driver errors have in causing crashes, and the degree to which current design standards and practices influence these driver errors.

Table 2. Prime causes of road accidents (Source: Sabey, 1980).

Cause	**Fraction of Accidents (%)**
Human factors alone	65
Human + road	25
Human + vehicle	5
Road factors alone	2
Vehicle factors alone	2
Human + road + vehicle	1
Total	**100**

PREVIOUSLY USED TAXONOMIES

Before outlining some of the previously used taxonomies that have been used to classify vehicle crashes, it is worthwhile to consider general human error taxonomies to determine if any such taxonomies shed light on the driver error problem. Presented below are selected sections from the extensive discussion of error taxonomies found in the Task A report for this project (see Wierwille, Hanowski, Hellinga, Early, Kieliszewski, and Dingus, 1998).

Human Error Models and Taxonomies

There are two basic methodologies to define and evaluate errors made by humans: (1) information-processing and (2) human reliability analysis. This section explores human error from an information-processing point of view; for information on error evaluations using human reliability analysis, refer to the Task A report (Wierwille et al., 1998).

Information-processing involves the intrinsic limitation of human abilities to attend to, perceive, remember, decide upon, and act upon a goal (Sheridan, 1981, as cited in Wickens, 1992). Error is an action that renders an undesirable consequence in the achievement of a goal and is influenced by factors such as the nature of the task being performed, environmental circumstances, influence of a mechanism upon performance, and the nature of the individual (Reason, 1990). The error type relates to the origin of an error. Cognitive stages in which an error can originate are planning, storage, or execution. Planning refers to the development of a goal. Storage, for goal execution, is the time duration between formulating a goal and acting upon achieving it. Execution is the actual implementation of the plan.

Within the information-processing domain, error definition and classification concentrates on the human cognitive aspect that failed (i.e., perception, memory, decision-making; Wiegmann and Shappell, 1997). Since the 1970s, a number of models to aid in defining errors have been developed. General models of human error include Rasmussen's (1986) Generic Error-Modeling System (GEMS), Rouse and Rouse's (1983) Conceptual Classification Scheme, and Reason's (1990) Classification of Unsafe Acts.

Rasmussen (1986) developed an iterative process for the analysis of error causes, and the development of models and classification schemes, within the nuclear power domain. The classification scheme was primarily directed at individuals in supervisory control roles. The skill-, rule-, knowledge-based model has three levels of human performance that reflect the limitation of, and the interference among, processes in human problem-solving. The model is considered to be a hierarchically organized set of cognitive control modes in which a person moves from one mode to the next to achieve a goal.

Skill-based performance is applicable to highly practiced tasks and is determined by stored patterns of information within a time-space domain. Errors at this level are linked to the variability of force, space, or time coordination (Reason, 1990).

Rule-based performance is applicable to solving familiar problems. The solutions are governed by stored rules of the type: IF (state) THEN (diagnosis), or IF (state) THEN (remedial action). Errors at this level are linked with the misclassification of situations that result in application of the wrong rule or the incorrect recall of procedures (Reason, 1990).

Knowledge-based performance is applicable to unfamiliar problems or situations for which actions must be planned using conscious analytic processes and stored knowledge, as opposed to the use of stored rules. Errors at this level are linked to human resource limitations and incomplete or incorrect knowledge (Reason, 1990). Figure 2 illustrates Rasmussen's GEMS and lists typical errors associated with each performance behavior.

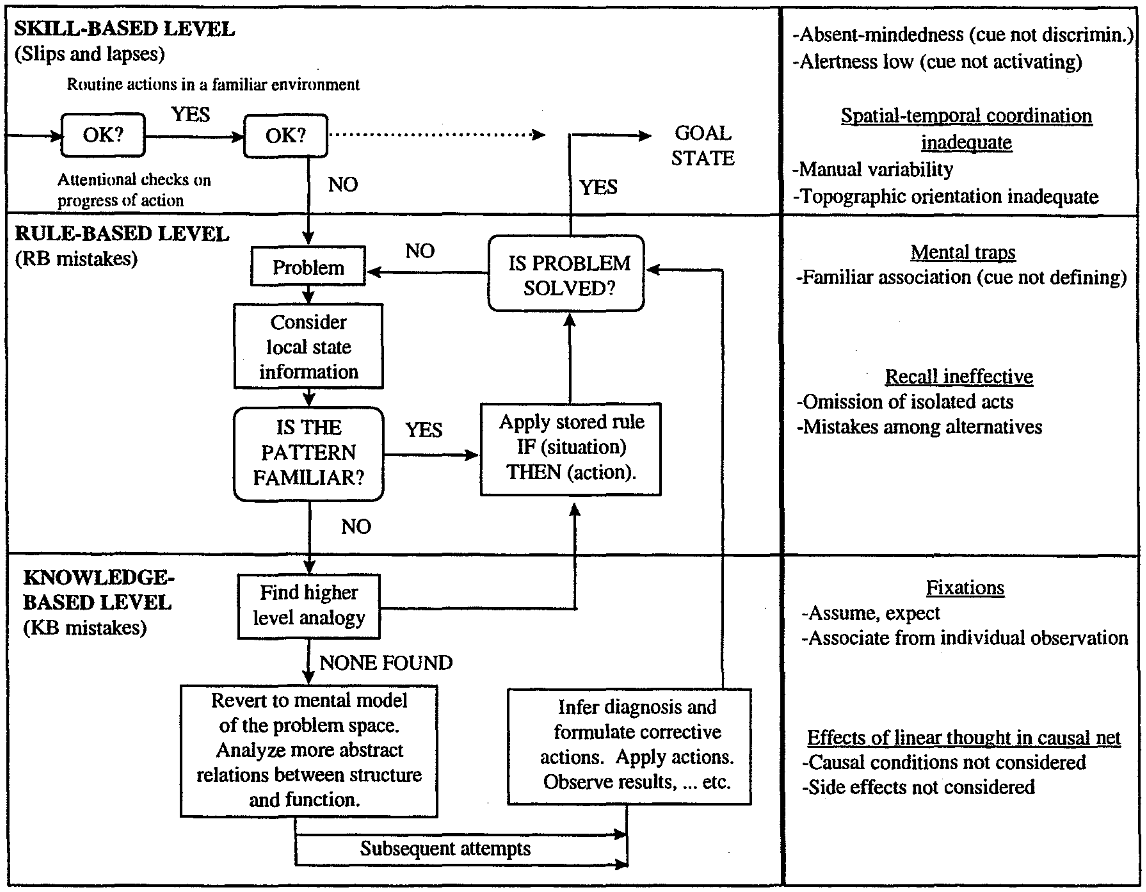


Figure 2. Generic Error Modeling System and typical errors associated with each performance behavior (Rasmussen, 1986).

From the skill-, rule-, knowledge-based model, Rasmussen, Pejtersen, and Goodstein (1994) have developed a detailed decomposition of human activity to define actions that lead to error. This model takes into account advances in human error modeling since GEMS was developed, and incorporates other work by researchers such as Rasmussen (1986), Reason (1990), and Norman (1988). A finer distinction between mental events that influence human acts has been created from the analyses of human involvement in failures of complex systems (figure 3).

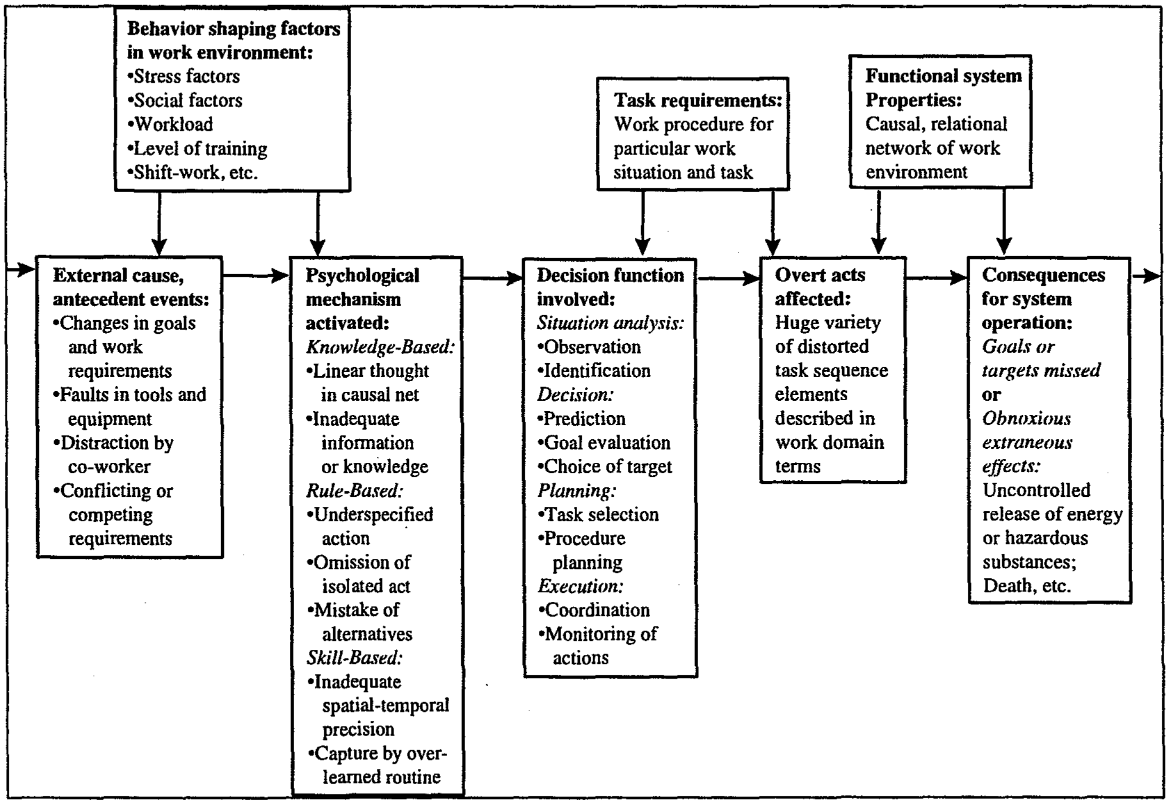


Figure 3. Decomposition of human activity to detail erroneous acts (Rasmussen et al., 1994).

This model has been developed to evaluate which psychological mechanism caused a decision-making function failure (i.e., situation analysis, goal evaluation, planning, or actual execution) once a component failure of a complex system has occurred. From this information, the input conditions of the individual can be defined, and external events that impacted psychological mechanisms can be identified. This method enables the researcher to evaluate erroneous overt behavior using a multifaceted description of human errors.

Reason's (1990) Classification of Unsafe Acts further expands how researchers categorize and define human error. An unsafe act is defined as an error or violation that is committed in the presence of a potential hazard and could cause injury or damage, and can be caused by either an active or latent failure. Active failures are actions or inactions of operators that are thought to directly cause an accident. The consequences of the actions are felt immediately. Latent failures stem from errors committed as a result of organization policy or management.

Unsafe acts are classified according to whether the action was intentional or unintentional (Figure 4). Intentions are the plans, and the expression of these plans, that an individual produces to attain a goal. Unintentional actions are behaviors that are executed, but not as planned, and are divided into two groups: those that succeed regardless of the action and those that do not succeed. Intentional but mistaken actions arise from poor planning (as opposed to unintentional actions that do not succeed). Unintentional actions are often associated with involuntary actions that occur due to automatism and are not considered in the evaluation of unsafe acts because there is no underlying plan.

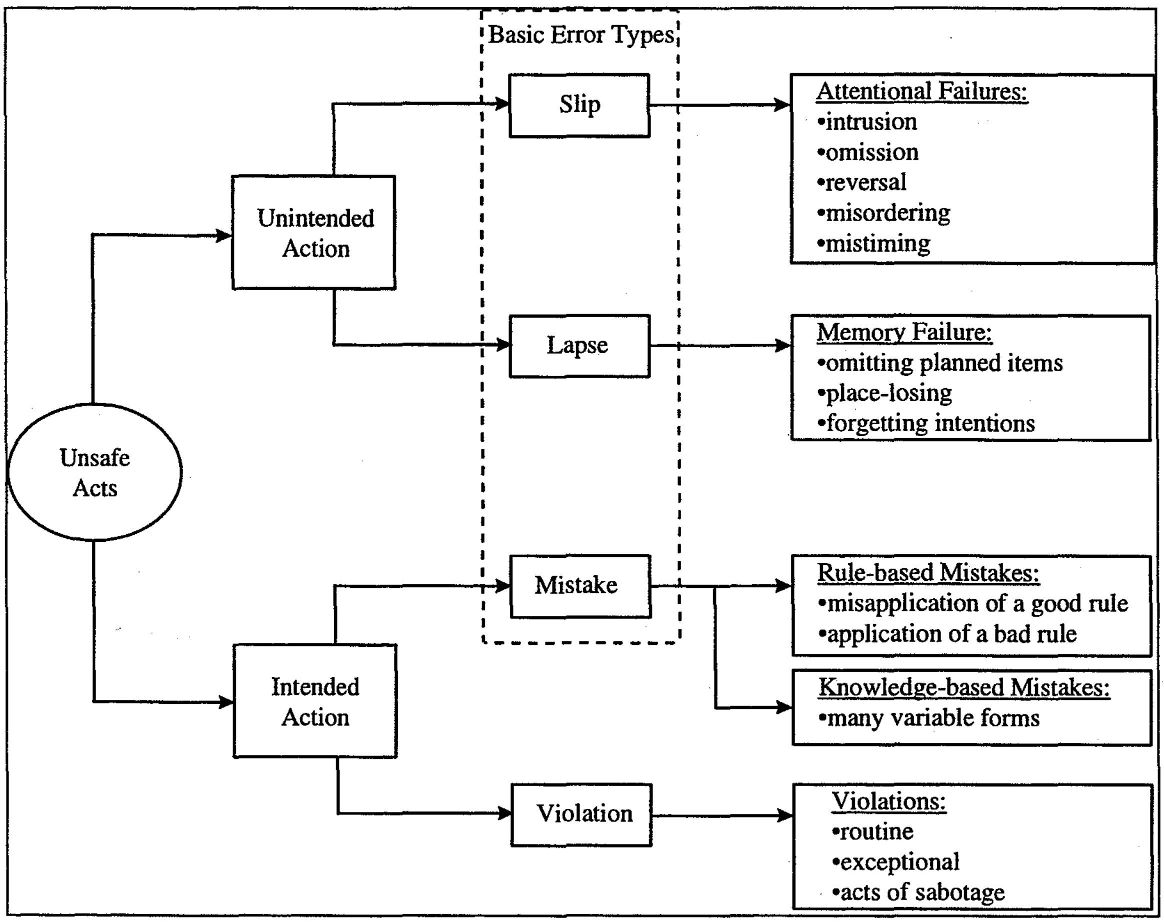


Figure 4. Classification of Unsafe Acts (Reason, 1990).

Actions, whether unintended or intended, are categorized further into basic error types of slips, lapses, mistakes, and violations. From there, the basic error types are categorized and defined by formal characteristics of the error types. Slips and lapses are categorized within unintended actions. In general, these errors result from a failure during the execution and/or storage stage of an action sequence, and ultimately result in execution failures (Reason, 1990). Specifically, slips are externalized as actions-not-planned and are due to attentional failures such as absent-mindedness or daydreaming (Reason, 1990; Wiegmann and Shappell, 1997). Lapses are due to memory failure and may not be externalized; that is, they are only apparent to the individual who experiences them.

Mistakes and violations are subsets of intended actions. Mistakes are deficiencies or failures in the judgment of an individual and occur when previously learned rules and procedures are misapplied or inappropriate for achieving a goal. Mistakes most commonly occur during the planning stage. Violations are not errors, but rather they are attributed to either (i) habitual behavior of an individual that is tolerated by the system (routine violations), or (ii) isolated and unacceptable departures from authority (exceptional violations).

Reason (1990) also suggested a classification of errors that distinguishes three levels: behavioral, contextual, and conceptual. Behavioral errors are defined by an observable feature of the erroneous action. Observable features may be evident through formal characteristics of the error (i.e., intrusion, omission, and reversal) or through the immediate consequences of performing the action (type of damage, injury, or hazard). Contextual errors exhibit the critical relationship between error type (slip, lapse, or mistake) and the situation in which it emerges. Conceptual errors are predictions based upon theoretical inferences into underlying causal mechanisms of erroneous actions. They do not rely upon observable characteristics or on the context in which the error occurs.

Hollnagel (1993) further defines human error in terms of erroneous actions. He defines human error as a descriptor of situations or events in which undesirable consequences occur due to some aspect of human action to which cause can be attributed. An erroneous action is defined as a descriptor of a specific type of action that does not imply cause. In addition, erroneous actions are those that fail to produce an expected result and lead to an unwanted consequence.

Erroneous actions are also defined in two ways: (1) in regard to whether their manifestation can be empirically classified through observation and data collection, or (2) in regard to their cause, which is an assumption of cognitive characteristics that contribute to a behavior. Manifestation of an erroneous action is referred to as the phenotype component, while the cause of an erroneous action is referred to as the genotype component.

Hollnagel (1993) has created a taxonomy of operationalized phenotypes from those used within engineering risk and reliability analyses (figure 5). The taxonomy takes the research from an event to an observable action, as opposed to moving from an event to a cause. This structure supports the reporting of abnormal events—in this case, abnormal events in nuclear power plants.

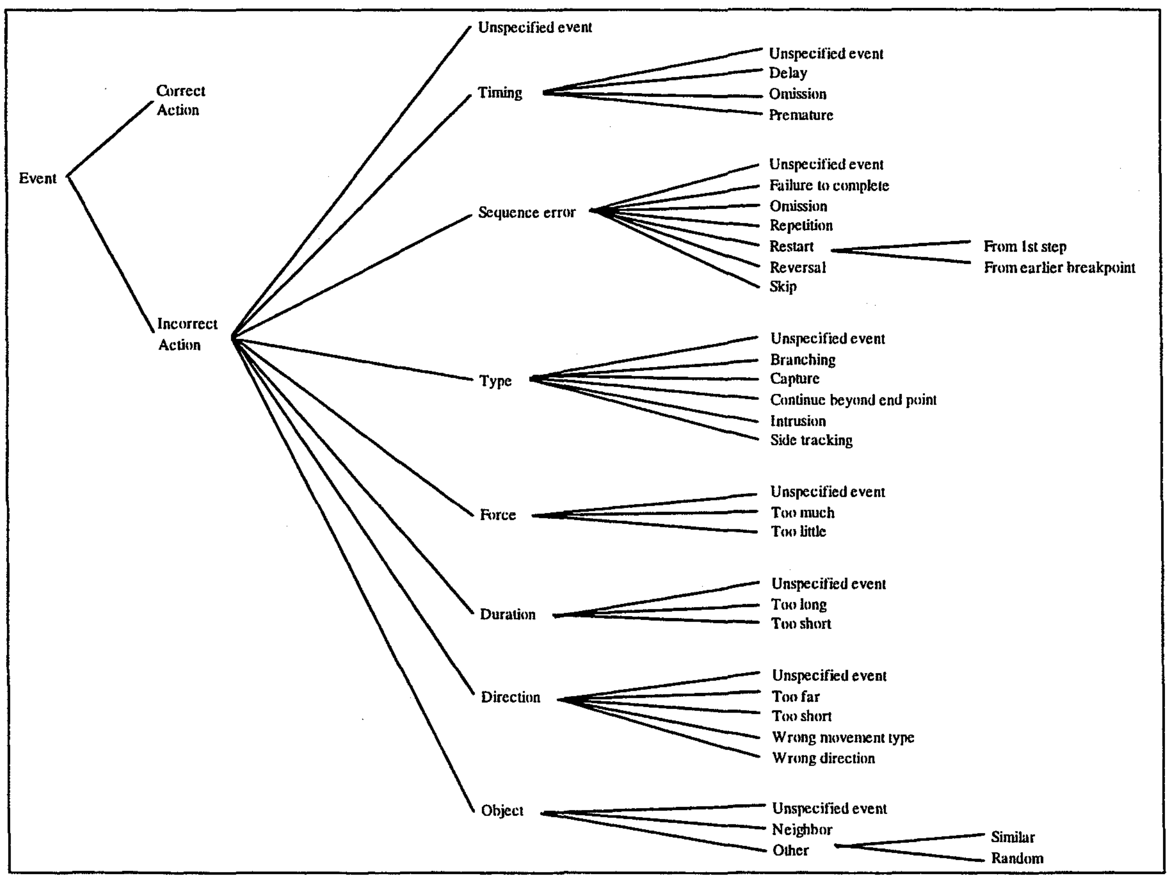


Figure 5. Operational classifications of phenotypes (Hollnagel, 1993).

Each of the above examples of information-processing, human error models contains elements of taxonomic development for the classification of errors. Fortunately, the models and taxonomies also build upon one another, thereby containing common components and definitions of the components. Applied research has extracted basic taxonomic components from the models for the development of task-specific error taxonomies. Rarely is only one model used for research in the area of human error. Domain- and task-specific taxonomies are developed using a combination of error models.

Summary of Review on Human Error Models and Taxonomies

After a review of the literature pertaining to general human error models and taxonomies, it is apparent that these general models and taxonomies shed very little light on the driver error problem. By design, the models and taxonomies that were reviewed are directed at general human error and, as such, do not provide enough detail or the appropriate domain to be useful in describing the many facets of driver error. Though general error taxonomies may be of limited use for describing driver error, Reason's (1990) classification of "unsafe acts" as "intended" and "unintended" is noteworthy. As will be shown later, classification of acts as intended and unintended is an important concept in the study of driver errors and one that has not been addressed in many crash taxonomies that include "driver error" as a category. That is, although driver error is included in many crash taxonomies, it is often not classified in terms of the driver's intent.

As in the previous discussion of general error models and taxonomies, the section that follows provides only a brief review of currently existing *driver* error taxonomies. The reader is directed to the Task A report (Wierwille et al., 1998) for a more detailed discussion of driver error taxonomies found in the literature.

Driver Error Taxonomies

This section provides a brief review of three models/taxonomies within the automobile driver domain. These three models/taxonomies are: (i) Indiana Tri-Level taxonomy developed by Treat (1980), (ii) crash contributing factors taxonomy developed by Tijerina (1996), and (iii) the tree diagram taxonomy developed by Wierwille and Tijerina (1996). Though only the highlights of each model/taxonomy are presented here, a more detailed discussion can be found in the Task A report (Wierwille et al., 1998).

Indiana Tri-Level Taxonomy

The first model being presented was developed out of a landmark study on accident causal factors. This study was conducted at the Indiana University Institute for Research in Public Safety during the early 1970s, and is known as the Indiana Tri-level Study. Treat (1980) has condensed the findings of the study and defined specific human errors involved in accidents. The objectives of the study were to:

- "Identify factors that initiate or influence the sequence of events resulting in a motor vehicle accident
- Determine the relative frequency of those factors and their causal contributions
- Assess the error/accident relationship as a function of driver age, driving knowledge, vision, driving experience, and vehicle familiarity
- Develop new methods for assessing the role of human factors in accident causation, and
- Assess the potential benefits of various improvements in vehicle systems" (p. 2).

These objectives were met through the collection of baseline data from documented accident cases, on-site investigations of accidents, and evaluations of cases by a multidisciplinary team. Accident causal factors were categorized at a high level as human, environment, and vehicular factors. Human factors were found to be the definite cause of accidents in 70.7 percent of the cases, and the probable cause of accidents in 92.6 percent of the cases reviewed.

A model of information-processing was used to develop taxonomies of human causal factors. Five categories of causal factors were defined, and each category included detailed sub-categories. The five causal factors were: (1) recognition errors, (2) decision errors, (3) performance errors, (4) critical non-performance, and (5) non-accident. Table 3 illustrates the five causal factors and their corresponding sub-categories.

Findings from the study indicated that recognition and decision errors were by far the most common types of errors recorded (41.4 and 28.6 percent, respectively). Other significant human factors that influenced accidents were dynamic visual acuity and insufficient familiarity with the roadway.

Table 3. Causal factors and sub-categories defined within the Indiana Tri-level Study.

Recognition Errors	Decision Errors	Performance Errors	Critical Non-performance	Non-accident
"... all situations where a conscious driver does not properly perceive, comprehend, and/or react to a situation requiring adjustment of speed or path of travel for safe completion of the driving task" (p. 21)	"... all situations where a driver is involved in an accident, or experiences an unnecessarily severe impact, because, having received information indicating the need for a change in speed or path of travel, he chooses an improper course of action, or takes no action" (p. 22)	"... situations where a driver properly perceives and comprehends information indicating the need for an adjustment in speed or path of travel, but commits driving errors which involve either impulsive improper actions, or lack of adequate skills. These are to be distinguished from errors involving an improper choice of action from among available alternatives, which are termed decision errors" (p. 23).	"... reflect instances where a driver ceases to perform as an information processor" (p. 7)	"... accommodate any intentional accident involvement" (p. 7)
Examples: • inattention • internal distraction • external distraction • improper lookout • other delays in perception, comprehension, or reaction	**Examples:** • misjudgment • false assumption • improper maneuver • improper driving technique or practice • inadequately defensive driving technique • excessive speed • tailgating • inadequate signal • failure to turn on headlights • excessive acceleration • pedestrian ran into traffic • improper evasive action	**Examples:** • overcompensation • panic or freezing • inadequate directional control	**Examples:** • passes out • falls asleep	**Example:** • suicide attempt

Crash Contributing Factors Taxonomy

Tijerina (1996) proposed a taxonomy of crash contributing factors to aid in the development of crash avoidance system technology. The taxonomy was developed using two steps. First, a database search and expert crash evaluations were performed to define crash types and their key applicable contributing factors. Second, crash contributing factors were then organized into a taxonomy that was defined by the author (Figure 6 on the next page). The following are definitions of the taxonomy categories:

- Driver Incapacitation: Drowsy driver or intoxication.
- Hazard Misperception: Failure of driver to adequately perceive critical driving situation features and information.
- Hazard Non-misperception: Failure of driver to perceive information because it was not expected or was not available.
- Driver Inattention: Driver is not paying attention to critical aspects of the driving situation.
- Sudden Encroachment: Another vehicle(s) enters into a collision course with an unsuspecting vehicle.
- Vehicle Failure: The vehicle ceases to function properly.

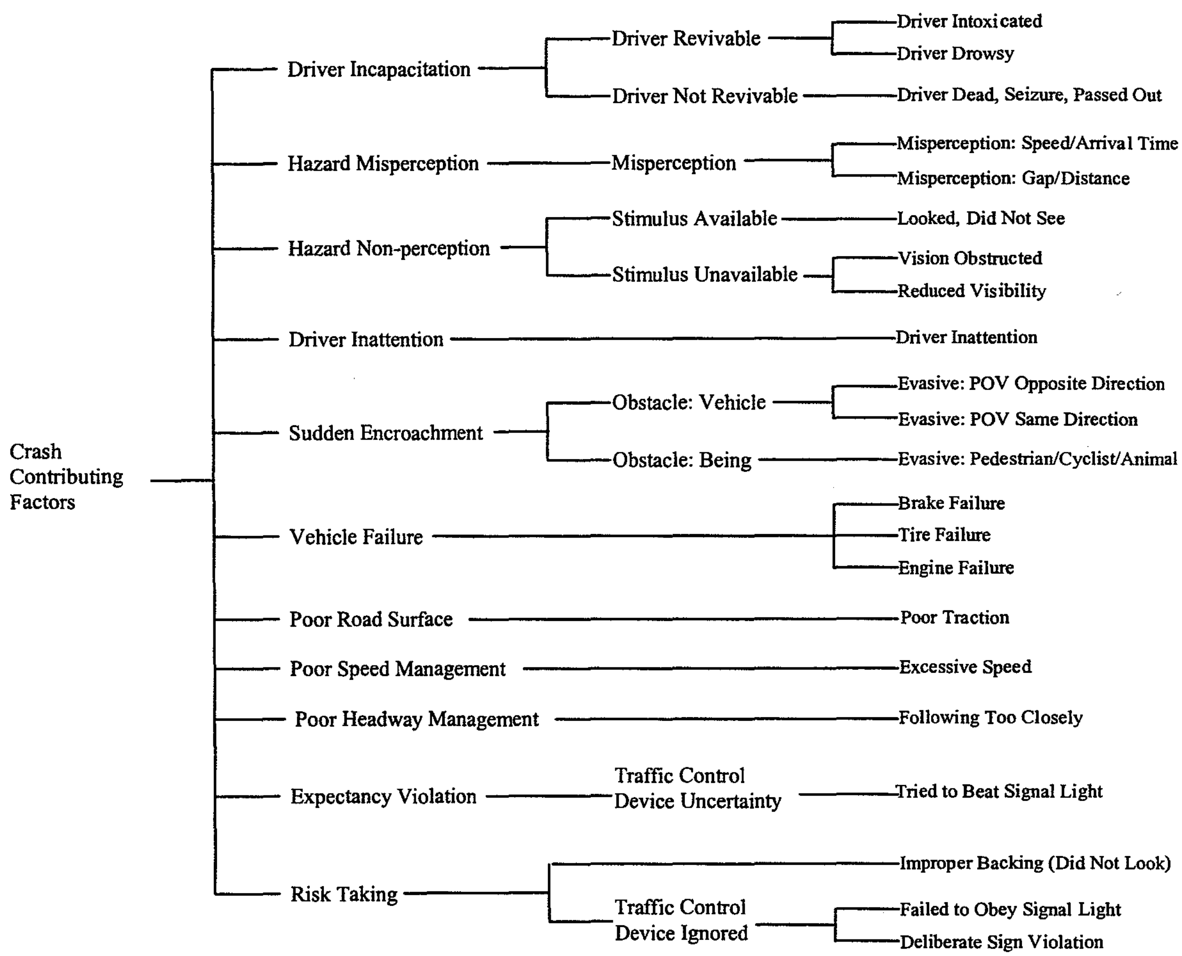


Figure 6. Crash contributing factor taxonomy (Tijerina, 1996).

Tree Diagram Taxonomy

An example of a finite, detailed taxonomy is defined and illustrated in visual allocation research by Wierwille and Tijerina (1996). They investigated the impact of visual allocation as an accident causal factor. The study was performed using a database search of keywords relevant to visual allocation and visual workload. Narratives of the accidents, including the keywords, were then categorized into one of three major categories of diverted visual allocation. The three major categories were: (1) interior source, (2) unspecified (interior or exterior sources), and (3) exterior source. These three major categories were then divided into the first level of sub-categories and, again, into finite subsequent second and third level sub-categories (figure 7). Criteria used for evaluating the narratives were:

1. “A driver’s vision was directed away from the forward scene, and
2. This visual allocation process was the primary cause of the accident” (p. 81).

Results from the study indicate that more than 50 percent of accidents were due to visual allocation being diverted into the vehicle. Visual allocation outside of the vehicle accounted for approximately 23 percent of accidents, and unspecified visual allocation accounted for approximately 21 percent of accidents. It should be stressed here, as this study shows, that if a taxonomy is thorough and contains finite categories to accommodate the numerous behaviors exhibited by drivers, there should be little or no overlap of data between categories.

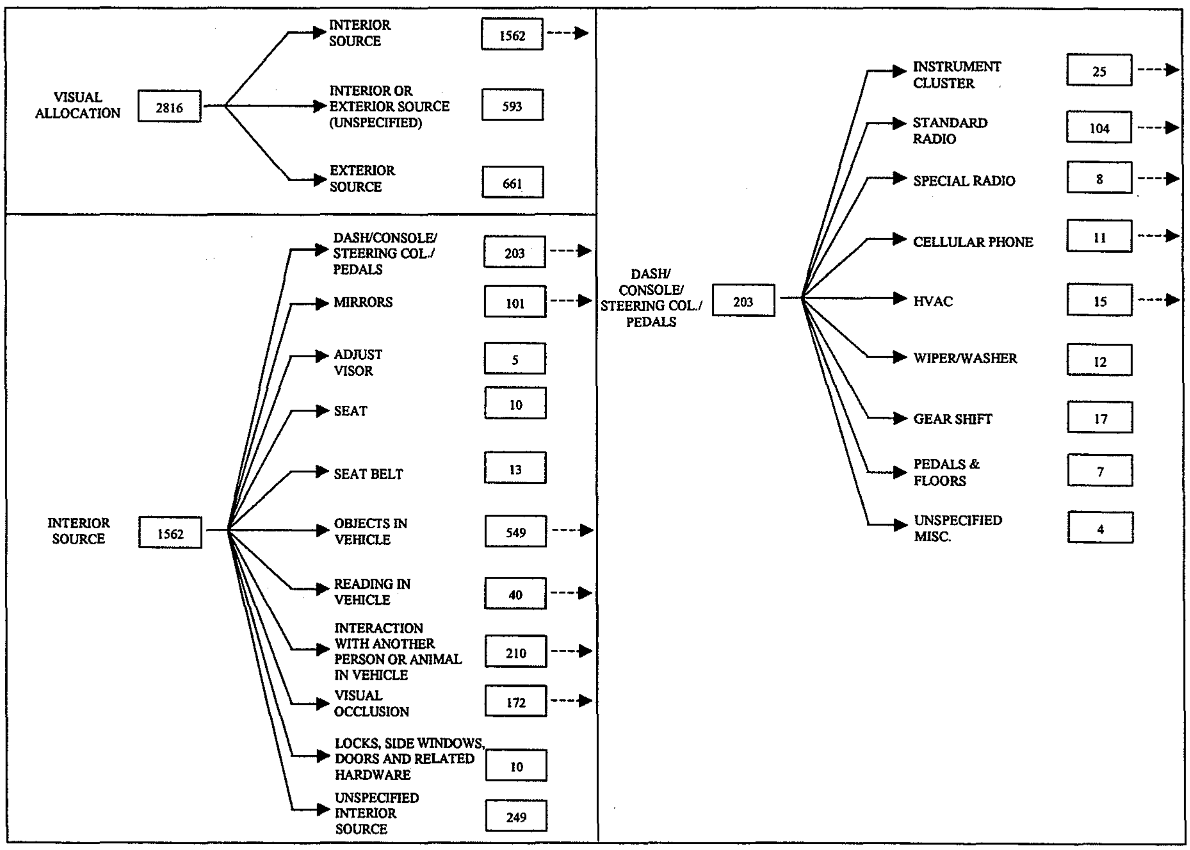


Figure 7. Tree diagram taxonomies of Wierwille and Tijerina (1996) showing first-level (upper left), second-level (lower left), and one of the third-level trees (right).

Causal Chains

Before leaving the discussion of the driver error models/taxonomies found in the literature, it is important to consider a caveat, put forth by Senders and Moray (1991), on "causal chains." This caveat applies to all human error taxonomies, both inside and outside the driving domain. In their book on human error, Senders and Moray (1991) point out that human error is "in the eye of the beholder," or context dependent. Context dependency in this case means that a given error and its cause are dependent on how the observer or investigator views the situation.

To illustrate the problems that exist with error type and causality, Senders and Moray (p. 105) provide three examples showing that there may be many contributing factors, several of which could be considered as important or principal. Figure 8 shows their simplest example. A driver begins to suffer a migraine attack brought on by any one of several factors including stress, anxiety, or, possibly, lack of a good night's sleep. The attack causes scotomata (a loss, blurring, or darkening of part of the visual field). The driver decides to drive anyway because of a pressing engagement. The driver misses detecting a vehicle on a conflicting path, and becomes involved in a collision.

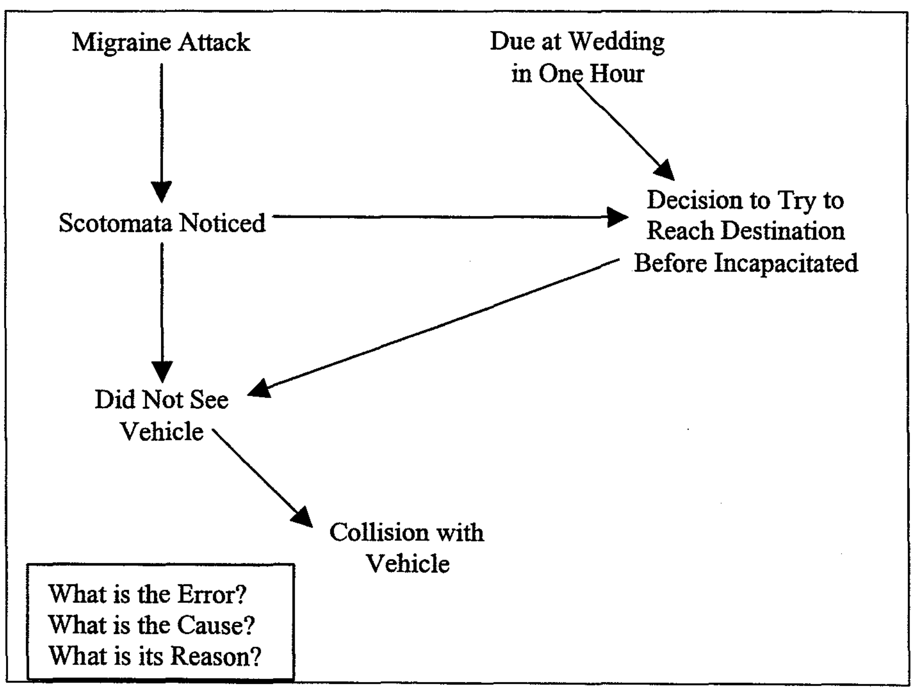


Figure 8. Why did the collision occur? (After Senders and Moray, 1991, p. 106.)

It is instructive to take Senders and Moray's (1991) example and list the possible causes, reasons, or contributing factors involved. Table 4 shows a list that was generated with just a few minutes of thought. The table shows very clearly that any taxonomy that might be developed is context-dependent and should be recognized as an aid to thinking, visualizing, or classifying. Most importantly, it should not be assumed to be unique.

Table 4. Candidate list of contributing factors.

Potential Contributing Factors
Inadequate rest
Job stress
Anxiety
Not heeding telltale signs of a temporary physical impairment
Migraine attack
Scotomata brought on by migraine
Physical impairment
Inadequate training regarding hazards of migraines
In a hurry – insufficient care taken
Improper lookout
Looked but did not see
Driver of "other" vehicle performed unsafe act, placing it on a collision course
Driver of "other" vehicle did not take evasive action (many possible reasons could be listed under this topic)

Summary

As outlined earlier, the primary agenda of this project was to develop driver error taxonomies. As a first step in the development of these taxonomies, the literature review served to (1) provide insight into driver error from the most knowledgeable experts in the field, (2) provide a means of critically evaluating driver error classification methods used in the past, and (3) investigate human error by focusing on how it has been classified and how it relates to causes or principal contributing factors.

Three primary conclusions can be drawn from the brief review of "driver error" that was presented here. The first conclusion is that *complex diagrams of cognitively developed modeling are of limited value*. In addition, in terms of domain-specific taxonomies that are directed at vehicle crashes, the taxonomies developed up to this point have focused on *what* happened in a crash, but have not considered *why* the crash happened. Consider that many of these taxonomies were developed using police reports and crash databases. Understandably, data of this type are not conducive to understanding *why* a crash occurred, but rather can best be used to determine *what* happened. It appears that a new taxonomy that focuses on driver errors, and why crashes occur, is needed to supplement existing crash taxonomies.

The second primary conclusion of this literature review is that *the underlying mechanisms that can cause a crash may be very complex.* Consider the example proposed by Senders and Moray (1991) in Figure 8. The point that they make is that in trying to determine why a collision occurred, one must be cognizant of a variety of potential contributing factors and the interaction between those factors. The implications of the Senders and Moray example is that a driver error taxonomy must contain, at the most detailed level, a list of contributing factors and a method for identifying multiple contributing factors or interactions between factors. One approach that would be appropriate for classifying crash data and listing potential contributing factors is the tree diagram method outlined by Wierwille and Tijerina (1996), shown in Figure 7. Using a tree diagram would provide a structured method in which to list potential contributing factors and minimize the amount of overlap between categories.

The third conclusion that can be drawn from the literature review is that *several models of human/driver error classification might be successfully merged to form a suitable taxonomy.* To the benefit of this project, some of the more proven and accepted models, features, and classification schemes used in the past could be combined to form valid and worthwhile driver error taxonomies. For example, consider a taxonomy that combines features from a variety of taxonomies including: the general error taxonomy presented by Reason (1990), shown in Figure 4, that accounts for the driver's intent; the causal factor sub-categories outlined by Treat (1980), shown in Table 3; and the detailed tree structure, outlined by Wierwille and Tijerina (1996), that is used to classify crash data. The development of a new taxonomy that integrates the strongest features from a variety of well-researched and previously developed taxonomies would provide a useful crash classification tool that could be used to better understand not only *what* happened in a crash, but *why* the crash occurred. Such a tool was successfully developed during this project and is presented later in this final report.

CHAPTER II. CRASH DATABASE ANALYSIS IN SUPPORT OF TAXONOMY DEVELOPMENT

OVERVIEW

One of the objectives of this project was to develop one or more taxonomies of driver error and to work toward determining associated causes. To this end, a large scale effort was conducted that involved: (i) national and state accident database studies, (ii) investigating officer focus groups, and (iii) critical incident driver interview studies. This chapter highlights the database studies. Appendix A contains a more complete overview of the database analyses that were conducted.

National and State Accident Database Studies

Both "traditional" and "non-traditional" databases were analyzed. To name only a few, traditional crash databases included the Fatality Analysis Reporting System (FARS), the Highway Safety Information System (HSIS), and the State Data Program (SDP). There are several characteristics of these databases that make them "traditional." For example, each of these databases usually includes data fields. Data fields contain keywords that can be used to search, for example, crash types of interest. "Non-traditional" database searches, on the other hand, involve searching narratives (written descriptions of accidents) entered into a database. Of the two approaches, it appeared that narrative searches provided somewhat better information on driver error-related issues as compared to searches using a traditional approach. The reason for this is that the narratives tend to contain more detailed, richer data. In structuring the data, it was found that a tree diagram methodology worked well (Wierwille and Tijerina, 1996). An example of a tree diagram is shown in Figures 9a and 9b. (Note that Figure 9b represents, in greater detail, the "failure to yield at intersection category" of Figure 9a.) The two highest levels of the taxonomy are shown. Note that the categories shown can be further detailed as appropriate. As can be seen, this type of structure allows an analyst to develop a clear understanding of not only the magnitude of factors associated with a crash type, for example, but also the relationship between factors. Unfortunately, traditional database searches do not lend themselves neatly into a tree diagram taxonomic structure. That is, the details associated with crash records are not as accessible via traditional database searches as they are with the non-traditional narrative approach.

261	Failure to yield at intersection
219	Hit lead vehicle in rear
200	Ran off road
78	Changing lanes
72	Avoiding animal, object, or person in roadway
31	Crossed center lane head-on
25	Improper backing
22	Other
20	Mechanical failure
17	Driver distracted
11	Driver physical condition
9	Driver misapplication of control
8	Making U-turn
6	Parking lot driving
5	Weather and roadway structure
3	False assumption
2	Driver did not see sign
2	Driver did not see vehicle because of weather
1	Made turn from wrong lane

Total: 992

Figure 9a. Sample taxonomy using the tree diagram methodology.

- **261 Failure to yield at intersection**
  - 188 Intersecting roads
    - 71 Make left turn across path
      - 53 General
      - 12 Failed to see
        - 10 General
        - 2 View obstructed by another vehicle
      - 6 Stopped initially
    - 64 Perpendicular path
      - 38 General
      - 12 Failed to see
      - 10 Pulled in front of oncoming vehicle to drive in the same direction
      - 4 Stopped initially
    - 22 Pulled in front or failed to yield right away
      - 15 General
      - 4 Failed to see
      - 3 Stopped initially
    - 15 Turned too tight or wide and side-swiped
      - 8 Turned too wide
      - 7 Turned too tight
    - 15 Waved through by another driver
    - 1 Fog obscured intersection
  - 37 Traffic signal
    - 22 Failed to stop at traffic signal
      - 19 General
      - 3 Failed to see signal
    - 12 Both had green light or started maneuver on green
    - 2 Saw a right or red turn and assumed had green light
    - 1 Made an incorrect right on red turn
  - 36 Stop sign
    - 22 Ran red light
    - 10 General
    - 8 Ran stop sign and continued off road
    - 4 Failed to see stop sign
      - 3 General
      - 1 Sign obscured by fog
  - 14 Stopped first then proceeded
    - 10 General
    - 4 Did not see oncoming traffic

Figure 9b. Sample taxonomy using the tree diagram methodology.

As indicated, the reader should refer to Appendix A for a more detailed discussion of the database analyses that were conducted. A complete description of all database analysis work that was conducted can be found in the Task C report (Hankey et al., 1999).

CHAPTER III. INVESTIGATING OFFICER FOCUS GROUPS ON THE TOPIC OF HUMAN ERROR

OVERVIEW

The highlights from the investigating officer focus groups that were conducted for this project are presented in the sections that follow. For a complete description of the focus group effort and a discussion of all results, the reader is directed to the Task C report (Hankey *et al.,* 1999).

OBJECTIVES

Focus group discussions were conducted with representatives from five law enforcement agencies in Virginia to expand understanding of driver errors and their linkages to roadway infrastructure. These law enforcement representatives included the individuals who complete the police reports that describe motor vehicle crashes. By citing their experiences and relating observed patterns of driving errors, it was hoped that the investigating officers would provide an important perspective in understanding the driver error component of crashes. The primary objective of the focus groups was to identify patterns of driving errors and to provide insight into the causes of such patterns, with an emphasis on relationships between driver behavior and specific infrastructure designs.

FOCUS GROUP METHODOLOGY

Five focus groups were conducted, each comprised of investigating officers with experience in crash investigating/reporting. The agencies were selected based on the nature of the driving environment in their jurisdiction. The aim was to access a cross-section of roadway types and congestion patterns to help establish patterns of similarities and differences in driver errors (Table 5).

Table 5. Focus group composition.

Agency	Driving environment	Population	# Participants
Blacksburg (VA) Police Dept.	Small urban	36,400	5
Roanoke (VA) Police Dept.	Medium urban	96,397	10
Arlington (VA) County Police Dept.	Large urban	175,334	8
Va. State Police Wytheville Div.	Rural	25,000	11
Va. State Police Northern Virginia Div.	Urban/Rural	393,000	8

Figures from Blacksburg and Arlington are based on 1996 census figures. Roanoke population based on 1990 census. Figures for the two State Police districts are based on the average population per county or independent city in these districts, based on the 1990 census.

Focus groups ranged in size from five to eleven participants. Forty-two officers participated. All discussions were held in the headquarters of the participating agencies, with the exception of the Blacksburg Police Department. The focus groups were audiotaped for use in transcribing the officers' comments. The moderator/facilitator used an outline (see Appendix 13 of the Task C report) to guide the discussions and stimulate the interest of the participants. Focus group participants in Arlington, Blacksburg, and Roanoke were paid $20.00 per hour for their time. The State Police indicated that it was against policy for their uniformed personnel to accept outside work. Their troopers' participation was part of their normal work shift for the day.

Focus Group Discussion

As indicated, the primary goal of the focus groups was to obtain investigating officers' opinions with regard to driver errors. As such, much of the focus group discussion, and questionnaires administered, centered around incidents that the officers had experienced and/or investigated that were related to driver error.

All sessions ended with a discussion of the motor vehicle accident (MVA) reporting forms. (One of the directives of the project was to recommend coding improvements for MVA reporting forms.) Because the investigating officers have experience filling out the forms for a variety of crash circumstances, they were able to explain what aspects were missing and what aspects could be reformatted or deleted from the form.

RESULT HIGHLIGHTS

As indicated, only the main results of the focus groups are presented here; the complete set of results can be found in Task C (Hankey et al., 1999).

What Proportion of Crashes is Caused by Driver Error?

At the beginning of each focus group, participants were asked to complete a questionnaire to gauge the officers' perceptions of driver errors. Interesting patterns were found in their responses to three of the questions. These questions appear below.

1. *On a scale from 1 to 100, rate the percentage of accidents in which you feel driver error plays a primary role.*
2. *Of the accidents in which **driver error played a significant role**, what proportion of the accidents that you have investigated are single vehicle?*
3. *Of the accidents in which **driver error played a significant role**, what proportion of the accidents that you have investigated required at least one person to go to the hospital?*

Table 6 shows the officers' responses to these three questions from the pre-discussion questionnaire. These results exhibit some interesting trends among the various agencies. The variety of responses also indicates that our five focus groups did indeed represent a wide range of driving environments.

As shown in Table 6, the average response to question #1 was 87 percent, with individual responses ranging from 50 percent to 100 percent (Figure 10). This general agreement was best represented by a comment made by a State Police Trooper in Northern Virginia who said, "there is no such thing as a single causative factor in an accident. We all know speed doesn't kill. It's speed and a deer runs out into the road and I swerve. Or, I speed, and you fall asleep at the wheel."

Table 6. Responses to questions on the pre-discussion questionnaire.

Listed below are the participating officers' responses to three questions on the pre-discussion questionnaire.

Focus Group Location	Measure	Percent of Accidents in which Driver Error Plays Primary Role	Percent of Driver Error Crashes that are Single Vehicle	Percent of Driver Error Crashes in which Someone goes to Hospital
Arlington	n	8	8	8
	Mean	84	13	39
Blacksburg	n	5	5	5
	Mean	89	38	32
Roanoke	n	10	10	10
	Mean	89	21	34
State Police NOVA	n	8	8	8
	Mean	83	39	44
State Police Wytheville	n	11	11	11
	Mean	88	61	45
Overall	n	42	42	42
	Mean	87	35	39

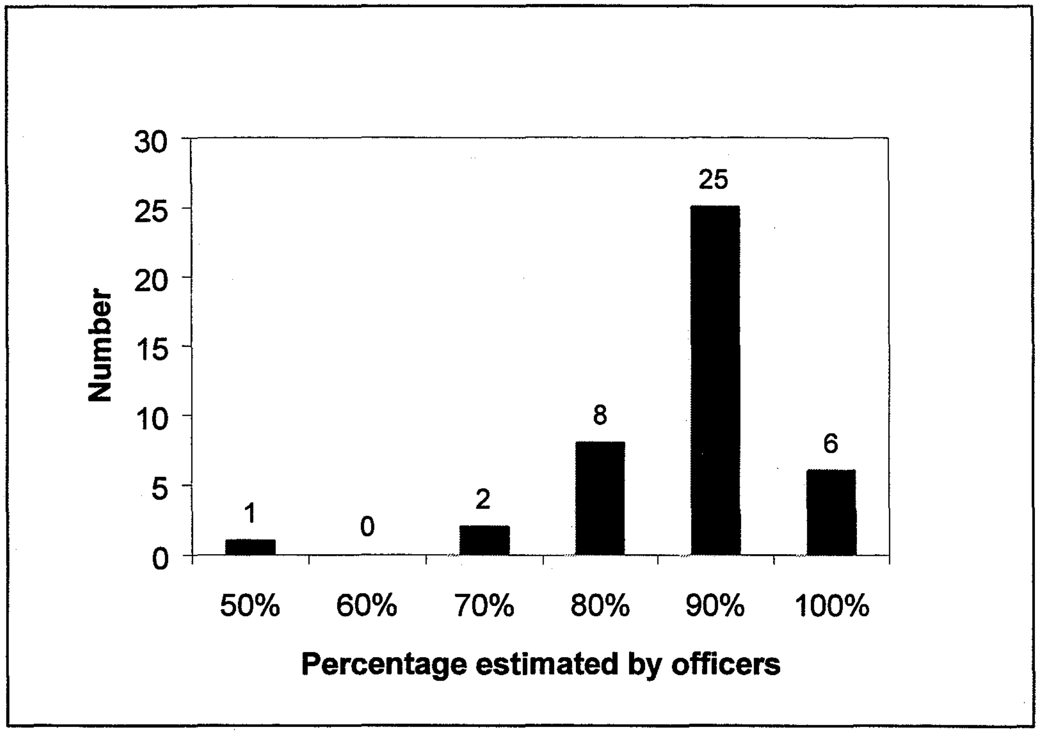


Figure 10. Driver error as the primary contributing factor.

In addition to the pre-discussion questionnaire results related to driver error, the focus group discussion itself revealed some interesting findings with regard to the officers' opinions of driver error. One exercise in the focus group was to have the officers list the most common driver errors and rank them in order of importance. Table 7 shows these results with "1" representing the highest rank. For tied ranks, the average of the ranks is used. As can be seen, the errors that were ranked the highest were "Inattention," "Speeding," and "Following too closely."

Table 7. Ranks of most common driver errors.

Driver Errors Ranked by Location

Driver Error	Arlington	Blacksburg	Roanoke	SP	SP
Inattention	1	1	1	1	2
Speeding	2	2.5	3.5	4	1
Following too closely	5	2.5	3.5	2.5	3
Failure to yield ROW	3.5	6	6		5
DUI	6	8.5		6	4
Stoplight and stop sign violations	3.5	6	7.5		
Aggressive driving	8.5	6	7.5		
Driving too fast for road conditions		8.5	2		6
Panic (Inexperience)				2.5	
Inexperience				6	
Lack of judgment				6	
Failure to maintain control of vehicle			5		
Disregarding highway signs	8.5				
Improper backing	8.5				
Poor distance and speed estimate	8.5				
Road rage			9.5		
Elderly			9.5		
Fatigue				10	
Unfamiliarity				10	
Angry/nervous led to panic				10	
Lack of education				10	
Inattention to traffic control devices*		1*		10	

* "Inattention to traffic control devices" is considered the same as "Inattention."

Inattention

As illustrated in Table 7, driver inattention was ranked as the number one driver error by four of the five focus groups and finished second in the Wytheville session. Our discussions with officers led us to the conclusion that inattention encompasses three dimensions: 1) out-of-vehicle distractions (40 percent), 2) in-vehicle distractions (40 percent), and 3) physical condition/tunnel vision (20 percent). State Troopers in Wytheville assigned the percentages. Officers in Roanoke did not specify percentages, but did indicate that out-of-vehicle distractions are more common than in-vehicle distractions, which are more common than inattention related to the driver's physical condition or daydreaming. Table 8 outlines examples of these three categories of inattention.

Officers in Roanoke stated that inattention usually happens at traffic signals, stop signs, and yield signs. This notion is corroborated by numerous references to inattention and various traffic control devices and roadway geometry found in subsequent portions of this report. However, inattention is not isolated to traffic control devices. This error is attributed to a wide array of crash types and geometries as well.

An officer in Blacksburg made the interesting point that "a lot of time the person not charged could have avoided the accident if they were paying attention." Thus, inattention can be a problem in crashes regardless of whether the driver was legally at fault or not.

Table 8. Examples of different types of inattention.

Out-of-vehicle distractions	In-vehicle distractions	Physical state/tunnel vision
Rubbernecking	Shaving	Day dreaming
Items on side of road	Reading	Concentrating on lane ahead
Billboards	Applying Makeup	"Driving like sheep"
Businesses	Eating	Thinking about work
Other motorists	Adjusting radio	Illness
Other vehicles	Conversing	Age
	Retrieving item from floor	
	Cell phones	

Speeding

Speeding is a major contributing factor in motor vehicle crashes according to our focus group participants. A State Police Trooper in Wytheville said that speeding is dangerous because it reduces time available to react and prompts bad judgement of drivers. This trooper also said that speeding is always about being in a hurry and that it is an aggressive act. An officer in Roanoke contended that speeding is usually aggressive driving, but that sometimes people will drive 10 to 12 miles over the speed limit because of inattention.

An officer in Roanoke stated that he sees speeding as more of a problem on his city streets because the speed limit is 25 m.p.h. Because motorists coming into the city are used to driving on interstates or major primaries at high rates of speed, they never "develocitize." "Velocitization" is acclimatization to high speed, which makes the speed seem slower than it actually is.

Following Too Closely

Failure to maintain a proper following distance was the third highest ranked driver error in our focus groups. A state trooper in Wytheville said that this occurs because "people think their reaction time is much (better/shorter) than it actually is. It boils down to being in a hurry." A trooper from Northern Virginia explained the driver's overconfidence this way: "No matter how badly you want your car to stop, it's bound by the laws of physics. No matter how energetically you put the … brake down, it's not going to help you."

Our participants indicated that following too closely is an aggressive act. "If you're at a prudent (following) distance, cars from other lanes come and get in front of you and fill in the space," said a Northern Virginia Trooper. Thus, drivers tailgate to protect their space and save time. Participants said that tailgaters are impatient, and that they do it habitually. Officers also say following too closely is a behavior exhibited frequently by inexperienced drivers.

According to troopers in Northern Virginia, following too closely would not lead to as many crashes if people would learn to look beyond the car in front of them. The participants claimed that tailgaters tend to pay attention to just the car in front of them and do not anticipate problems that arise ahead of that vehicle. By the time the tailgater realizes he or she needs to react, it is too late to avoid rear-ending the car immediately in front.

Accident Reporting Form Design

In addition to discussing "driver error," the focus group discussions also included accident report forms. In general, the officers were asked how they would improve them. Listed below are their suggestions:

1. Get rid of carbon paper. Have to white out and correct things.
2. Eliminate unnecessary information: driver's occupation (mentioned in three groups) and number of years driving.
3. Enlarge diagram area (mentioned in three groups).
4. Get rid of diagram to show where car was damaged. This could be handled in narrative.
5. Eliminate codes around the edges. This would be easier to convey in narratives or with an attached checklist.
6. Provide template of basic intersections.
7. Format codes better.
8. Add space for more than two vehicles. If there are more than two vehicles involved, an additional face sheet must be attached.
9. Make the pages bigger.
10. Provide more space to describe property damage.
11. Reduce the number of blank spaces for recording names of injured persons.

CONCLUSIONS

Driver errors are the main reason for motor vehicle crashes according to law enforcement officers. It is not traffic control devices, roadway geometry, lighting, or delineation. While it is true that infrastructure and other factors play a significant role, the officers believe that only rarely do they comprise the principle contributing factor. Theoretically, most crashes are preventable, which leaves a number of options for combating the problem of driver errors.

Our focus groups with law enforcement officers were very enlightening. The officers helped establish relationships between driver errors and infrastructure features. They identified 62 different driver errors to be considered for a taxonomy. These crash investigators also provided extensive clarifications of driver errors and the underlying motivations. Their unique perspective provided knowledge that was unobtainable in other data sources for this study.

CHAPTER IV. DRIVER INTERVIEWS

OVERVIEW

A driver interview study was conducted to gain information on driver errors from a driver's perspective. The results from this effort were not particularly useful for the taxonomy development that occurred later in the project. A very brief description of this effort is presented here. The reader is directed to the Task C report for a full description of these interviews and the results.

OBJECTIVE

The primary objective in interviewing drivers was to uncover contributing causes of collisions and close calls. Infrastructure factors such as roadway geometry, traffic control devices, and environmental characteristics that directly contributed to mishaps were explored. For the purpose of this study, roadway geometry was considered to be any aspect of the road design such as curvature or changes in elevation. Traffic control devices were considered to be any controlling agent such as regulatory signs, warning signs, or traffic lights. Environmental characteristics were considered to be objects on the roadway or adjacent to the roadway that hamper safe driving practices such as parked vehicles, objects dropped from vehicles, or trees, grass, and bushes.

Other factors were also explored, such as driver influences connected directly to the incident that interviewees perceived to have directly impacted traffic incidents. Secondary objectives of this study included:

- Exploring the problems of drivers from different driving environments. This was done to determine if people who drive in predominantly rural/small town, medium-sized city, or large city/metropolitan area driving environments experience different driver errors and contributing factors.
- Exploring the problems of drivers from different age groups. This was done to determine if drivers within different age ranges experience or exhibit different driver errors and contributing factors.

DRIVER INTERVIEW METHODOLOGY

Table 9 shows a breakdown of some of the relevant driver characteristics that were used to categorize drivers. As can be seen, 54 drivers participated in the study. Drivers were selected to participate based on their gender, age, and their typical driving environment.

Table 9. Number of interviews from each gender, age, and driving environment.

	Rural/Small Town		Medium-sized City		Large City/ Metropolitan Area		
	M	**F**	**M**	**F**	**M**	**F**	
18-25	3	3	3	3	3	3	18
35-45	3	3	3	3	3	3	18
65 or Older	3	3	3	3	3	3	18
	18		18		18		54

RESULT HIGHLIGHTS

As indicated, only the main results of the driver interviews are presented here; the complete set of results can be found in Task C (Hankey *et al.,* 1999).

Overview of Event Causal Factors

The greatest number of driver errors (66 percent) was attributed to "Human direct causes" (Table 10). Twenty percent of the events were attributed to "Environmental factors," and 13 percent of the events were attributed to "Human conditions and states." "Vehicular factors" accounted for 1 percent of the events. Because "Vehicular factors" are not considered to be driver errors, they will not be described further.

Table 10. Number and percentage of collision and close call events for each causal group.

Causal Group	Number of Collision Events	Number of Close Call Events	Combined Number of Events	Percentage of Total Number of Events
Human Conditions and States	30	7	37	13 %
Human Direct Causes	133	53	186	66%
Environmental Factors	42	13	55	20%
Vehicular Factors	4	0	4	1%

"Human direct causes" were attributed to 133 collision events and 53 close call events. Of the collision events, there were five factors that together contributed to more than half of these events: "Inadequate or improper lookout" (17 events), "Inadequate defensive driving technique" (17 events), "Delay in recognition for other or unknown reasons" (16 events), "Improper maneuver" (15 events), and "False assumption" (12 events) (Figure 11). Of the close call events, there were four factors that contributed to more than half of these events: "Inattention" (eight events), "Delay in recognition for other or unknown reasons" (eight events), "Inadequate or improper lookout" (seven events), and "Improper driving technique or practice" (seven events).

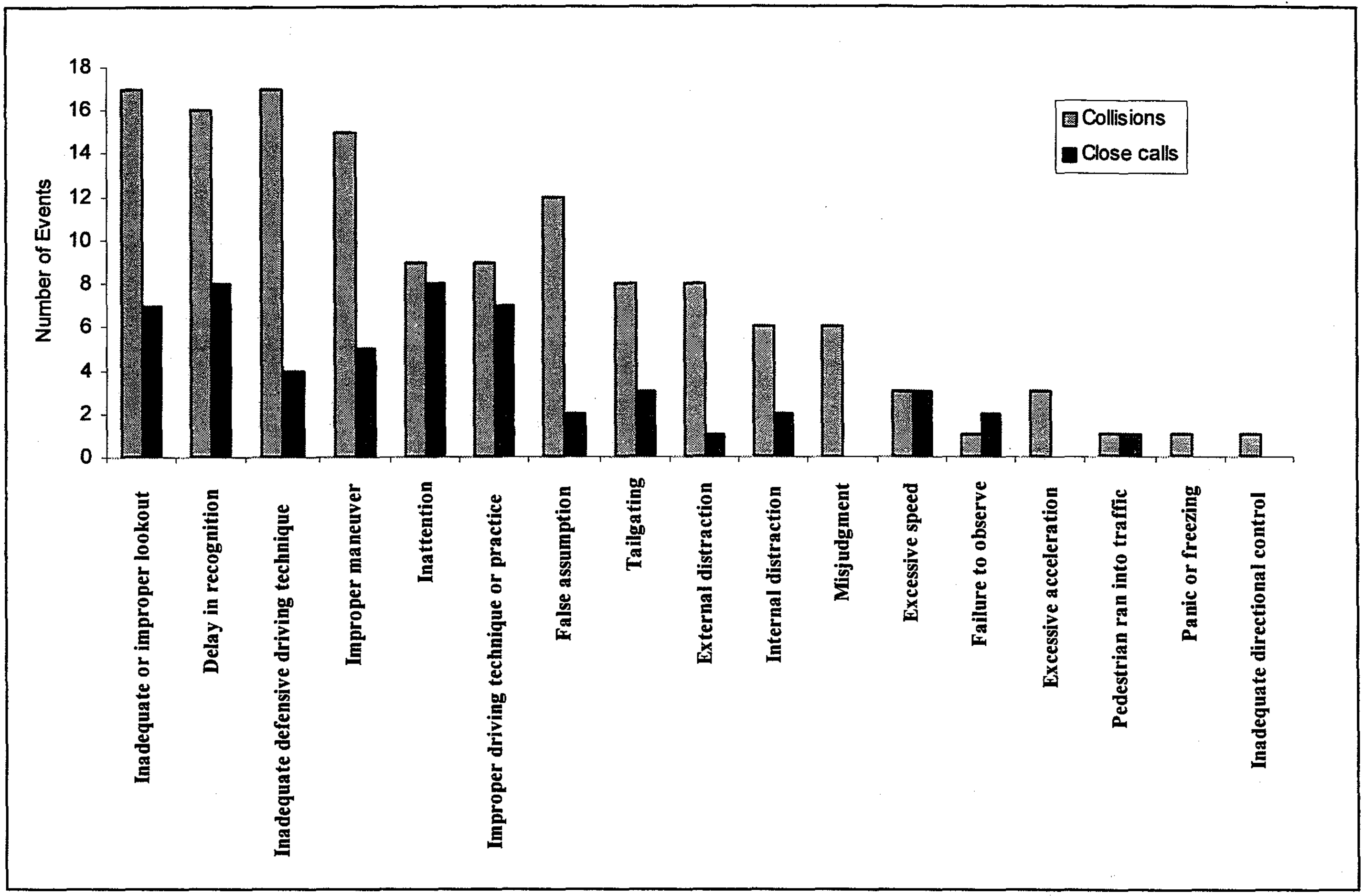


Figure 11. Human Direct Causes for collision and close call events.

"Environmental factors" were attributed to 42 collision events and 13 close call events. Of the collision events, three factors were found that contributed to more than half of these events: "Special/Transitory hazards" (10 events), "Slick roads" (nine events), and "View obstructions" (six events) (Figure 12). Of the close call events, the factor "View obstructions" (seven events) contributed to more than half of these events.

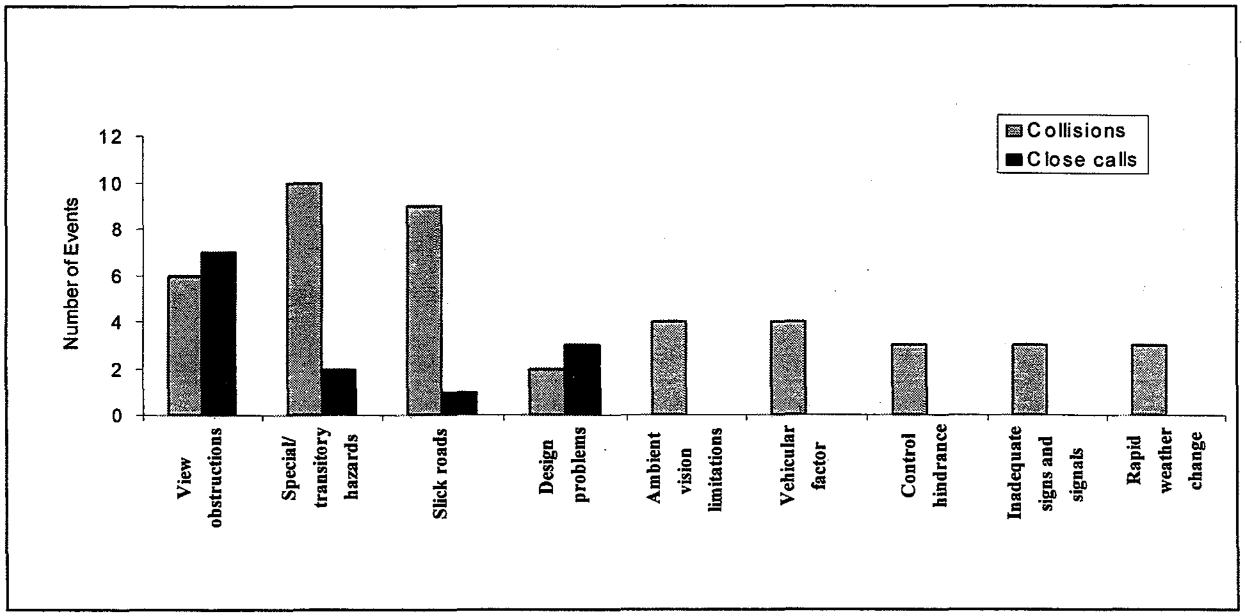


Figure 12. Environmental Factors for collision and close call events.

"Human conditions and states" were attributed to 30 collision events and seven close call events. Of the collision events, two factors were found that contributed to more than half of these events: "Alcohol impairment" (10 events) and "In a hurry" (six events) (Figure 13). Of the close call events, the factor "Critical non-performance" (four events) contributed to more than half of these events.

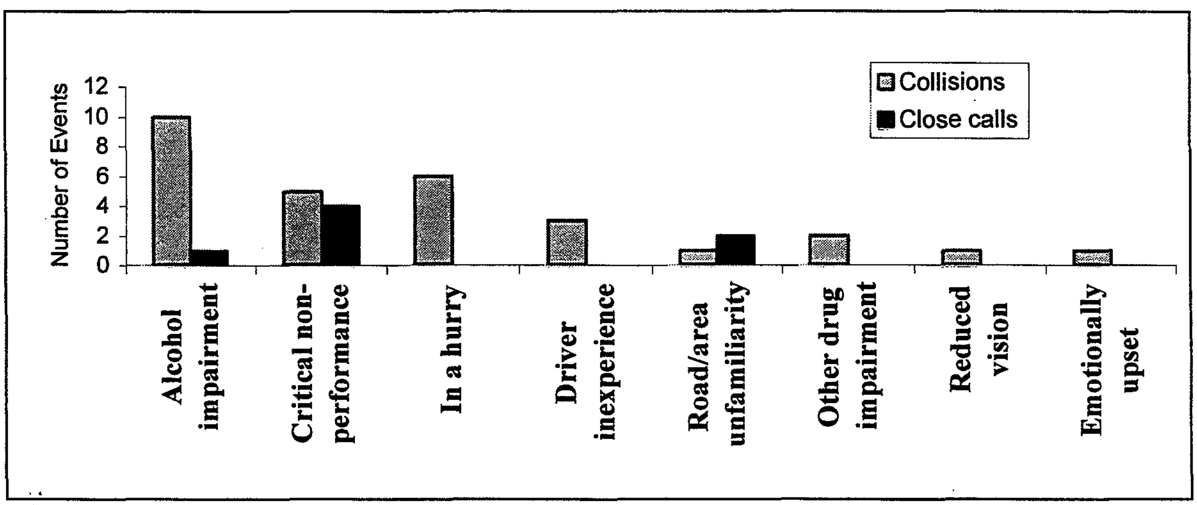


Figure 13. Human Conditions and States for collision and close call events.

CONCLUSIONS

Two primary groups of problems were found from the driver interviews: (1) infrastructure-related problems of sight distance and lack of signing on curves, and (2) driver-related problems of inattention, false assumptions, improper lookout, and impatience. The findings from the driver interviews, though interesting in- and-of-themselves, were not particularly helpful in the taxonomy development. That is, interviewing drivers did not add to what was learned from the database analyses and the investigating officer focus groups.

CHAPTER V. EARLY CONTRIBUTING FACTORS TAXONOMY

One of the general objectives of the project was to develop driver error taxonomies and to obtain a better understanding of the nature of driver error. The analyses described up to this point provided several good taxonomies and a variety of insights. Nevertheless, the need remained for a more rational explanation of driver behavior that contributes to crashes.

The results presented from the various studies conducted show that most crashes have more than one contributing factor and that there is a plethora of combinations that result in crashes. How does one assemble this myriad of results into a meaningful explanation? Is there a way to organize the findings such that most crashes can be explained in a single overall framework? This was the challenge set before the project team. After reflecting on this for some time, a hypothetical framework was developed that seems to fit most crash situations (Figure 14). The framework shown in Figure 14 is labeled the "early" Contributing Factors Taxonomy. As will be described in a later section, information obtained from the field data gathering effort lead to a revision in this taxonomy (hence this taxonomy is labeled "early").

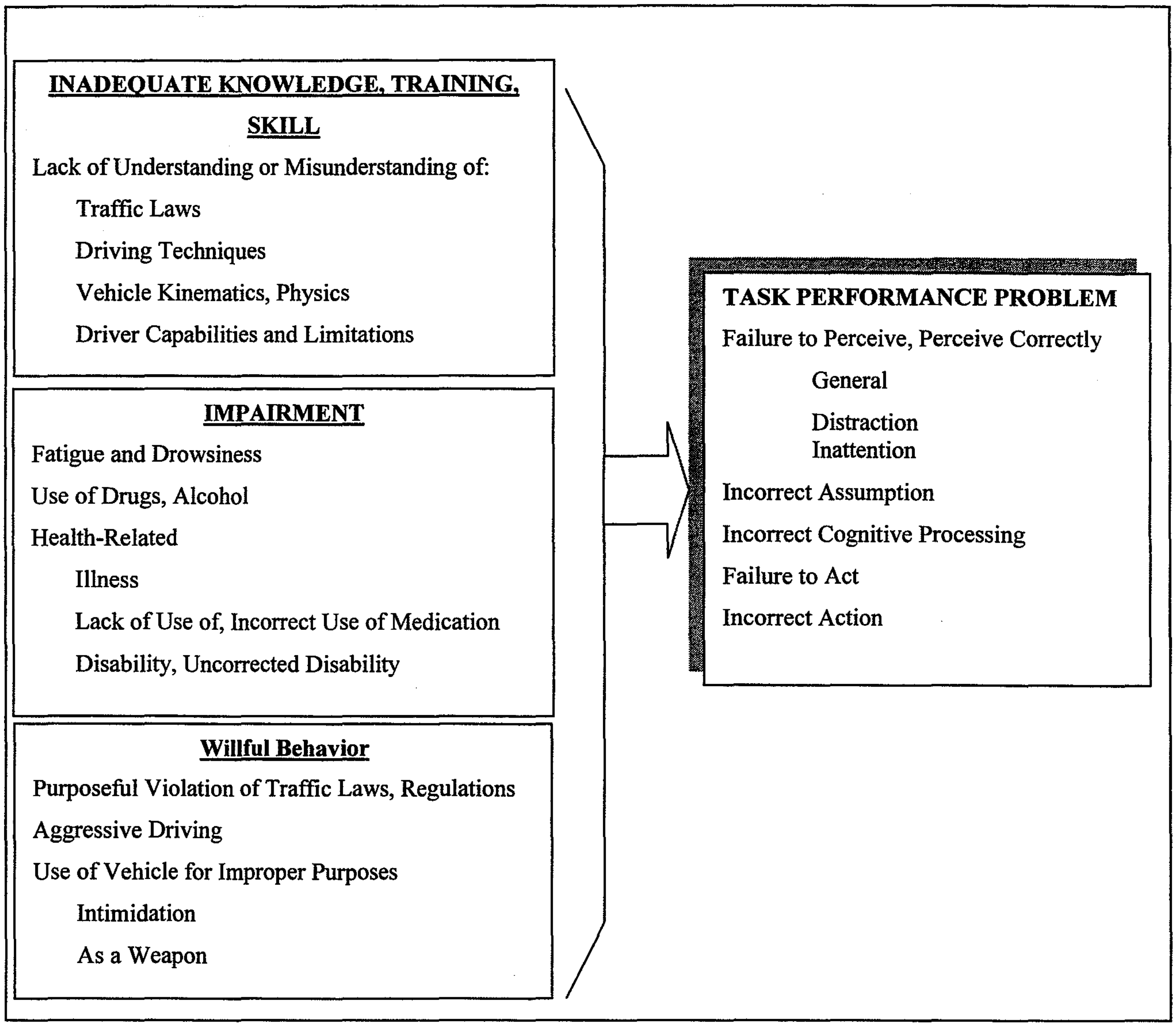


Figure 14. Early Contributing Factors Taxonomy.

As shown in Figure 14, there appear to be three main aspects of driver factors that contribute to task performance problems occurring in crashes. The first of these is "Inadequate knowledge, Training, Skill," the second is "Impairment," and the third is "Willful inappropriate behavior." Each of these aspects can be subdivided into individual factors. These individual factors may combine in unusual ways to influence driver task performance that results in a crash. Illustrative examples follow.

Assume that after a hard day's work, a driver starts driving home. The driver remembers something that should have been taken care of at the office and dials a cell phone to call the office. Because of impatience with traffic, the driver is also tailgating the vehicle in front. As a result of a sudden stop by the lead vehicle, the driver rear-ends the lead vehicle. Several factors may have contributed to this crash, including:

1. Lack of training on reaction times and stopping distances,
2. Lack of knowledge of risk associated with taking eyes off the road to dial the cell phone,
3. Fatigue due to the long day's work,
4. Aggressive driving by tailgating, and possibly,
5. Intimidation by following too closely.

The task performance problem associated with this crash is probably failure to perceive that the lead vehicle was braking (decelerating). Such a failure could be considered a result of distraction or inattention. While it is also true that the driver failed to act, the critical task performance problem would be failure to perceive. Similarly, the driver may have incorrectly assumed that the lead vehicle would continue to move at a more-or-less constant velocity. However, once again, failure to perceive the deceleration was the critical task performance problem.

As a second hypothetical crash scenario, consider a situation in which a driver leaves a party and on driving home discovers that it has been sleeting. The driver nevertheless momentarily finds by trying the brakes that adhesion is good. However, on passing over a bridge, the driver encounters glare ice, skids, and departs the roadway, striking the bridge structure.

The candidate factors contributing to this crash are lack of knowledge that bridge surfaces may freeze before ordinary road surfaces, possible alcohol involvement, and possible need for vision correction. The resulting critical task performance problem is probably failure to perceive correctly. If the roadway before the bridge had a warning about the bridge surface freezing, then failure to perceive (the message of the sign) would also be a critical task performance problem. (The critical task performance problem could also be considered to be an incorrect assumption that all portions of the road had good adhesion.)

These examples demonstrate that in most cases, there are combinations of factors involved as contributors to the driver's lack of proper task performance. The taxonomy shown in Figure 14 illustrates and explains how and why drivers do not always perform their tasks correctly. The fundamental concept is that various blends or weightings of factors on the left in Figure 14 contribute to one or more of the task performance problems shown on the right. This conceptual arrangement seems to provide a better explanation of why crashes occur. The conceptual arrangement also shows that, although these are indeed general classes of crashes, the details differ from one crash to another.

As previously indicated, the taxonomy shown in Figure 14 was an early version of the final taxonomy that was developed for this project. The revision to the taxonomy came during the field data-gathering portion of the project.

CHAPTER VI. FIELD DATA GATHERING OF INCIDENTS

INTRODUCTION

The information presented in this chapter provides an overview of the work that was conducted in Task E. For a complete description of Task E, the reader is referred to the Task E report (Wierwille, Kieliszewski, Hanowski, Keisler, and Olsen, 2000). As an overview, Task E consisted of several subtasks and objectives. They can be stated briefly as follows:

1. Use of the critical incident method (also referred to as the *Traffic Events Method*) in an experimental setting to determine the types of errors that drivers are making and to assess contributing factors.
2. Use of the critical incident method in an experimental setting as a means of uncovering infrastructure (i.e., roadway, signing, signaling, and alinement) problems.
3. The development of probability models of driver behavior to support occurrence likelihood as well as to provide improved understanding of driver behavior.
4. The development of a recommended procedure for conducting site analysis as a means of determining effective infrastructure changes.
5. The verification of driver error taxonomies associated with critical incidents.

Before proceeding further, it is important to define the meaning of the term "critical incident." A critical incident is a traffic conflict that includes a "near miss" in which at least one vehicle is placed in danger of a collision, with at least one driver having to take action to avoid a collision.

Another term used throughout this chapter that is important to define is "traffic event." This is defined as any event where a driver commits an error, and includes both events where there was a conflict (i.e., critical incident) and events where there was no conflict. For example, an event where a driver performs a rolling stop at a stop sign (i.e., does not come to a complete stop), but does *not* affect other traffic, would be classified as a "traffic event." A critical incident classification would be made if, for this same rolling stop event, the driver cuts-off another vehicle while performing the maneuver. Therefore, "critical incidents" can be viewed as a subclass of "traffic events" in which a conflict occurs.

The relationship between critical incidents and accidents has been well established. Sanders and McCormick (1987) note that there is evidence from various sources (e.g., Edwards and Hahn, 1980) that indicate that observed unsafe acts (i.e., "critical incidents") are closely related to accidents and injuries. Given that a strong relationship exists between critical incidents and accidents, critical incidents can be used as surrogates for studying accidents. This is an important consideration because, as Chapanis (1959) notes, accidents are rare events and people are often reluctant to report them. Therefore, by studying critical incidents (much less rare phenomena compared to accidents), the characteristics of the situation that could potentially result in an accident can be investigated.

Overview of Field Data Gathering

As indicated, Task E involved a wide range of subtasks and objectives. Figure 15 depicts the task elements of Task E in block diagram form. On the left are the main data gathering and data reduction elements. Briefly, data were gathered via videotape surveillance and simultaneous researcher/observer surveillance at 31 problematic traffic sites. While all of the sites were studied for one entire day, two of the sites were studied for five days in an effort to gain some understanding of time-of-day and day-of-week effects. The main purpose of the site surveillance was to detect and record critical incidents as they occurred naturally at the various sites. Shown in the middle part of Figure 15, multiple analyses were conducted with the site surveillance data. The completion of these analyses lead to a variety of results and products.

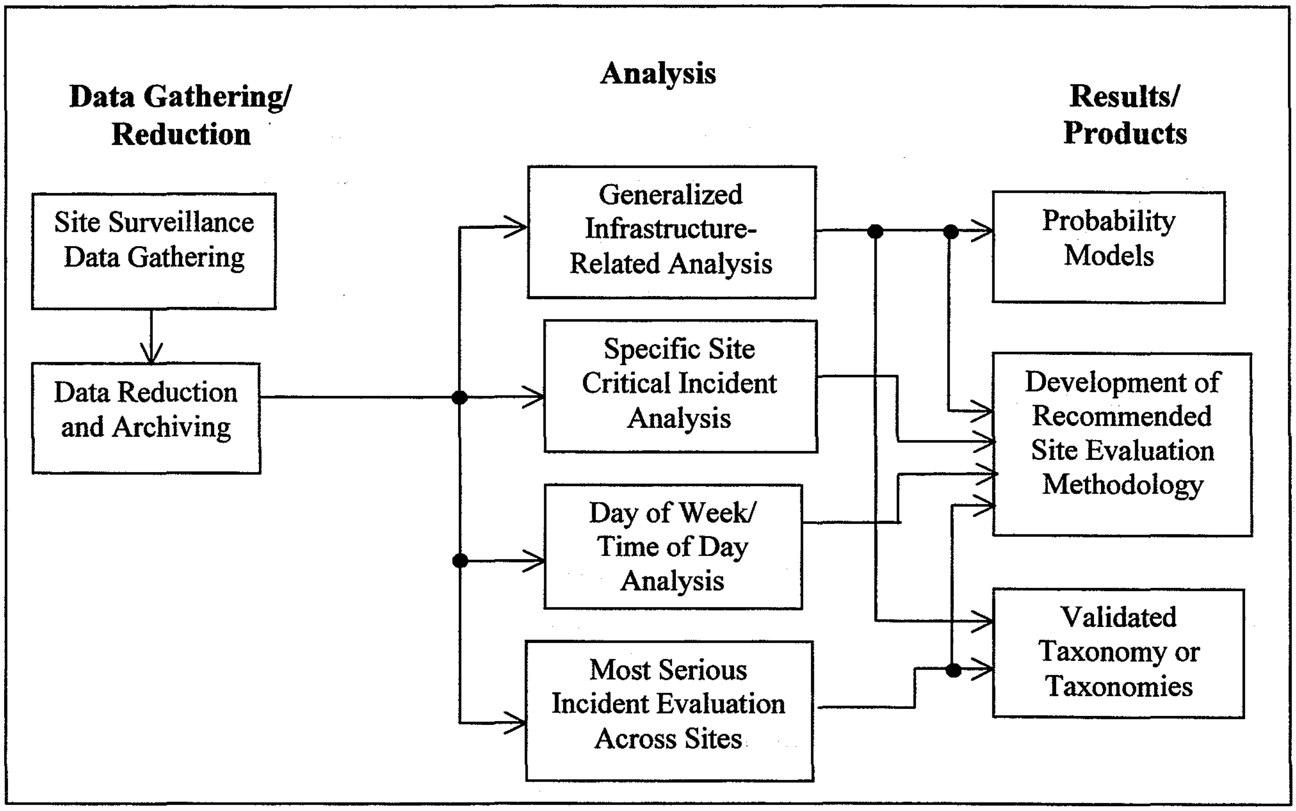


Figure 15. Task E subtasks and objectives.

The remainder of this chapter will highlight a select set of the subtasks and objectives outlined in Figure 15. (As indicated, the reader should refer to the Task E report for a full description of all work conducted under Task E.) Before moving on, it is important to point out that the study of critical incidents at select roadway sites is not new. For example, U.S. researchers Parker and Zegeer (1989a, 1989b) and European researchers Almqvist and Hyden (1994a) outlined the Traffic Conflict Technique (TCT) to investigate traffic conflicts at intersections (see also Almqvist and Hyden, 1994b; Svensson, 1998). This technique uses a trained observer and a data recording form, and bases conflicts on time to accident and conflicting speed. There are several differences between the TCT method and the method presented in this project report. Perhaps the two most distinguishing are (1) the inclusion of the four detailed analyses conducted for the present effort, and (2) the use of human factors principles in the analysis process and in the development of an evaluation methodology. It is suggested that the four analyses comprise a critical component of the methodology presented here, and the results from these analyses provide the necessary data to support the infrastructure and non-infrastructure related improvements that are recommended. In addition, as will be demonstrated, the application of human factors principles to the critical incident evaluation methodology is believed to improve on other approaches that are based solely on traffic engineering concepts and principles. For example, the inclusion of human factors principles allows for investigation of critical incidents from several perspectives (e.g., willful inappropriate behavior, inadequate knowledge/training/skill) that cannot be determined through traffic engineering principles alone.

DATA GATHERING/REDUCTION

Site Selection

One of the first steps in the data gathering effort was to select surveillance sites. To remain consistent with earlier driver error tasks, sites were selected to match the three regions defined in the Task C report: metropolitan/urban, medium-sized city, and town/rural (Hankey *et al.,* 1999). In determining specific locations, information obtained from the officer focus groups and the driver interviews (described previously) were used. In addition, because most of the sites selected were based in Virginia, the Virginia Department of Transportation (VDOT) crash prevalence data (Virginia Department of Transportation, 1996a; 1996b) were relied upon to aid in the site selection process.

A total of 151 sites were identified and initially considered for site surveillance. Upon careful assessment, 32 sites were selected for surveillance (the criteria used for selecting sites can be found in the Task E report). Twelve of these sites were in metropolitan areas, 10 were in a medium sized city, and 10 were in a town/rural area.

Data Collection Intervals

Once the sites had been selected, the data collection time intervals were determined. So as to maximize the amount of data collected, surveillance recording occurred during three peak traffic periods (from approximately 6:30 a.m. to 9:30 a.m., 11:00 a.m. to 1:00 p.m., and 3:30 p.m. to 6:30 p.m.). Note that because of variations in traffic flow and congestion, these time intervals varied somewhat from site to site.

For most sites, data collection occurred during a single day. However, data were collected at two of the sites for an entire work week (Monday through Friday). The reason for this additional data collection was to determine the impact of day-of-week and time-of-day on event occurrence. The sites that were selected for extended data gathering were two that had a relatively high number of documented traffic events from the single day observations and were generic in appearance (so that the data collected could be generalized to other sites with similar features).

Site Data Gathering Procedures

Data collection was performed in the same way regardless of region, location geometry, or whether data were being collected for the single day observation sessions or the extended (weekly) data gathering sessions. Six data gathering techniques were used to gain a full understanding of each location's geometry, control, surrounding environment, and driver behavior that would contribute to traffic events. The six techniques were: (1) videotape surveillance of the site, (2) experimenter annotations in the form of field notes, (3) in-vehicle drive through video, (4) site inventory, and (5) photography. (Note that the TCT does not include several of these techniques.) Perhaps the most interesting aspect of the site gathering procedure was the videotape surveillance technique. As such, a discussion of this technique is presented here. For a complete discussion of all six techniques, the reader is directed to the Task E report.

During the entire observational session, sites were videotaped using one color video camera to capture traffic events. The videotaping package consisted of a sheltered video camera, camera mount, external monitor, portable power supply, connection unit, and 50-foot cable. Figure 16 illustrates the videotaping package, and descriptions of the equipment are as follows:

- **Video Camera.** A Sony Handycam®Vision Camcorder (model CCD-TRV66) was used for video capture. The primary camcorder feature for this project was that it was capable of Hi8™ XR extended resolution, which extends the luminance bandwidth to provide improved image clarity in low contrast situations. Other features of this camera that were valuable to this project included:
    - SteadyShot® image stabilization for windy days,

- Titler that was programmed to time and date stamp the image,
- 20x optical/360x digital zoom that afforded camera placement at a safe and inconspicuous distance from the observation site,
- Audio/video output that allowed for remote viewing of the video image via a separate monitor, and
- Self-contained rechargeable InfoLithium® battery.

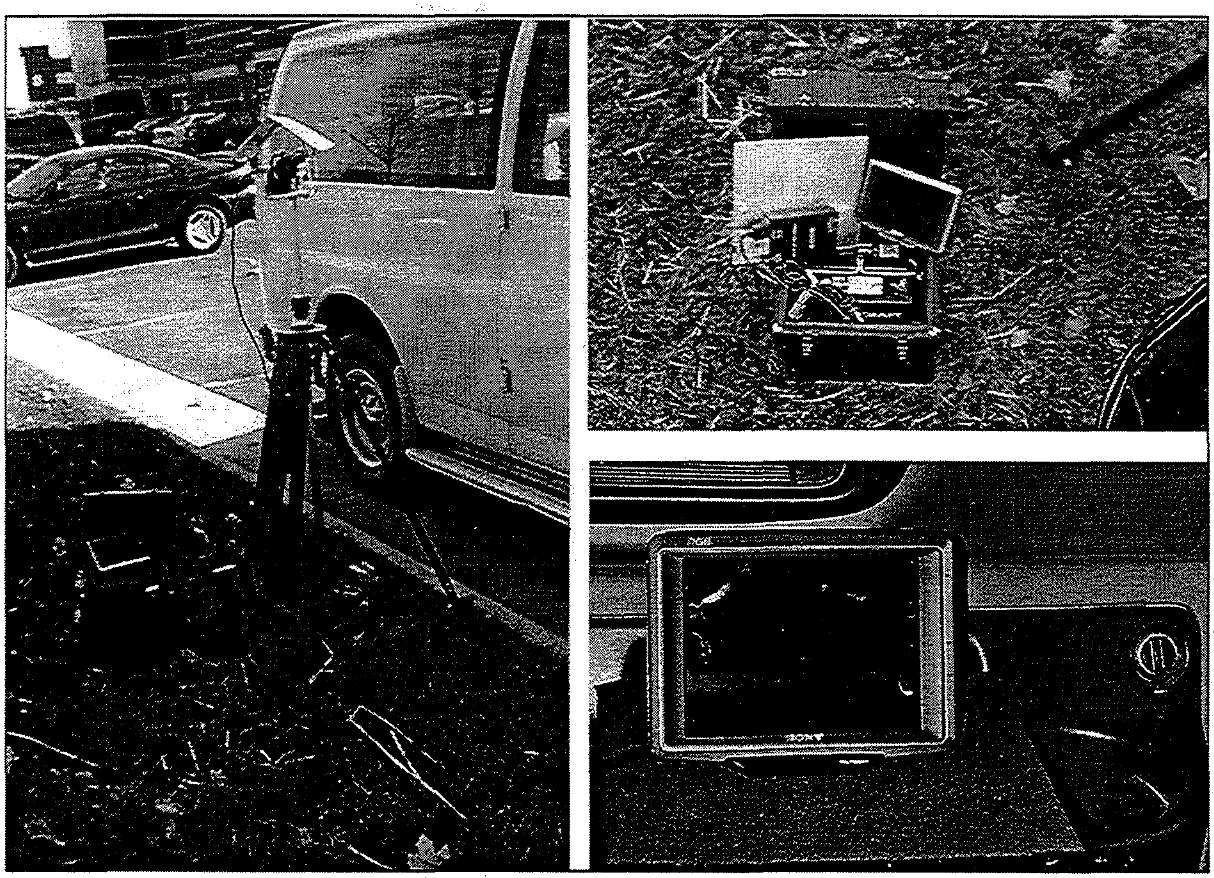


Figure 16. Videotaping package. Video camera set-up shown at left. Upper right shows components of the videotaping package. Lower right shows the monitor used for remote viewing.

- **Wide Angle Lens and Polarizing Filter.** A wide angle lens or a polarizing filter were added to the camera if the camera's zoom and optical features needed to be enhanced. Each camera had an additional wide angle lens to capture a larger image. One was a Sony VCL-ES06 37mm one-touch wide conversion lens (0.6x), the other was a Sony VCL-0637H wide conversion lens. The filter was a Tiffen® 37mm circular polarizer used to generate a clearer image by reducing glare and reflections from the sun, roadway, and vehicles.
- **Camera Shelter.** The camcorder was mounted within an open aluminum shelter to protect the camera from overheating that may have resulted from being in the sun for extended periods of time. (Data gathering took place over the summer and early fall months.)
- **Camera Mount.** A surveyor tripod with an antenna mast (SECO model #5300-11) was modified to accommodate mounting the camera and camera shelter. The tripod legs extended to approximately 5 feet 4 inches (1.63 m), and a solid mast was milled to telescope another 4 feet 0 inches (1.23 m) for a total linear height of 9 feet 4 inches (2.86 m). The camera mount allowed researchers to adjust the camera's vantage point to obtain an acceptable view of the site by adjusting the height of the tripod leg(s) (tilt) and turning the mast (pan).
- **Monitor.** A Sony RGB mobile color monitor system XVM-6100 was used as an additional monitor for camera set-up, remote viewing of the videotaping, and time/date stamp information. The XVM-6100 was a super slim design with a high resolution TFT active matrix monitor that allowed for audio/video inputs and RGB signal transmission.
- **Power Supply.** An AutoCraft™ lawn and garden 12-volt battery (part no. U1-3, group size U-1) was used to power the monitor.
- **Connection Unit.** A Sony connection unit XA-605 allowed for power hook-up (12V DC in) to the monitor with the power supply for camcorder video input and monitor output.
- **50-foot Cable.** Coaxial cable (RG59U MIL-C-170) was used to connect camera output with the connection unit and monitor.
- **8-mm Videocassette.** Hi8 videocassettes were used to provide higher image clarity and definition than that provided by standard 8-mm videocassettes.

The videotape was time and date stamped so that observed incidents could be easily found and identified for data reduction. Finally, efforts were devoted to making the instrumentation and the observers as inconspicuous and safe as possible. This was accomplished by setting up the videotaping package near the site and allowing the observers to monitor the site from a remote location or from within a van or passenger car (Figure 17).

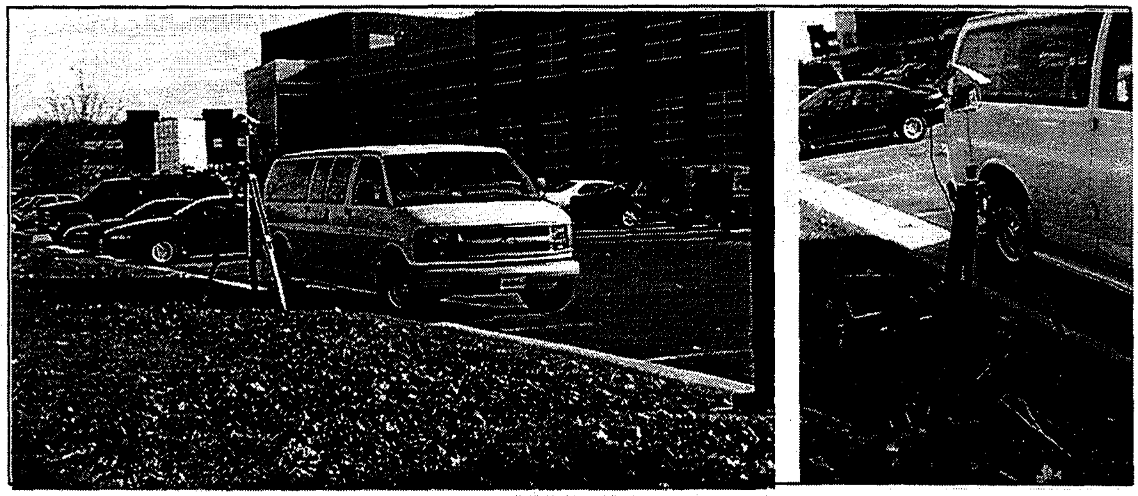


Figure 17. Van and camera set-up.

Data Reduction and Archiving

The data gathering effort resulted in the categorization of 1,262 traffic events and the extraction of contributing factors for each vehicle involved in the event. Each event was classified using a Traffic Event Rating Scale. The rating was used to differentiate and categorize the traffic events for further analysis. The Traffic Event Rating Scale expands upon the Conflict Severity Classifications used by Older and Spicer (1976) by including the conflict severities defined by Heinrich, Peterson, and Roos (1980) and the hazard categories defined by Dingus, Hetrick, and Mollenhauer (1999).

Initial plans were to use Older and Spicer's (1976) original severity categories, which included two "slight" and three "serious" grades. The two slight grades covered maneuvers such as precautionary braking, lane changes, and controlled braking, whereas the three serious grades covered more severe maneuvers such as rapid deceleration, emergency braking, and collision. However, it was found in preliminary traffic event evaluations that the Older and Spicer categories were too limited for the range of driving behaviors documented and captured on videotape. The Older and Spicer severity categories were intended for actual conflicts and do not account for driving aspects that do not result in a conflict such as poor driving technique, aggressive behavior, or willful action. Hence, because these aspects were considered to be important for the current study (under the umbrella of driver errors), the severity categories were expanded to include maneuvers regardless of whether they resulted in a near-crash or crash situation.

An iterative process was used to combine scales and definitions from three sources for purposes of generating the expanded rating scale. In its final form, the expanded severity rating scale encompassed all types of documented traffic events regardless of their impact upon the driver or other traffic. Table 11 operationally defines each of the severity ratings and lists the corresponding conflict severity and hazard category.

Table 11. Final Traffic Event Rating Scale and definitions and corresponding conflict severities and hazard categories.

Hazard Category	Conflict Severity	Severity Rating	Definition
Error, no hazard present	Negligible	1	Poor driving behavior that did not cause a conflict or result in an interaction with another vehicle or object. Commonly a single vehicle traffic event.
Error, hazard present	Marginal	2	Precautionary braking or lane change with minimal risk of a near-crash, such as blocking an intersection with very slow moving or stopped traffic or backing at an intersection when there is no vehicle to the rear.
Serious error, hazard present		3	Controlled acceleration, deceleration, lane change, and/or a warning behavior such as sounding the horn with slight risk of a near-crash, such as tailgating.
Near-crash	Critical	4	Rapid controlled acceleration, deceleration, lane change, or stopping to avoid a crash.
Serious near-crash		5	Emergency braking or violent swerve to avoid a crash, resulting in a very near-crash situation.
Non-injury crash	Catastrophic	6	Crash resulting in only property damage.
Injury crash		7	Crash resulting in bodily injury and/or property damage.
Fatality		8	Crash resulting in death and/or severe property damage.

Once all events had been assigned a severity rating, the events were then divided into one of two groups: (1) traffic events of low severity but with a high frequency of occurrence and (2) traffic events of high severity but with a less frequent occurrence. The severity categories in the Traffic Event Rating Scale were divided into two groups with Severity 1 and Severity 2 comprising the first group, and Severity 3 and greater comprising the second group.

Events of low severity have been found to occur with a high frequency of occurrence (Dingus *et al.,* 1999; Heinrich *et al.,* 1980). With this in mind, it was determined very early in data gathering that the researchers would not be able to document every low severity event. Thus, it was understood that the low severity events would be sampled.

The maneuver lists for each location were then combined to generate a master list of maneuvers that drivers exhibited but that did not appear to cause any traffic anomalies. To determine the frequency of occurrence of the low severity events compared to higher severity events, a 15-minute sample from each observation period at each location was performed. It was assumed that the occurrence of the low severity events remained constant throughout the observational period. The 15-minute sample periods were the same as those used to calculate traffic counts.

Higher severity events were all analyzed (they were not sampled) because of their fewer numbers. The events noted in the experimenter annotations (notes) were used to find and identify the traffic events on video. Once located on videotape, the event was reviewed as often as needed by the data reduction analyst to extract the required event information for inclusion in the database. The analyst was also required to update any inaccurate or incomplete information from the field notes. Data the analyst extracted from the video included weather, roadway and traffic conditions, event description, number of vehicles involved in the event, and contributing factors for each vehicle. In addition, the analyst was to assign a more accurate severity rating to the event if, after having reviewed the event on video, the initial severity required revision. It should be noted that the same data reduction process was performed on the *sampled* events with a severity rating of 1 or 2.

A data reduction software program was developed for this project. This program, detailed in the Task E report, facilitated the extraction and archiving of a wide range of information about the event. The data extracted using the software program was used in the multiple analyses that were conducted. An overview of these analyses, and the subsequent results, are presented in the next section.

ANALYSES

Four analyses were conducted on the data that were extracted from the event video recordings. These analyses consisted of:

- The Most Serious Incident Analysis,
- Specific Site Critical Incident Analysis,
- Day-of-Week/Time-of-Day Analysis, and
- Generalized Infrastructure Analysis/Probability Model Development.

A complete description of each of these analyses and the results are presented in the Task E report. Abridged discussions of these analyses are presented in this section.

Most Serious Incident Analysis

Description and Purpose

As has been described previously, the critical incidents at each site were graded in terms of severity. The purpose of the most serious incident analysis was to analyze the incidents with the highest level of severity and examine the patterns of occurrence. It could be argued that the incidents rated as most severe would be the most indicative of crash likelihood.

Part of the reason for performing this analysis was to determine how the results would compare to the accident database-derived taxonomies presented in the Task C report. If there is a reasonable level of correspondence, then it may be concluded that incidents are indeed indicators of crashes. Of course, one-to-one correspondence should not be expected because of the major differences in analysis procedures.

General Methodology

The first step in the analysis procedure was to gather and re-record all high-severity incidents on a single videotape. An analyst accessed each level 5 and level 6 incident from the traffic event database, found the corresponding location on a videotape, and then re-recorded the incident. The analyst also downloaded the corresponding reduced event data and description to a new file that was then printed out for further study.

Note that level 6 involves collisions/physical contact between vehicles or between a vehicle and an object, but without injury. (There were no incidents higher than level 6 in the data set.) Level 5 incidents involved close calls in which substantial braking or emergency maneuvering was necessary to avoid a collision. There were 52 incidents at levels 5 and 6: 46 incidents at level 5 and 6 incidents at level 6.

The overall results of the traffic event analysis show that frequency of occurrence increases as the severity level decreases. Figure 18 shows these results for severity ratings from 3 to 8. The decision was made to include levels 5 and 6 in the current analysis because the number of such incidents was manageable for detailed analysis, and as stated, the more severe incidents were more likely to be indicative of crashes.

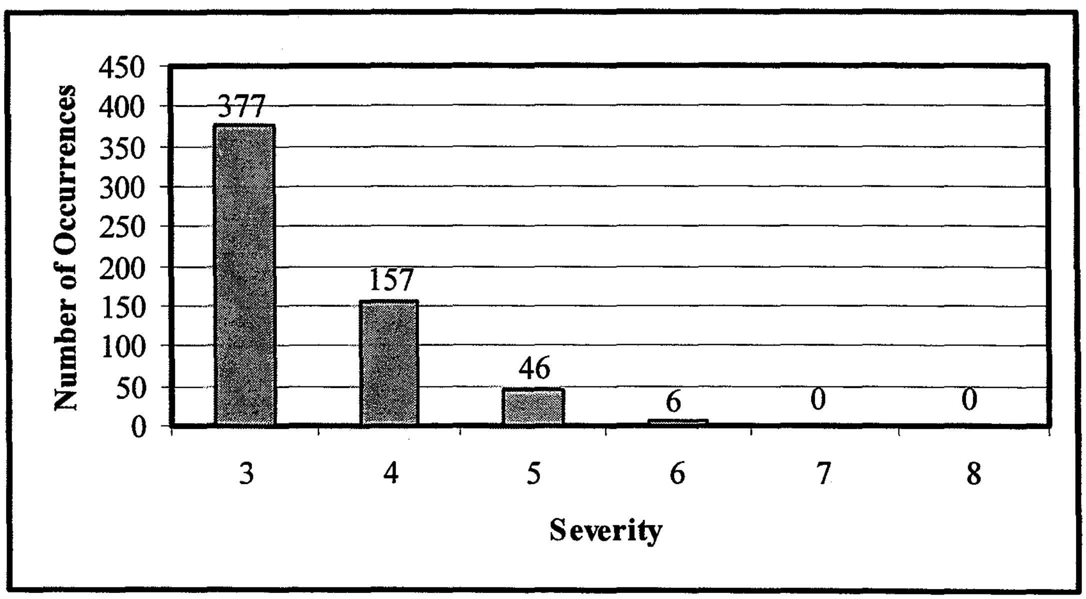


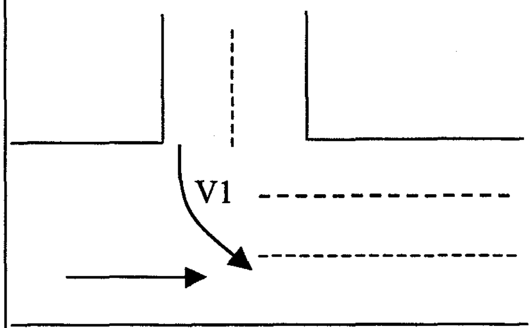
Figure 18. Incident occurrence by incident severity rating (for levels three and above).

Once the video and other data were in hand, the incidents were individually studied in detail. A master sheet was developed, and each incident was diagrammed and analyzed. Figure 19 shows a typical master sheet. As can be seen, the sheet contains data about location type (metropolitan/city/town), the type of site (intersection or roadway), the severity rating, the contributing factors in the various categories, and the "principle contributing factor," which is circled.

It is important to note that in many incidents, more than one driver was a contributor to the incident. For example, one driver may have performed an inappropriate maneuver and another driver may have responded inappropriately. However, analyzing these very complex interactions proved to be unwieldy and made categorization difficult. Therefore, the master sheets were always developed in terms of the driver who initiated the incident. Correspondingly, the initiating driver's vehicle was designated as V1 (i.e., Vehicle 1) in the diagrams.

Location No. *4* Tape Sequence No. ***M-75*** Location Type: M C T

Sketch:



Location Descrip: Signalized
Signed
Merge
Exit
Roadway

Other: ***T-intersection***

Severity Rating: *5*

Incident descriptive phrase:
Left turn at T-intersection into wrong lane.

Contributing factors (Circle Principle Factor)
Inadequate Knowledge, Training, Skill

Lack of understanding or misunderstanding of traffic laws. Did not read or did not understand sign. Lack of familiarity with intersection.

Impairment
(None)

Infrastructure~~, Environment~~
Roadway alignment
Lane direction change between morning and evening rush
TCD
Signing is difficult to understand

Willful Behavior
(None)

Failure to perceive correctly (general)

Inattention

Task Performance

Incorrect action
Turn into wrong lane

Figure 19. Example of a master sheet for a serious incident.

As indicated, a single master sheet was developed for each of the 52 incidents. The concept was to summarize on a single sheet the essence of the incident and its contributing factors. It should be noted that there are certain limitations on what can be learned from observation alone. For example, it may not be possible to determine whether a driver simply did not understand a certain element of traffic law or was knowingly violating that element. In the master sheets, this can result in redundant statements where there is no way to resolve an issue. In addition, certain aspects of driver impairment are difficult to discern. As an example, a driver under the influence of alcohol may have initiated an incident, but it would be difficult to determine alcohol involvement without corroborating evidence. In a few cases there was additional information. For example, the driver may have behaved erratically *after* the incident, thereby providing greater evidence of alcohol or drug involvement. Nevertheless, it is to be expected that the driver impairment category in the master sheets under-represents the true magnitude of impairment among drivers. Notwithstanding these shortcomings, the analysis technique is believed to be a powerful approach in determining infrastructure and driver performance problems.

With the master sheets developed, the following specific analyses were conducted: (i) Incident Description Analysis, (ii) Principle Contributing Factors Analysis, (iii) Willful Inappropriate Behavior Analysis, (iv) Knowledge and Driving Technique Problems Analysis, and (v) Infrastructure Analysis. The highlights of each of these analyses are presented next.

Incident Description Analysis

The most accurate and non-controversial data contained in the master sheets was the "incident descriptive phrase." The purpose was to indicate "what happened" in as few words as possible. These descriptions might be considered as analogous to brief accident reporting form statements.

The descriptions of the 52 incidents were placed in a decision-tree taxonomy where the first level of categorization was metro/city/town. Metro in this case refers to data taken in the Washington, D.C./Northern Virginia metropolitan area; City refers to data taken in and around Roanoke, Virginia, a medium size city; and Town refers data taken in and around Blacksburg, Virginia, a moderate size town. The taxonomy appears in Figure 20a, and detailed taxonomies for each location type are shown in Figures 20b (Metro), 20c (City), and 20d (Town).

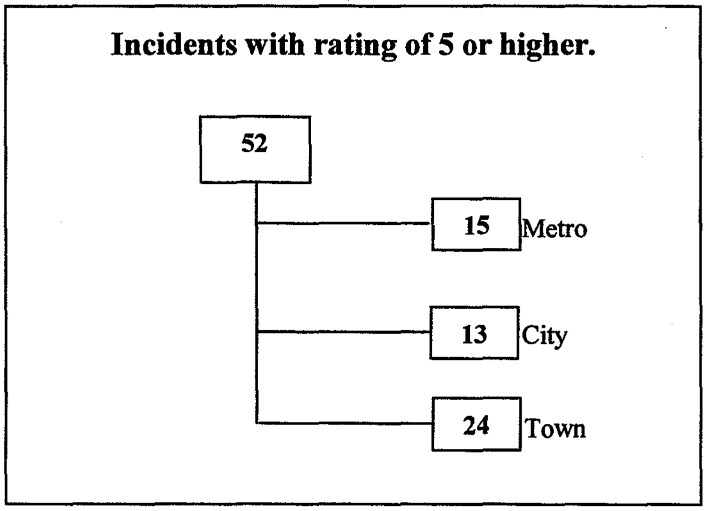


Figure 20a. Incident Description Taxonomy by Metro/City/Town categorization.

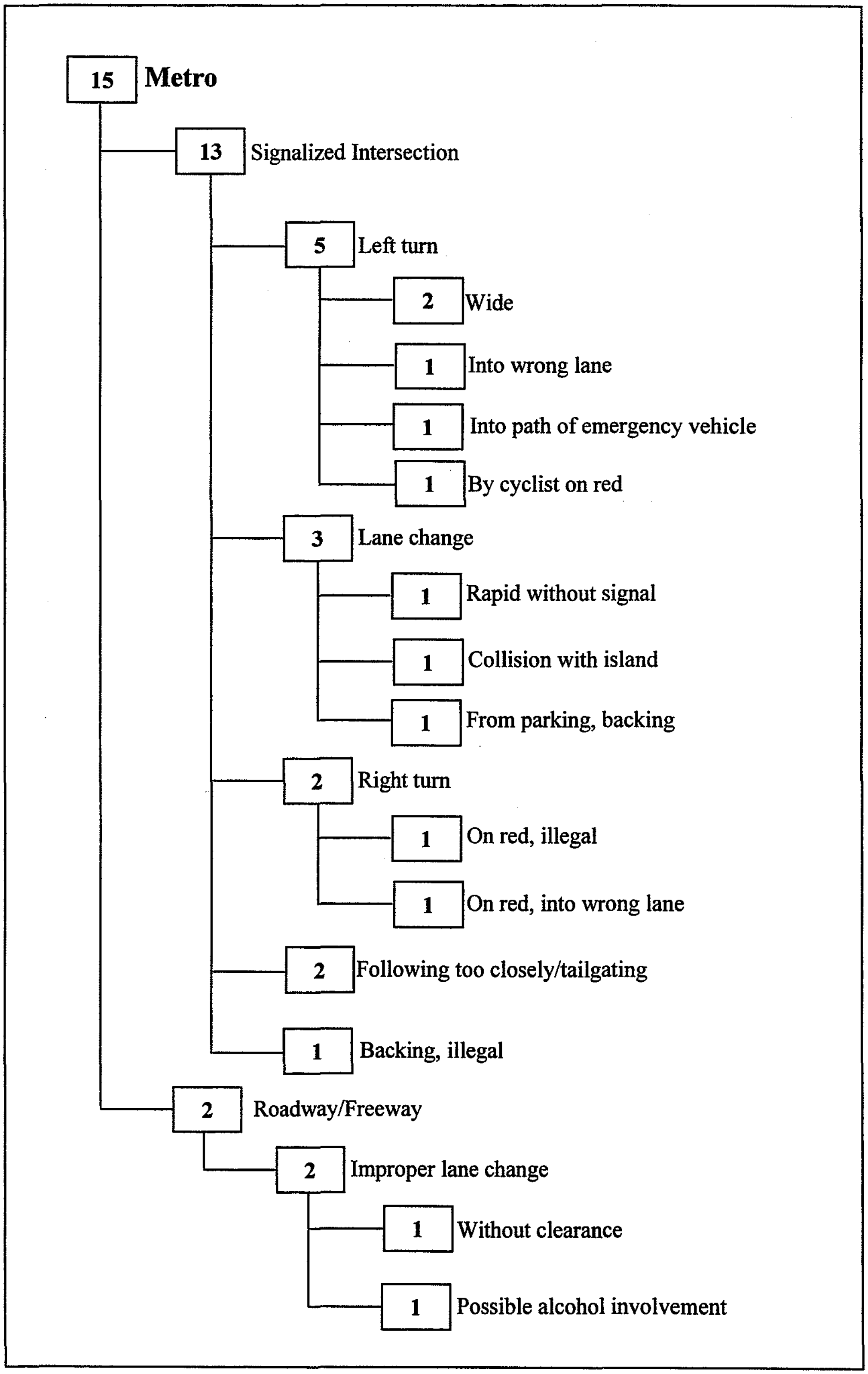


Figure 20b. Incident Description Taxonomy by Metro/City/Town Categorization.

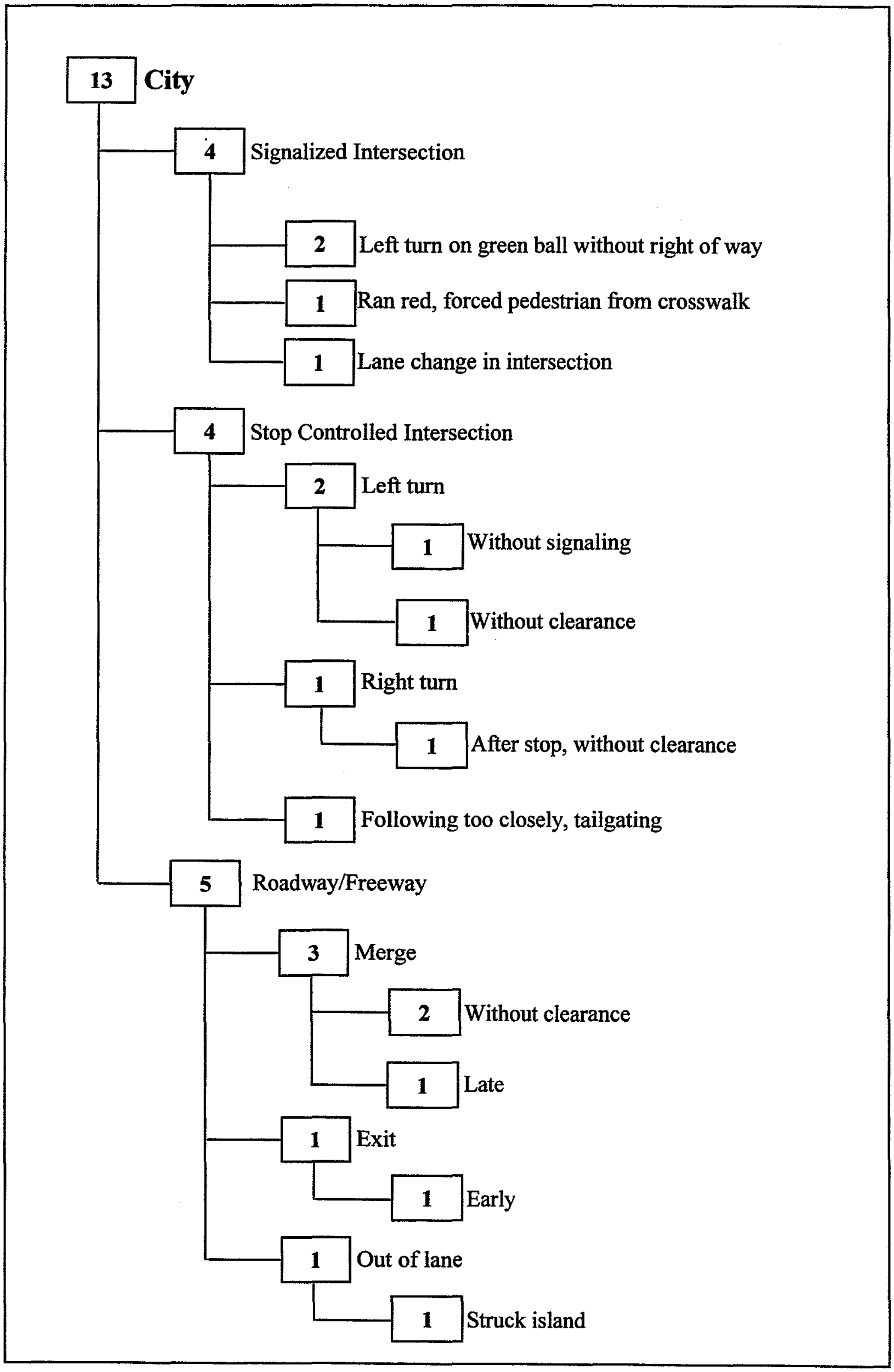


Figure 20c. Incident Description Taxonomy by Metro/City/Town Categorization.

- **24 Town**
  - 4 Signalized Intersection
    - 2 Left turn without clearance (right of way)
    - 1 Right turn without clearance (right of way)
    - 1 Straight Through
      - 1 Failure to yield to pedestrian in crosswalk
  - 11 Stop Controlled Intersection
    - 6 Through/Straight
      - 5 Failure to yield to cross traffic
      - 1 Failure to yield to pedestrian in crosswalk
    - 4 Left turn
      - 2 Without clearance (right of way)from oncoming traffic
      - 2 Without clearance (right of way)from cross traffic
    - 1 Right turn
      - 1 Without clearance from cross traffic
  - 5 Roadway
    - 4 Improper lane change without clearance
    - 1 Improper backing
  - 4 Merge
    - 2 Illegal right turn across merge lane
    - 1 Into wrong lane without clearance
    - 1 Rear-end collision in merge

Figure 20d. Incident Description Taxonomy by Metro/City/Town Categorization.

An important consideration in the first level categorization is exposure. The amount of data gathered in the three types of environments was not the same, primarily because additional data were gathered in the city and town environments to complete the time-of-day and day-of-week analyses (described later). For the metropolitan environment, approximately 67 hours of data were gathered; approximately 95 hours of data were gathered at both the city and town environments. Noting the number of serious incidents in Figure 20 and the number of hours of exposure, it is possible to calculate the number of incidents per hour. These values are 0.224 (15/67) serious incidents per hour for the metropolitan environment, 0.137 (13/95) for the city environment, and 0.253 (24/95) for the town environment. As will be shown later, the town environment results were heavily influenced by a two-way stop controlled intersection. This intersection had numerous incidents and probably could easily have met warrants for signalization.

The second level of characterization shows that there is reasonable correspondence among the three environments. In particular, "Left turns at intersections," whether signalized or signed, are problematic. Fifteen of the 52 incidents were associated with left turns. Several other categories can be gleaned from the taxonomy. Figure 21 shows one such arrangement, where it can be seen that "Lane changes," "Right turns," and other "Failures to yield" are prominent. In addition, "Improper merges/exits" and "Failure to yield to pedestrians" incidents are contributors, as are "Backing" incidents. In explaining this histogram, it is important to note that most of the left turn and right turn problems are "Failure to yield" problems of one type or another. Thus, "Failure to yield" is an extremely important factor in serious incident occurrence even though it does not show up as such in the histogram.

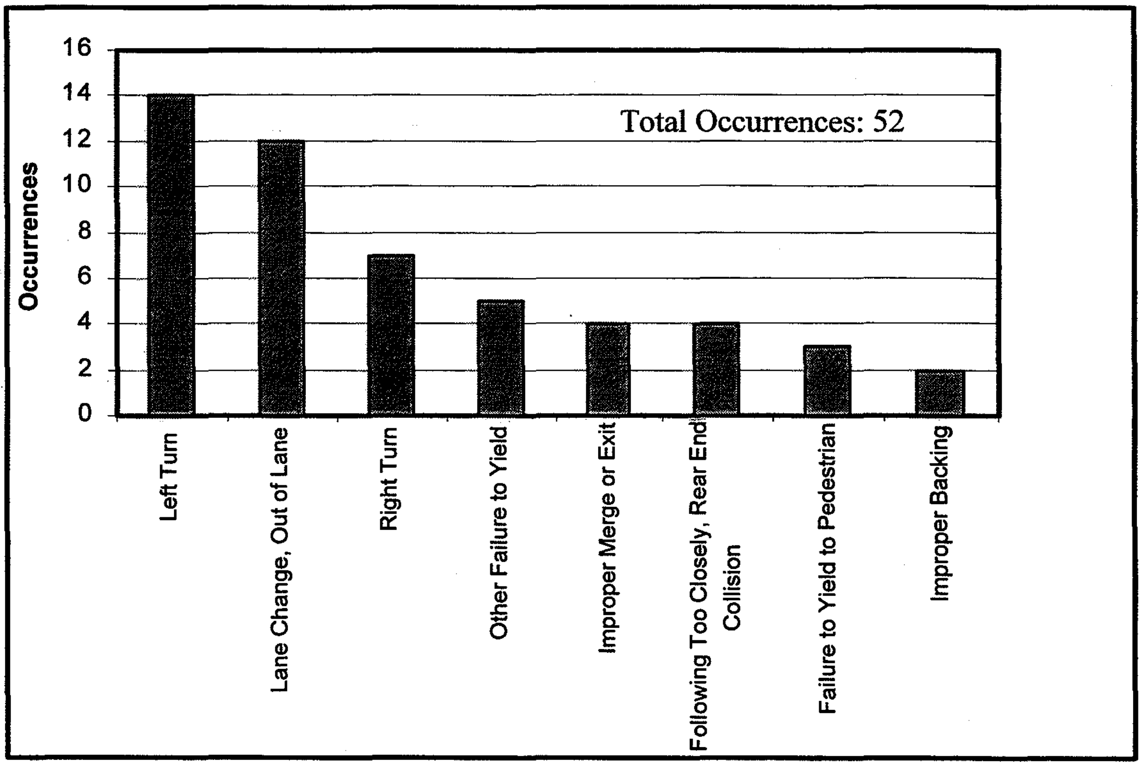


Figure 21. Occurrences by selected major categories. (Note that several categories implicitly involve failure-to-yield incidents.)

In the way of comparison with the results of Task C (Hankey *et al.*, 1999), the uniform sample of narratives shown in Figure 22 shows a degree of similarity to the results of Figure 21. In particular, the "Failure to yield at intersection" shows that many of the critical incident results correspond to the accident database narrative uniform sample of results. (Further comparisons can be drawn by examining the taxonomy associated with Figure 6a of the Task C report, Hankey *et al.,* 1999). In particular, many of the "Failure to yield at intersection" branches involve left turns, right turns, and other types of failures to yield. Additionally, similarities exist for the categories of "Lane changes," "Backing," and "Following too closely/Rear-ending." However, "Rear-ending" is more prevalent in the accident taxonomy than is "Following too closely" in the incident occurrence distribution. In general, though, there is substantial similarity.

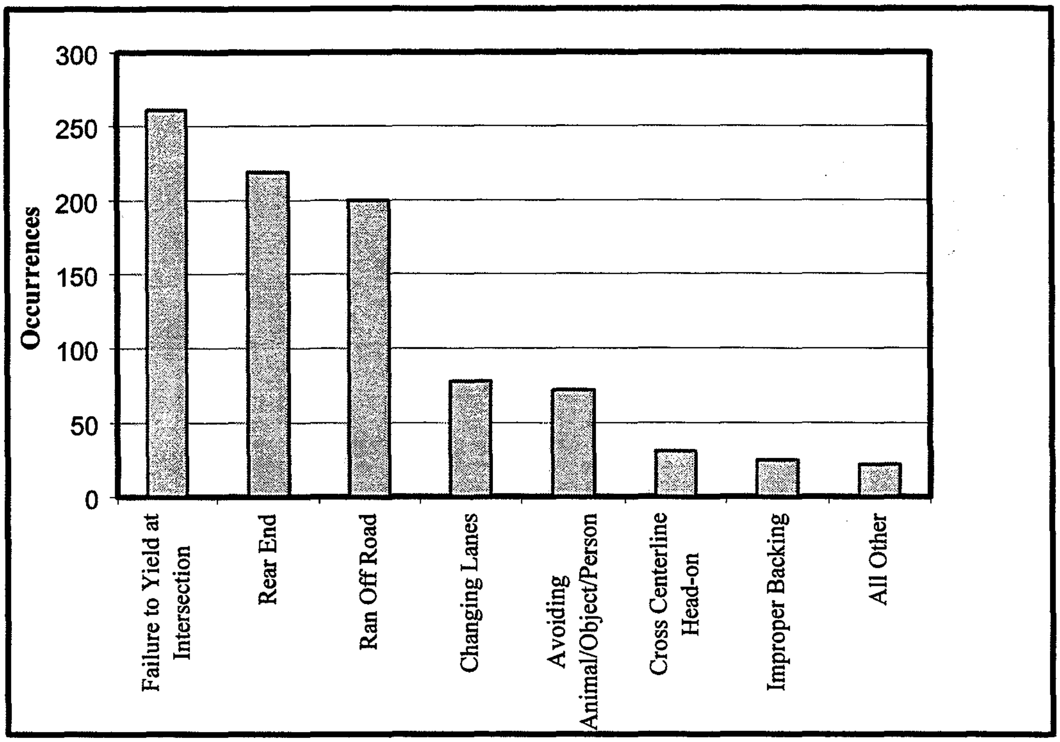


Figure 22. Reproduced form of Figure 6a of the Task C report. (Major categories of the uniform accident database sample.)

Principle Contributing Factors Analysis

As mentioned, for each serious incident, the analysts selected a single category on the summary sheet as the "principle contributing factor."

A principle contributing factor is one that contributes most heavily to the incident occurrence. The idea is similar to "proximate cause" in litigation, which uses the test phrase, "But for... the accident would not have occurred." In other words, given the constraint that only one factor may be chosen, what factor had the most influence on the occurrence of the incident?

With one principle contributing factor per serious incident, the 52 resulting occurrences could be plotted as shown in Figure 23. The results are surprising in that they show that "Willful inappropriate behavior" is the principle contributor to more than half of the incidents. "Inadequate knowledge/driving technique" ranked second in occurrences with slightly less than one-fourth of the incidents under this heading, and "Infrastructure" ranked third with approximately one-fifth of the incidents listed under this heading.

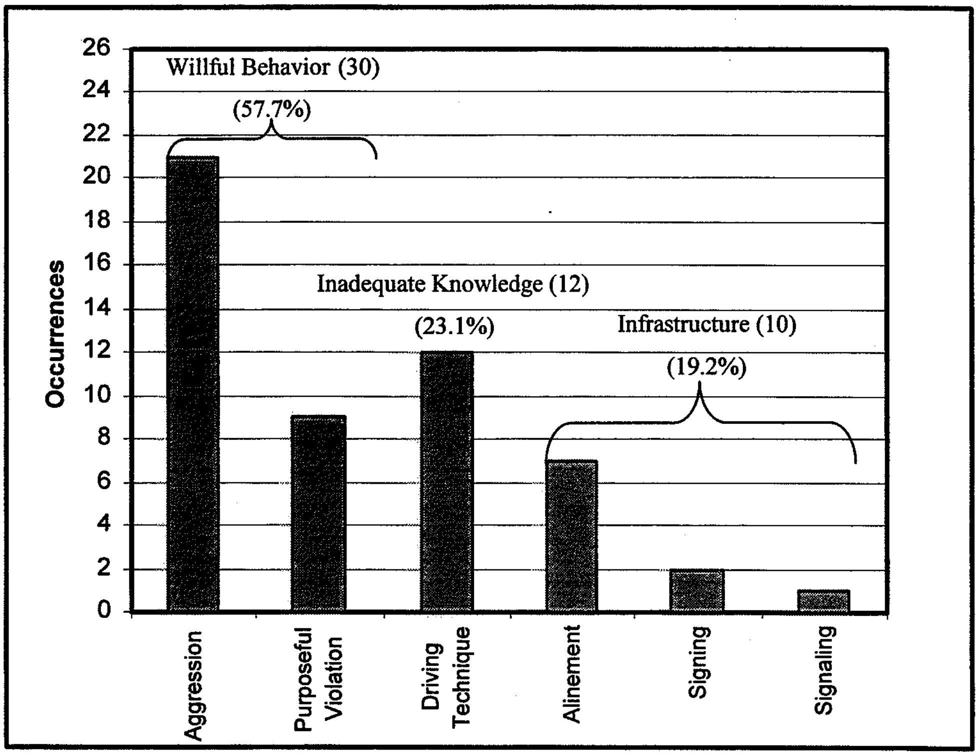


Figure 23. Distribution of Principle Contributing Factors.

Willful Inappropriate Behavior Analysis

The results presented in the previous section indicate that willful inappropriate behavior is a major contributor to serious incidents. To examine willful inappropriate behavior in more detail, *all* willful inappropriate behavior factors listed on the summary sheets were studied (not just those with willful inappropriate behavior as the *principle contributing* factor). To accomplish this, the descriptions were extracted from the summary sheets and then placed in categories that seemed to provide the best fit to the data. In all, 56 such factors were extracted from 36 summary sheets. Obviously, some of the sheets listed more than one willful inappropriate behavior factor, and a few had more than two. The willful inappropriate behavior factors were then placed in a taxonomy (Figure 24). "Aggressive driving" (n=37) and "Purposeful law violation" (n=19) were identified as the two categories of willful inappropriate behavior that were prominent in the data.

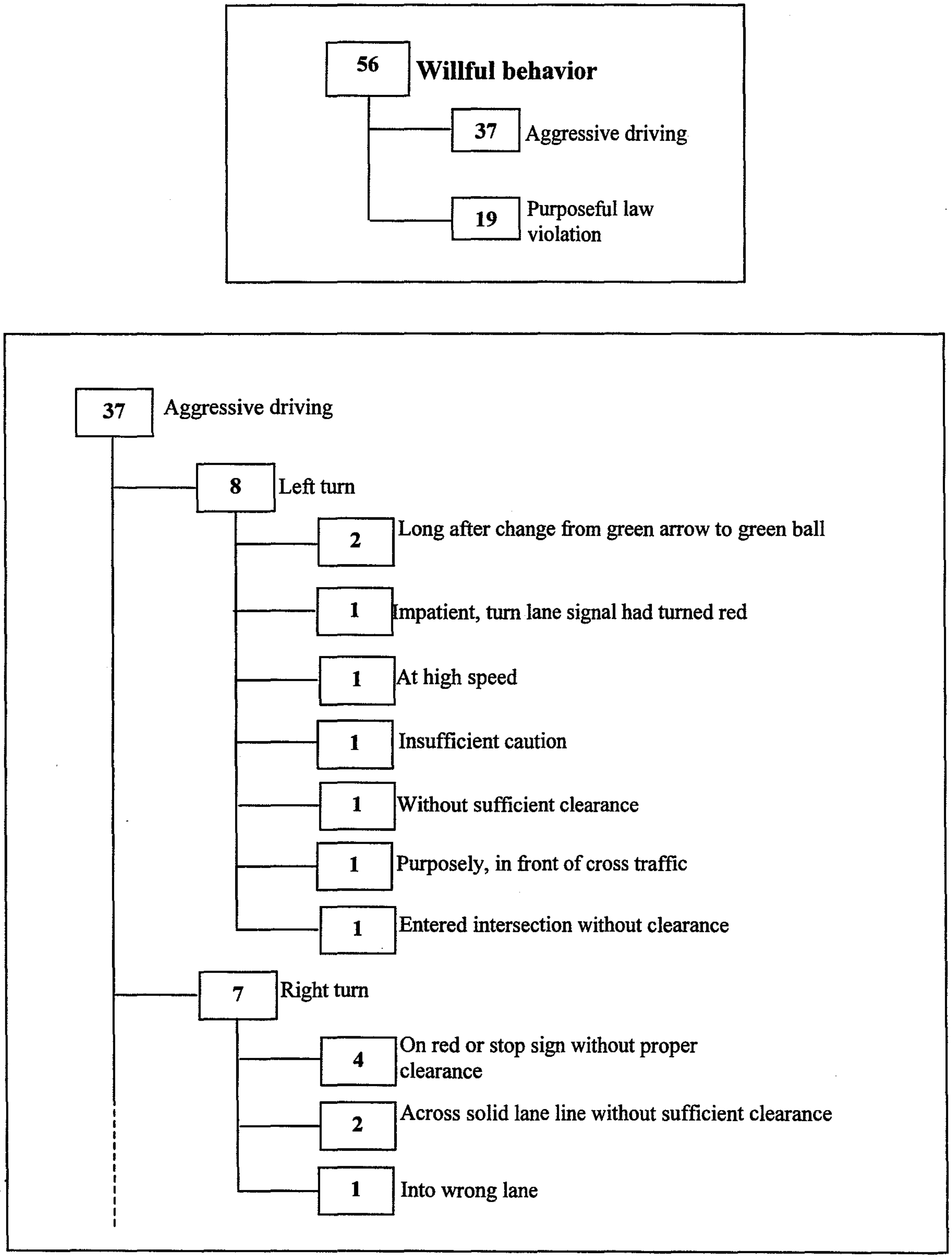


Figure 24. Taxonomy of willful inappropriate behavior contributing factors.

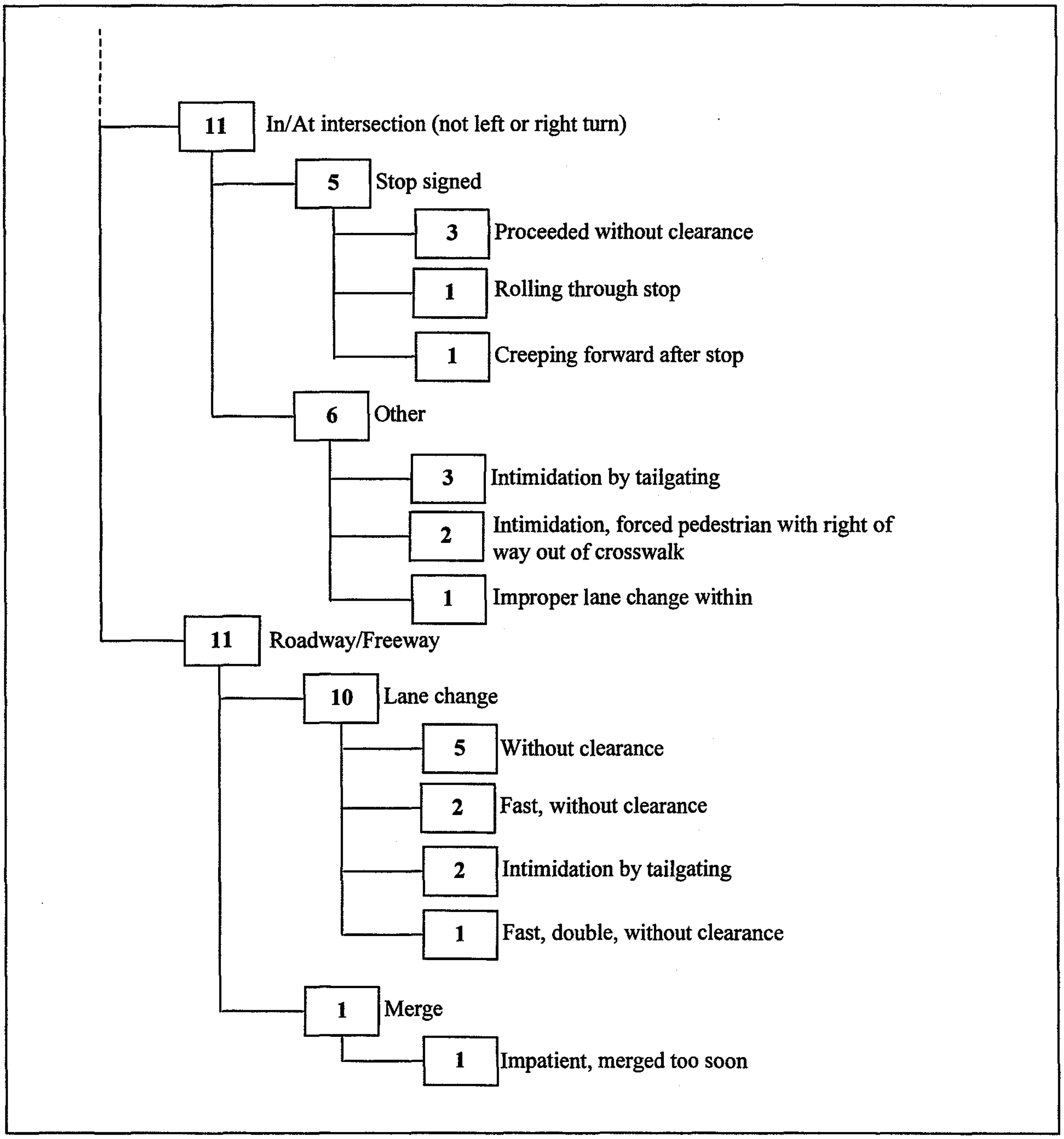


Figure 24. Taxonomy of willful inappropriate behavior contributing factors (continued).

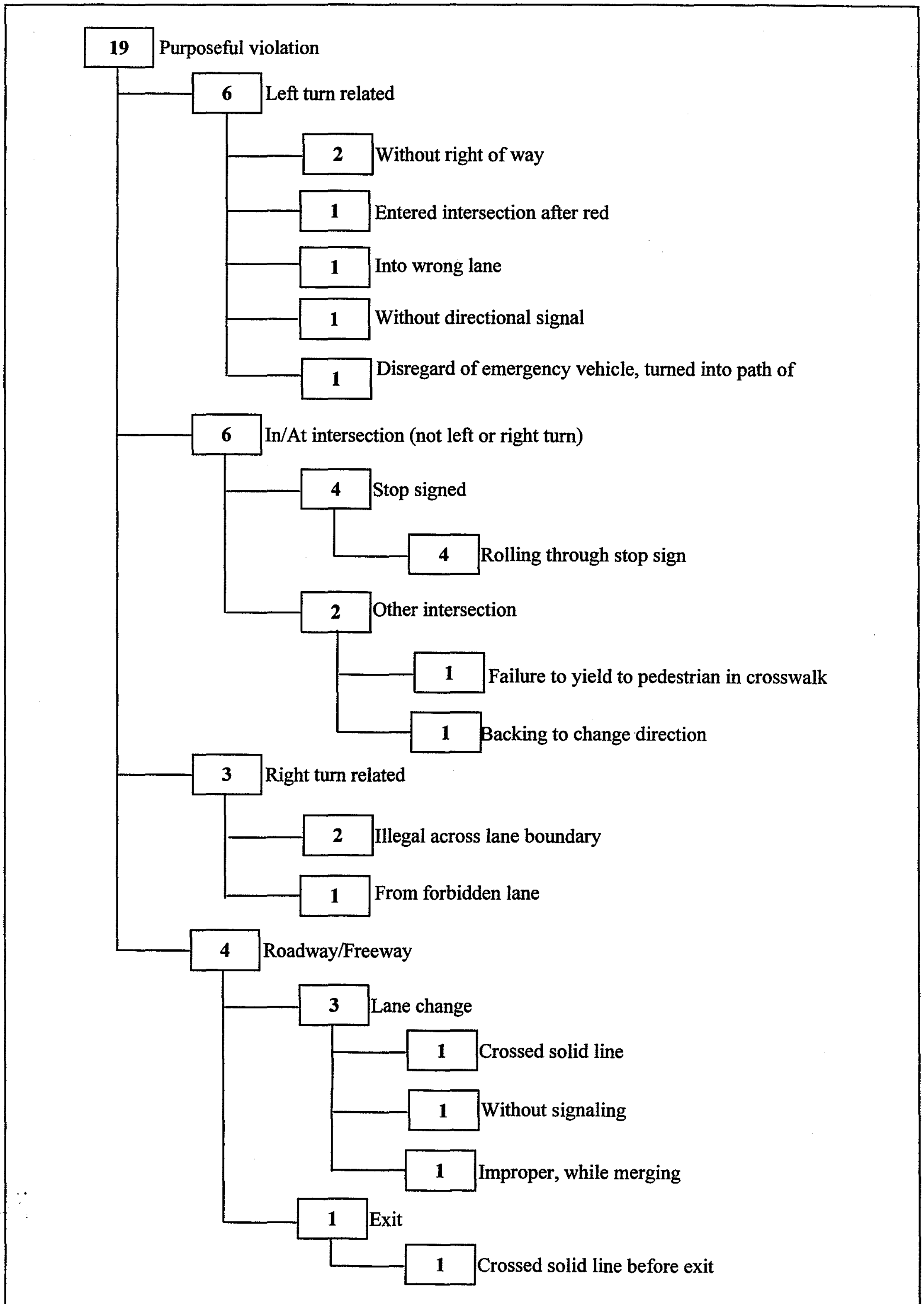


Figure 24. Taxonomy of willful inappropriate behavior contributing factors (continued).

The results from this analysis indicated that left turns (and to a slightly lesser degree, right turns) are prominently associated with willful inappropriate behavior. Behavior at intersections (other than left and right turns) is also a source of problems. Acts of intimidation and failure to yield to pedestrians are particularly troublesome. Finally, roadway and freeway problems occur with relatively high frequency; these occurrences primarily involve improper lane changes, merges, and exits. It is acknowledged that almost all drivers have a lapse in behavior from time to time; however, when this behavior results in a critical incident, the matter is more serious. This analysis shows that much remains to be done in the area of driver attitudes and behavior modification.

Problems with Knowledge and Driving Technique

As indicated previously, driving technique can also play a role in incidents. Recall that nearly one-fourth of all principle contributing factors were attributed to driving technique (Figure 23). Therefore, in a manner similar to the willful inappropriate behavior analysis of the previous section, *all* knowledge and driving technique factors were extracted from the summary sheets and categorized. In total, 71 contributing factors were extracted. Almost all of the incidents (49) had at least one factor listed, and many had more than one. The top factors, listed in descending frequency of occurrence, were: "Lack of proper visual scanning" (n=12), "Left turn without proper clearance/right-of-way" (n=11), "Lane change without proper clearance" (n=7), "Right turn without proper clearance/right-of-way" (n=6), and "Rolling through stop sign" (n=5). Twelve other factors were identified, each with a frequency of four occurrences or less.

The results suggest that in some circumstances drivers may not be aware that their behaviors involve improper driving technique, or inadequate knowledge of proper driving technique. However, as mentioned, the line between driving technique and willful inappropriate behavior is often not clear. The combination of improper technique and willful inappropriate behavior seems to suggest that driver education and behavior modification could potentially lead to a reduced number of incidents.

Infrastructure Analysis

The infrastructure analysis was conducted in a manner similar to the previous analyses. In total, there were 38 entries for infrastructure in the incident summary sheets. Of the 38 entries, 22 of them appeared singly on the master summary sheets, and 8 appeared in combination with a second factor. Thus, 30 of the 52 summary sheets contained one or more infrastructure contributing factors. The Task E report provides a complete list of the infrastructure contributing factors that were identified. A sample set of factors is shown in Table 12. Note that for each factor, an applicable portion of the Manual on Uniform Traffic Control Devices (MUTCD, 2000) and/or the so-called AASHTO "green book" (1994) are also cited. These citations are intended to show what current practice is with regard to the infrastructure contributing factor. In some cases, the infrastructure factor conflicts with existing practice, and in other cases it is not fully covered.

The listing shows that the great majority of infrastructure factors are associated with intersections, and fewer numbers are associated with merges, exits, and construction sites. Considering that much of the surveillance was at intersections, particularly those having high accident rates, it is not surprising that the infrastructure problems uncovered were at intersections. The most prevalent occurrence was use of two-way stop signs at an intersection that would likely have passed warrants for signalization. This was followed by factors at a combined merge/exit interchange with ramps that were believed to be too short, and a construction zone that created traffic backups/tie-ups during rush hour. All other factors were cited either twice or only once.

The results of this analysis suggest that many of the infrastructure factors became quite obvious to analysts reviewing the incident videotapes and the corresponding site diagrams. As in the specific site analysis (to be discussed next), problems with infrastructure appear to be relatively easy to uncover.

Table 12. Partial list of infrastructure contributing factors by prevalence, with relevant sections of standard practice documents cited. (See the Task E report for the complete list.)

Occurrences	Description	Relevant Citations
10	Intersection traffic volume appears too high for two-way stop signing.*	Section 4C, Warrants, MUTCD.
4	Short entrance ramp into freeway combined with short exit ramp.	Ch. II, pp. 84, 91, Weaving sections, Ramp terminals, AASHTO. Ch. X, Interchanges, AASHTO.
4	Construction creating congestion.	Part 6, Temporary Traffic Control, MUTCD.
2	Lane direction change by time of day.	Ch. 4J, Lane-use control signals, MUTCD. Ch. 2D, Guide signs, MUTCD. Ch. VII, pp. 541-542, Reverse flow operation, AASHTO.
2	Traffic control message sign difficult to understand.	Ch. 2D, Guide signs, MUTCD.
2	Unsignalized, unsigned entrance into complex intersection.	Ch. 2B, Regulatory signs, MUTCD. Ch. 4C, Traffic control signal needs studies, MUTCD. Ch. IX, pp. 641-642, Multi-leg intersections, AASHTO.
2	Roadway entrance/exit too close to complex intersection.	Ch. 4C, Traffic control signal needs studies, MUTCD. Ch. IX, pp. 641-642, Multi-leg intersections, AASHTO.
2	Unsignalized, signed entrance near complex intersection.	Ch. 4C, Traffic control signal needs studies, MUTCD. Ch. IX, pp. 641-642, Multi-leg intersections, AASHTO.
2	Private roadway connecting to merge ramp.	Ch. IX, p. 793, Driveways, AASHTO.

* One site receiving extended surveillance contributed all of these occurrences.

Specific Site Critical Incident Analysis

Overview

One of the goals of this project was to develop a protocol, or *Site Evaluation Methodology*, for determining solutions to site problems. More specifically, it was intended that one of the outputs of this project would be a set of steps that could be used by a team of engineers with expertise in human factors and in traffic to assess *problem* sites in terms of high frequency or severity of critical incidents. One of the analyses used in developing this protocol was a *specific site critical* *incident analysis.* This analysis entails a detailed evaluation of the critical incidents captured on videotape at a particular roadway site. As detailed in the Task E report, specific site critical incident analyses were carried out on two different sites. The results from one of the sites are presented in this report. The remainder of this section outlines the method that was used in conducting this analysis, a discussion of the results, and the conclusions based on these results.

Method

Figure 25 outlines the method that was used in conducting a specific site critical incident analysis. As can be seen, there were four primary steps in reaching the final output of the analysis, which was a list and description of "incident clusters" (detailed later). The four steps that led to this output were: (1) selection of a site, (2) careful review of the site's critical incident data, (3) determining the potential critical incident contributing factors, and (4) identification of incident clusters. Each of these four steps, along with the final output (cluster list/description), is outlined below.

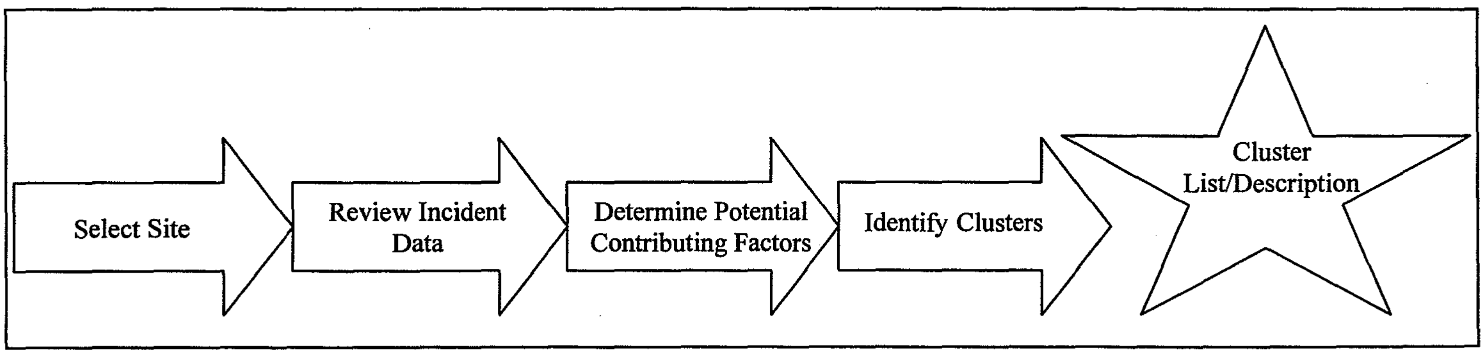


Figure 25. Method for conducting a specific site critical incident analysis.

Select Site

The first step in this analysis was to select a suitable roadway site. There were three primary criteria for selecting a site to be analyzed. First, a site was desired that had a relatively large number of recorded high-severity incidents (i.e., incidents with a severity rating of 4 or higher). This was important so that there would be a sufficient amount of data to make the analysis worthwhile and meaningful. The second criterion was that a site be selected that was of moderate complexity and, therefore, reasonably representative of the entire set of sites that were investigated during this research. Recall that a primary goal of this project was to develop a protocol for re-designing problem sites. As such, it was important to select a site that would enable results to be generalizable to a variety of sites. The third criterion was that the site should have apparent "incident clusters." The term "incident clusters" refers to groups of incidents that appear to have similar underlying contributing factors (described in more detail later).

Review Critical Incident Data

The second step in the specific site critical incident analysis was to carefully review the critical incident data for the site selected. There were four components to reviewing the site-specific incident data. First, the written descriptions of the events were gathered and carefully reviewed. Second, the video recordings were used to re-evaluate each event. Third, the written descriptions were edited to reflect changes in the event re-evaluation. And fourth, basic sketch/drawings were made to capture the essential elements of the critical incidents.

Determine Potential Contributing Factors

The third step in the analysis was to determine the potential contributing factors that were present in each critical incident. To this end, each critical incident was evaluated for the presence of one or more of the following: (1) driver proficiency problems such as lack of understanding or misunderstanding of traffic laws, driving techniques, vehicle kinematics, driver capabilities, or limitations; (2) driver impairment problems such as fatigue and drowsiness, use of drugs/alcohol, or health-related; (3) willful inappropriate behavior problems such as purposeful violation of traffic laws/regulations, aggressive driving, or use of vehicle for improper purposes; and (4) infrastructure or environmental problems potentially associated with traffic control devices, roadway alignment and delineation, weather, or visibility. Note that these four categories represent those included in the early Contributing Factors Taxonomy presented previously.

Identify Incident Clusters

Based on the previous step where each incident was classified as to the potential contributing factors, the incidents were then grouped into incident clusters. An incident cluster is a group of critical incidents that show a similar pattern or common characteristics. Grouping individual critical incidents into clusters was conducted by (1) assessing the potential contributing factors and (2) overlaying the events on a site schematic. As will be shown, presenting the events on a site schematic is a particularly effective method for identifying incident clusters. Incident clusters provide compelling elucidation of roadway infrastructure contributions to driver error.

List and Describe Critical Incident Clusters

Based on the identification of the incident clusters, the output of the specific site critical incident analysis is a list and description of the clusters. The clusters are presented in descending order of frequency, or the apparent order of importance. From this list, potential solutions to remedy the problems associated with each incident would, hopefully, become apparent. The purpose of presenting the clusters is to provide an indication of what the problems are, not to provide remedies or redesign solutions.

Results and Discussion

In a similar manner to the *Method* section outlined above, the *Results and Discussion* section is structured using the four primary analysis steps and the final output. As indicated previously, two specific site critical incident analyses were conducted for this project; both analyses are included in the Task E report, while one analysis is re-presented in this final report.

Site Selected

A specific site critical incident analysis was performed on Location 7 (complex intersection in metro location). Table 13 outlines how Location 7 rated on each of the three site selection criterion.

Table 13. Criteria for site selected (Location 7).

Site Selection Criteria	Assessment
Moderate number of higher-severity incidents	Eleven of 36 site incidents were assessed at severity 4 or higher.
High complexity	Site was one of the most complex sites studied.
Incident clusters present	From preliminary review of incidents, clusters seemed evident.

Location 7 can be found in Appendix A of the Task E report. This site is in Washington, D.C., and involves a group of signalized and non-signalized controlled intersections. The main roadways are Minnesota, Pennsylvania, 25th, and a street labeled "Side Street Parking" (actually southbound Minnesota). This particular location has a relatively high volume of traffic. Other noteworthy features of this site include:

- Eastbound Pennsylvania has four lanes leading to Minnesota.
- 25th Street is one-way traveling southeast with an access road into a gas station (i.e., access from 25th).

Critical Incident Data Reviewed & Potential Contributing Factors Determined

Recall that there were four components to reviewing the site-specific incident data: (1) the written descriptions of the events were gathered and carefully reviewed, (2) the video recordings were used to re-evaluate each event, (3) the written descriptions were edited to reflect changes in the event re-evaluation, and (4) basic sketch/drawings were made to capture the essence of the critical incident. Based on the review of the available data, *potential* contributing factors for each event were assessed. Note that the potential contributing factors were subjectively determined by viewing the videotapes; as such, the factors can only be considered *potential* contributing factors. The results of the review process for the incidents and the determination of the potential contributing factors are shown in table 14, where all 36 events collected during the 9 hour and 7 minute data collection period are briefly described.

As can be seen in table 14, few of the assessed potential contributing factors seemed to involve "Infrastructure." Sketches of Event 1 and Event 6, sample events that were assessed to have "Infrastructure" as a potential contributing factor, are shown in figure 26. In addition, figure 26 shows a sample of two other events that had the most commonly assessed potential contributing factor, "Willful inappropriate behavior."

Table 14. Description of the 36 critical incidents at Location 7.

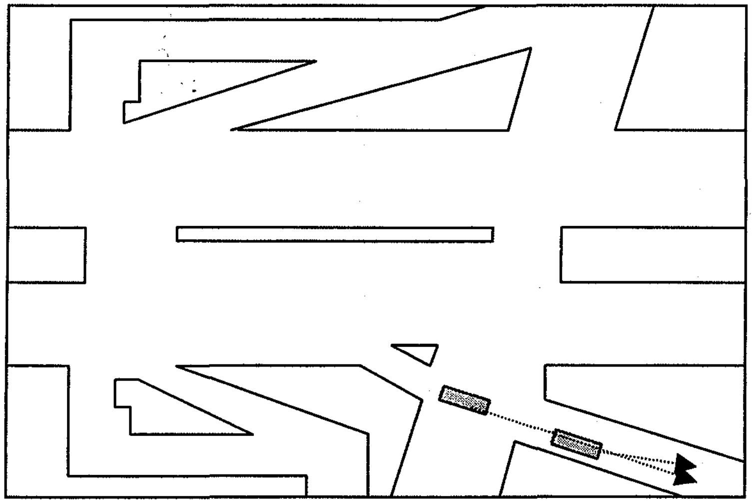
Event Number	Time Stamp	Severity Rating (Low, 1 to High, 5)	Event Summary	Potential Contributing Factors
1	11:51:55 AM	5	Lane change left into through lane from parked position, conflict with traffic passing through intersection.	Driver proficiency (not yielding right-of-way); Willful inappropriate behavior (aggressive driving); Infrastructure (potential sight distance problem).
2	12:00:03 PM	3	Wrong way on one-way; conflict with opposing through traffic due to vehicle entering intersection from gas station exit.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (lack of conspicuous signing for vehicles exiting gas station).
3	12:29:10 PM	4	Left turn on red; conflict with cross traffic from left in intersection.	Willful inappropriate behavior (aggressive driving).
4	12:30:25 PM	3	Wrong way on one-way; conflict with opposing through traffic due to vehicle accessing intersection from gas station exit.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (lack of conspicuous signing for vehicles exiting gas station).
5	12:31:09 PM	3	Wrong way on one-way; conflict with opposing through traffic due to vehicle accessing intersection from gas station exit.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (lack of conspicuous signing for vehicles exiting gas station).
6	12:55:03 PM	4	Wrong way on one-way; conflict with opposing through traffic due to vehicle accessing intersection from gas station exit.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (lack of conspicuous signing for vehicles exiting gas station).
7	1:27:18 PM	4	Vehicle parallel parking; conflict with traffic passing through intersection.	Willful inappropriate behavior (aggressive driving); Infrastructure (potential sight distance problem).
8	1:05:14 PM	3	Illegal left turn; conflict with adjacent through traffic in intersection.	Willful inappropriate behavior (purposeful violation of laws).
9	12:21:48 PM	3	Vehicles traveling in same direction; right turn conflict with lead vehicle being stopped, waiting to proceed straight from right turn only lane.	Willful inappropriate behavior (purposeful violation of laws).
10	12:22:01 PM	3	Bicycle, wrong way on one-way; conflict with opposing through traffic at intersection.	Willful inappropriate behavior (purposeful violation of laws).
11	12:27:34 PM	3	Illegal U-turn, conflict with pedestrians crossing opposing traffic lanes at intersection.	Willful inappropriate behavior (purposeful violation of laws).
12	12:31:15 PM	3	Illegal U-turn; conflict with oncoming through traffic at intersection.	Willful inappropriate behavior (purposeful violation of laws).
13	12:34:11 PM	3	Illegal U-turn; conflict with oncoming through traffic at intersection.	Willful inappropriate behavior (purposeful violation of laws).
14	12:35:51 PM	3	Right turn, ran stop sign; conflict with cross traffic from left at intersection.	Willful inappropriate behavior (purposeful violation of laws).

Table 14. Description of the 36 critical incidents at Location 7 (continued).

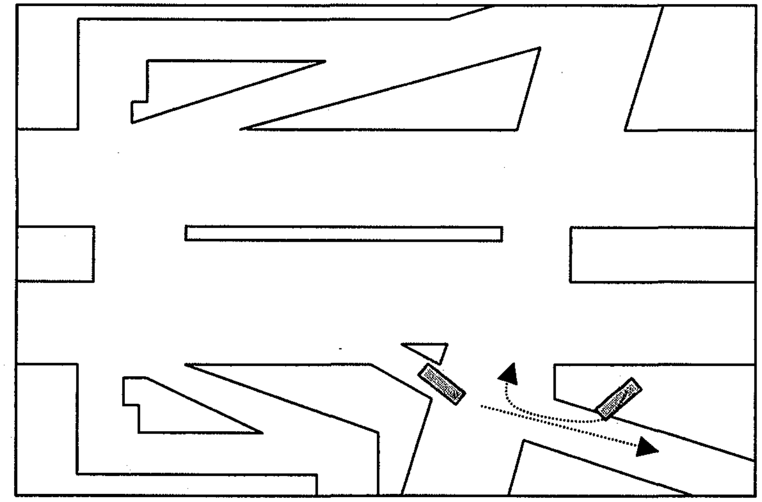
15	12:41:00 PM	3	Vehicles traveling in same direction; conflict with lead vehicle having stopped in intersection.	Driver proficiency (poor driving techniques); Willful inappropriate behavior (purposeful violation of laws).
16	12:45:46 PM	4	Pedestrian walking against red light; conflict with cross traffic from right in intersection.	Willful inappropriate behavior (purposeful violation of laws).
17	2:54:30 PM	3	Right turn from left lane; conflict with traffic in right lane.	Driver proficiency (poor driving techniques); Willful inappropriate behavior (purposeful violation of laws).
18	2:35:45 PM	3	Vehicles traveling in same direction; conflict due to higher vehicle speed of following vehicle.	Willful inappropriate behavior (aggressive driving).
19	3:36:25 PM	3	Vehicles traveling in same direction; conflict with lead vehicle stopped to pick up pedestrian.	Willful inappropriate behavior (purposeful violation of laws).
20	3:03:57 PM	3	Vehicle backing wrong way on one-way; conflict with oncoming traffic.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (potential sight distance problem).
21	3:21:32 PM	3	Vehicle backing wrong way on one-way; conflict with oncoming traffic.	Willful inappropriate behavior (purposeful violation of laws); Infrastructure (potential sight distance problem).
22	4:09:00 PM	6	Lane change to left from right turn only lane; conflict with through traffic resulted in crash with median.	Willful inappropriate behavior (aggressive driving).
23	1:59:19 PM	3	Vehicles traveling in same direction; right turn conflict with lead vehicle having stopped in intersection.	Inadequate knowledge (appeared unfamiliar with location).
24	4:41:27 PM	3	Illegal U-turn, conflict with pedestrians crossing opposing traffic lanes at intersection.	Willful inappropriate behavior (purposeful violation of laws).
25	4:49:52 PM	4	Lane change left into through lane from parked position; conflict with adjacent through traffic in intersection.	Willful inappropriate behavior (aggressive driving).
26	5:01:52 PM	4	Right turn on red; conflict with cross traffic from left in intersection.	Willful inappropriate behavior (purposeful violation of laws, aggressive driving).
27	2:47:22 PM	3	Vehicles traveling in same direction; through conflict with lead vehicle having stopped in intersection.	Willful inappropriate behavior (purposeful violation of laws).
28	3:13:54 PM	4	Left turn from right turn only lane; conflict with adjacent through traffic on left in intersection.	Willful inappropriate behavior (purposeful violation of laws).
29	3:43:50 PM	3	Vehicles traveling in same direction; right turn conflict with lead vehicle traveling slowly in intersection.	Inadequate knowledge (apparent confusion about right-of-way).
30	3:49:48 PM	3	Vehicles traveling in same direction; through conflict with lead vehicle slowing to make an illegal U-turn.	Willful inappropriate behavior (purposeful violation of laws).
31	3:52:05 PM	3	Illegal U-turn; conflict with oncoming traffic making left turn in intersection.	Willful inappropriate behavior (purposeful violation of laws).

Table 14. Description of the 36 critical incidents at Location 7 (continued).

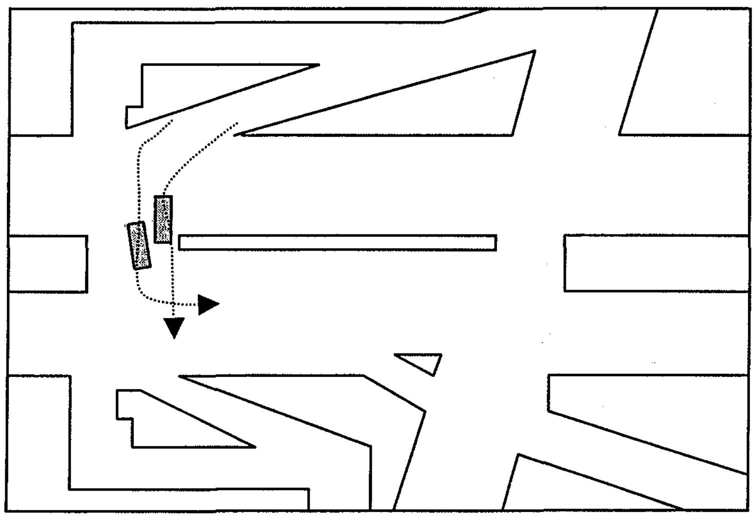
32	3:57:16 PM	3	Run red light; conflict with cross traffic in intersection.	Willful inappropriate behavior (aggressive driving).
33	4:01:15 PM	4	Left turn from right turn lane only lane; conflict with adjacent through traffic on left in intersection.	Willful inappropriate behavior (purposeful violation of laws).
34	4:13:09 PM	3	Vehicles traveling in same direction; through conflict with lead vehicle slowing to make an illegal U-turn.	Willful inappropriate behavior (purposeful violation of laws).
35	4:16:41 PM	3	Pedestrian walking against red light; conflict with cross traffic from right in intersection.	Willful inappropriate behavior (purposeful violation of laws).
36	4:22:46 PM	4	Left turn from right turn only lane; conflict with adjacent through traffic on left in intersection.	Willful inappropriate behavior (purposeful violation of laws).



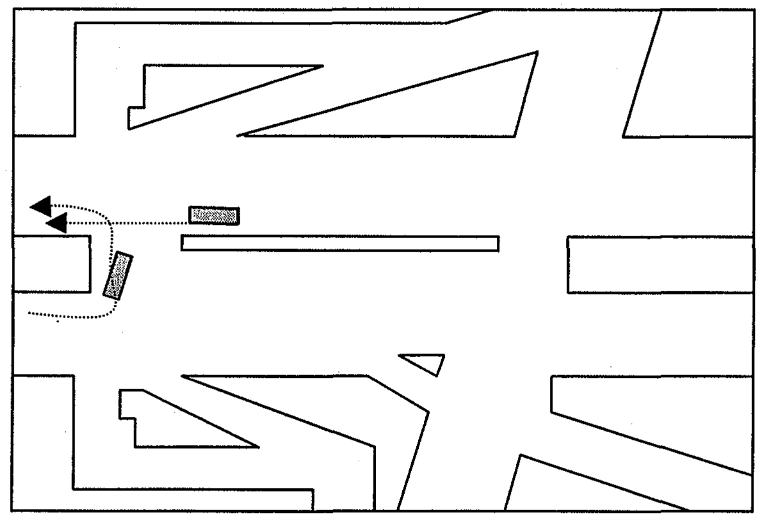
Event 1



Event 6



Event 33



Event 13

Figure 26. Drawings of four of the 36 critical incidents captured at Location 7.

Incident Clusters Identified

The grouping of incidents into clusters is shown in figure 27. It was hypothesized that similar incidents that occur over and over again in a given location within an intersection may be caused, at least in part, by the infrastructure. When each incident was considered independently (table 14), potential infrastructure-related causes were assessed to one or more events found in Clusters IV and V. Additionally, independent consideration of the events shown in Clusters I, II, and III did *not* have "Infrastructure" listed as a potential contributing factor. Nonetheless, as shown in the figure, a clustering of events seems apparent for Cluster II, III and, perhaps to a lesser degree, Cluster I.

In Cluster I, Cluster II, and Cluster III, the incidents that occurred had similar features and, as such, were circled and identified as a "cluster." For example, all the events in Cluster II involved an illegal U-turn made by drivers driving eastbound on Pennsylvania. Considering each of the events in Cluster II independently, one might conclude that the drivers' disregard for the posted "No U-turn" sign and, therefore, "Willful inappropriate behavior" was the lone cause of the incident.[1] However, it may seem curious that these identical events that occurred in the exact same location were all due solely to "Willful inappropriate behavior." For the case of the driver making an illegal U-turn, consider his/her alternatives to changing directions of travel from eastbound to westbound Pennsylvania. Aside from making an illegal U-turn, the other alternative would be to continue eastbound on Pennsylvania until an access street was available to make a legal U-turn, or make two left turns and then a right turn (i.e., drive "around the block") where such turns are permitted. (Note that although a driver is permitted to make a left turn on northbound Minnesota, he/she is not permitted to make a left turn from northbound Minnesota onto southbound Minnesota.) It seems reasonable to hypothesize that it is the simpler alternative that drivers are most apt to select when making a navigation or directional decision. This hypothesis would explain why the drivers captured in the Cluster II events made an illegal U-turn. Evidently, assuming that they noticed the "No U-turn" sign, these drivers were not willing to follow the directions posted on the sign. Hence, the potential cause of the incident must be attributed to "Willful inappropriate behavior." However, as suggested, "Willful inappropriate behavior" does not tell the whole story.

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[1] This assumes that the drivers saw the posted "No U-turn" sign.

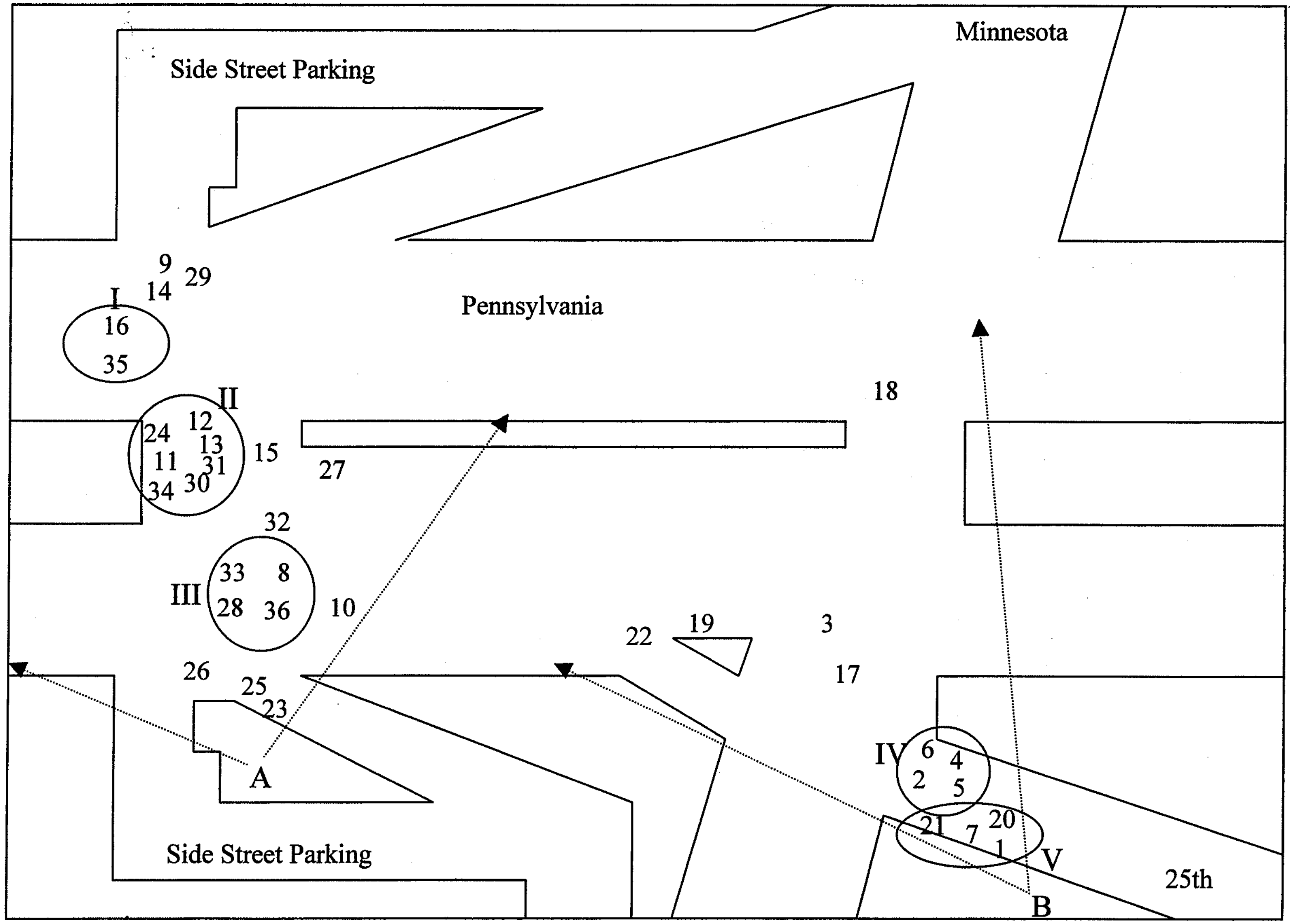

Figure 27. Approximate location of vehicle interaction at Location 7; clusters shown in circles. (A and B refer to the camera positions, and the dashed arrow lines refer to the approximate angle of coverage.)

One of the strengths of the analytical approach being presented here is that it allows one to look beyond the apparent causal factors of any one event. (If this were not the case, then the only clusters that would have been listed in figure 27 would be Clusters IV and V.) Once again, consider the events shown in Cluster II. Taking all of the Cluster II events into account, what can be learned by the volume of the apparent blatant errors? As suggested, one lesson that can be learned is that the alternative for drivers wanting to change directions and travel west on Pennsylvania rather than east on Pennsylvania was unacceptable and that an illegal U-turn was more appealing. If this is the case, one wonders if the infrastructure could be altered such that drivers would not be violating the law by choosing the simplest, most logical, or most convenient path (i.e., making a U-turn). For example, consider the solution of programming the traffic signals such that eastbound traffic is given an opportunity to make a safe and legal U-turn (i.e., on green arrow). The result of this possible solution might serve to eliminate Cluster II altogether (albeit, different problems could arise from this solution). Nonetheless, the point of this discussion is to highlight the idea that, in keeping with sound human factors design principles, designers should design with the users in mind (a well-known principle referred to as "user-centered design"). In the situation shown in Cluster II, this would suggest considering *why* drivers are compelled to make illegal U-turns at this intersection. If it truly is "Willful inappropriate behavior," then consideration must be given to the needs of the driver such that convenient and legal access from eastbound to westbound Pennsylvania is provided. The conclusion is that, just as clusters that have apparent blatant underlying infrastructure-related causes can lead to potential re-design solutions, clusters that at first glance appear unrelated to the infrastructure can also lead to potential infrastructure-related design improvements.

Critical Incident Cluster List and Description

The clustering procedure used in this site example led to the identification of five distinct clusters. Table 15 lists and describes each cluster. The clusters outlined in table 15 are listed by the frequency of events that made up the cluster. Additionally, potential infrastructure-related solutions to help reduce or eliminate the cluster are also suggested. As discussed in the previous section, it is noteworthy that independent considerations of Clusters I, II, and III have no potential infrastructure problems. Nonetheless, close scrutiny of the clusters revealed potential solutions going beyond "Willful inappropriate behavior." For Cluster I, the possible solution recommended may include training and education directed at drivers to clarify that pedestrians *always* have the right-of-way in a crosswalk. For Cluster II, as discussed in the previous section, one possible solution is to make a U-turn at this location safe and legal by altering the current traffic signal system. Similarly for Cluster III, drivers traveling southbound on Minnesota (in either of the two lanes) do not have legal access to eastbound Pennsylvania.

Table 15. Outline of incident clusters at Location 7.

Cluster #	Reference Name	# Events in Cluster	Proportion of Infrastructure Problems	Cluster Description
II	U-Turn	7	0	Illegal U-turn made with "No U-turn" sign posted; drivers changing directions from east to west Pennsylvania. Complex alternative to illegal U-turn.
III	Left-turn Infraction	4	0	Driver in outside lane makes left turn and cuts off vehicle in inside lane. Southbound Minnesota drivers do not have legal access to eastbound Pennsylvania from either southbound lane. Complex alternative to making illegal left-turn.
IV	Gas Station Exit	4	1.0	Vehicles exiting gas station turn wrong way on one-way. One-way signs are posted on 25th, though they are not in direct line-of-sight with vehicles exiting gas station and, as such, may not be conspicuous to drivers.
V	One-way Backup	4	1.0	Vehicles backing up on one-way to parallel park, or for other reasons. Interaction with vehicles exiting off eastbound Pennsylvania. Though incidents were initiated by the backing vehicle, may be a site distance issue and/or speed issue for the driver exiting Pennsylvania.
I	Cross-Walk	2	0	Cross-walk area. Drivers not respecting right-of-way of pedestrian.

Summary

As indicated previously, the Task E report details the results of specific site analyses conducted at two different locations. The first location presented in the Task E report was Location 22 (moderate complexity intersection at a town location). It should be noted that the potential infrastructure-related problems described for Location 22 were fairly straightforward. In contrast, Location 7, re-presented in this final report, was much more complex and the potential contributing infrastructure problems were not as salient. However, the methodology used in this specific site critical incident analysis was robust enough to identify possible infrastructure-related solutions to problems that, at first glance, seemed to have no infrastructure-related contributing cause. The analysis tool used in this example demonstrates that the design of the infrastructure can be an underlying factor in critical incidents with assessed "Willful inappropriate behavior." Note that the term "Willful inappropriate behavior" is still correct because drivers are performing maneuvers that violate rights-of-way, signing, or other traffic law. Only by examining groups of critical incidents that have common precipitating factors can a more complete picture of the problem, and potential solutions, be determined.

Figure 27 shows the coverage angles of the two cameras used at Location 7. As can be seen, all of the analyzed incidents fell within the area of coverage. It can be said, therefore, that all of the incidents were captured as a function of the vantage point of the camera. This notion has obvious ramifications for conducting a specific site analysis. It is suggested that for intersections of moderate complexity, a single camera position in an area with a good vantage point of the intersection is probably adequate for capturing events and uncovering potential problems. However, for highly complex intersections, such as that in Location 7, it is likely that multiple cameras would be required, unless a specific part of the intersection is associated with a large number of incidents. For Location 7, for example, four or more camera positions may be necessary to cover the entire intersection. A strategy for camera placement must be worked out in advance to ensure incidents are captured that: (1) are representative of the entire intersection, or (2) concentrate on the part of the intersection associated with a large number of incidents (based on previous data). It is also worth noting that for intersection data-collection efforts such as the one conducted in this project, it is important that the location of the camera be as unobtrusive as possible. As a final consideration on this topic, it is important to highlight the fact that despite the limited coverage in Location 7, the results of the analysis demonstrated that even a partial view of the intersection can provide substantial insight into possible design problems and potential improvements.

One issue that has not yet been raised is that of enforcement of the traffic laws relevant to the critical incidents captured at the intersections. Anecdotally, no traffic citations were observed to have been written to offending drivers (e.g., drivers making illegal U-turns) at any of the sites that were videotaped. It is recognized that without enforcement of traffic laws, there may be little that can be done to deter "Aggressive driving" or "Purposeful violation of laws." Nonetheless, the apparent lack of enforcement should have no impact on the desire to optimize the design of a roadway or intersection. Although the apparent lack of enforcement is worth mentioning, it is not particularly relevant to the goals associated with this project.

As suggested, the potential solutions noted should be considered examples of ways to address the apparent infrastructure-related problems that were observed at these sites. Also, it is recognized that when these intersections were designed, it is likely that the design decisions were made based upon trade-offs that would preclude possible solutions suggested here. The important "take-away" from this analysis is that the procedure used appears to be an efficient and robust tool for evaluation.

Day-of-Week and Time-of-Day Analysis of Critical Incidents

Overview

One of the goals of this project was to examine the effects of day-of-week and time-of-day (if any) on the number and severity of critical incidents. In the Task E report, where this analysis was first presented, it was indicated that another goal of the project was to recommend a procedure for data gathering that could be used as a tool for site evaluation. With these goals in mind, work was directed at determining appropriate sampling patterns in order to obtain a representative sample of incidents for the given site. If incident occurrence has patterns by day-of-week and time-of-day, then such patterns would be recommended to be taken into account in the sampling process. For this analysis, incidents with a severity rating of 3 and above were included. Data from two sites, a stop-controlled intersection in a town environment and a signalized intersection in a city environment, were used. Analyses were performed both on raw incident occurrence and on incident occurrence corrected for traffic count. These analyses were intended to provide an indication of both raw trends and trends that might be independent of traffic count.

Method

Site selection and data gathering

Two sites were selected for extended data collection over a period of 5 days. Details of the sites are presented in the Task E report, and summary descriptions are presented in table 16.

The sites were selected because they had different TCDs represented (stop-controlled and signalized intersections), and also because the sites were relatively straightforward in design. Both had perpendicular crossroads and were chosen for their potential generalizability to other sites.

Table 16. Summary table of weekly sites used for observation.

Type of Intersection	Primary Control	Location	Region
Perpendicular 4-legged	Stop sign (2 way)	Spring Road/Tech Center Driver and Southgate Drive, Blacksburg, VA	Town
	Signal (4 way)	Elm Avenue and Jefferson Street, Roanoke, VA	City

Events rated with severity ratings of 3 and above were used in these analyses. No events rated above 6 were observed. For the reader's convenience, the severity rating scale for events rated between 3 and 6 is repeated here in table 17.

Table 17. Severity rating scale definitions used.

Hazard Category	Conflict Severity	Severity Rating	Definition
Serious error, hazard present		3	Controlled acceleration, deceleration, lane change, and/or a warning behavior such as sounding the horn with slight risk of a near-crash, such as tailgating.
Near-crash	Critical	4	Rapid controlled acceleration, deceleration, lane change, or stopping to avoid a crash.
Serious near-crash		5	Emergency braking or violent swerve to avoid a crash, resulting in a very near-crash situation.
Non-injury crash	Catastrophic	6	Crash resulting in only property damage.

Traffic Control Officer Presence

For the Town site, a traffic control officer was present to direct traffic during peak times for both the midday and the evening data-collection sessions. The officer stood in the middle of the intersection to direct traffic. In a previous report on techniques to control speeding of drivers in work zones, it was found that drivers reduced speed when law enforcement was present. Specifically, law enforcement was found to be effective in reducing average speeds by as much as 13 mi/h (Garber and Patel, 1994). In the current study, for all days except Monday, an officer was present from approximately 11:55 a.m. to 12:10 p.m. and from 4:50 p.m. to 5:20 p.m.

Traffic control officer presence would be expected to have a "calming" effect on traffic and the corresponding number and severity of incidents. Therefore, a method had to be developed that accounted for this effect. To compensate, the intervals during which a traffic control officer was present were temporarily deleted for purposes of analyses. These times were reasonably consistent from Tuesday through Friday.

As indicated, no officer was present on the Monday that data were gathered, and a method to account for this had to be developed. An average of the start and end times for officer presence on Tuesday through Friday was calculated. Data collected on Monday during this time were deleted from the analysis. In other words, although no officer was present on Monday, deleting data for the time when the officer *might* have been present produced a reasonably unbiased sample for that day. This procedure made comparison across days possible.

The fact that an officer was not present on Monday, but was present on the remaining days of the week, provided an unanticipated benefit. By comparing the time interval on Monday that the officer *might* have been present (but was not) with the same intervals for the other four days when the officer *was* present, an indication of traffic control officer presence/absence on incidents could be determined. Of course, such an analysis is influenced by day-of-week effects.

Time of Data Collection and Traffic Volume

Data were collected during October 1999 before the end of Daylight Saving Time. Had the data gathering continued after the time change, the evening rushes would have occurred in twilight, thereby causing a confound in the data.

A potential influence on incident occurrence is traffic volume. Therefore, traffic counts were obtained for use in the analysis. To calculate traffic count data during data-collection periods, 15-min samples were taken from the videotapes during peak times for each site.

Analyses and Results

The complete set of results from this analysis can be found in the Task E report. A summary of the main findings are re-presented here.

Effect of Traffic Control Officer Presence

As previously indicated, the effect of officer presence/absence could be studied by comparing an interval on Monday at the Town site with the same interval on the remaining days of the week. Table 18 shows the results.

Table 18. Number of critical incidents by day-of-week and time-of-day.

Officer	Day	Time	CIs ≥3	CIs ≥4	Time period
Absent	Monday	Midday	3	3	11:58-12:09
		Evening	3	3	4:55-5:21
Present	Tuesday	Midday	0	0	11:58-12:11
		Evening	0	0	5:01-5:19
	Wednesday	Midday	0	0	11:59-12:11
		Evening	0	0	5:00-5:23
	Thursday	Midday	0	0	11:55-12:05
		Evening	1	1	4:49-5:26
	Friday	Midday	0	0	12:01-12:12
		Evening	0	0	4:51-5:16

It is very clear that traffic control officer presence had a major effect on incident occurrence. One incident occurred in the 4 days that an officer was present, and six occurred on the Monday that the officer was absent. On a per-day basis, this represents a ratio of 24 to 1, well above any value that could be a result of chance, day-of-week effect, or traffic-count effect.

There are two apparent reasons for the traffic control officer presence effect. First, the officer directs and smoothes the traffic flow, thereby reducing the likelihood of close-calls and mishaps. The officer can adapt to the situation at hand, for example, by allowing longer queues to receive precedence. Secondly, the officer represents law enforcement and authority, which has the effect of putting drivers on their best behavior. For example, it is unlikely that drivers would exhibit aggressive driving in the presence of such authority. The results obtained are in agreement with both intuition and the previous study by Garber and Patel (1994).

Critical Incidents for Each Site

For the Town site, the number of critical incidents per hour on average was greater than or equal to the corresponding number at the City site. However, the traffic volume was substantially lower at the Town site as compared to the City site (302 counts/15-min vs. 478 counts/15-min, for midday and evening combined). Thus, it appears that while traffic volume was moderate at the Town site, the mean numbers of critical incidents were high as compared to the City site. This may be a result of the fact that the Town site, which used two-way stop signs, might have passed warrants for a traffic signal. The fact that a traffic control officer was often present at peak times suggests that the hazards at the intersection were recognized.

Day-of-Week Effect

Before and after adjusting for traffic count, for the City site in the evening where critical incidents were rated ≥ 4, the number of critical incidents was higher earlier in the week. In addition, before and after adjusting for traffic count, and for the City site where midday and evening were combined, the ratio of incidents/traffic count seems to be higher earlier in the week. This may suggest that, at least for the City site, more critical incidents are apparent earlier in the week as opposed to later in the week, with or without adjustments for traffic count. This finding is supported by the previous findings of Hanowski, Wierwille, Garness, and Dingus (2000), who studied local short-haul drivers. Their findings indicated that for this set of drivers, the frequency of critical incidents was more prominent early in the week and tended to diminish late in the workweek.

No significant findings were observed regarding a day-of-week effect for the Town site. However, the Town site was unusual in that a special event late in the week probably caused unusual effects. Unfamiliar drivers may have been passing though the intersection later in the week, offsetting the trend observed for the City site. One indication that the Town site was unusual is the traffic count data. That is, there was an increasing trend in the evening traffic count for the Town site, whereas there was a decreasing trend for the City site. It is believed that the City trend is more typical, because work dismissal times and flex-time schedules may lower evening rush traffic counts later in the week.

Time-of-Day Effect

Before adjusting for traffic count, it seemed that at least for the Town site, differences were apparent between the number of critical incidents observed between midday and evening. Additionally, it appeared that a higher severity of incidents occurred later in the day (i.e., evening time). This seems reasonable in that in the evening drivers may be (1) tired from the day's work, (2) anxious to get home, and (3) under additional stress due to increased traffic volume. However, after adjusting for traffic count, no reliable differences between midday and evening were observed. No significant findings were observed regarding a time-of-day effect for the City site, whether corrected for traffic count or not.

<u>Summary</u>

The purpose of the analyses described in this section was to examine day-of-week and time-of-day trends in the critical incident data. Analyses were conducted both with and without traffic volume taken into account. The overall results suggest that there is a mild decreasing trend in incident occurrence as the week progresses. The results also suggest that there is a small difference in the number of incidents occurring during midday as compared with evening, and that this difference is a result of traffic count. Generally, higher counts were observed during evening sessions. When results were corrected for traffic count, there was no residual reliable difference between the number of incidents occurring around midday and the number occurring in the evening.

The effects of time-of-day and day-of-week were not profound. The effects found, while reliable in a few cases, were at best of only moderate magnitude. Considering that the numbers of incidents decrease in the evening as the week wears on, data should definitely be gathered earlier in the week. However, to ensure that all eventualities are covered, data should also be gathered for the remainder of the workweek, at least.

It *does* appear that increasing traffic count has a mild increasing effect on number of incidents. Thus, for efficiency, data gathering should be concentrated at times of peak traffic. However, once again, rushes at the various times of day should be sampled for the sake of obtaining a comprehensive data set. We are led to the conclusion that data gathering definitely should be done early in the week and at high traffic times. However, all days and all rushes should be represented to ensure thoroughness.

This analysis had the unexpected benefit of demonstrating conclusively that traffic control officer presence produced a major reduction in the number of critical incidents. A ramification of this finding is that critical incident data should not be gathered during officer presence because critical incidents are likely to be infrequent and corresponding results atypical. However, there may be cases where officer-controlled traffic is normal operations. In this case, this analysis should be conducted when the officer is present.

PROBABILITY MODEL DEVELOPMENT

Review of Probability Concepts Underlying Models

The probability of occurrence was calculated for each type of critical incident captured in the site surveillance effort. In developing these probabilities, a calculation was made to account for vehicle exposure and the expected number of incidents per hour. The method in which the probabilities were determined is briefly presented. A more detailed discussion of the development of the probability models is presented in the Task E report. It should also be pointed out that a Generalized Critical Incident Analysis was conducted as a precursor to the probability model development. Details of this generalized analysis can also be found in the Task E report.

Calculating Vehicle Exposure

For each critical incident, an estimate was made of the number of vehicles per hour passing through the incident location and taking the same path (and making the same maneuver) as the primary vehicle involved in the incident. This was accomplished by taking a 15-min sample traffic count and determining the number of vehicles-per-hour that traveled the same path as the primary vehicle involved in the incident. To control for differences in total surveillance time between different sites, the vehicle-per-hour exposure rates were multiplied by the hours of observation for the corresponding surveillance session and then divided by the total amount of surveillance time at the location. The exposure rates for each observation session were then summed for a total estimated vehicle-per-hour exposure rate for the location. Table 19 shows an example of how vehicle exposure was determined.

Table 19. Example to illustrate method of determining vehicle exposure.

			AM	Noon	PM
Number of vehicles traveling southbound through intersection in 15-min sample period			5	11	13
Hours of observation in each surveillance session*			2.0537	2.0162	2.4542
Estimated number of vehicles exposed per session	=	(Number of vehicles counted during one sample count) X 4 X (Hours of observation in corresponding surveillance session)	41.074	88.713	127.618
Total estimated number of vehicles exposed per hour	=	Σ Vehicles exposed per session / Total amount of surveillance time at the location in hours	= 39.4545 vehicles per hour		

* Time from individual surveillance sessions was used in calculations to control for time differences between surveillance sessions and differences in total surveillance time between locations.

Expected Number of Critical Incidents Per Hour

The expected number of critical incidents per hour was calculated using the total number of critical incidents of a given type at a location and the amount of surveillance time at that location, such that:

$$\text{Expected number of incidents per hour of a given type at Location A} = \frac{\text{Total number of incidents of a given type at Location A}}{\text{Surveillance time at Location A}}$$

Consider an example in which four incidents of a particular type (type Q) were found to have occurred at three locations (locations A, C, and F). The estimated total number of critical incidents per hour for the incident type would be:

Incident type Q at Location A = 1 critical incident/4.893 h = 0.2044 incidents per hour

Incident type Q at Location C = 1 critical incident/6.524 h = 0.1533 incidents per hour

Incident type Q at Location F	=	2 critical incidents/5.0542 h	=	0. 3958 incidents per hour

Probability of Critical Incident Occurrence

The equation used to calculate the probability of occurrence for the individual critical incident types was:

$$\text{Probability of occurrence of incident type Q at Location A} = \frac{\text{Expected number of incidents per hour of incident type Q at Location A}}{\text{Expected number of vehicles potentially exposed to incident type Q per hour at Location A}}$$

As shown in the example below (table 20), the individual critical incident probabilities for each location were then averaged using the total number of sites included in the relevant infrastructure group in the denominator.

Table 20. Example of an individual critical incident probability calculation.

	Expected number of incidents per hour	Expected number of vehicles exposed per hour	Probability of Occurrence of incident type Q for each location		
Location A	0.2044	39.454	0.00518		
Location C	0.3958	80.654	0.00491		
Location F	0.1533	123.187	0.00124		
Probability of Occurrence of incident type Q across all surveillance sites		=	$\frac{0.01133}{6^{*}}$	=	0.001889

*In this example, there are six locations where incident type Q could have occurred (e.g., rolling stop for red light could only occur at sites with traffic lights). Hence, the denominator to calculate the average is 6 even though this particular type of incident was found at only three sites (Location A, C, and F).

This series of calculations resulted in probability of occurrence values for each critical incident. The critical incident taxonomy developed in Task E was structured with four levels. Top down, from highest to lowest level, the taxonomy structure was: Infrastructure Group, Maneuver Class, Conflict Type, and First Harmful Factor. A definition of each level is provided in table 21. Using the critical incident probabilities, probabilities for higher levels within the taxonomy can easily be determined by summation. The next section provides an example of one of the taxonomies developed in Task E and the corresponding probabilities at each level in the taxonomy.

Table 21. Definitions of levels in the taxonomy.

Taxonomy Level	Definition
Infrastructure Group	The general geometry (e.g., intersection, ramp, roadway) and primary control (e.g., traffic signals or stop signs) of the site.
Maneuver Class	The maneuver performed by the primary vehicle involved in the incident (e.g., left turn, right turn, forward, entering auxiliary lane).
Conflict Type	The interaction between the primary vehicle and other traffic or pedestrians (e.g., conflict with traffic from right, conflict with lead vehicle having stopped/slowed).
First Harmful Factor	The observed precipitating element that affected the path and position of the primary vehicle (e.g., wide turn into incorrect lane, rolling stop at stop sign).

Taxonomies of Probabilities

Figure 28 presents one of the taxonomies developed in Task E. As can be seen, the corresponding probability of occurrence values are presented along with each element in the taxonomy. The taxonomy shown in figure 28 is for a signalized complex intersection. Of course, the data used to develop this, and the other taxonomies presented in this section, were collected during the site surveillance of problem sites. As such, the results should be considered accordingly. For this particular Infrastructure Group, incidents of any type occur with a probability of 0.0327. Working down the taxonomy, it can be seen that Left Turns account for 0.0146 of the overall incident probability for this Infrastructure Group, while Right Turns account for 0.0046, Forward accounts for 0.0044, Lane Changes account for 0.0041, Pedestrian/Bicycle account for 0.0026, U-Turns account for 0.0022, and Backing accounts for 0.0002. Adding these probabilities together (0.0146 + 0.0046 + 0.0044 + 0.0041 + 0.0026 + 0.0022 + 0.0002) equals the overall probability of 0.0327 for this particular Infrastructure Group. Similarly, adding up the individual probabilities for the Conflict Types results in the overall probability for the corresponding Maneuver Class. Finally, summing the probabilities for each First Harmful Factor results in the probabilities for the corresponding Conflict Type.

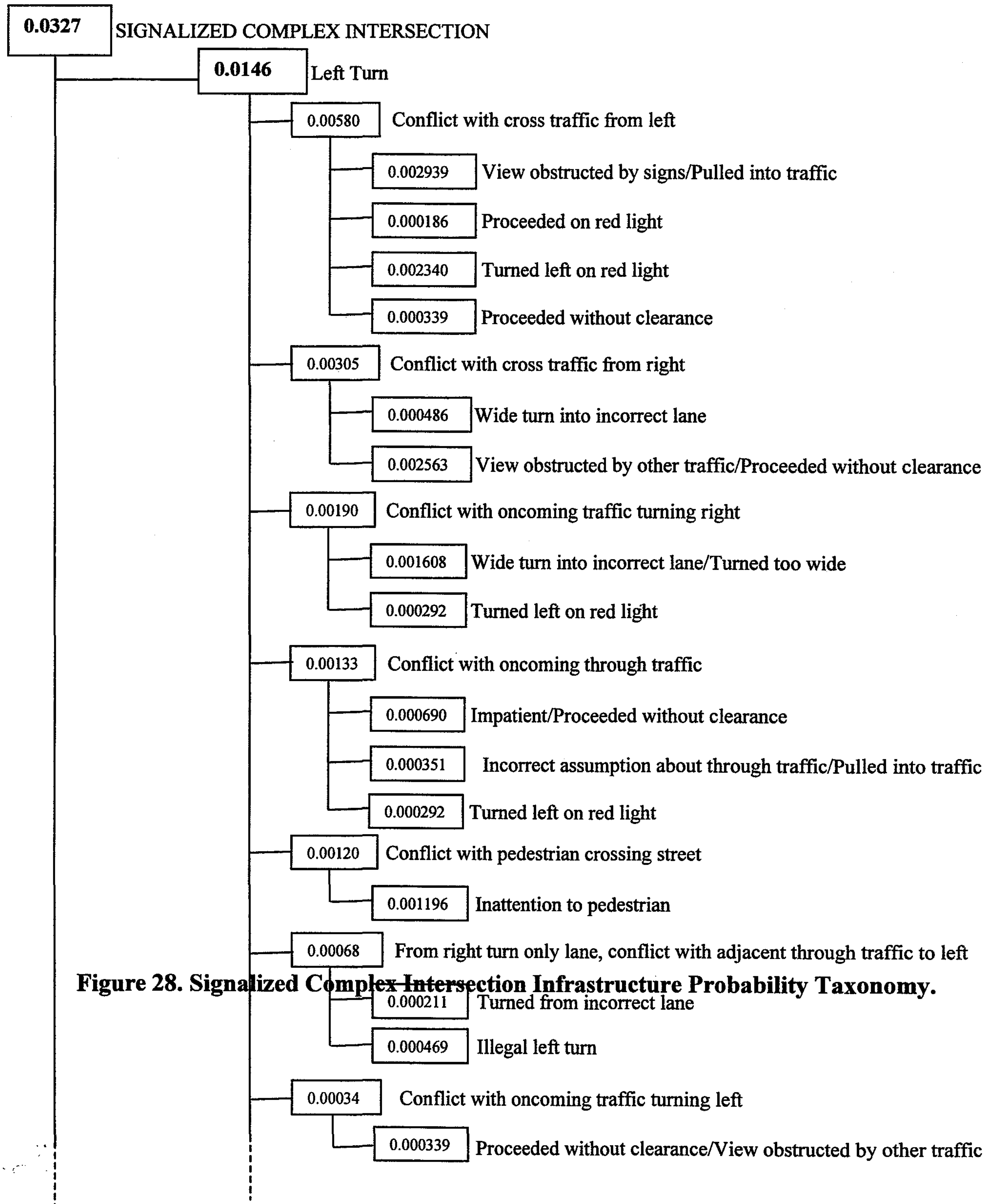

Figure 28. Signalized Complex Intersection Infrastructure Probability Taxonomy.

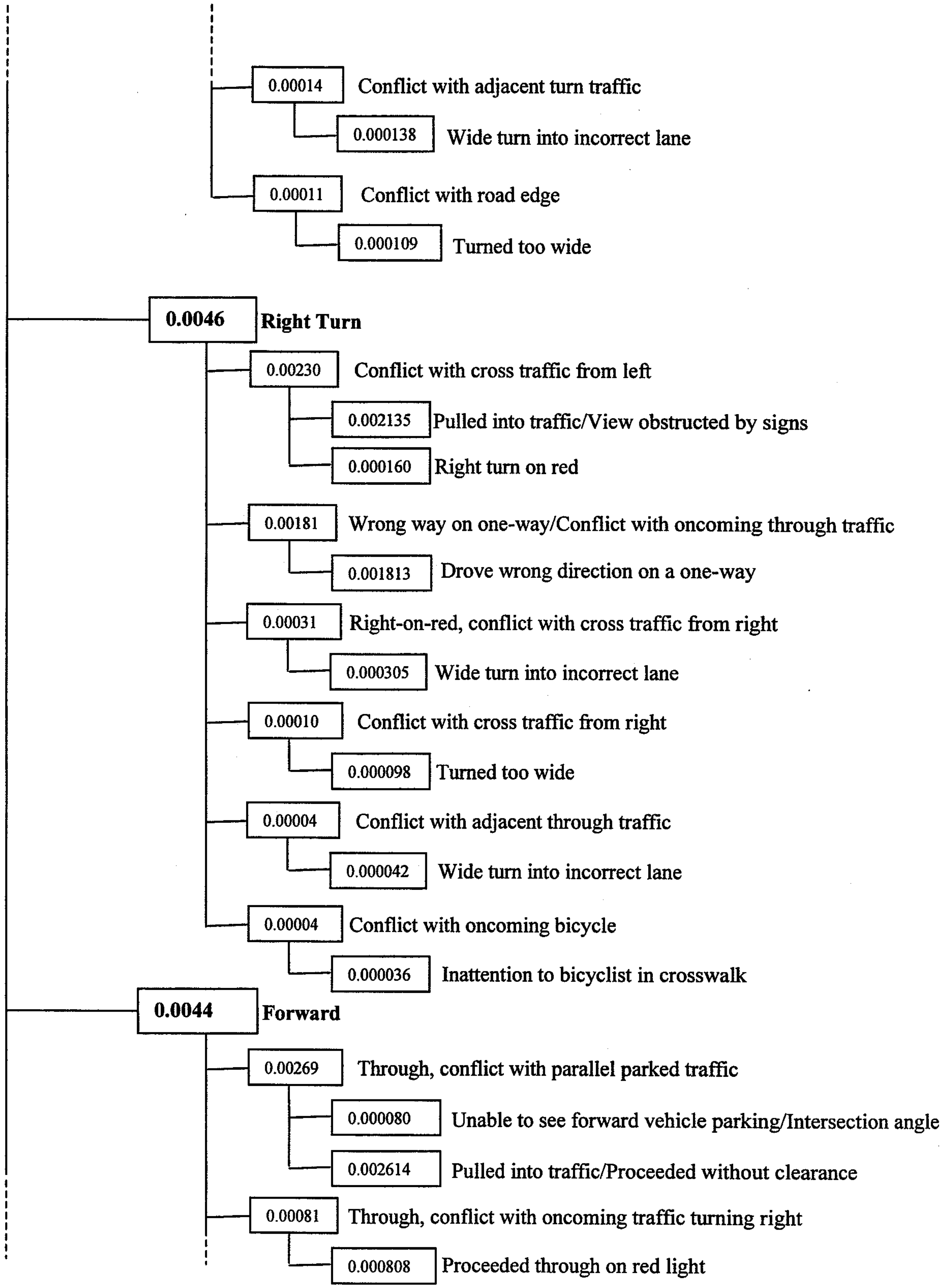

Figure 28. Signalized Complex Intersection Infrastructure Probability Taxonomy (continued).

- 0.00050 Same direction, conflict with lead vehicle having slowed/stopped to turn right
  - 0.000136 Trying to beat red light
  - 0.000220 Following too close
  - 0.000048 Misjudgment of distance and speed
  - 0.000098 Following vehicle made incorrect assumption for right-on-red
- 0.00023 Same direction, conflict with lead vehicle having stopped to turn left
  - 0.000160 Inadequate/Improper look-out
  - 0.000071 Lead vehicle stopped abruptly to make turn
- 0.00013 Same direction, conflict with lead vehicle having slowed/stopped
  - 0.000044 Following too close
  - 0.000090 Stopped to pick up pedestrian
- 0.00005 Straight, conflict with pedestrian crossing in crosswalk from left
  - 0.000045 Inattention to pedestrian

0.0041 Lane Change

- 0.00302 To left from a parked position, conflict with through traffic
  - 0.003022 Did not see through traffic/Intersection angle
- 0.00030 To left from right turn only lane, conflict with through traffic
  - 0.000218 Straight through intersection from right turn only lane
  - 0.000078 Drove onto median to avoid adjacent traffic on the left
- 0.00028 To left, conflict with through traffic
  - 0.000280 Multiple lane change to left
- 0.00025 To right, conflict with through traffic in right lane
  - 0.000245 Lane change in intersection

Figure 28. Signalized Complex Intersection Infrastructure Probability Taxonomy (continued).

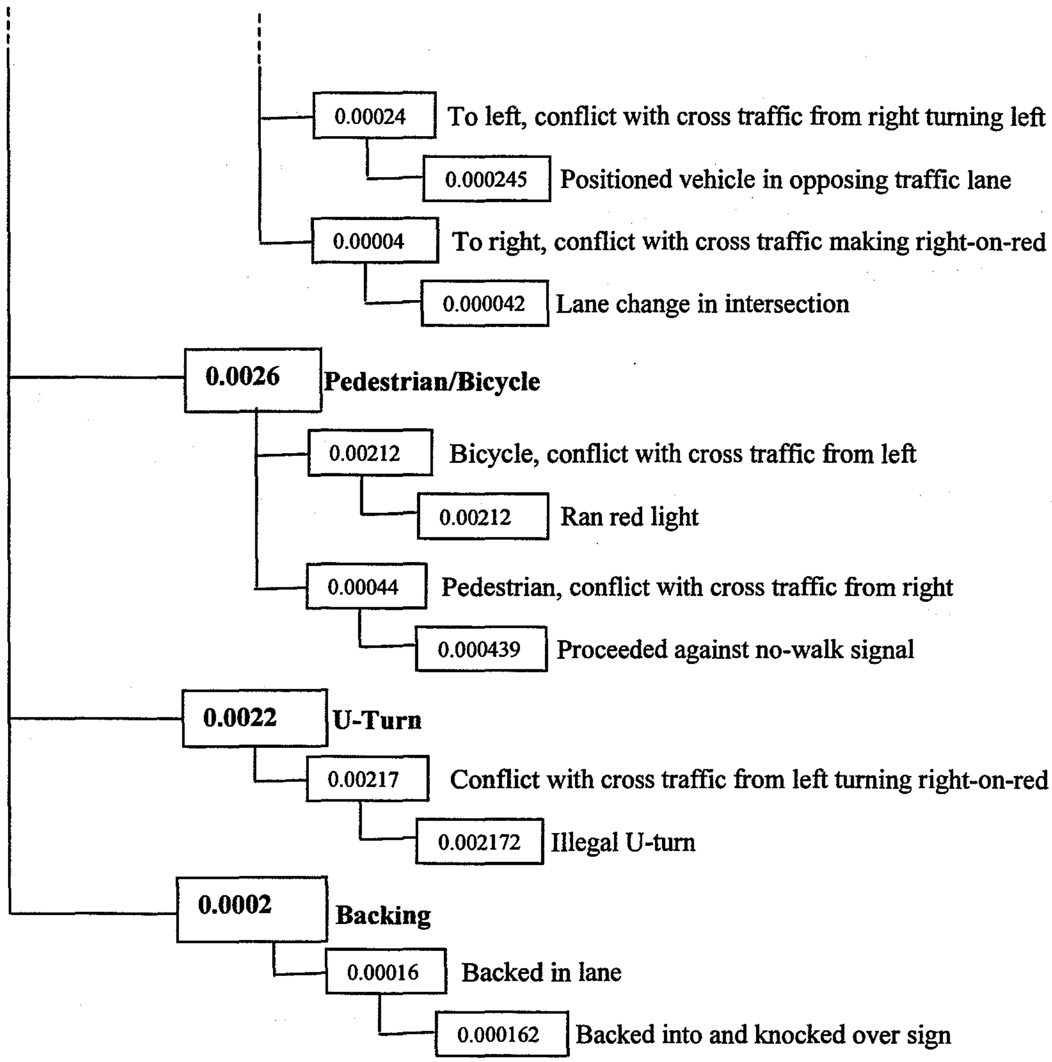

Figure 28. Signalized Complex Intersection Infrastructure Probability Taxonomy (continued).

Potential Relationship to Crashes

It must be stressed that the data that went into determining the probabilities described here were for critical incidents and not crashes. Because traffic simulations such as IHSDM (see the following web site for details: http://www.tfhrc.gov/safety/ihsdm/ishdm.htm) and INTEGRATION (Van Aerde and Rakha, 1999) do not use critical incidents, but rather crashes, a method of estimating crashes from the Task E probability models had to be developed.

Heinrich's Triangle is one method that has been used to estimate crashes from critical incidents (Heinrich, et alo, 1980). Developed for industrial accidents, Heinrich's Triangle provides estimated ratios between fatalities, severe injuries, moderate injuries, minor injuries, and near-accidents (figure 29). Using these ratios, it can be seen that for every fatal accident, there are an estimated 10,000 near-accidents.

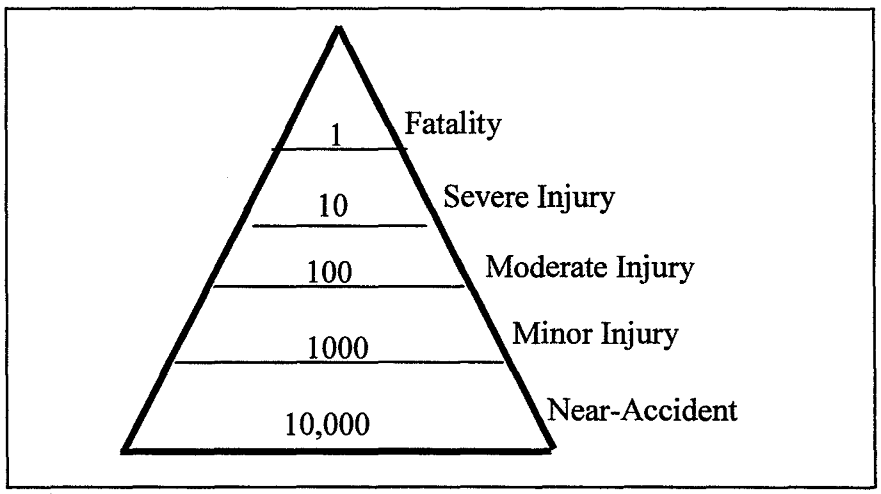

Figure 29. Heinrich's Triangle.

Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman (1995) adapted Heinrich's Triangle for use in transportation research. In this adaptation, shown in figure 30, Dingus et al., estimate that for every fatality there are 100,000 errors with a hazard present and 1,000,000 errors with no hazard present. To test this model, Dingus, et al. (1999) collected on-road near-accident data supplemented with published injury accident and non-injury accident data. Their results are shown in figure 30.

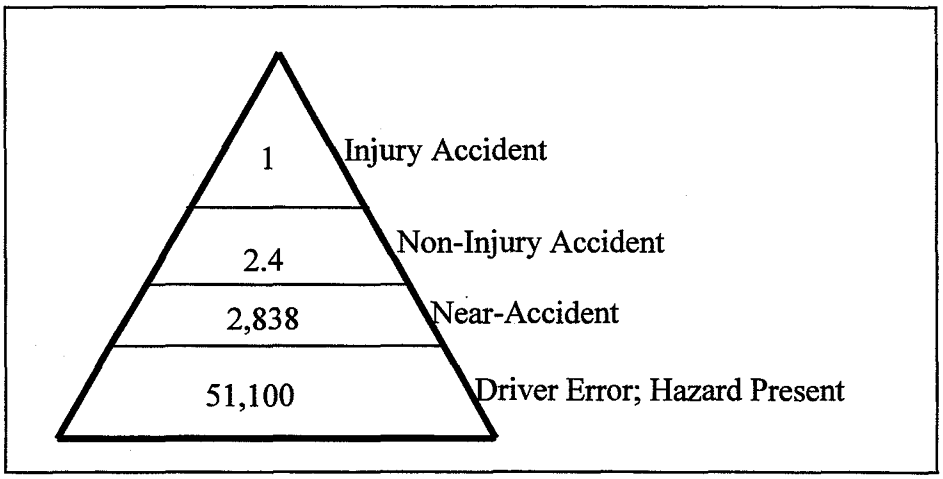

Figure 30. Modified version of Heinrich's Triangle using automobile driving data from Dingus, et al. (1999).

Deriving Crash Probabilities From Critical Incident Probabilities

The findings from Dingus, et al. (1999) suggest that critical incident data could be used to estimate crashes. The crash estimation approach that can be taken involves combining the "Injury Accident" and "Non-Injury Accident" categories listed in figure 30. For the purpose of the crash estimates made for the current effort, the combination of these two accident categories will be labeled "Accident," and, because of a lack of data, the severity of the accident will not be considered. Referring to figure 30, combining "Injury Accident" and "Non-Injury Accident" categories results in a value of 3.4.

In developing the critical incident probabilities in Task E, only data that had a severity rating of 4 or higher were included. These ratings involved near-crash events. Referring to figure 30, the comparable category would be "Near-Accident." The value of this category is 2,838. Normalizing the data so that the new Accident category is "1," we end up with a ratio of Accident to Near-Accident (i.e., critical incident) of 1:835. That is, for every accident in the Dingus, et al. (1999) data set, there were 835 near-accidents.

To estimate crashes from the critical incident data collected in Task E, the ratio of 1:835 can be applied to each probability value. For example, the critical incident probability for the signalized complex intersection group is 0.0327. Therefore, the estimated crash probability is 0.000039 (or 0.0327/835). Put another way, for every 25,641 vehicles that travel through a signalized complex intersection, one crash would be predicted. Crash predictions for the probability values of the different Infrastructure Groups, Maneuver Classes, Conflict Types, and First Harmful Factors can be determined in a similar manner (i.e., dividing the critical incident probability value by 835). It should be noted that the taxonomies developed in Task E were driver error taxonomies for different surveillance sites. That is, these taxonomies involved careful evaluation of driver errors; design features of the site (e.g., driveways within complex intersections, ramps with specific speed differentials, merge area distances, and proximity to intersections) were not specifically and/or independently evaluated. (Note that the project focus was on driver error and not on specific design features, per se.)

Fine Tuning the Crash Probability Estimates

When examining the results of estimating crash probabilities from critical incident probabilities, it becomes apparent that the crash probabilities are higher than reality might suggest. To accurately estimate the crash probabilities that were derived from the critical incident probabilities, actual crash probabilities are required for calibration. However, actual crash probability models are very difficult and time consuming to obtain. Fortunately, in another project conducted at the Virginia Tech Transportation Institute, a crash probability model was determined for a site classified as a "Signalized Complex Intersection." The pertinent data for this particular site are:

- Location: Prices Fork and Tom's Creek Road in Blacksburg, VA
- Time of study: February 1994 - June 1998 (or ~1,580 days)
- Number of crashes documented: 70
- Daily number of vehicles using intersection: 3,748

Using this information, it can be determined that the crash probability for this particular intersection is 0.000012. That is, (70 crashes ÷ 1,580 days) ÷ 3,748 vehicles/day = 0.000012. Compare this to the signalized complex intersection estimated crash probability, derived from the critical incident data, of 0.000039. Why is there a large discrepancy? There are at least three explanations. First, the data collected for the previous research were from 1994 to 1998. The data collected for the Driver Error project were from 1999. Arguably, the volume of traffic and the aggressiveness of drivers may have increased from 1994 to 1999. Second, the Driver Error project estimates are based on data collected from seven different intersections, but the actual crash probability data are from one intersection. Third, the derived crash probabilities are based on a hypothetical link between critical incidents and crashes (Heinrich, et al. 1980). There may also be a difference created by the need to "interpret" the categories used by Dingus, et al. (1999) when applying them to the incident data of the current project.

Knowing the actual crash probability of a signalized complex intersection allows us to adjust the crash probability values that were derived from the critical incident probabilities. To make this adjustment, each of the estimated crash probabilities should be divided by 3.25 or (0.000039 ÷ 0.000012). Dividing each critical incident-derived crash probability by this constant may provide a more representative probability value for the Infrastructure Groups, Maneuver Classes, Conflict Types, and First Harmful Factors.

As indicated, actual crash probability models are very difficult and time consuming to determine (this was one of the reasons for estimating crash probabilities from the more easily collected critical incident data). As demonstrated, knowledge of actual crash probabilities allows the researcher to derive more realistic probabilities for the various taxonomy levels.

It must be stressed that the probability examples shown here are just that, *examples*. The purpose of this discussion is to illustrate how the process of estimating critical incidents, and crashes, can be accomplished. However, the values presented here should not be considered valid for all signalized complex intersections. Rather, the take-away should be an understanding of the procedure that was used for making these calculations using data collected in the field.

RECOMMENDED SITE EVALUATION METHODOLOGY

Overview

Recall that one of the goals of this project was to develop a protocol, or Site Evaluation Methodology, for identifying potential countermeasures to driver errors. More specifically, it was intended that one of the outputs of this project would be a set of steps that could be used to assess problem sites in terms of high frequency or severity of critical incidents. This section outlines the recommended Site Evaluation Methodology.

Problem Statement

Consider the situation wherein a given site is reported to have a high incidence of traffic conflicts and/or crashes. To remedy this situation, an effort is required to determine the sources of these conflicts and the contributing factors. Given a thorough understanding of characteristics of the traffic conflicts, it is suggested that countermeasures aimed at resolving these conflicts might be developed. Therefore, the purpose of the Site Evaluation Methodology is to provide a protocol to be followed to gather the data necessary so that a thorough understanding of the conflicts at a particular site may be obtained.

Steps in the Site Evaluation Methodology

The method for determining the sources and contributing factors associated with traffic conflicts and/or crashes is presented below. As evidenced by the successful completion of the four analyses conducted in this task, it is suggested that this protocol has been shown to be an effective tool for conducting traffic site analyses.

1. **Site Survey**. Conduct a site survey to ensure that a particular site is appropriate for in-depth investigation (i.e., is a problem site).
   a. The site visit(s) should be made during prospective data collection times (e.g., 11:00 a.m. to 1:00 p.m.). The researchers should familiarize themselves with the site and note site specific factors (e.g., sun angle, presence of traffic control officer).
   b. A site sketch should be made and photos taken.

2. **Site Drive-Through.** Conduct a site drive-through with a car equipped with a video camera and drive through the site using all relevant entrances/exits.
   a. Drive-through allows video documentation from the driver's vantage point, which can provide insight into the incidents.
3. **Site Diagram and Description.** Diagram the site in a bird's-eye (plan) view to provide insight into traffic conflicts that occur.
   a. Diagrams should be developed using available "official" drawings (e.g., police, city, county drawings). Careful attention must be paid to road markings, signs, traffic signals, etc. It is imperative that the site diagrams are accurate.
   b. A high-quality written description of the site is also desirable. These descriptions should provide a detailed portrayal of each approach and corresponding options the driver faces in passing through the site.
4. **Videotape Surveillance.** Conduct a videotape surveillance of the site to collect traffic event data. The video recordings of traffic events can be conveniently analyzed in the lab at a later time.
   a. Use a high-resolution camera and recording system. Select lenses and lens attachments to obtain appropriate fields-of-view.
   b. Choose camera positions that will go unnoticed by drivers. Video cameras must be set up unobtrusively so that traffic is not influenced by the presence of the equipment or the observers.
   c. Choose a position that encompasses most of the site, or alternatively use two or more cameras in different locations. Note that single position surveillance is preferred because of its simplicity.
   d. Select a camera site that is safe for the researchers. As mentioned, researchers should be as inconspicuous as is feasible, which will usually provide an additional measure of security.
   e. Record sound because it can provide useful information (e.g., screeching tires).
5. **Data Collection.** Collect videotaped data at specified time intervals.
   a. Collect during time periods of interest. For example, if previous information suggests that the noon and evening rush hours are problematic, ensure that data are gathered over these time intervals. If no such information is available, it is recommended that

data collection occur early in the week (i.e., Monday or Tuesday) and at peak traffic times.

b. Gather data for 1 to 5 days at the site, and for each specified interval.

c. At least one researcher (and preferably two) should be present at the site while recording data. The site-researchers should keep a log documenting all incidents that occur and note the time of the occurrence. This information can later be used to help identify incidents on the videotape. Use a copy of the site diagram (Step #3) to note the location of incidents.

d. Ensure time of incidents is recorded accurately by using a digital watch that is synchronized to the video recorder. Alternatively, use instrumentation that allows the researchers to observe the time being recorded on the video image.

e. A clear description of the data-collection particulars (e.g., site number, day of week) should be written on all videotapes and research notes. Afterwards, the videotapes and notes should be archived. This step serves to simplify the data-retrieval process that occurs later.

6. **Data Reduction and Extraction.** Retrieve relevant information about the traffic events from the videotape and site-researchers' notes.

    a. Detailed information on the method of data reduction and extraction is presented in this report.

7. **Incident Cluster Development.** After data collection is complete, indicate on a site diagram the precise location of each incident.

    a. Perform this step using the video recording of the incident, the reduced data file, and the site-researchers' notes.

    b. Use reference numbers to document incident location (e.g., incident 1 to incident N).

    c. Highlight apparent incident clusters.

8. **Conduct Other Appropriate Analyses.** As appropriate, conduct the following analyses: (1) Generalized Infrastructure-related Analysis, (2) Time-of-Day/Day-of-Week Analysis, and (3) Most Serious Incident Evaluation Across Sites Analysis.

    a. Detailed information on the method of conducting these analyses is presented in this report.

b. Results of analyses will lead to recommendations for infrastructure and non-infrastructure-related changes to remedy the site problems.
c. In most cases, these additional analyses would not be necessary. However, there may be reasons in specific situations for performing them.

Figure 31 provides an overview of the steps involved in the Site Evaluation Methodology. Note that the methods used for conducting the four analyses for this project were primarily based on the site surveillance, as indicated in the six steps presented above. That is, the eight steps outlined previously are detailed steps directed at site surveillance, which was the primary method of collecting data that was used to conduct the four Task E analyses. However, in addition to site surveillance, the flow chart in figure 31 includes data collection through investigating officer interviews and a crash database search. It is suggested that for all practical purposes, with regards to implementing the Site Evaluation Methodology in the field, the site surveillance approach is the most useful and will provide field engineers with the most information. However, as time and finances permit, site surveillance could be supplemented with investigating officer interviews and crash database searches in order to achieve more in-depth information in regard to the problems at a particular site.

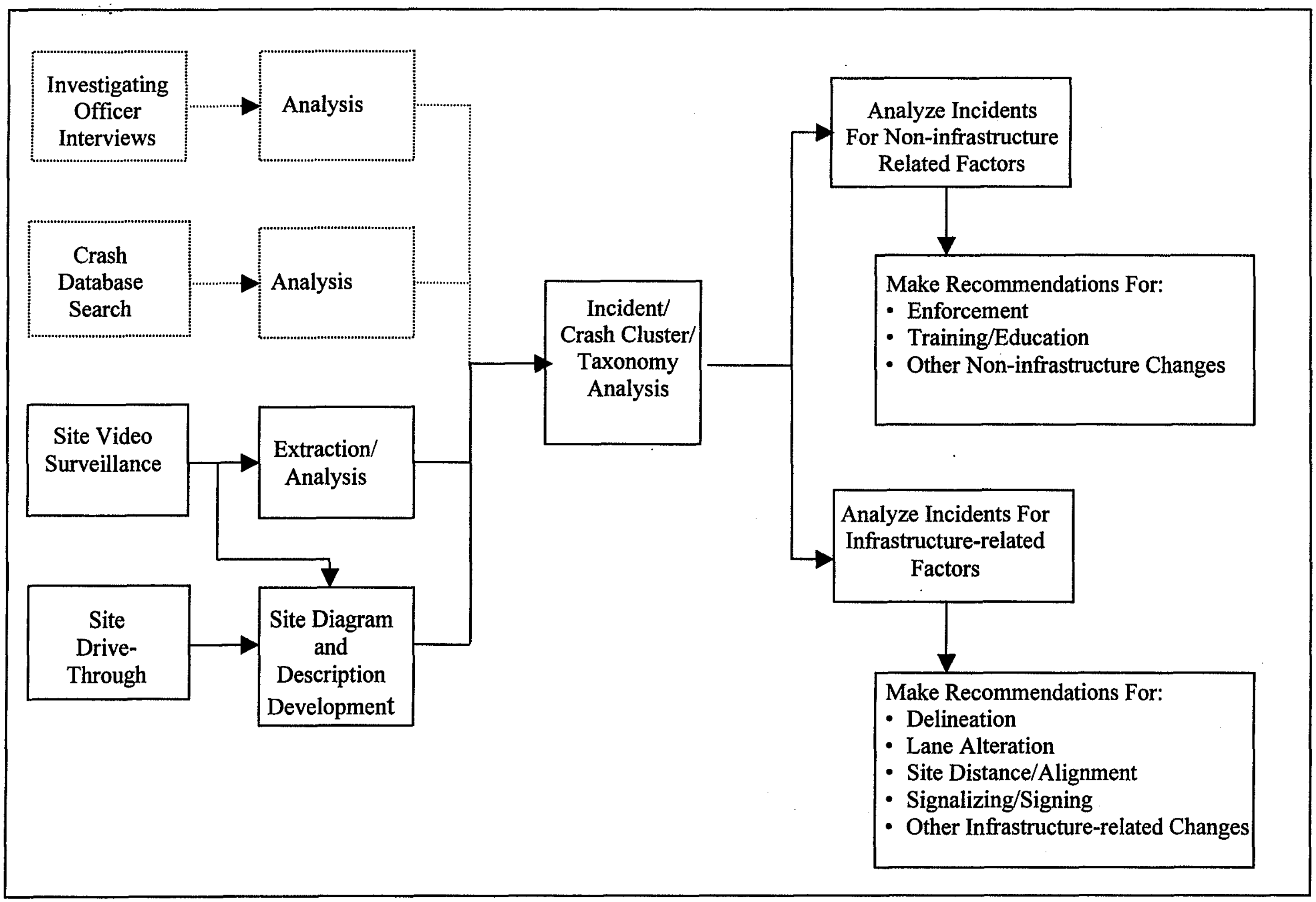

Figure 31. Overview of Site Evaluation Methodology.

CHAPTER VII. INFRASTRUCTURE-RELATED COUNTERMEASURES DEVELOPMENT

INTRODUCTION

The development of infrastructure-related countermeasures was detailed in the Task F report (Wierwille, Hanowski, Kieliszewski, and Medina, 2000). The information presented in this chapter has been abstracted from Task F. The Task F effort involved careful examination of the serious incidents that were recorded and analyzed in Task E (presented in the previous chapter of this final report). These incidents were first separated into those that had infrastructure contributors and those that did not. The incidents that had infrastructure contributors were then carefully re-analyzed in an effort to determine the exact nature of the infrastructure-related driver errors. The fundamental concept associated with Task F was that infrastructure contributes to driver errors in some cases and, that if countermeasures can be developed, then the number of occurrences of driver errors (and corresponding critical incidents and crashes) should decrease.

Up to this point, the information that has been presented has dealt with the general problem of driver errors such as definitions, taxonomies, and prevalence of occurrences in today's traffic environment. In this section, the focus shifts to examining the infrastructure contributors in greater detail. The fundamental concept is that one of the component contributors to some (but not all) driver errors is infrastructure, that is, signing, signaling, delineation, alignment, and geometry. If problems with the infrastructure can be removed or remedied, then, hopefully, the frequency of driver errors and incidents should be reduced.

METHOD

Infrastructure-Related Driver Error Descriptions

There were 52 critical incidents in the data set with severity ratings of 5 or 6. These were the most serious incidents and involved a collision (rating of 6) or a close call in which substantial braking or emergency maneuvering was necessary to avoid a collision (rating of 5). Recall that for each of these incidents, a "master sheet" was developed. The idea was to summarize on a single sheet the essence of the incident and its contributing factors. The sheets containing infrastructure factors were separated from those not having infrastructure factors. The research team took each infrastructure factor and examined it in detail. This analysis included the development candidate countermeasures. In total, 43 infrastructure-related driver error descriptions were developed along with corresponding candidate countermeasures.

Countermeasures Concepts

Once the error statements had been developed, the research team set about developing countermeasures for each error type. The idea was to provide the most logical set of possible countermeasures, regardless of whether they were standard practice or not. In some cases, more than one countermeasure was developed. Emphasis was placed on infrastructure countermeasures, as the objective of Task F was to determine appropriate infrastructure solutions to driver errors and incidents. In some cases, other forms of countermeasures could be used, including driver education and law enforcement, but these were not emphasized.

It was found that many of the driver error descriptions involved standard practice. Therefore, many of the countermeasures are based on the application of standard practice. In those cases where standard practice does not seem to be applicable, the countermeasure description so states and also indicates whether or not additional research is needed.

Research Problem Areas

Once the driver error statements and their countermeasures had been completed, questions arose regarding the possible generalities that were observed. Are there repeating themes and general problem areas that seem to be worthy of further examination, or are the infrastructure problems relatively independent of one another? Careful examination of the driver error statements and the recommended countermeasures, as well as review of the previous project documentation, suggested that several groups of problems have similar infrastructure origins. These areas suggest possibilities for future research.

INFRASTRUCTURE ERROR DESCRIPTIONS AND COUNTERMEASURES

This section presents a sample of the Infrastructure-Related Driver Error Descriptions and the corresponding Candidate Countermeasures that were originally presented in the Task F report. For the complete set (there were 43) of error statements and countermeasures that were developed for this project, the reader is referred to the Task F report. The statements were classified into one of five categories, as shown in table 22. The categorization scheme was developed based on the error descriptions, and took into account typical categories of infrastructure elements such as signals, signs, alignment and geometry, and delineation. The final category in the scheme is pedestrians and bicycles. Pedestrians and bicycles did not fit neatly into any of the other categories and were therefore classified separately. The right-hand column in table 22 lists the error numbers from the Task F report that are included in the current report.

Table 22. Categorization of infrastructure aspects in incidents.

Category	Example Error Included in This Report
1. Signals	
1.1 Confusing Multiple Signals	
1.2 Signals Not Visible	No. 2
1.3 Signals Creating Bunching	No. 4
1.4 Uncoordinated Signals	
2. Signs	
2.1 Signs Readable But Ineffective/Apparently Ignored	No. 6
2.2 Signs Unclear/Confusing/Missing	No. 11
2.3 Stop Sign, Confusion Regarding Right-of-Way	No. 15
3. Alignment and Geometry	
3.1 Intersections In Close Proximity To One Another	No. 17
3.2 Private Entrances/Exits In/Near Intersections	No. 21
3.3 Short Weaving Sections	No. 23, 24, 25
3.4 Short Merge/Entrance/Acceleration Lane	
3.5 Visibility Difficulties Resulting Directly From Alignment/Geometry	No. 28
3.6 Visibility Difficulties Resulting From Blockage By Other Vehicle	No. 31
3.7 Visibility Difficulties Resulting In Encroachment	
4. Delineation	No. 38
5. Pedestrian and Bicycle Interactions	No. 42

Infrastructure-Related Driver Error Descriptions

Each infrastructure-related driver error description begins with a Type of Error statement. This is a concise, specific statement of the observed error. It is intended to convey the essence of the error without embellishment. The Type of Error statement also includes categorization number(s) and title(s) to clarify how the error has been grouped.

The next item in the error description is the Typical Location. It includes a reference to Appendix A of the Task E report. That appendix consists of a detailed description and drawing of the infrastructure site where the error was typically observed. Also included in the Typical Location section is a detailed description of the infrastructure site in terms directly relevant to the error type. In other words, only details about the site that are germane to the error type are included. Therefore, there is some generality in the description since irrelevant aspects may vary.

Next, a typical scenario is presented. The kind of incident observed is described. The intent is to provide a complete description but to do so in approximately one full paragraph. In most cases the example is followed by a sketch (of a Typical Example). This sketch is a stylized version of the detailed drawing in Appendix A of the Task E report. The sketch is simple, and it leaves out much of the detail that is irrelevant to the error.

The Infrastructure-Related Driver Error description is intended to convey the error in a way that is accurate, understandable, and concise. Since 43 error statements were developed, the goal was to make the presentation as readable and manageable as possible, without oversimplification.

Candidate Countermeasures

The countermeasures associated with each error use a similar concept, namely to convey the countermeasure(s) accurately in a concise format. The countermeasures are made up of a Recommendations section and an Other Countermeasures Considered section. The Recommendations section provides a detailed description of each recommended countermeasure, whereas the Other Countermeasures Considered section provides only brief descriptions of alternatives, if any.

The Recommendations section includes a Description that is a detailed presentation of the concept in paragraph form. It is usually followed by a sketch intended to convey how the countermeasure is envisioned. In most cases this is a bird's eye view of the modified infrastructure elements, sometimes supplemented by auxiliary diagrams of signs, signals, or other important details.

The Recommendations section also includes citations of Relevant Standard Practice, if any. In general, the citations are taken from the AASHTO "green book" (1994) and the MUTCD (U.S. Dept. of Trans., FHWA, 2000). The Relevant Standard Practice section usually includes a statement as to whether the countermeasure is conventional and within standard practice, or whether it is subject to future research. In general, the Relevant Standard Practice section is intended to frame the countermeasure within the context of current standards.

The final section in the Recommendations section is entitled Economic Aspects. This section is intended to provide a general indication of the costs that would be associated with implementation of the countermeasure. Rather general terms are used. For example, if the countermeasure involves re-signing and modifications to delineation, the costs are considered to be "low." If the countermeasure requires installation of a full set of traffic signals and accompanying analysis for optimization of traffic flow and signal timing, costs are considered to be "moderate." If the countermeasure requires development of a grade-separated intersection modification, for example, then the costs are considered to be "high." These benchmarks are intended to provide some indication of costs that might be associated with the given countermeasure. Personal communications with the VDOT (Salem, VA office) and information from the Internet were used to estimate costs for these three categories. These cost approximations are as follows:

- Low:[2] Up to $50,000
- Moderate:[3] From $50,000 to $700,000
- High:[4] Over $700,000

Detailed economic analyses and tradeoffs were considered to be beyond the scope of the present effort because a single reasonably detailed analysis would have consumed the resources of the

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[2] Cost to put up four stop signs at intersection with labor and maintenance for 1 year is estimated to be approximately $1,000 (estimate from VDOT). Upper bound for "low" category based on upper bound from "moderate" category.

[3] Estimated cost for traffic signals is $50,000 to $100,000 to install. Estimate obtained online at http://www.memun.org. Note that estimate from VDOT is $100,000 to $125,000 for same installation (note that website data may be dated and/or regional price variation may exist). Upper bound set based on lower bound of "high" category.

[4] Project about to begin to lengthen road is estimated by VDOT to cost approximately $700,000. Project to install a ramp is expected to cost approximately $3.9 million.

entire Task F effort. However, an approximate cost/benefit analysis was completed for one example in which stop signs are replaced by a set of traffic signals. The example appears immediately following the infrastructure error statements and countermeasures.

As indicated, the Other Countermeasures Considered section is intended to provide possible alternatives for consideration. These alternatives are not fully developed, and they appear on the surface to be less desirable than approaches appearing in the Recommendations section.

INFRASTRUCTURE-RELATED DRIVER ERROR 2

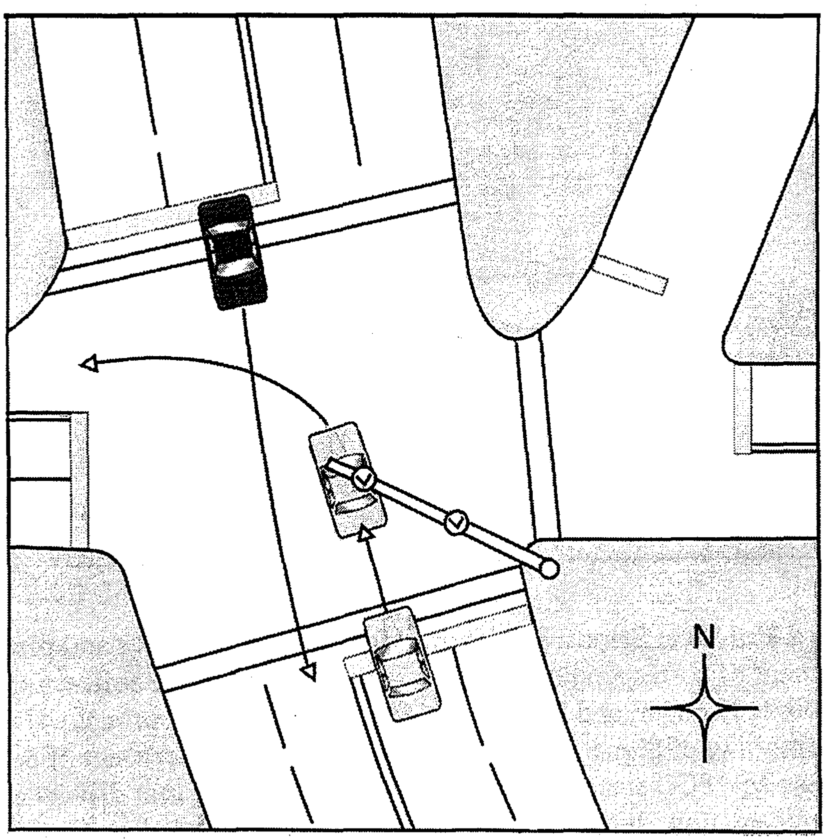
Type of Error
Traffic signal visibility: Drivers of left-turning vehicles are unable to see traffic signals upon entering intersection.

Category: 1.2 Signals Not Visible

Typical Location (See location 22)
Large signalized intersection with overhanging traffic signal bar and no dedicated turn signal (green arrow).

Description by Typical Example
At a signalized intersection, a driver enters and proceeds into the middle of the intersection on a green ball. The position of the traffic signal is such that the driver can no longer see the signal once in the middle of the intersection and must wait for a break in the oncoming traffic, without reference to the traffic signal, to complete the maneuver.

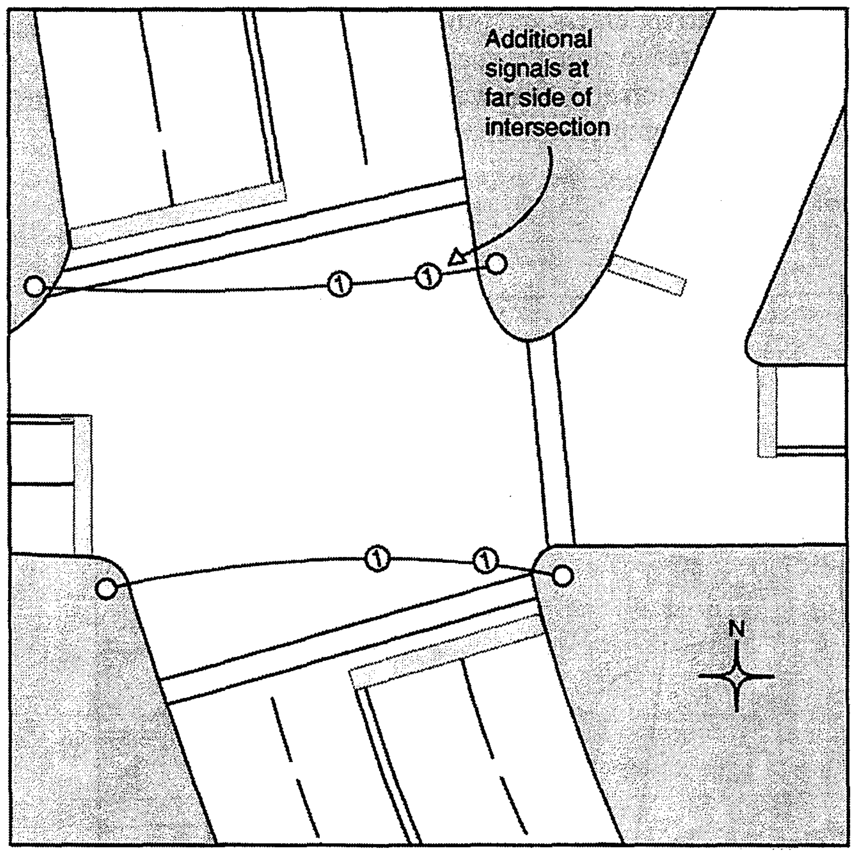
Sketch of the Typical Example

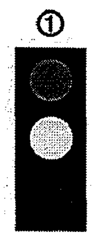


ERROR 2, CANDIDATE COUNTERMEASURES

Recommendation

Description: The traffic signals that are placed inside the intersection do not allow visibility by drivers who have entered the intersection. This situation can be avoided by moving the signals to the far side of the intersection, that is, opposite the driver. Alternatively, if it is believed that the signals are needed in their present positions, a supplementary signal can be placed on the opposite side of the intersection. However, it is important to check for confusion if there is more than one signal for a given traffic lane. The diagram shown below illustrates the concept of moving the signal for a typical situation. What is needed is a conventional traffic signal analysis for determining signal placement for each lane and content of each signal.





Relevant Standard Practice: Standard guidelines for optimal visibility and placement of traffic signals, and placement of corresponding supports are addressed in the following MUTCD sections: 4D.15—Size, Number, and Location of Signal Faces by Approach, 4D.17—Visibility, Shielding, and Positioning of Signal Faces, and 4D.19—Lateral Placement of Signal Supports and Cabinets. These MUTCD standards were developed to ensure that drivers can see the signal after entering the intersection. It appears that the intersection design described in Error 2 does not follow these existing guidelines. Since this solution is conventional, supporting research is not needed.

Economic Aspects: This countermeasure requires the replacement of traffic signals and corresponding supports. It is likely that the current signals would have to be supplemented or modified, thus requiring new signals, supports, and controllers. Costs for this countermeasure are expected to be moderate.

Other Countermeasures Considered
None.

INFRASTRUCTURE-RELATED DRIVER ERROR 4

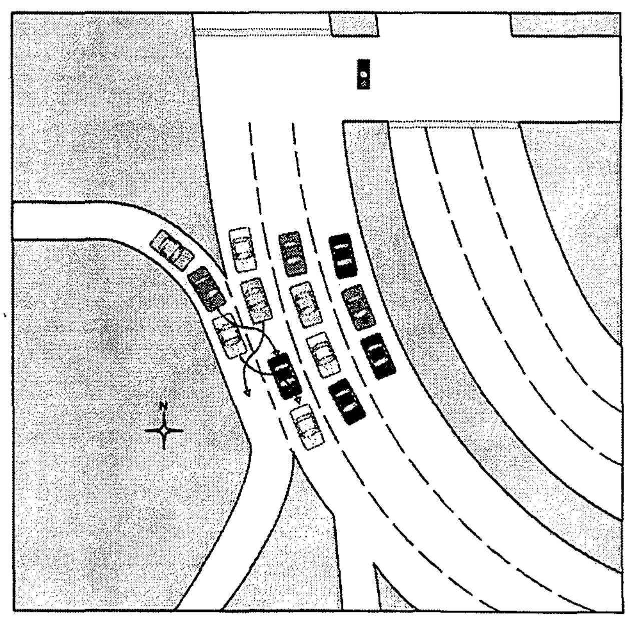
Type of Error
Congestion at a weaving section because of the proximity of the traffic signal.

Category: 1.3 Signals Creating Bunching

Typical Location (see location 8)
Roadway with multiple through traffic lanes adjacent to a weaving section meant to accommodate both entering and exiting traffic. Traffic on the roadway is controlled by a traffic signal about 100 yards (~91 m) before the start of the weaving section. The location also has a series of two exits, one that utilizes the weaving section and another beyond the weaving section.

Description of Typical Example
Although the additional weaving lane appears to have adequate length, heavy traffic in the through lanes tends to block passage between the right-most through lane and the weaving lane for all merging traffic. All traffic has a difficult time maneuvering because vehicles are spaced very close to one another in all lanes. The blockage appears to be a result of heavy traffic advancing along the roadway in clusters caused by a traffic signal that is about 100 yards before the weaving section. Drivers in the right through lane who intend to take the second exit tend to obstruct the weaving movements of other drivers.

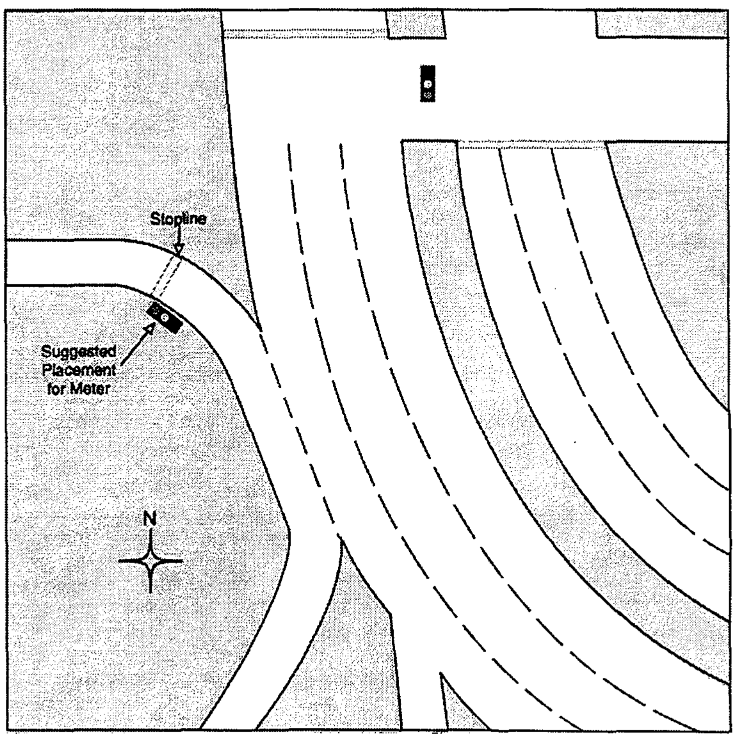
Sketch of the Typical Example



ERROR 4, CANDIDATE COUNTERMEASURES

Recommendation

Description: Waves of congestion result at a weaving section because of a traffic signal prior to the weaving section. This causes problems for drivers who are trying to either exit or enter through traffic because there often is little or no room for drivers to maneuver their vehicles. To reduce congestion, traffic on the ramp should be metered when the traffic signal changes from red to green. The metering could be dependent upon the amount of traffic flow through the intersection and the traffic signal cycle. Ramp traffic should be stopped when through traffic is at its heaviest (e.g., high to very high traffic levels in all through lanes). An intermittent stage could be used to gradually allow more ramp traffic to enter through traffic as it thins. Once through traffic has thinned or is stopped at the traffic signal, ramp traffic would be permitted to self-regulate merging maneuvers. The diagram shown below illustrates where ramp metering may occur. A traffic flow study would have to be performed to identify the amount of time ramp traffic would not be permitted to enter through traffic, and to determine a metering rate that would be dependent upon through traffic flow.



Relevant Standard Practice: Ramp metering is a common practice at locations that have to accommodate merging traffic that accesses a high traffic flow or congested traffic situation. Chapters in the AASHTO policy guide (Chapter X—Grade Separations and Intersections: Other Interchange Design Features: Ramp Metering), and the *Highway Capacity Manual* (HCM) (Chapter 4H—Traffic Control Signals for Freeway Entrance Ramps) currently address these issues. As outlined in the AASHTO green book, "the ability to accommodate high volumes of traffic safely and efficiently through intersections depends largely on what arrangement is provided for handling intersection traffic" (p. 805). It is suggested that further study on the optimal design solution for the type of intersection configuration outlined in Error 4 is necessary, and that this solution may be found through conventional design practices as outlined in those sources listed previously.

Economic Aspects: This countermeasure requires the addition of ramp meters and signals, and corresponding supports and control devices. Costs for this countermeasure are expected to be moderate.

Other Countermeasures Considered
Close off intersection by rerouting traffic to an intersection that is farther away from the merge area.

To reduce the amount of through traffic in the far right lane, add signage, prior to the weaving section, that indicates to through traffic that the far right lane is an "exit only lane" (see Recommendation 2, for Error 25).

Change the signal timing.

INFRASTRUCTURE-RELATED DRIVER ERROR 6

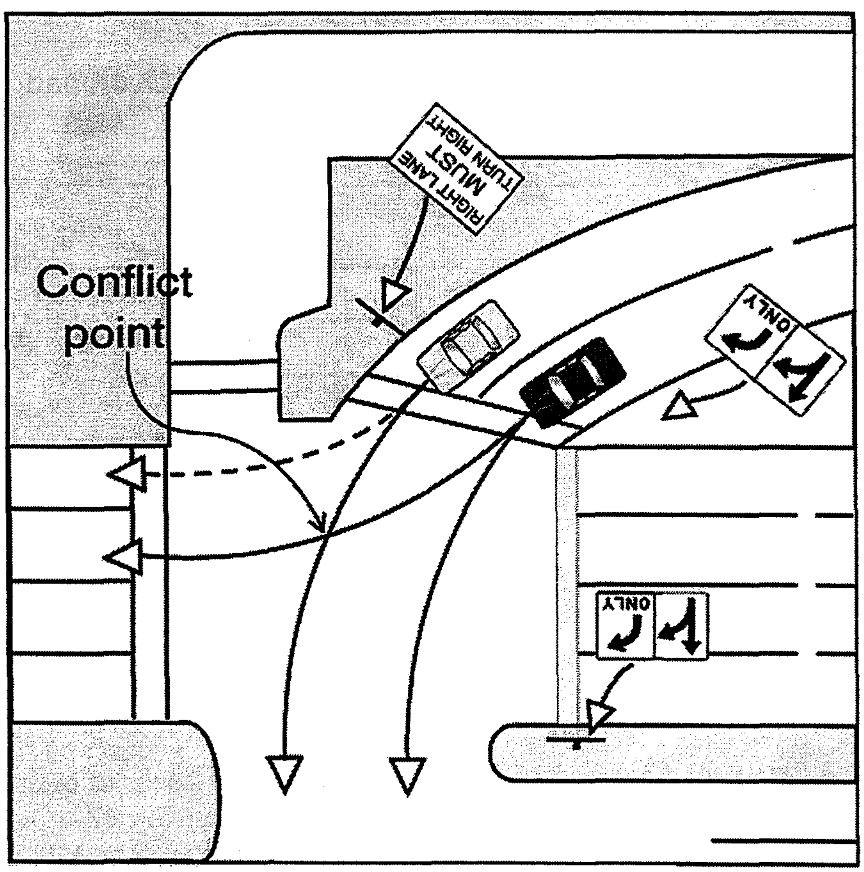
Type of Error
Ineffective "Right Lane Must Turn Right" sign: Drivers do not follow sign directions.

Category: 2.1 Signs Readable but Ineffective

Typical Location (See location 7)
Extremely complex intersection with moderately dense, fast-flowing traffic. "Right Lane Must Turn Right" sign is posted at a point after the driver is committed to the lane. Sign is posted near several other signs, which may reduce its conspicuity.

Description by Typical Example
Highly complex intersection in busy urban setting. Controlled (signalized) intersection has "Right Lane Must Turn Right" sign posted. Many drivers proceed through intersection (some opting to make a left turn). The consequence of proceeding through intersection from the right lane is that vehicles in the left lane, having the option of making a right turn or proceeding straight, are cut off.

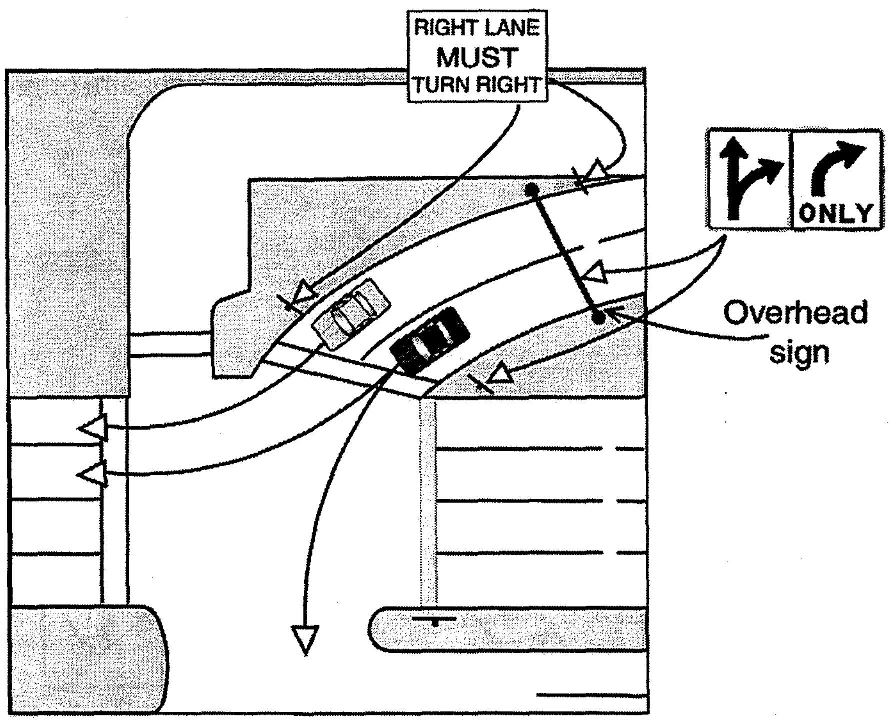
Sketch of the Typical Example



ERROR 6, CANDIDATE COUNTERMEASURES

Recommendation

Description: The traffic signs indicating direction of travel for each lane are not followed. It is hypothesized that this error is a result of poor sign visibility caused by less than optimal sign positioning. This situation can be avoided by increasing the visibility of the signs. Drivers would then have time to move to an appropriate lane for their desired direction of travel. The addition of signs above lanes, in combination with presenting the "Right Lane Must Turn Right" sign earlier, may remedy this error. The diagram shown below illustrates the concept of (1) adding an overhead sign that provides lane-direction information and (2) moving or adding a supplementary sign farther back from the intersection that directs drivers in the right lane to turn right.



Relevant Standard Practice: Chapter 2 of the MUTCD addresses issues of optimal sign location and position in sections 2A.16—Standardization of Location, 2A.17—Overhead Sign Installations, 2A.18—Mounting Height, and 2A.20—Position of Signs. The MUTCD guidelines cited suggest that signs should be positioned to provide the driver with sufficient time to react. The recommended countermeasure presented here would, in effect, provide the driver with more time (than is currently provided) to react and join the appropriate lane. Because this solution is conventional, supporting research is probably not needed.

Economic Aspects: This countermeasure requires the addition of traffic signs. Costs for this countermeasure are expected to be low.

Other Countermeasures Considered

An alternative to the countermeasure described is to restrict direction of travel in the left lane to "straight only" as compared to the current practice of "straight or right turn." A study of traffic flow optimization would be required prior to implementing this approach.

The addition of lane striping in the intersection may also be considered as a supplement to signage.

INFRASTRUCTURE-RELATED DRIVER ERROR 11

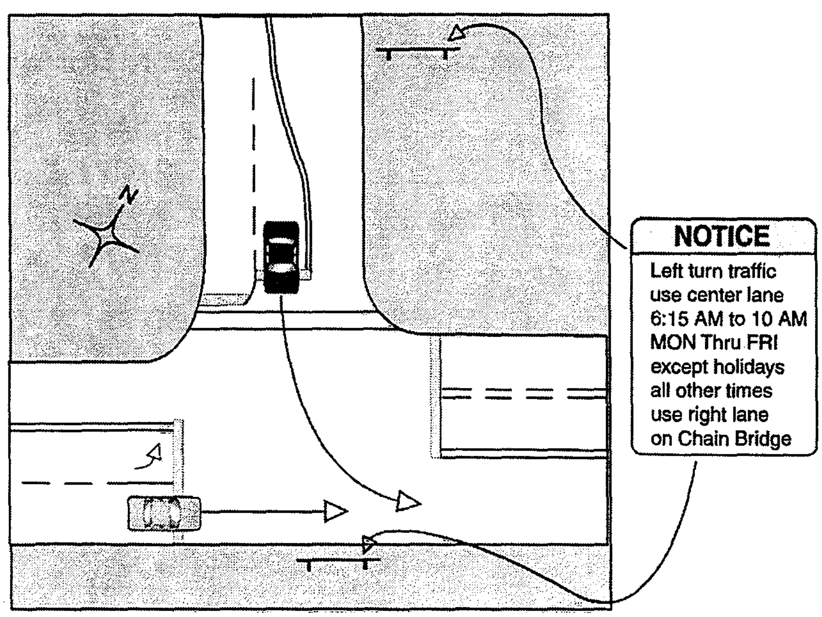
Type of Error
Apparently, the signage/signaling to warn drivers of time-of-day traffic pattern change is confusing. The driver does not appear to know which lane to enter.

Category: 2.2 Signs Unclear/Confusing/Missing
4.0 Delineation

Typical Location (See location 4)
The typical location for this error type is an intersection that has a change in the traffic pattern to improve flow during peak traffic hours. The change in the traffic pattern allows through traffic and cross traffic that are turning left to simultaneously enter designated adjacent lanes to depart the intersection. That is, through traffic, traveling in the right lane, continues through the intersection and occupies the right lane when it departs the intersection. Left-turning traffic turns into the center lane.

Description of Typical Example
The driver fails to correctly maneuver a left turn by entering into the incorrect lane during a period of the day when there is a change in the traffic pattern. This results in a conflict with cross traffic traveling through the intersection in the correct lane.

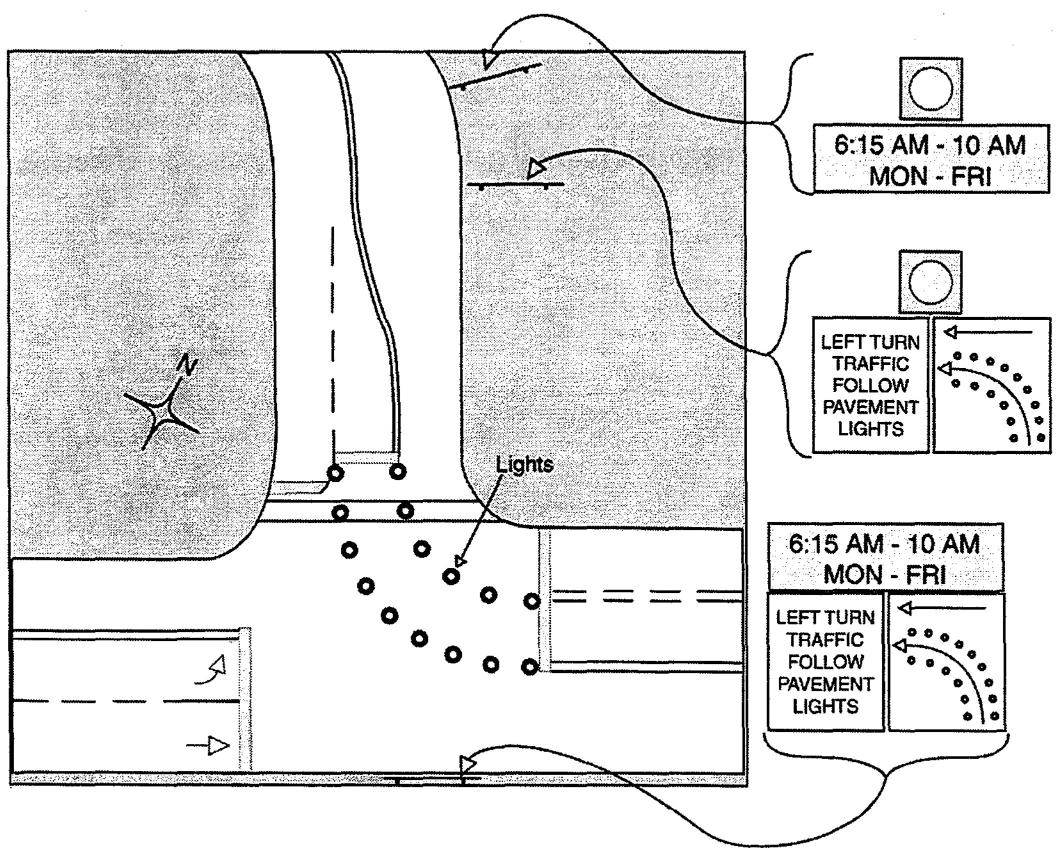
Sketch of the Typical Example



ERROR 11, CANDIDATE COUNTERMEASURES

Recommendation

Description: A time-of-day traffic pattern change causes confusion for drivers who are unfamiliar with the area. Confusion appears to result from ineffective signage and ineffective roadway delineation. The signage to warn drivers of the time-of-day traffic pattern change has a very long message with several lines of text. Signage can be improved either through a shorter message (appropriate message length could be determined through human factors experimentation), a combination of iconic and textual messaging, and/or a series of signs along the approach. If necessary, a hazard identification beacon can be added to signage to attract driver attention. Information should be simplified/clarified to promote drivers' understanding. Once at the intersection, the roadway markings are also confusing because the traffic pattern change requires drivers making a left turn to enter into a lane delineated for oncoming traffic. One possible countermeasure is to use illuminated markings that are embedded within the pavement to guide drivers into the correct lane (research required to test the viability of this solution). The combined signage changes and lighted pathway would provide redundancy and guide drivers into the correct lane.



Relevant Standard Practice: The embedded pavement light solution is not considered to be conventional for this error type, and supporting research is recommended. However, conventional guidance and channelizing practice should be applied when selecting lamp color and spacing (e.g., MUTCD Sections 3B.08—Extensions Through Intersections or Interchanges, 3B.01—Yellow Center Line and Left Edge Line Pavement Markings and Warrants, and 3B.04—White Lane Line and Right Edge Line Pavement Markings and Warrants). Conventional practice should also be taken into consideration for the design and placement of signage (e.g., MUTCD Sections 2B.18—Intersection Lane Control Signs, 2B.19—Mandatory Movement Lane Control Signs, and 4K.03—Warning Beacon). Additionally, insight may be gained from guidance presented in MUTCD Chapter 4L—In-Roadway Lights, though the application described is related primarily to pedestrian crosswalk lighting.

Economic Aspects: This countermeasure requires the modification of signage and corresponding supports along with the addition of lights embedded in the pavement and corresponding control devices. Costs for this countermeasure are expected to be moderate to high.

Other Countermeasures Considered
Addition of lane-use control signal and signs (for further explanation, refer to Candidate Countermeasure for Error 12 detailed in the Task F report).

If necessary, two sets of illuminated lane markings could be used. The first set would be as shown in the figure. The second set would direct drivers to the far lane during the alternate hours, that is 10:00 a.m. to 6:15 a.m. This concept would provide guidance regardless of the time of day.

Variable message signs and changeable overhead guidance signs may also be effective.

INFRASTRUCTURE-RELATED DRIVER ERROR 15

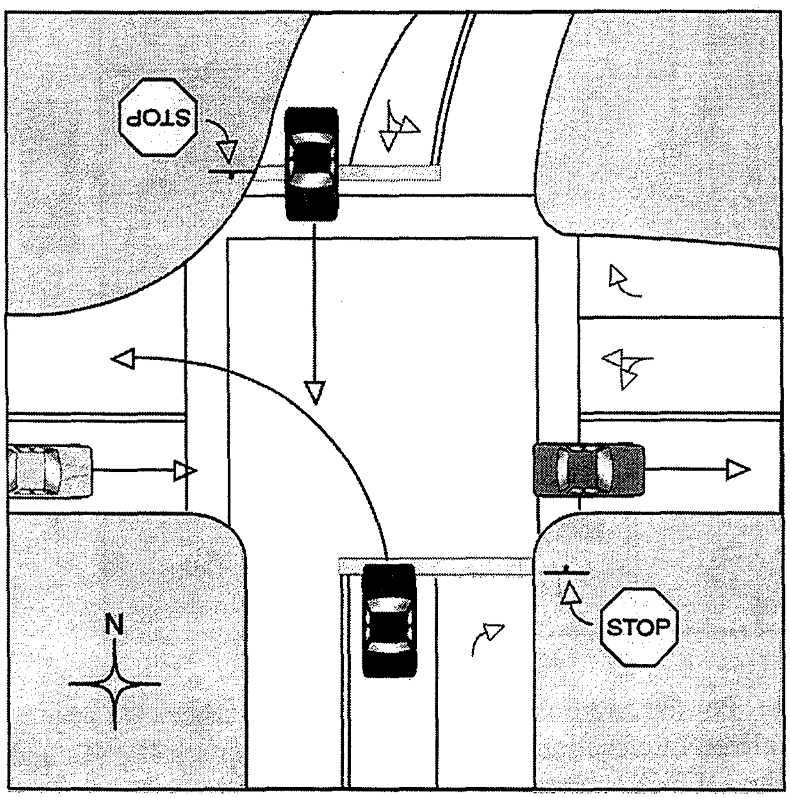
Type of Error
Right-of-way confusion: Driver uncertainty regarding who has the right-of-way, which seems to be caused, in part, by two-way stop signing.

Category: 2.3 Stop Sign, Confusion Regarding Right-of-Way

Typical Location (See location 25)
This location is a four-legged, stop controlled intersection. For this error type, two opposing legs have stop signs while the other two legs do not. There is a high volume of traffic at rush hour periods in all four directions of travel.

Description by Typical Example
Vehicles are stopped at each of the legs with stop signs. Traffic is flowing freely on the other two legs. A break in the traffic occurs. One of the stopped vehicles indicates a left-turn, while the other intends to travel straight ahead. A left-turning vehicle, which perhaps reached the stop sign prior to the vehicle proceeding straight, begins to turn. This leads to a conflict with the vehicle proceeding straight.

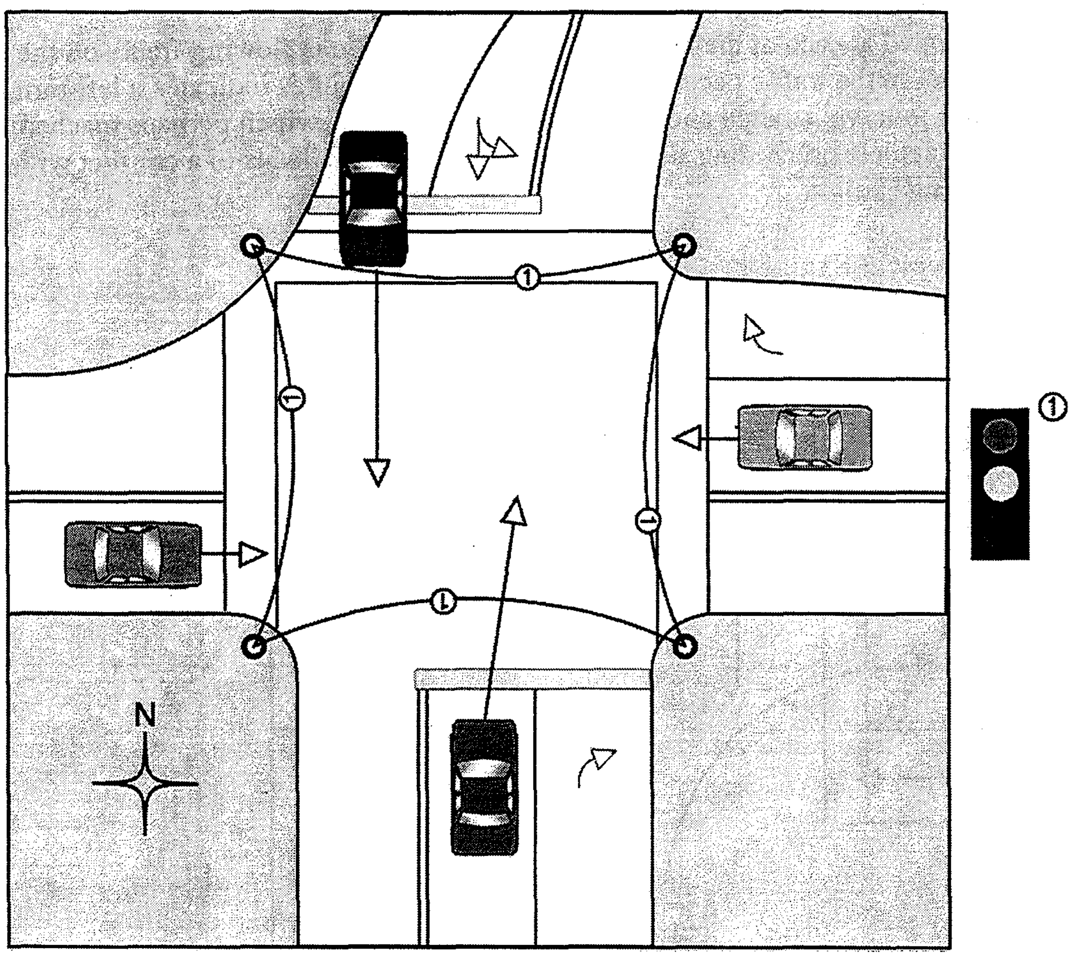
Sketch of the Typical Example



ERROR 15, CANDIDATE COUNTERMEASURES

Recommendation

Description: Two facing legs of a four-legged intersection have stop signs. Drivers stopped at the stop signs are uncertain as to which driver has the right-of-way. This "right-of-way confusion" becomes apparent when one of the vehicles turns left while the other proceeds straight. This uncertainty leads to conflicts between vehicles. This situation can be avoided by controlling the intersection with traffic signals. Traffic signals would control the flow of traffic in all directions and may reduce the right-of-way ambiguity. This candidate countermeasure is shown in the figure below. A conventional traffic signal analysis for determining signal placement for each lane and the content of each signal would be required prior to implementation of this countermeasure.



Relevant Standard Practice: For the addition of traffic signals at an otherwise stop-controlled intersection, Chapter 9 (Signalized Intersections) of the HCM and Chapters 4B, 4C, and 4D (Traffic Control Signals) of the MUTCD should be consulted to determine what type of traffic signal operation and controllers are best for the given traffic characteristics. Signal design and location issues are addressed in MUTCD Chapter 4 in sections 4D.15—Size, Number, and

Location of Signal Faces by Approach, 4D.16—Number and Arrangement of Signal Sections in Vehicular Traffic Control Signal Faces, 4D.17—Visibility, Shielding, and Positioning of Signal Faces, 4D.18—Design, Illumination, and Color of Signal Sections, and 4D.19—Lateral Placement of Signal Supports and Cabinets. Because this solution is conventional, supporting research is not needed. However, errors with stop sign right-of-way confusion would be a worthwhile topic for future research.

Economic Aspects: This countermeasure requires the addition of traffic signals and corresponding supports. Costs for this countermeasure are expected to be moderate.

Other Countermeasures Considered

An alternative to the countermeasure described is to control all four legs of the intersection with stop signs (i.e., change this from a two-way stop intersection to a four-way stop). One of the benefits of this approach would be to reduce the speed of vehicles in all directions. This would serve to minimize the damage associated with a crash. It is acknowledged that this particular alternative may have little impact on "right-of-way confusion." That is, cross vehicles reaching the stop signs at the same time would still face uncertainty regarding which driver has the right-of-way. In addition, converting this intersection to a four-way stop may hamper traffic flow through the intersection.

A second alternative, and perhaps in addition to the alternative suggested above, is to add signs to the legs with stop signs indicating a "right-of-way rule." For example, a sign might be erected next to each stop sign that reads, "Turning Traffic Must Yield To Through Traffic." It is suggested that this may help to reduce driver confusion with regard to who has the right-of-way.

A third alternative is to convert the intersection into a roundabout.

INFRASTRUCTURE-RELATED DRIVER ERROR 17

Type of Error
Lane changing maneuver.

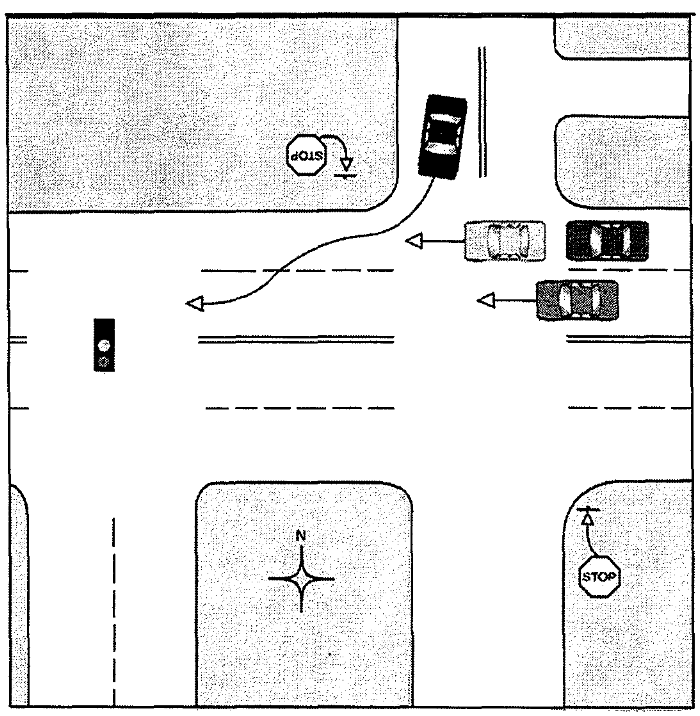
Category: 3.1 Intersections in Close Proximity to One Another

3.6 Visibility Difficulties Resulting From Blockage By Other Vehicles

Typical Location (See location 16)
The typical location is a four-legged intersection. Two opposing legs have stop signs while the other two do not. There is a second intersection controlled by a traffic signal located very close to this intersection (50 ft). During peak hours there is heavy traffic in the direction that is not controlled by the stop sign.

Description by Typical Example
A vehicle turns right from the street controlled by the stop sign with the purpose of turning left at the next intersection, which is controlled by the traffic light. To perform this maneuver, the vehicle must change lanes quickly in the direction where traffic flows freely. The driver must find a gap that allows the right turn and also the quick lane change prior to the traffic signal. The vehicle has a very short distance to change lanes. Also, there can be a visibility-related error for the vehicle turning right because the vehicle coming straight in the inner lane of the major street can be blocked by a vehicle in the outer lane.

Sketch of the Typical Example

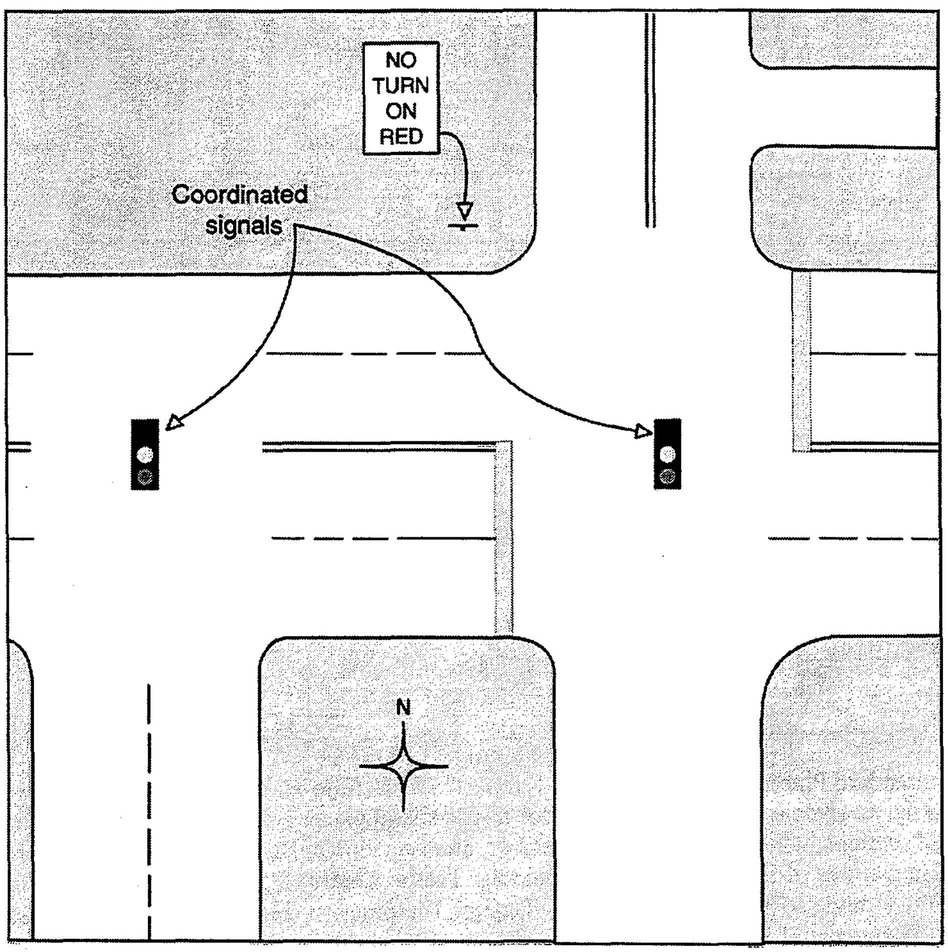


ERROR 17, CANDIDATE COUNTERMEASURE

Recommendation

Description: At a four-legged, perpendicular intersection, two opposing legs have stop signs while the other two perpendicular legs are an arterial street and have the right-of-way. The traffic flow is very heavy, especially at peak hours. In addition, there is a close downstream intersection (50 ft) controlled by a traffic signal. Drivers wanting to turn right at the stop sign at the first intersection and then turn left at the next intersection need to merge with traffic and move into the left lane within a very short distance.

The solution recommended for Error 16 (see the Task F report) also applies to this error; namely, that a traffic signal be installed at the current stop controlled intersection and the two signals for the closely-spaced intersections be coordinated. To prevent Error 17 from occurring, a "No Right Turn On Red" sign should be added as shown in the following diagram. The sign for a right turn would then provide complete control and would make the right followed by a rapid left feasible without conflict.



Relevant Standard Practice: This problem is similar to Error 9[5] (see Task F) and Error 15 (previously presented error in this report), and the reader is referred to the Relevant Standard Practice for these problems for general traffic signal guidelines. In addition, it is considered to be standard practice to determine optimal signal timing using traffic simulation models such as Highway Capacity Software, Transyt 7F, Synchro, and INTEGRATION. Auxiliary signs should also be included at the intersection (addressed in MUTCD, Part 2 (Signs), section 2B.40—Traffic Signal Signs). The solution recommended here involves accepted signaling practice, and signalized intersections with good timing coordination often enhance arterial flow. However, further research is needed to determine the impact of signal coordination for closely placed intersections upon the intersections themselves, arterial, and continuing network.

Economic Aspects: This countermeasure requires a traffic study to evaluate the impact of a traffic signal on the capacity of the intersection, the installation of the traffic signal, and support and controllers. In addition, signs must be posted. This alternative is expected to have a moderate cost.

Other Possible Solutions
None.

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[5] The Relevant Standard Practice for Error 9 (Task F report) was as follows: MUTCD Part 4, Highway Traffic Signals, defines the conditions that need to be met for traffic signal placement and the physical characteristics of this signal. Relevant sections include 4D.15—Size, Number, and Location of Signal Faces by Approach, 4D.16—Number and Arrangement of Signal Sections in Vehicular Traffic Control Signal Faces, 4D.17—Visibility, Shielding, and Positioning of Signal Faces, 4D.18—Design, Illumination, and Color of Signal Sections, and 4D.19—Lateral Placement of Signal Supports and Cabinets. Closely spaced signalized intersections with good coordination can enhance arterial flow. Chapter 9 (Signalized Intersections for Urban Streets) of the HCM identifies procedures for time allocation of phase and traffic signal coordination. Guidelines for the installation of auxiliary signs at the intersection can be found in Part 2 (Signs) of the MUTCD, section 2B.40—Traffic Signal Signs.

INFRASTRUCTURE-RELATED DRIVER ERROR 21

Type of Error
Gap or visibility error; private entrance.

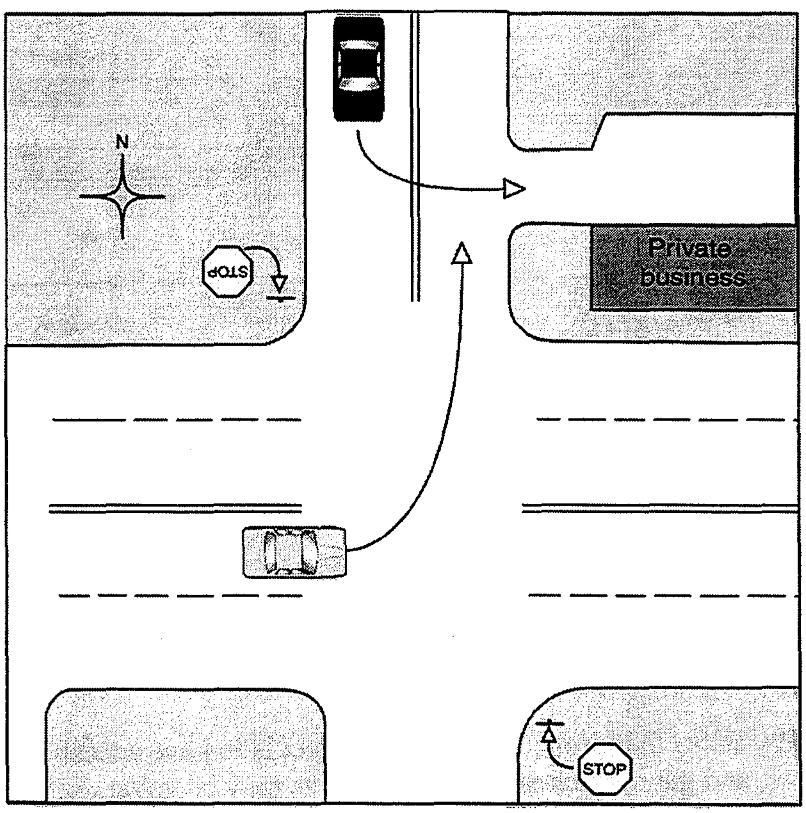
Category: 3.2 Private Entrances/Exits In/Near Intersections

3.5 Visibility Errors Resulting Directly From Alignment/Geometry

Typical Location (See location 16)
The typical location for this error type is a four-legged intersection. Two opposing legs have stop signs while the other two do not. A private business has access to a parking lot on a side street controlled by the stop sign. This access is located near the intersection (20 ft).

Description by Typical Example
A vehicle is stopped to turn left. The conditions are present for a safe maneuver across the intersection. The driver does not expect to cross the path of a vehicle in the minor street turning left to access the private parking lot. The available maneuver time is short.

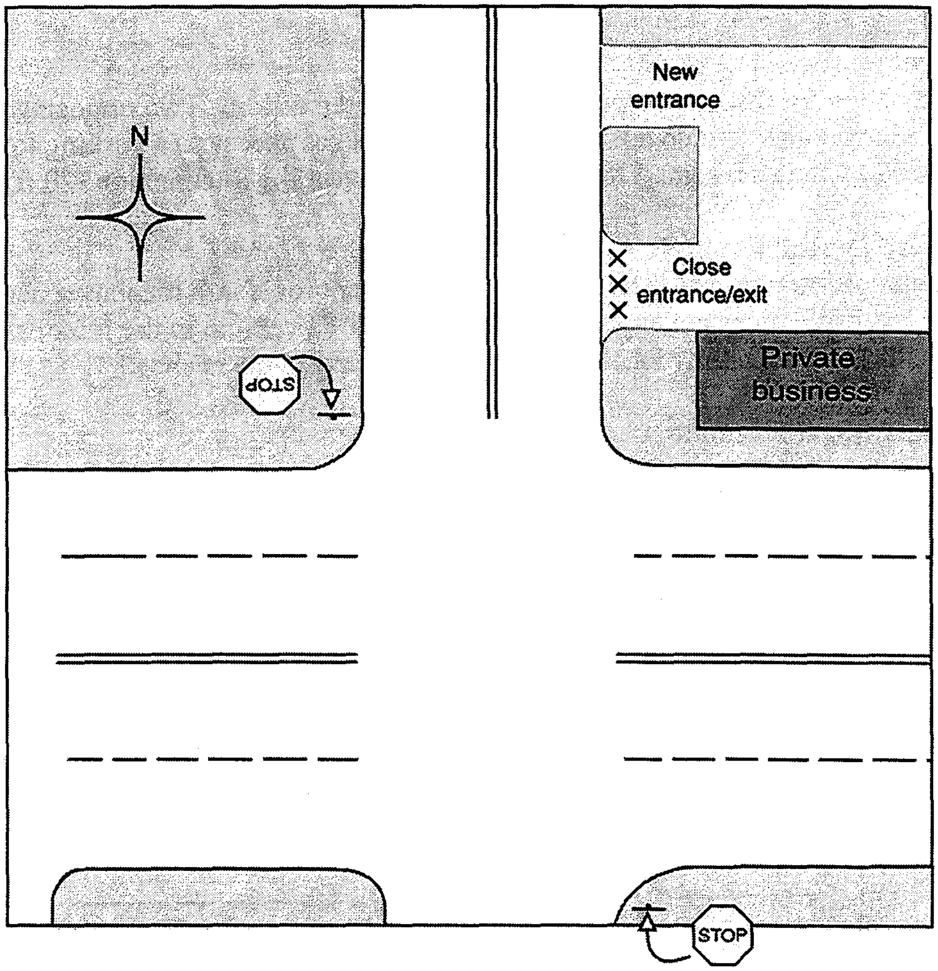
Sketch of the Typical Example



ERROR 21, CANDIDATE COUNTERMEASURE

Recommendation

Description: A driver turning left from a major street to a minor street does not expect to cross the path of a vehicle in the minor street turning left to access a private business parking lot. The entrance/exit is located very close to the intersection (20 ft). This error can be avoided by moving the entrance/exit of the private business farther away from the intersection. This countermeasure would give the driver making the left turn from the major street enough time to see the other vehicle.



Relevant Standard Practice: AASHTO identifies global concerns for the design of driveways and private entrances in Chapters II—Design Controls and Criteria: Access Control and Access Management, and V—Local Roads and Streets: Local Urban Streets: General Design Considerations: Driveways.

The AASHTO policy states that property abutting a street is to have access to that roadway, but the location, number, and geometrics of the access points may be governed by specific driveway or approach regulations. Property abutting an urban arterial should also be provided some access, but a driveway should be situated as far away from an intersection as practicable, especially for intersections of arterial streets.

Specific regulations governing business access are often covered in State, county, and/or municipality standards. Such references cover restrictions for the location and geometric design of an entrance/exit that has access to a State highway. Because the solution is conventional, supporting research is probably not needed. However, the determination of the minimum recommended distance of an entrance/exit to the intersection may require supplemental research.

Economic Aspects: This alternative implies the closing of one entrance and opening of another. Costs are expected to be low.

Other Countermeasures Considered

An alternative is to not allow the left-turn movement into the parking lot. Of course, this limits access to the business, which may be undesirable.

INFRASTRUCTURE-RELATED DRIVER ERROR 23[6]

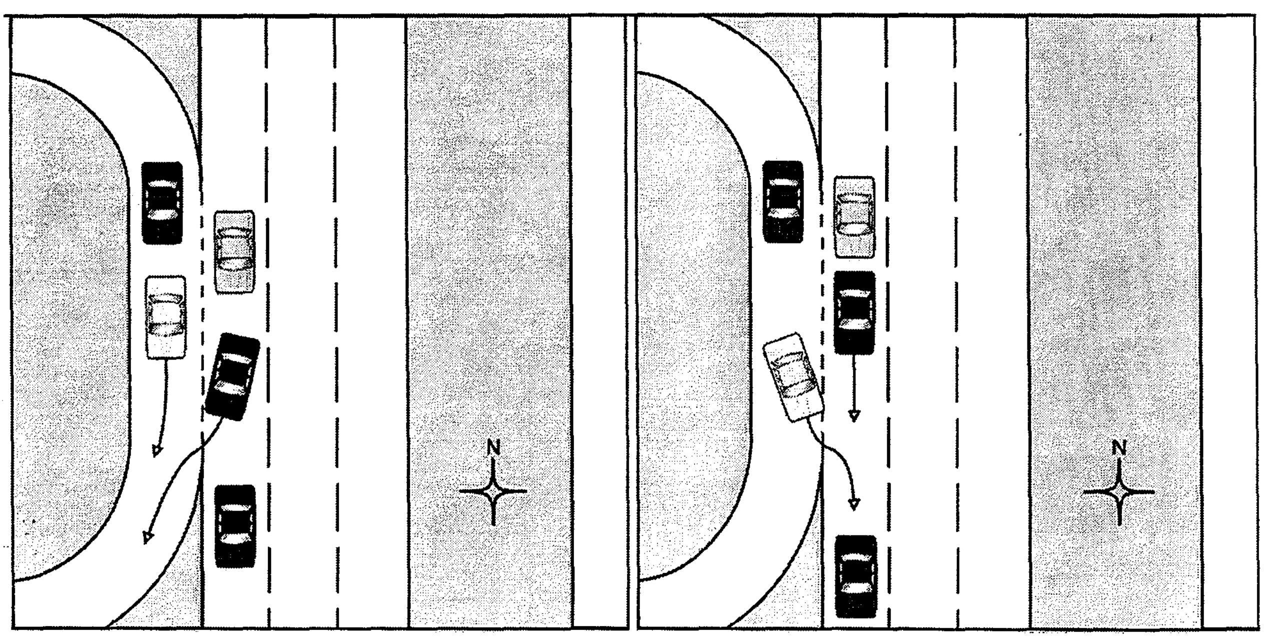
Type of Error
Short weaving section: Vehicles merge/Exit late.

Category: 3.3 Short Weaving Sections

Typical Location (See location 19)
The typical location is an entrance ramp onto an interstate that is directly followed by an exit ramp in a two quadrant cloverleaf design. A simple weaving section that is approximately 35 yards (~32 m) long connects the two ramps. The weaving section has typical markings of solid white channelizing lines delineating the neutral area at the start and gore point of the weaving section. A yield sign controls traffic on the entrance ramp. The speed limit on the ramp is 25 mi/h while the speed limit for through traffic is 55 mi/h.

Description by Typical Example
High volume of traffic, short weaving section, and disparate speeds of entering/exiting vehicles cause conflicts in the weaving section. These conflicts result when two or more vehicles need to occupy the same space at the same time. Vehicles wanting to enter the interstate are forced to merge at the last possible moment. These vehicles do so by crossing the solid white gore line. Similarly, vehicles exiting the interstate cross over late and drive over the solid white gore line.

Sketch of the Typical Example



[6] Errors 23, 24, and 25 have common countermeasures, which appear following Problem 25.

INFRASTRUCTURE-RELATED DRIVER ERROR 24[7]

Type of Error
Short weaving section: Vehicles merge/Exit prematurely.

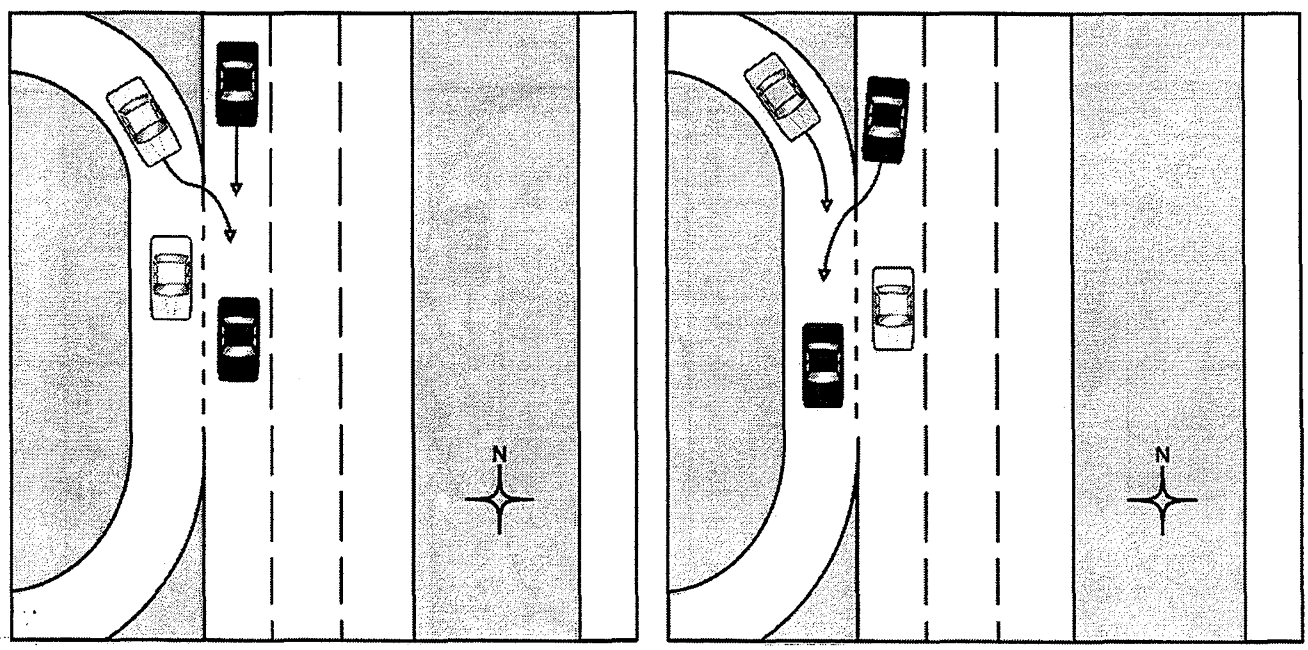
Categories: 3.3 Short Weaving Sections

3.4 Short Merge/Entrance/Acceleration Lane

Typical Location (See location 19)
Same location as described in Error 23.

Description by Typical Example
High volume of traffic, short weaving section, and disparate speeds of entering/exiting vehicles cause conflicts in the weaving section. These conflicts result when two or more vehicles need to occupy the same space at the same time. To avoid conflict, drivers at the end of the off-ramp merge immediately onto the interstate, while crossing the solid white gore line. Similarly, vehicles wanting to exit the interstate, and avoid the weaving section, immediately drive across the solid white gore line onto the on-ramp approach.

Sketch of the Typical Example



[7] Errors 23, 24, and 25 have common countermeasures, which appear following Error 25.

INFRASTRUCTURE-RELATED DRIVER ERROR 25

Type of Error
Short weaving section: Following vehicle passes lead vehicle and merges/exits out of turn.

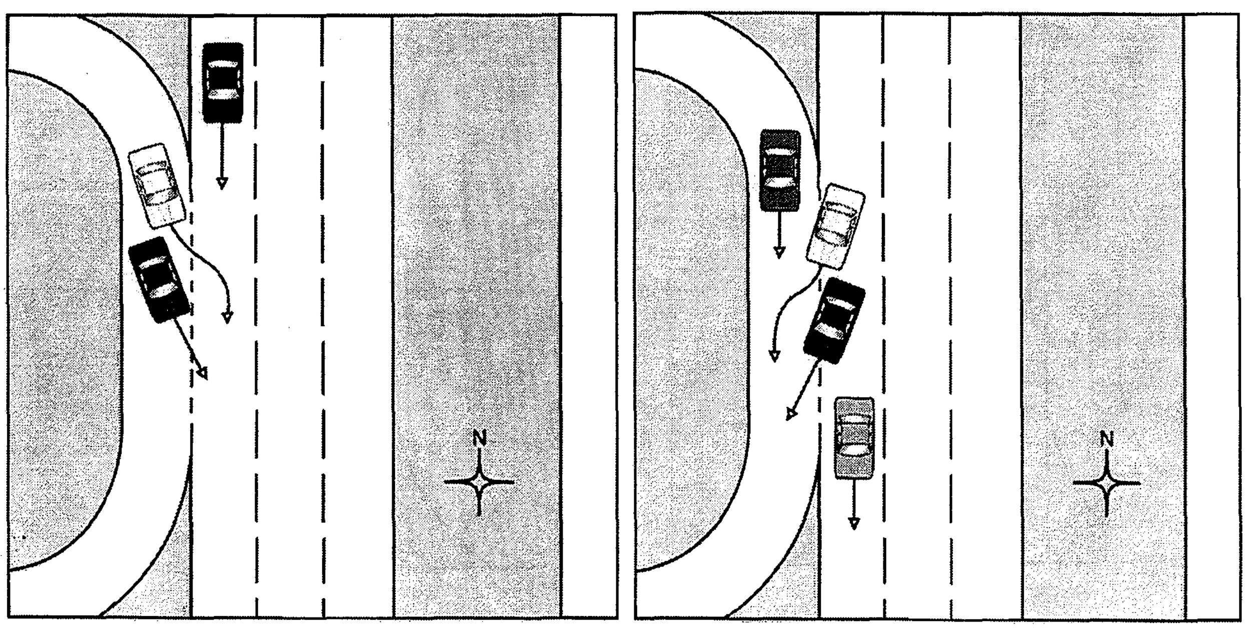
Categories: 3.3 Short Weaving Sections

3.4 Short Merge/Entrance/Acceleration Lane

Typical Location (See location 19)
Same location as described in Error 23.

Description by Typical Example
High volume of traffic, short weaving section, and disparate speeds of entering/exiting vehicles cause conflicts in the weaving section. These conflicts result when two or more vehicles need to occupy the same space at the same time. Consider two or more vehicles queued on the entrance ramp to enter interstate. Following vehicle merges onto interstate before the lead vehicle. This causes the lead vehicle to be "trapped" on the weaving section. Similarly, two or more vehicles may be lined-up and wanting to exit the interstate. The following vehicle passes the lead vehicle and moves to the on-ramp prior to the lead vehicle. The action of the following vehicle prohibits the lead vehicle from entering the exit lane safely.

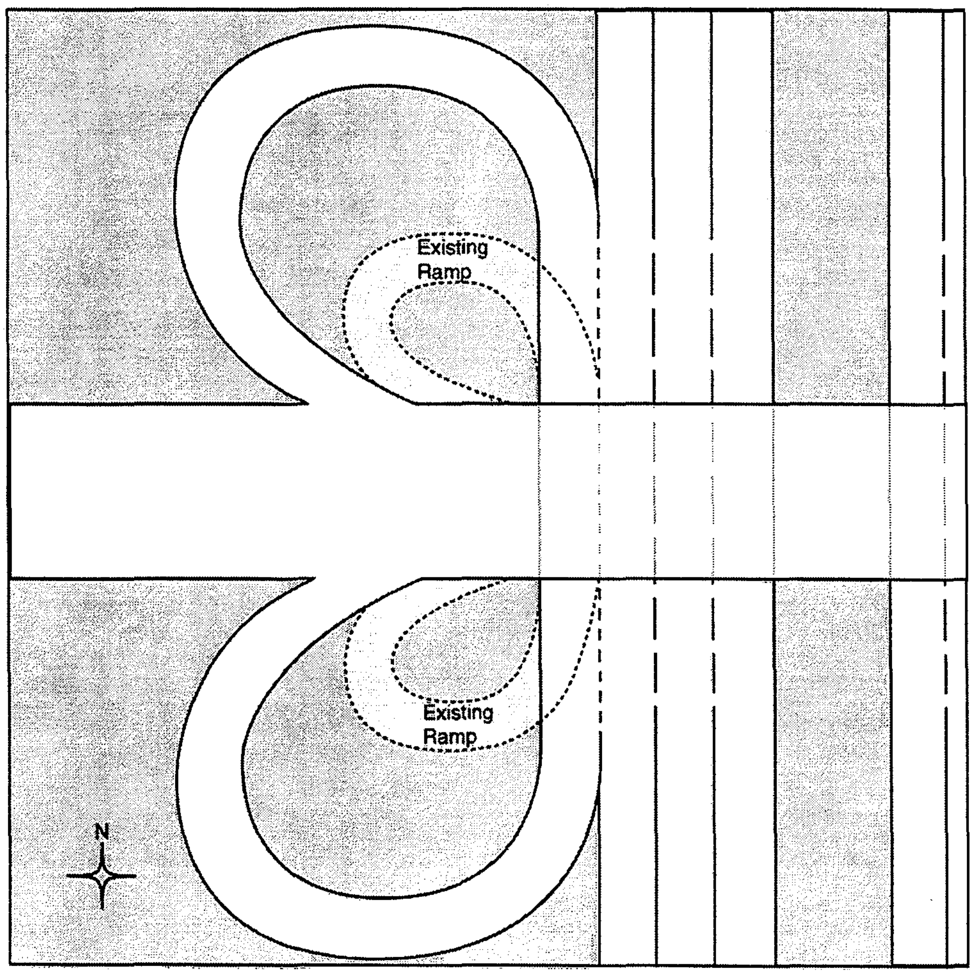
Sketch of the Typical Example



ERRORS 23, 24, AND 25, CANDIDATE COUNTERMEASURES

Recommendation 1

Description: A high volume of traffic, short weaving lane, and disparate speeds at an entrance/exit ramp for a multilane highway all result in conflicts between vehicles entering and exiting the highway. Vehicles entering the highway from the ramp or exiting the highway to the ramp sometimes merge too early or too late (and cross a solid white line). Also, on occasion, following vehicles merge before lead vehicles and make the merge maneuver for the lead vehicle difficult. Three candidate countermeasures for this error are proposed. First, it is suggested that this situation can be avoided by lengthening the weaving section for merging vehicles. As shown in the figure below, this countermeasure would require increasing the radius of the traffic loops for entering and exiting vehicles. It is suggested that increasing the weaving section would allow vehicles more time to merge from the ramp onto the highway and to exit from the highway.



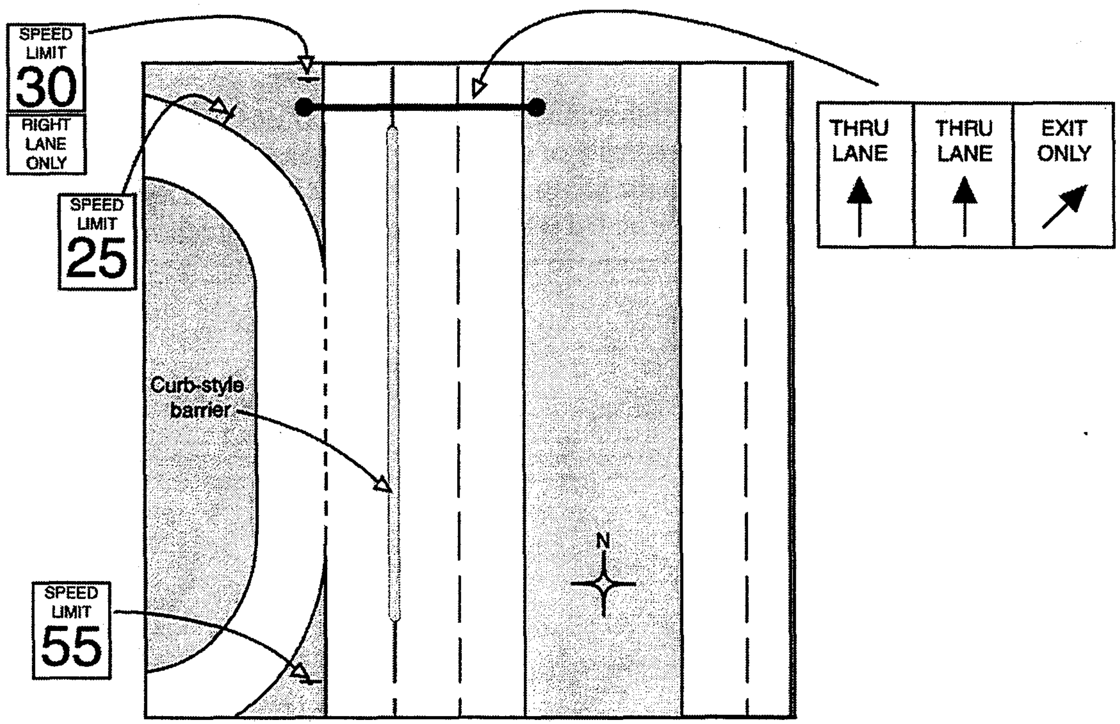
Relevant Standard Practice: The HCM and AASHTO policy address issues of traffic flow, weaving section design, and interchange design. Chapter 4 (Weaving Areas) of the HCM and the Weaving Sections portion of Chapter II (Design Control and Criteria: Highway Capacity:

Factors Other Than Traffic Volume) of the AASHTO policy are specific to traffic flow and weaving section design. Chapter 10 (Grade Separations and Interchanges) of the AASHTO policy globally addresses interchange design. Since this solution is conventional, supporting research is not needed.

Economic Aspects: This countermeasure requires expanding the traffic loops. Costs for this countermeasure are expected to be high.

Recommendation 2

Description: A second candidate countermeasure for this error is to restrict the right lane of traffic on the highway to "exit only" (i.e., traffic in right lane must exit). This countermeasure could be achieved through (1) overhead signing indicating direction of travel for each lane, (2) a reduction of speed for the right lane, and, if desired, (3) a curb-style barrier to separate the right lane from the other (through) lanes. This countermeasure is shown in the figure below. It is suggested that this countermeasure would help to reduce the number of non-exiting vehicles in the right lane, thereby reducing congestion at the merge point. In addition, a reduction of speed for the right lane would counteract the large disparity between speeds of the highway and ramp traffic. The addition of a barrier would help promote the notion that the right lane is distinct from the other lanes.



Relevant Standard Practice: The reader is referred to the Relevant Standard Practice for Recommendation 1 for Errors 23, 24, and 25. In addition, guidelines to restrict traffic using barriers or medians for channelization are included in MUTCD Chapter 3F—Barricades and Channelizing Devices. The AASHTO policy has general standards for traffic barriers and more specific guidelines for crash cushions (within the Traffic Barriers of Chapter IV—Cross Section Elements) and curbs (also in Chapter IV).

Signage, marking, and delineation guidelines for advance warning and direction are covered in the MUTCD within:

- Signage: section 2A.17—Overhead Sign Installations and Chapter 2E—Guide Signs—Freeways and Expressways.
- Markings: Chapter 3A—General, and sections 3B.08—Extensions Through Intersection or Interchanges, 3B.05—Other White Longitudinal Pavement Markings, 3B.12—Raised

Pavement Markers as Vehicle Positioning Guides with Other Longitudinal Markings, and 3B.13—Raised Pavement Markers Supplementing Other Markings.
- Delineation: Chapter 3D—Delineators.

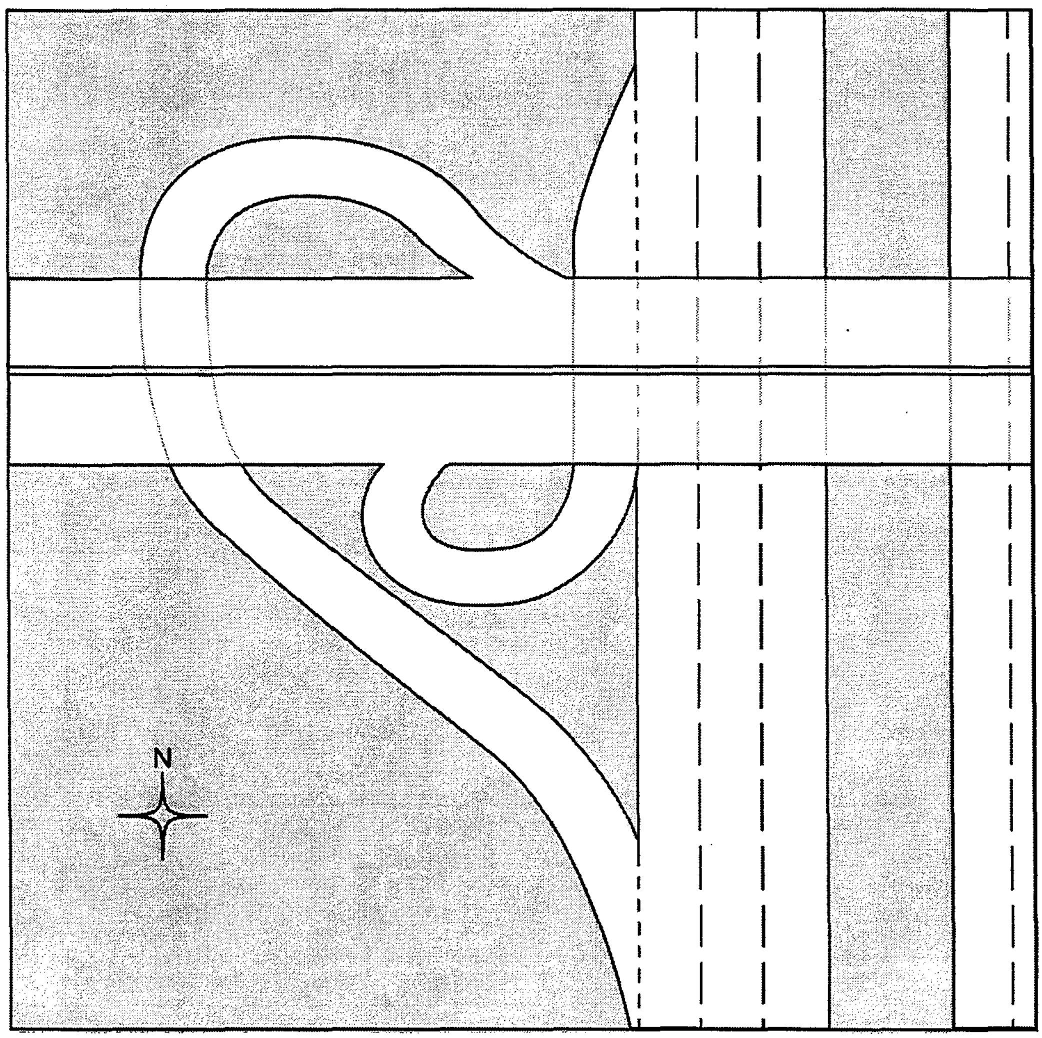
Chapter 2 (Signs) of the MUTCD explains the guidelines for speed reduction signage in the right lane within sections 2B.11—Speed Limit Sign and 2B.16—Reduced Speed Ahead Signs. To determine an appropriate speed limit, Part II—Free-Flow Speed Adjustments of Chapter 7 (Rural and Suburban Highways, Multilane Rural and Suburban Highways) of the HCM should be consulted.

The MUTCD cautions that barriers may serve as a channelizing agent. However, barrier use should be determined through engineering analyses to ascertain the protective requirements for the location, not the channelizing needs. The suggested solution is not conventional and additional research should be performed to determine the effect of barriers as channelizing devices at weaving sections.

Economic Aspects: It is suggested that this candidate countermeasure might be implemented in two stages. The first stage would consist of adding the overhead lane direction signing and the speed limit reduction signs. Costs for phase I are expected to be low. Depending on the success of phase I, a second phase could be added whereby a barrier to isolate the right lane is added. Costs for phase II are expected to be low to moderate.

Recommendation 3

Description: A third candidate countermeasure is directed at grade separation whereby the weaving section is no longer shared between entering and exiting traffic. For example, the current merge lane would be in one direction only, that is, for traffic exiting the highway onto the ramp. A second, non-shared merge ramp could be constructed for vehicles entering the highway. A diagram of this countermeasure is shown below. The lane for vehicles entering the highway would go under the existing roadway (bridge). It is suggested that this countermeasure would effectively reduce the interaction between vehicles exiting and entering the highway at the same location, as is currently the case.



Relevant Standard Practice: This solution is considered to be conventional and supporting research is not needed; however, it does require redesign and new construction for implementation of the countermeasure. General standards that should be addressed include Chapter 4—Weaving Areas of the HCM, and Weaving Areas of Chapter II (Design Controls and Criteria: Highway Capacity: Design Service Flow Rates) and Chapter X—Grade Separations and Interchanges of the AASHTO policy manual.

Economic Aspects: This countermeasure requires creating a new lane of traffic that runs under the existing roadway. Costs for this countermeasure are expected to be high.

Other Countermeasures Considered

One alternative to the candidate countermeasures described is to control vehicles in the weaving section through ramp metering. That is, vehicles on the ramp would enter the highway at a more controlled pace. This alternative may help to reduce the amount of traffic attempting to enter the highway at any one time. However, the speed differential between entering and exiting traffic may be exacerbated by this alternative ramp meters. This consequence could be ameliorated by making the ramp meters sensitive to available gaps on the main line.

INFRASTRUCTURE-RELATED DRIVER ERROR 28

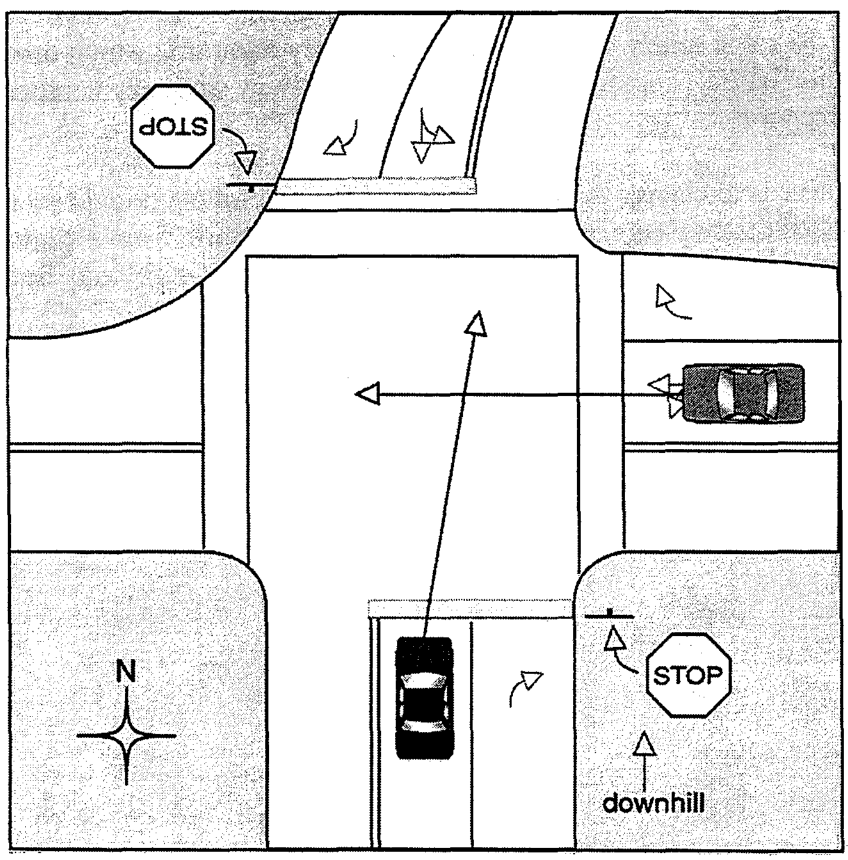
Type of Error
Visibility (line-of-sight) obstruction due to interaction of hill, speed of vehicle, speed of cross traffic, and vehicle A-pillar.

Category: 3.5 Visibility Difficulties Resulting Directly from Alinement/Geometry

Typical Location (See location 25)
The typical location is a four-legged, stop-controlled intersection. Two opposing legs have stop signs while the other two legs do not. One of the legs with a stop sign is at the bottom of a hill. There is a high volume of traffic at rush hour periods in all four directions of travel.

Description by Typical Example
A driver drives down the hill to the stop sign. Given the speed of the vehicle, the speed of cross traffic, the hill, and the driver's vehicle's A-pillar, other vehicles traveling right to left are hidden in a blind-spot. Thinking no cross traffic is present, the driver does not come to a complete stop at the bottom of the hill (stop sign), and continues into the intersection as a vehicle enters the intersection from the right and emerges from the driver's blind spot.

Sketch of the Typical Example



ERROR 28, CANDIDATE COUNTERMEASURES

Recommendation

Description: Two facing legs of a four-legged intersection have stop signs. One of the legs with a stop sign is at the bottom of a hill. A blind spot is created for the driver coming down the hill. The driver coming down the hill may not see a vehicle on the cross street and, if the driver should roll through the stop sign, an incident may result. The candidate countermeasure to this situation is the same as described in Error 15; that is, control all four legs of the intersection with traffic signals. (See Error 15, presented earlier in this report, for more details on this solution.)

Relevant Standard Practice: The reader is referred to the Relevant Standard Practice suggested for Error 15. Since this solution is conventional, supporting research is probably not needed.

Economic Aspects: This countermeasure requires the addition of traffic signals and corresponding supports. Costs for this countermeasure are expected to be moderate.

Other Countermeasures Considered

An alternative to the countermeasure described is to control all four legs of the intersection with stop signs (i.e., change this from a two-way stop intersection to a four-way stop). One of the benefits of this approach would be to reduce the speed of vehicles in all directions. This would serve to minimize the damage associated with a crash. It is acknowledged that this particular alternative may have little impact on "right-of-way confusion." That is, cross vehicles reaching the stop signs at the same time would still face uncertainty regarding which driver has the right-of-way. In addition, converting this intersection to a four-way stop may hamper traffic flow through the intersection.

A second alternative is to change the road curvature for vehicles coming down the hill. If vehicles approached the stop sign, located at the bottom of the hill, from a slight angle, then the blind spot drivers now experience may be eliminated (i.e., line-of-sight may be improved).

A third alternative is to convert the intersection into a roundabout. This would eliminate many unnecessary stops and eliminate the blind spot problem.

INFRASTRUCTURE-RELATED DRIVER ERROR 31

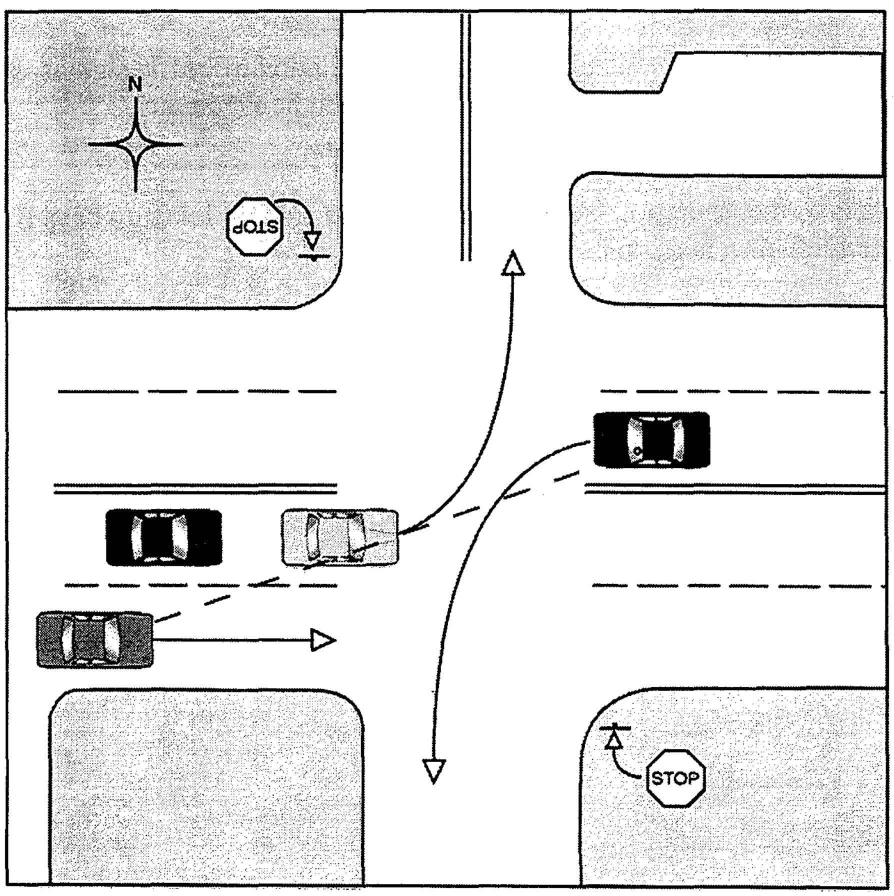
Type of Error
Visibility: Blockage by other vehicles.

Category: 3.6 Visibility Difficulties Resulting from Blockage by Other Vehicles

Typical Location (See location 16)
The typical location is a four-legged intersection. Two opposing legs have stop signs while the other two do not. One of the legs without a stop sign has a dedicated left-turn lane. The other leg has through and dedicated left-turn lanes.

Description by Typical Example
A driver stops at the intersection to turn left. Simultaneously, a driver in the opposite direction is stopped to turn left. The two vehicles block each other's view of oncoming through traffic. To make a safe maneuver, the driver must wait until the opposite left-turn lane is free. Note also that the recent increase in size of some vehicles (vans and SUVs) in the traffic mix can exacerbate the error because of the additional obscuration they create.

Sketch of the Typical Example



ERROR 31, CANDIDATE COUNTERMEASURE

Recommendation

Description: At a four-legged, perpendicular intersection, two opposing legs have stop signs, while the other two perpendicular legs serve as arterials and have the right-of-way. The traffic flow is very heavy, especially at peak hours. When both left-turn lanes are occupied, the drivers block each other's view of oncoming through traffic. Due to the heavy traffic volume, a traffic signal is recommended. The signal must have a left-turn-only phase and, if possible, should not have a left-turn on green ball (the left-turning vehicle must have a red arrow signal when the light is green for the through traffic). However, a traffic simulation study must be done to evaluate how this measure would affect the capacity of the intersection, particularly for the approaches that have a dedicated left and through lane. If, as a result of the traffic analysis, a protected left turn on green ball is needed, warning signs such as, "Yield On Green Ball" must be posted for the vehicles turning left.

Relevant Standard Practice: The reader is referred to the Relevant Standard Practice cited in Errors 9 (Task F, and re-represented in Error 17 from the current report) and 15 (presented previously in this report). Since the solution to this error is conventional, supporting research is probably not needed. However, the error of increased vehicle size and corresponding visual blockage is recommended for further research study.

Economic Aspects: This countermeasure requires installation of traffic signals, supports, and controllers. Costs for this countermeasure are expected to be moderate.

Other Countermeasures Considered

One alternative is to incorporate offsetting left-turn lanes, adding left-turn bays if necessary, and having dedicated left-turn lanes in both directions.

INFRASTRUCTURE-RELATED DRIVER ERROR 38

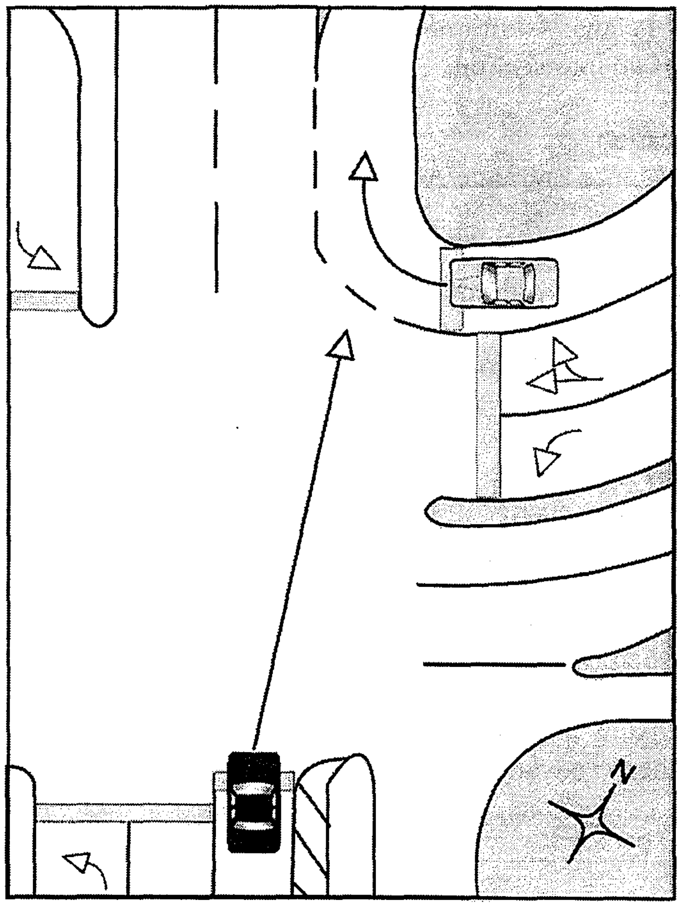
Type of Error
Location of ramp access lane: Additional lane to access interstate entrance ramp starts as a third lane at the departure of an intersection.

Categories: 4.0 Delineation
3.4 Short Merge/Entrance/Acceleration Lane

Typical Location (See location 1)
The typical location is a signalized intersection with multiple through lanes for each approach and departure of the intersection. The intersection also has designated right- and left-turn lanes and is adjacent to the entrance/exit of a nearby interstate. Each approach lane has a designated signal(s) and sign(s) to control and guide traffic.

Description of Typical Example
Through traffic makes a lane change in the intersection to access an additional lane that funnels traffic directly onto an interstate entrance ramp immediately downstream of the intersection. Through traffic needing to access the ramp makes a lane change in the intersection to align with the access lane. At the same time, cross traffic is making a right-on-red into the same additional lane. The conflict is when both vehicles attempt to occupy the same space in a departure lane. The additional lane to access the ramp interchange is short and too close to the intersection. The error is also compounded by a line-of-sight factor. The through driver and the turning drivers are unable to see one another in advance of the intersection because of a retaining wall for a frontage road.

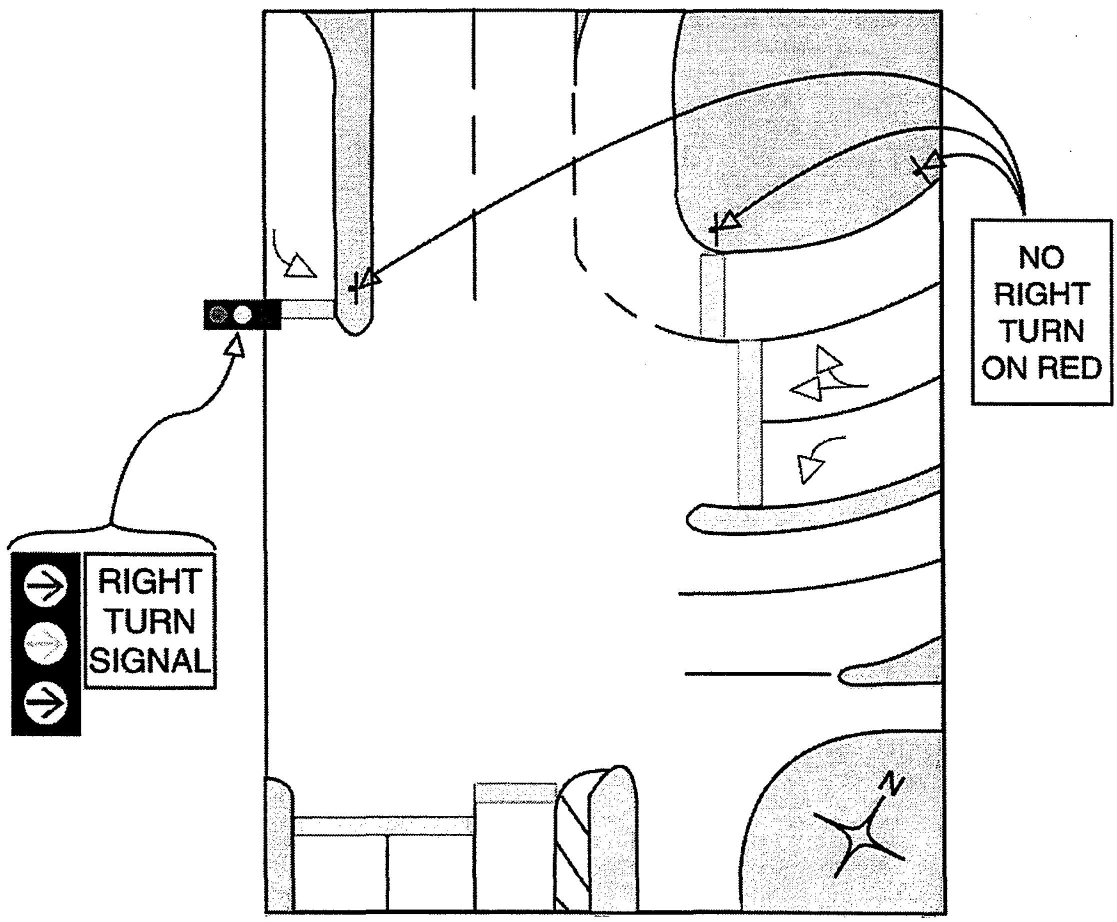
Sketch of the Typical Example



ERROR 38, CANDIDATE COUNTERMEASURES

Recommendation

Description: An additional lane to access a nearby bypass starts as a third lane at the departure of the intersection. There is also a visibility error resulting from a retaining wall that is adjacent to the primary roadway. Cross traffic making a right turn is required to use the additional lane to enter the through traffic flow. However, through traffic tends to perform a lane change in the intersection to access the additional lane. An error exists when a right-turning driver proceeds to make a right-turn-on-red and a through driver simultaneously makes a lane change to enter the additional lane. Although the through driver is performing an illegal lane change maneuver, the design of the location affords little time for through traffic to depart the intersection and then access the additional lane. This situation can be avoided by not allowing right-turn traffic to turn on a red light by changing the traffic signal lenses and adding "No Turn On Red" signs.



Relevant Standard Practice: Standard guidelines for control at traffic signals, traffic signal lens and face design, and inclusion of auxiliary signs at traffic signals can be found in the MUTCD sections 4D.09—Unexpected Conflicts During Green or Yellow Intervals, 2B.40—Traffic Signal Signs, and 4D.16—Number and Arrangement of Signal Sections in Vehicular Control Signal

Faces. The warrants outlined in MUTCD Chapter 4C—Traffic Control Signal Needs Studies, are also relevant. Since this solution is conventional, supporting research is probably not needed.

Economic Aspects: This countermeasure requires the addition of signage notifying drivers that a right turn is not allowed on a red light. It is also likely that the lenses of the traffic signal controlling the right lane would have to be modified from balls to right arrows. However, because drivers who routinely use this route are accustomed to make a right-on-red, short-term enforcement may be required to ensure compliance. Cost for this countermeasure is expected to be low.

Other Countermeasures Considered

For intersections with more than two approach lanes, the right-turn lane could become a designated "exit only lane." Traffic turning right to enter cross traffic could then be routed into the adjacent lane to the left of the "exit only lane."

A ramp system could also be incorporated into the intersection. Traffic wishing to access the bypass would be diverted from the intersection.

INFRASTRUCTURE-RELATED DRIVER ERROR 42

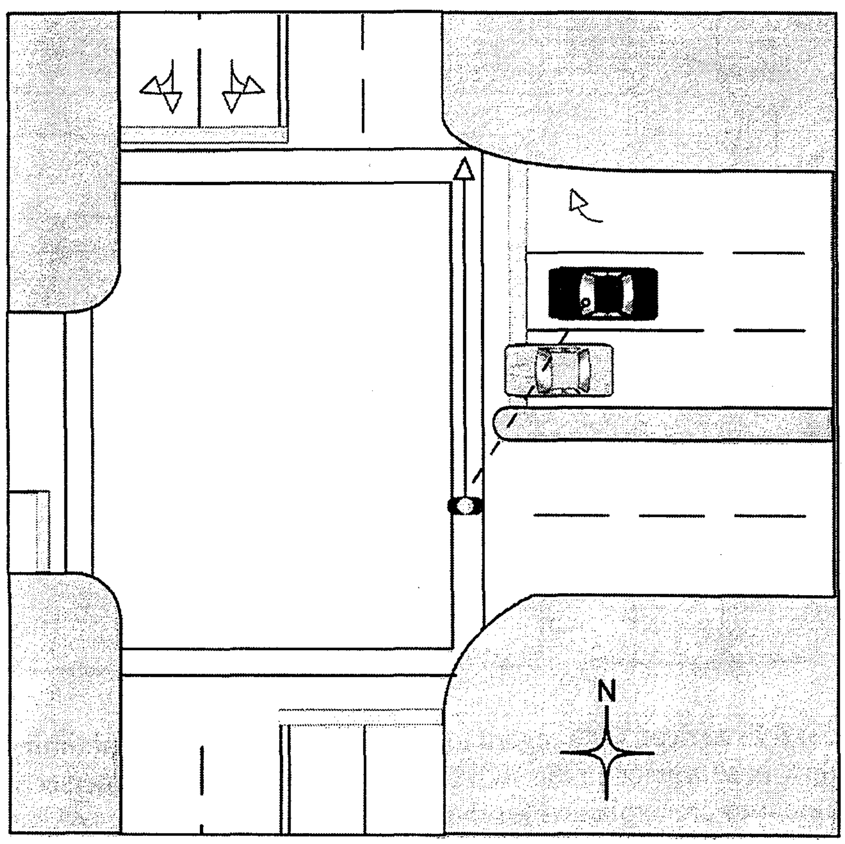
Type of Error
Poor visibility: Drivers do not notice pedestrian crossing the street.

Category: 5.0 Pedestrian and Bicycle Interactions

Typical Location (See location 14)
Four-leg intersection controlled by a traffic signal. The approaches accommodate at least two lanes of traffic. Some of the approaches are dedicated lanes for left-turn, right-turn, or through, whereas other lanes may serve two directions of traffic. There are also pedestrian crosswalks at all four approaches.

Description by Typical Example
The drivers stop at the stop bar in all lanes when the signal is red for that approach. A pedestrian begins to cross on green for the cross street. When the light changes to green for the stopped traffic, the driver farther from the pedestrian is unable to see that the pedestrian is still crossing the street because the vehicle closer to the pedestrian blocks the view of other drivers. The error seems to be the result of the width of the street and timing of the traffic signals, particularly the short duration of the amber.

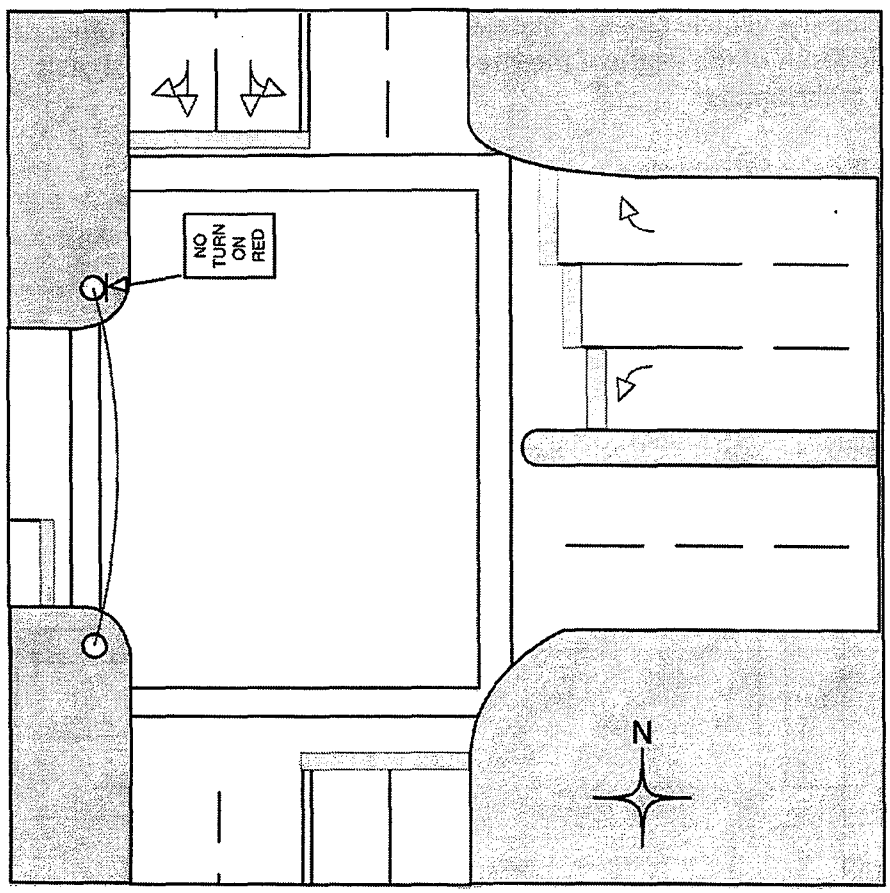
Sketch of the Typical Example



ERROR 42, CANDIDATE COUNTERMEASURES

Recommendation

Description: The time that the pedestrian has to cross the street and reach the opposite side is insufficient. Because of the location of the stop bar, the driver stopped closest to the pedestrian blocks the view of other drivers. It is assumed that the error is the result of a combination of the width of the intersection (five lanes in that approach) and the timing of the traffic signal. A combination of different countermeasures can be used to avoid or minimize this conflict. The signal can be retimed, allowing for more time for pedestrian crossing. Also, the "Do Not Walk " signal can be activated early to ensure that the pedestrian has enough time to cross the intersection. In addition, the signal timing can have an all-red phase that gives more time for the pedestrian. The position of the stop bar can also be changed according to the location of the lane, as shown in the figure below. A "No Turn On Red" sign should also be added for the westbound traffic. This would prevent having drivers in the right lane conflicting with pedestrians.



Relevant Standard Practice: With regard to signal timing, traffic signal timing for traffic flow and pedestrian flow is addressed in the HCM Chapters 9—Signalized Intersections and 13—Pedestrians. Guidelines are explained for the location and characteristics of the stop bar in Section 3B.16—Stop and Yield Lines in the MUTCD. The MUTCD also addresses standards for relevant signs in section 2B.40—Traffic Signal Signs. Since this solution is conventional, supporting research is probably not needed. However, errors with pedestrian rights-of-way and innovative solutions would be a worthwhile topic for future research.

Economic Aspects: This countermeasure involves the change of pavement markings, the re-timing of the signal, and the placement of new signs. The cost of this alternative is expected to be low.

Other Countermeasures Considered

One possible alternative to this error is to remove the pedestrian crossing and change it to another location along the street. For this alternative to be considered, further research is needed. Another possible countermeasure is the construction of a pedestrian overpass or underpass. In regard to both of these alternatives, pedestrians may be reluctant to use approaches that they believe are more time consuming. In addition, specifically for the overpass/underpass alternative, there are security reasons for not wanting to use this option. Moving the pedestrian crossing upstream or downstream would have lower implementation costs than constructing an overpass/underpass.

Cost/Benefit Analysis

To justify the recommendations presented, a sample cost/benefit analysis was performed. One sample countermeasure was selected for this analysis. One of the recommended countermeasures for Errors 15, 28, and 31 was to install traffic signal controls in place of the stop sign controls. The cost/benefit analysis, shown below, calculated the benefits of this recommendation as a function of implementation costs and savings due to reduced crashes. The result of this analysis was that the time to recoup the installation costs would be 5 years. If a fatal crash were to occur, associated costs with the injury would be substantially greater and the time to recoup the costs would be reduced substantially.

Step 1: Accident reduction when adding traffic signals (using EBEST[8]) method = 25 percent.

Step 2: Mean cost of injury and non-injury crash = \$20,250.[9,10]

Step 3: Probability of an incident at stop-controlled intersection = 0.0304.

- Converting to probability of a crash[11]:
    - Heinrich's model = 0.0304/835 = 0.000036
    - Fine tuning = 0.000036/3.25 = 0.000011
- Probability of a crash = 0.000011

Step 4: Calculating vehicle exposure = 39.45 vehicles/h (Task E report) for a single direction of traffic.

- Exposure calculated at peak traffic times during morning, lunch, and evening commutes.

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[8] Information on Empirical Bayes Estimation of Safety and Transportation (EBEST) can be found online at http://www.tfhrc.gov/safety/hsis/94-082.htm.

[9] Information on costs of motor vehicles crashes can be found online at http://www.nsc.org/lrs/statinfo/estcost7.htm.

[10] Calculable costs included wage and productivity loses, medical expenses, administrative expenses, motor vehicle damage, employer costs, and disabling injury. Details can be found online at: http://www.nsc.org/lrs/statinfo/estcost7.htm#DEFINE.

[11] See section on Probability Model Development in Chapter VI.

- Adjustment required to determine mean vehicles per hour for a 24-h period, and to include traffic in all four directions of travel.
- 39.45 veh/h * 4 directions of travel = 157.8 veh/h across all four directions.
- Traffic samples taken at three peak times (morning, noon, and evening commutes). Multiply 157.8 * 3 peaks = 473.4 vehicles for the three peak times.
- Rule of thumb suggests that each hour of peak traffic represents approximately
- 12 percent of the total traffic at the site (Roess, McShane, and Prassas, 1998). As such, 473.4 vehicles for the three peak times represents 36 percent of the traffic at the site, per day. To calculate remaining number of vehicles; 473.4* (100/36)= 1,315 vehicles per 24-h day.
- Therefore, it is estimated that 1,315 vehicles use the site in a 24-h period.

Step 5: Cost Savings: 1,315 veh/d * 0.000011 (probability of a crash) = 0.014, or 1.4 percent probability of a crash per day

- Therefore, assuming the number of vehicles remains constant throughout the year, there is expected to be approximately (365 d/yr) * (0.014) = 5.1 crashes per year at this site.
- 5.1 crashes/yr * $20,250 per crash = $103,275 per year as the cost for crashes at this particular stop-sign-controlled intersection.
- $103,275 * 0.25 (reduction in crashes when installing signals) = $25,819 cost savings per year by putting in signals.

Step 6: Cost for Installing Signals = $123,000[12]

Step 7: Calculate Years to Recoup Costs: $123,000/$25,819 = 4.8 yr

- Therefore, society should recoup the costs for this project in less than 5 years. Note that this time will be much shorter if a fatality crash were to be included in the calculations (i.e., the cost for a crash would increase).

[12] Estimate from VDOT on traffic signal, installation, controller, and 1-yr maintenance is approximately $110,000 to $136,000. Mean of this range is $123,000.

Summary and Next Step

On completion of the error statements and corresponding recommended countermeasures, it became clear that some form of generalization would be desirable. While the information presented in the Infrastructure-Related Driver Errors should be quite valuable in remedying specific errors, it does not provide a clear-cut path for general improvements in infrastructure elements directed toward the reduction of driver errors. Therefore, an attempt was made by the research team to find common threads among the various error statements. Careful examination of the driver errors, combined with a review of the project's previous reports, showed that generalizations could be developed.

The next section presents these generalizations in the form of brief research problem statements. They are intended to provide FHWA with possible new topics that could be studied in greater detail. The objective of each study would be the development of techniques and design methods capable of reducing the infrastructure contribution to driver errors. Eight problem areas were developed. Brief summaries for each research problem area follow.

RECOMMENDED RESEARCH PROBLEM AREAS

Research Problem Area 1

Larger Vehicle Visibility Blockage Problem

Several incidents were detected in which the large size of certain vehicles caused visual blockage (obstruction of sight) for drivers of passenger cars. In the past decade there have been large increases in traffic volume and greater disparity in vehicle sizes. Increased traffic volume makes it necessary for drivers to remain fully aware of their surroundings and to watch carefully for other vehicles with which they might come into conflict. However, the change in size of many of the vehicles on the roadway has caused a decrease in the capability of passenger car drivers to detect and track vehicles that should be monitored. The popularity of SUVs, vans, large pickup trucks, and other high-profile vehicles has increased their numbers in traffic, and these vehicles create visibility blockage problems for passenger car drivers.

One specific and important issue is the hidden vehicle problem. For example, when two vehicles attempt opposing left turns, there is the strong possibility that the larger vehicle will obscure large portions of the oncoming lanes from the smaller vehicle. Particularly hazardous is the lack of detection of a smaller vehicle directly behind, or diagonally behind, the larger vehicle. Upon initiating the left turn, the turning passenger car can come into conflict with a hidden vehicle. In another scenario, the hidden vehicle may change lanes (to its right) as it approaches the larger vehicle from behind. This is particularly hazardous because the hidden vehicle may be traveling at highway speed. Yet another scenario that causes difficulty occurs at two-way stop-controlled intersections where there are multiple lanes in the through direction. Drivers at the stop signs often cannot see all lanes in the through roadway clearly because of large vehicle visual blockage.

The main research question proposed is whether effective infrastructure countermeasures can be developed to reduce both the likelihood of visual blockage by larger vehicles and the consequences of this type of visual blockage. It appears that certain combinations of infrastructure elements are hazardous from the visual blockage standpoint while others are not. There may also be *new* techniques that could be developed to account for visual blockage in some way so that incidents are far less likely to occur.

Of course, there may be research issues in vehicle design that would reduce visual blockage. These might include the use of larger (and less darkened/shaded) window areas, allowing vision through the vehicles. Another approach involves lowering the profiles of the vehicles, which would have additional safety advantages in terms of handling and reduced rollover. Such issues would, of course, necessitate involving the National Highway Traffic Safety Administration (NHTSA) and vehicle manufacturers.

Sample Research Design

To explore the visibility blockage problem, research might be directed at exploring the effectiveness of various infrastructure and non-infrastructure solutions. Independent variables might include, but would not necessarily be limited to, the following: (i) infrastructure characteristics such as grade variation between lanes in and around intersections, and (ii) vehicle characteristics such as vehicle height and window shading. The primary dependent variable to investigate this problem would be driver's ability to detect other vehicles, pedestrians, etc., that are positioned on the far side of another vehicle.

Research Problem Area 2

Pedestrian Right-of-Way Violations

Many of the incidents detected in the data gathered involved pedestrian right-of-way violations. These incidents need to be taken seriously because pedestrians are essentially unprotected when they do come in contact with motor vehicles. There seem to be several reasons for the prevalence of vehicle-pedestrian conflicts, including the following:

1. Many drivers do not know the law. These drivers assume they have the right-of-way when in fact the pedestrian does. One typical example involves proceeding to turn either left or right when the light turns green. Some drivers do not seem to realize that the pedestrian leaving the curb on green has the right-of-way, whether on the same side as the driver (causing a left-turn conflict) or on the opposite side from the driver (causing a right-turn conflict).
2. Drivers often drive aggressively and blatantly disregard pedestrian rights-of-way. In one recorded incident, the driver entered the intersection on red and forced a pedestrian, on the far side of the intersection, out of the crosswalk. The pedestrian was proceeding legally on green. While this incident was extreme, it illustrates the effects of aggressive driving. Other aggressive driving acts included purposely disregarding pedestrian rights-of-way on left or right turns. This reason differs from reason -1 above in that drivers know the law and choose to violate or disregard it.
3. Drivers may not be watching for pedestrians and therefore may not detect them. This problem is similar to lack of bicycle and motorcycle detection by drivers. It may be that some drivers are inadvertently narrowing their information-processing focus to objects that are at least the size of passenger cars. Lack of vigilance regarding pedestrians can lead to either late or missed detection.
4. In some cases, incidents occur because of visual blockage by other vehicles. For example, in one case, drivers at a four-lane intersection were stopped and waiting for the light to change green. A pedestrian in the crosswalk coming from the left could not be seen by the driver on the right because of the blockage created by the vehicle on the left. When the light turned to green, the driver on the right had a close encounter with the pedestrian.

5. Growth in traffic volume and increases in vehicle size (as described in Research Problem Area 1) have increased the potential for vehicle-pedestrian conflicts. More traffic means more chances of an incident, and vehicle size increase (relative to passenger cars) means a greater likelihood of visual blockage. Because of these changes, there are now intersections where it would be dangerous to proceed on foot.
6. Right turns on red can create conflicts with pedestrians. Drivers seem to focus on other vehicles and ignore pedestrians. This problem is actually a combination of 1, 2, and 3 above.

The incidents recorded that involved pedestrians suggest that current laws, standards, designs, and procedures are not working as well as desired. Therefore, a thorough review of driver-pedestrian interactions should be undertaken. At present, the roadway system in the United States is set up so that vehicles and pedestrians share the roadway at intersections. This approach means that time separation is being relied upon for avoidance of conflicts. Several countermeasures can be used, and there may be additional new ones that should be tried. Most of these rely on physical separation rather than time separation. Examples of physical separation include pedestrian underpasses (assuming security problems can be solved) and overpasses, and moving pedestrian crosswalks to the center of city blocks (with signals) rather than having them at intersections. The advantage of the latter approach is that drivers have fewer visual sampling points (fewer things to monitor) and can therefore concentrate on the pedestrians and corresponding traffic signals. Additional novel approaches need to be developed and tested so that pedestrians can be better served.

Of course, both pedestrian education and driver education are important components in driver-pedestrian interaction. Both must know the law and both must practice it. In addition, both must be sensitive to the possibility of violations that put the pedestrian at risk. When such violations occur, drivers and pedestrians should know what to do to avoid a conflict. Drivers license testing and re-testing should include rules regarding right-of-way when pedestrians are involved.

Finally, law enforcement can play a role in addressing the problem. Drivers who disregard the law, either through ignorance or as a result of aggressive driving, should receive citations. These driver actions are very dangerous and need to be given greater emphasis by law enforcement.

The vehicle-pedestrian interaction problem is not a new one and has been the subject of much previous research. However, the problem needs to be re-emphasized and more resources need to be allocated, both in research and in implementation.

Sample Research Design

To explore the pedestrian right-of-way problem, research might be directed at exploring the effectiveness of various laws, standards, designs, and procedures. Because the current project is focused on infrastructure-related issues, the problem presented here will be considered accordingly. To this end, a research effort might focus on alternative infrastructure design solutions to minimize or eliminate the problem. Candidate independent variables would include physical separation design solutions such as those presented. The independent variables would be the alternative design approaches themselves that could be compared to baseline (current) designs (i.e., proof-of-concept evaluation). Pedestrian underpasses and overpasses have been implemented in various locations. Crash data could be carefully examined where underpasses/overpasses are being used and compared to similar locations (in terms of vehicular and pedestrian traffic, for example) where a time-based separation approach is used. We are unaware of any locale where the crosswalk has been positioned away from the intersection (i.e., center of city blocks); however, the effectiveness of this approach could be tested quite easily. Pedestrian incident data could be collected before (baseline) and after (test condition) the design change was implemented. Both objective and subjective data could be collected. For example, the dependent variables could include, but not necessarily be limited to, (i) the pedestrian incident rate and (ii) the acceptability of the new designs from both the pedestrian and driver perspectives.

Research Problem Area 3

Left Turns at Signalized Intersections

Throughout this project, problems were observed with left turns at intersections. Many of the taxonomies show that left-turn incidents are frequent and often severe. The observed driver performance problems included the following:

1. Drivers often turn left without the right-of-way, long after a green arrow has changed to a green ball. Drivers coming from the oncoming direction must then brake to avoid a crash. Such turns are usually a form of aggressive driving resulting from not wanting to wait for another full cycle of the signals.
2. Drivers often enter intersections and turn left long after the signal has changed to red. In some cases, drivers tailgate other drivers through the left turn. This is a serious act of aggressive driving and a clear violation of traffic laws that stems from impatience.
3. Drivers are confused about whether to enter the intersection immediately when the light goes from red to green ball, or to wait until there is a gap in the oncoming traffic that will make the left turn safe. Both driving behaviors were observed. Since it is not known what a given driver will do in such a situation, there is a lack of predictability. It would seem that a fixed convention should be established and taught.
4. Closely related to problem 3 above is the problem of being "trapped" in the intersection as the signal turns to yellow and then red. This problem is caused by oncoming traffic continuing through the intersection on yellow and even red. When the signal for the cross traffic turns green, the trapped vehicle comes into conflict with the cross traffic. This problem is caused by the aggressive behavior of oncoming traffic, which continues on late yellow and even red.
5. Driver workload on left turns is increasing. Higher traffic speeds, greater traffic densities, and large vehicles causing greater visual obstructions all make left turns more hazardous than they were in the past. There are more information gathering points for left-turning drivers to sample, more closing rates to estimate, and more chances of a missed detection.

Left turn procedures, signaling, signing, and delineation should be reexamined. Numerous problems are occurring with these turns, and novel approaches need to be developed.

The AASHTO green book (1994) includes a discussion of various approaches for designing for indirect left turns and indirect U-turns. One such approach is that which is used in the Detroit area (and possibly elsewhere), where drivers first make a right turn onto a perpendicular street. The driver then moves left into a dedicated U-turn lane. Once the U-turn is completed, drivers are heading in the correct direction (equivalent to a left turn from the starting street). This eliminates the problem of crossing the path of oncoming traffic, but does require substantial changes in infrastructure including an addition of the dedicated U-turn lane and modifications of the signals. Pages 768 through 777 in the AASHTO green book (1994) provide a good description, with several diagrams, that outline various alternatives for this problem.

Because aggressive driving is one of the causes of left-turn problems, improved enforcement methods may be needed. Among these, automated ticketing and greater conventional enforcement might be effective. Driver education and awareness campaigns may also be helpful.

In summary, a research project that examines the many aspects of left turns and problems resulting therefrom seems to be warranted.

Sample Research Design

As described in the previous problem, research could be undertaken to carefully analyze the effectiveness of various infrastructure design solutions. The research question to be posed is: What is the impact on incident rates if indirect left-turn design solutions are used? The various design alternatives would serve as the independent variable in this proof-of-concept evaluation. The effectiveness of the design could be measured (dependent variables) in terms of the incident rate changes whereby the incident rate of the current configuration is compared with the incident rate of a location, with a similar set of traffic characteristics, that has incorporated one of the novel intersection designs. In addition, data could be collected with regard to driver satisfaction with the new design and the degree of driver confusion with the novel design (e.g., instances of drivers failing to perform their directional change using the new design).

Research Problem Area 4

Right-of-Way Confusion at Two-Way Stop-Controlled Intersections

Many incidents were attributed to driver confusion with regard to right-of-way. Of these, several occurred at four-way intersections in which only two of the four legs were controlled by stop signs. The problems occurred when two opposing drivers were unclear as to who had the right-of-way. Was it the driver who reached the stop sign first, or was it the driver proceeding straight through the intersection? If both drivers were proceeding straight, conflicts did not develop. However, conflicts developed when Driver 1 reached the stop sign prior to Driver 2, and Driver 1 wanted to make a left turn while Driver 2 wanted to go straight through the intersection.

During peak periods when traffic volume is high, there are additional problems. Both Drivers 1 and 2 have to scan in both directions for a gap. This requires looking to the left and right. The left and right scanning in the through direction is also complicated by the possibility that drivers coming from these directions may slow to make turns. The matter is complicated further when drivers from the through directions do not use their directional signals to indicate their intention to turn. At the same time, the drivers at the stop signs must decide who will proceed first. The combined demands of the situation can overwhelm drivers and lead to incidents and crashes.

One solution to this problem would be to control all four lanes of the intersection. This can be accomplished either through the addition of traffic signals or four-way stop signs. However, there may be situations where these alternatives are not appropriate. For example, on a university campus where safety may in some cases take a back seat to aesthetics, the optimal solution (from a safety standpoint) may not be selected. It is important to take a step back and consider conventional as well as novel approaches to address safety concerns.

The main research question to be considered is: What are the infrastructure-related alternatives that can reduce driver confusion and visual workload in this situation? How can drivers stopped at a stop sign, in this situation, be confident that a clear understanding exists for both drivers as to who has the right-of-way? Assuming that signals to control all lanes of the intersection are not an option, consideration should be given to various conventional and novel alternatives.

Sample Research Design

Research should be directed at methods of reducing driver confusion at intersections. It is suggested that right-of-way rules must be stressed during driver education courses and in the Department of Motor Vehicles manuals. Education aside, research into infrastructure design solutions may serve to reduce confusion. One approach would be to study various signing approaches. Independent variables for such research would consist of the various design/sign approaches. For example, one approach would be to position a traffic sign near the intersection that instructs drivers on the appropriate right-of-way rules. A second design solution would be to introduce a novel stop sign that would indicate to drivers which vehicle has the right of way. Sensors in the pavement could be linked to "smart" Stop Signs and notify the driver when it is his/her turn, and when it is safe, to proceed into the intersection. These different approaches could be compared with the baseline approach (i.e., current infrastructure design). Comparisons could be made with regard to a variety of dependent variables including rate of incidents and driver acceptance.

Research Problem Area 5

Entrance and Exit Lane Inadequacies

Several critical incidents were recorded at merge and weaving sections. It is suggested that the problems associated with merge lane conflicts can be attributed to three primary factors. First, and perhaps most important, the merge lanes were not long enough to facilitate safe merging or weaving. In some cases, the merge lanes that caused the greatest difficulties were less than 35 m in length. Second, there is a high volume of traffic in the weaving area. Third, there is a large speed discrepancy between merging vehicles. In one case, the primary roadway speed limit was 55 mi/h while the ramp speed limit was 25 mi/h. The speed discrepancy problem is further exacerbated by the short weaving sections.

A merging maneuver is considered to have a high level of driver workload associated with it; therefore, it requires a large amount of driver attention to complete safely. Drivers must be cognizant of traffic in the adjacent lane as they merge. In addition, drivers must judge the gaps between vehicles to be able to merge safely into the traffic flow, while monitoring any vehicle directly in front. A merging maneuver increases in difficulty when the speeds of the vehicles in the adjacent lanes are substantially different. Driver workload also increases when vehicles in adjacent lanes are weaving, that is, vehicles are switching positions between lanes. While a merging maneuver in and of itself has a high driver workload, decreasing the length of the merge lane greatly increases this workload, especially when traffic volume is high.

Infrastructure-related candidate countermeasures for problems 23, 24, and 25 address one or more of the factors outlined above and are directed at reducing driver workload. For example, longer merge lanes, congestion reduction, slower speeds, and separate merge lanes for entering and exiting vehicles might make merging maneuvers less difficult for drivers and, therefore, reduce the critical incidents in these areas. One of the main research questions related to this problem area is: What are the alternatives to reducing merging/weaving incidents?

Sample Research Design

The research recommended here would be proof-of-concept evaluations and investigations of the effectiveness of alternative infrastructure design solutions. The independent variable would be the design solution and comprise the different design approaches that are tested, along with the baseline (current) design. Dependent variables would include the rate of incidents and driver satisfaction with the design. For this particular problem, researchers may conduct the assessment in phases whereby minimal changes are implemented first. For example, one of the issues discussed was that the speed discrepancy can be quite high between vehicles on the ramp and vehicles on the highway. These large speed variations between weaving vehicles seem to have had a significant role in the incidents that were recorded for this project. As a first step to reducing incidents, researchers might post a reduced speed limit sign for vehicles on the highway and measure the impact that this change has on the incident rate and driver satisfaction. Depending on the results of this relatively minor change, a decision to implement more substantial changes can be made. One of the factors that would have to be considered when dealing with various degrees of change to the infrastructure would be the costs involved with each change. Though not strictly a factor in determining the effectiveness of a design solution (in terms of reduced incidents), it is certainly a parameter that must be carefully considered in the real-world application of a solution.

Research Problem Area 6

Private Entrances and Exits Near Intersections

Many of the conflicts that were captured during this effort occurred at intersections. This is not surprising because the inherent nature of intersections is that they involve crossing (or *intersecting*) traffic from three, four, or possibly more directions. At intersections, vehicles often have the opportunity to change direction of travel in one or more directions; therefore, they often cross paths with other vehicles. If these directional changes, or interactions, are not carried out in a controlled and deliberate manner, conflicts are likely. Therefore, one must keep in mind that intersections, by their nature, are inherently prone to vehicle conflicts owing to the crossing patterns of traffic.

Several critical incidents that were captured occurred at or near intersections where a private business entrance/exit was in close proximity. It is suggested that the presence of a private entrance/exit near an intersection adds to the intersection's complexity and alters drivers' expectations with regard to what actions other vehicles will take. As such, drivers are required to increase their attention in such situations. It is hypothesized that many conflicts for drivers unfamiliar with an intersection arise when the given intersection does not fit a driver's preconceived expectations (or mental model) of how the intersection *should be*. That is, the driver may incorrectly assume that the intersection fits some standard intersection model. The existence of private entrances and exits at or near intersections is a good example of a deviation from the standard intersection layout. Such an intersection was highlighted in Error 18 (described in the Task F report) where a private business entrance/exit was *inside* the intersection. To complicate this particular problem further, the entrance/exit to the business was not controlled. This feature particularly affected drivers exiting the private business into the intersection.

Human factors engineering describes the importance of following convention and standards in design. Maintaining consistency across systems is a way to promote ease-of-use and reduce confusion. For intersections, consistent design convention leads to consistent traffic flow patterns. In the problems described where private entrances/exits are either inside the intersection or are in close proximity to the intersection, traffic flow is likely to have aberrations/deviations that drivers do not expect. Designs that are inconsistent and do not fit the driver's pre-conceived notion of how things should be (i.e., do not fit the driver's mental model) are candidates for redesign. There are likely to be situations where "optimal" design is not possible (due to business locations, etc.). However, as outlined in the candidate countermeasures for these particular intersections, there are solutions that can be applied to reduce conflicts.

Two primary research areas of focus are related to this problem. First, what are drivers' expectations with regard to intersection design and layout? And second, how can infrastructure-related redesign approaches be applied to meet these expectations? It is suggested that both conventional and novel solutions may be appropriate in redesigning an intersection so that it fits the driver's mental model and thus maintains driver expectations, thereby reducing traffic conflicts.

Sample Research Design

An important principle in human factors design is the notion of "user-centered" design. User-centered design refers to a design approach whereby the needs of the user are considered early on in, and throughout, the design process. It is suspected that many of the problem intersections studied in this project, and perhaps many of the guidelines and standards that have been developed with regard to intersection design, were developed without the input of the end-users. It is hypothesized that this factor may contribute to the confusion that drivers experience. A study is suggested that may result in user-centered intersection design guidelines.

Consider a study whereby users (drivers) have an opportunity to help design an intersection (this study could be conducted in the lab on a computer). Sitting next to a traffic engineer, who would be present to guide the user and facilitate the process, the user would be presented with various intersection design characteristics (i.e., the independent variables in the study). For example, drivers would be given the demands and parameters of the intersection (e.g., four legs, signals, etc.) and asked how they would design it. (Of course, some concepts would be naïve, but others might provide important insight.) This exercise would be expected to shed light on the expectations that drivers have with regard to intersections (and intersections given certain characteristics). It is expected that users' designs would have common characteristics. These common characteristics could be compared with (1) problematic real-world intersections with similar characteristics and (2) relevant design guidelines currently in practice. Researchers could determine the degree of similarity (dependent variable) between the user's designs and those in the real-world. Contradictions between users' designs and real-world designs would be seen as opportunities for improvement and change. As part of this study, it would also be important to ask drivers their opinions on atypical intersections. The problem described in this section, where private entrances were found in and near intersections, could be explored using this approach. It is expected that users would be able to generate various ideas with regard to how infrastructure design engineers might assimilate these variations.

Research Problem Area 7

Intersections in Close Proximity to One Another

Consider a situation where two intersections are within 50 m of one another. Both intersections have four legs, with four lanes of traffic (two lanes in each direction) in each leg. One of the intersections has stop signs controlling two opposing legs (e.g., N and S), while the other two legs (e.g., E and W) do not have stop signs. One of the legs not impeded by a stop sign leads to/comes from the second intersection (for purposes of illustration, say, to the west) that is controlled with traffic signals. Several conflicts were captured with this infrastructure configuration. These conflicts were categorized into three problem types: (1) traffic backed-up from the signalized intersection blocks the stop-controlled intersection, (2) limited line-of-sight for drivers of straight-proceeding vehicles at the stop-controlled intersection when traffic builds at the signalized intersection, and (3) vehicles making a right (or left) turn at the stop-controlled intersection, followed by a left (or right) turn at the signalized intersection, are forced to quickly cross a lane of traffic.

The first problem type arises when traffic volume is heavy and vehicles are backed-up at the signalized intersection. For example, westbound queued traffic waiting at the red light backs-up toward the second, stop-controlled intersection. Drivers who have not yet proceeded through the stop-controlled intersection and are moving toward the signalized intersection, and who are inattentive or impatient, may continue the queue into the stop-controlled intersection, thus blocking passage for N and S flowing vehicles proceeding through the stop-controlled intersection.

The second problem type is similar to the first type in that it involves westbound queued vehicles waiting to proceed through the signalized intersection. However, unlike the first problem where the stop-controlled intersection was blocked, this second problem type involves a clear stop-controlled intersection with queued vehicles lined up for the signalized intersection. Conflicts arise when N and S flowing vehicles wish to proceed straight through the stop-controlled intersection. However, because of the westbound queued vehicles, drivers may have difficulty seeing cross traffic as they proceed through the stop-controlled intersection.

The third problem type involves drivers wanting to make a right turn at a stop-controlled intersection followed by a left turn at the signalized intersection. Similarly, a second problem also involves drivers making a left turn at the stop-controlled intersection followed by a right turn at the signalized intersection. Vehicles making these consecutive opposite-direction (diagonal) turns are forced to change lanes quickly so as to be in the correct lane for the upcoming turn. Because the distance between the intersections is small (30 to 50 m), drivers have little time or space to change lanes. Any existing traffic in the free-flowing lanes adds to the complication of the maneuver.

Several research areas could be directed at addressing these infrastructure-related driver errors. First, it is suggested that a conventional approach might be to signalize both intersections. If this approach is taken, research might explore the optimal timing strategy for the two intersections given the limited distance between them. Related to this, an investigation might be undertaken to avoid "trapped" vehicles that may have a green light at one intersection, but a red light at the next intersection. An alternative research approach would be to consider redesign alternatives to separate the intersections, thereby increasing the distance between them. One method by which this might be accomplished is to use a frontage road.

The main research question to be answered is: What are the best procedures for remedying and redesigning intersections in close proximity to one another? This research problem falls completely within the charter of FHWA because it involves signing, signaling, and alignment.

Sample Research Design

A proof-of-concept evaluation study is suggested that would empirically test various design solutions to address this problem. As outlined in the sample research designs of some of the other problems, the independent variable in this study would be the various design alternatives. An evaluation of the different solutions could be conducted to determine the differences in effectiveness between them. Effectiveness might be determined through determining incident rates for the different solutions, as compared with baseline and driver opinions (i.e., these would serve as the dependent variables).

Research Problem Area 8

Beginning and Endpoint Control of Time-of-Day Directional Lane Usage

In some metropolitan areas, specific lanes of certain major roadways use time-of-day direction changes to increase roadway capacity. The concept is to make maximum use of the existing highway roadbed by matching the number of lanes to the need in the rush direction. This concept seems to work well in practice and has been in use for decades. Nevertheless, the beginning and endpoints for change-of-direction lanes can cause confusion and incidents. Several were observed at a T-intersection where one of the lanes had a time-of-day change endpoint. Researchers who observed the intersection and gathered data surmised that the problems were a result of confusing message signs and lack of positive guidance as to which lane to enter.

The specific problems encountered (see Error 11 described previously) were that drivers would turn into the wrong lane, creating two types of hazards. If they turned from the base of the T to the left outside lane incorrectly (for the given time of day), they would conflict with traffic going in the same direction in that lane. On the other hand, if they turned incorrectly (for the given time of day) from the base of the T to the left inside lane, there was the possibility of a head-on conflict. The problem was so prevalent that drivers familiar with the intersection would take defensive postures when entering the intersection. They would monitor for drivers unfamiliar with the intersection who might perform the wrong maneuver, and they would be prepared for defensive maneuvers such as braking or lane changing.

These incidents suggest that entry and exit points from direction-change lanes could be improved. While all of the incidents encountered in the data gathering involved the combination of beginning/endpoints and intersections, it might be prudent to examine all beginning/endpoints, that is, both straight and turning.

There are several suggested methods for improvement of the beginning/endpoint traffic flow for direction change laws. Improvements in, and standardization of, signing should provide important benefits. If drivers always encountered the same types of signs and directions, and if these were unambiguous and placed correctly, drivers would quickly become familiar with them and would know how to respond when they saw them. Another concept that could be studied would be illuminated lane edge guide markers in the pavement. The concept is to illuminate the lane (and path) the driver should follow for the specific time of day. When not illuminated, these markers would not be visible. Where needed, two sets of lane markers could be embedded per lane, with only one set illuminated at a time. The concept, once again, would be to direct the driver to the correct lane for the corresponding time of day.

This research problem area appears to be totally within the domain of the FHWA because it involves delineation, signing, and traffic control. The research would involve examination of current practices, study of incidents and driver confusion, development of standard signing and delineation, development of innovative approaches, and implementation and testing.

Sample Research Design

The research recommended here would be directed at investigating the feasibility and effectiveness of implementing embedded pavement lights to illuminate the turning path for drivers. This proof-of-concept investigation would examine (i) if drivers would intuitively understand the meaning of the lights and be able to follow their guidance, (ii) if this approach would serve to reduce the number and degree of incidents in this type of intersection, and (iii) what drivers' opinions are with regard to these lights. Using these three dependent measures, a comparison would be made between the new system of embedded lights and the current conventional system (independent variable would be the design approach). It is recommended to FHWA that this innovative embedded light approach be investigated; the research team hypothesizes that this will have an immediate and positive impact on the driver errors observed at this type of intersection.

CONCLUSIONS

The work conducted for Task F carefully examined the relationship among infrastructure, driver error, and critical incidents. This was accomplished by first determining which incidents appeared to have an infrastructure component. The incidents containing such components were then reexamined to determine the precise nature of the infrastructure components. The components were summarized in problem descriptions of one to two pages. Once the problems had been identified, countermeasures were suggested.

Because 43 problems were developed, and because independent countermeasures for most of them were devised, it became apparent that recommendations should be made regarding generalized research issues. Therefore, an attempt was made to identify general research issues from the 43 problems and their candidate countermeasures. Eight such issues were described.

What then are the conclusions of this study? Was it successful in linking incidents and infrastructure elements and, if so, to what degree? It is certainly clear to the research team that many of the incidents recorded could be contributed to infrastructure components. The Task E report identified 62 critical incidents with severity ratings of 5 or 6. Of these, 22 had one infrastructure contributor, and 8 had two infrastructure contributors. Thus, infrastructure plays a very important role in many conflicts. While "cause" is very difficult to pin down, this report demonstrates that infrastructure contributes to factors such as driver confusion and uncertainty, visual and cognitive workload, and possibly to risk taking. On the other hand, infrastructure is far from the sole contributor in most conflicts. One way of summarizing all of this would be to say that there are incidents in which infrastructure plays no role, there are incidents in which infrastructure plays a minor role, and there are incidents in which infrastructure plays a major role.

While the research problem area statements presented in this chapter represent many of the conclusions of this study, a few additional observations should be included. First, it is very clear that, in many cases, recommended practices are not followed. Examples that could be cited are numerous, but a few will be mentioned. Traffic signals near entrances to intersections (instead of on the far sides), uncontrolled private roadways entering intersections, uncontrolled private roadways very near intersections, major intersections near one another, extremely short merge lanes, extremely short weaving sections, and confusing signs. The findings from this effort demonstrate the importance of conforming to existing standards.

Another factor that seems to play a major role is growth in traffic volume. The population of the United States is increasing and there are more vehicles on the roads. Higher traffic volume has several profound effects. It increases driver workload; drivers have to sample more points visually and estimate the speeds of more vehicle. Higher traffic volumes also tax the simpler designs of roadways and intersections. It is hypothesized that, in many cases, these infrastructure elements were designed for much lower traffic volumes. With fewer vehicles, drivers could sample without difficulty. But when traffic volume is high, drivers may sample inadequately, and they may be forced to take risks. Higher traffic volume also increases the likelihood of conflicts and crashes, simply because there are more opportunities (i.e., increased exposure). The number of possible interactions that can exist between vehicles confined to a given space, say an intersection, is $n(n-1)/2$, where n is the number of vehicles. Higher traffic volume can also lead to greater driver frustration because of the drivers' inability to maneuver freely and because of reduced mean traffic speed. This frustration can take the form of aggressive driving. These manifestations of higher traffic volume are well recognized, but the current study demonstrates them very clearly.

It is also clear that, even though general areas of future research were gleaned from the data, incidents and countermeasures for a given location remain specific. Usually, a given site has unique elements that will require careful study and engineering analysis prior to redesign. That having been said, the general research areas recommended should provide guidance and new techniques for handling some of the problems. In summary, each site is different, but additional research may provide new answers that are widely applicable.

It should be noted that the incidents detected and analyzed often involved some form of willful inappropriate behavior, namely, purposeful law violation or other aggressive driving. While development of improved infrastructure can go a long way toward reducing congestion and consequent frustration, it is expected that much of the willful inappropriate behavior will remain. The Department of Transportation should consider funding efforts directed toward improved methods for reducing willful inappropriate behavior. The problem goes beyond infrastructure development and may require novel behavioral and enforcement approaches.

Finally, this chapter is a demonstration of the synergistic effects of combining human factors engineering techniques with traffic engineering. By broadening the earlier traffic conflict technique to include greater consideration of driver behavior, with emphasis on generalized driver errors, a better understanding of critical incidents and their corresponding countermeasures has been obtained.

CHAPTER VIII. DEVELOPMENT OF GUIDELINES BASED ON PROJECT RESULTS

PART I. GUIDELINES FOR IMPROVED CODING OF ACCIDENT DATA

Background

Task G calls for the development of guidelines for the improved coding of accident data. These guidelines are based on findings from earlier tasks in the study, specifically, Task C (Driver Error Taxonomy Development) and Task E (Investigation of Critical Incidents). The previous tasks were carefully reviewed for information relating to the coding of accident data. Work on other projects using accident databases and contacts with local police departments also proved helpful in developing these guidelines.

The severity of a crash is one of the primary factors that determines whether that crash will be entered into an accident database. In many States, a crash on private property, such as a commercial parking lot, will not warrant an accident report unless there is an associated injury. In most States, crashes that do not result in a certain monetary amount of damage to at least one of the vehicles will not result in an accident report, even when they occur on public roads. Common monetary cut-off values are $500 and $1,000. Thus, accident reports are commonly filled out by police for crashes resulting in injury or death, regardless of where they occur, and for crashes involving monetarily significant vehicle damage that occur on public roads.

The accident report process (up to and including coding) may follow one of a number of processes. The following scenarios are known to have occurred in Virginia, and are likely to be similar in other States:

- An officer fills out a paper accident reporting form at the scene of the crash or elsewhere shortly thereafter. The appropriate codes are entered into the form using an overlay, guide sheet, or manual (an overlay fits over the accident reporting form, has arrows pointing to the coding boxes, and lists the possible codes for each box). The officer types the report into the State accident database back at the police station.

- An officer fills out a paper accident reporting form at the scene of the crash or elsewhere shortly thereafter. The appropriate codes are entered into the form using an overlay, guide sheet, or manual. A clerk at the police station enters the report into the State accident database. If the clerk has questions, the officer is available to answer them, but the clerk may be tempted to interpret the officer's handwriting or meaning in the interest of saving time.
- An officer fills out a paper accident reporting form at the scene of the crash or elsewhere shortly thereafter. The appropriate codes are entered into the form using an overlay, guide sheet, or manual. The form is sent to the appropriate State office where it is entered into the State accident database by a clerk unknown to the reporting officer. The clerk will often be required to interpret the officer's handwriting or meaning (intent) in the interest of saving time.
- An officer fills out a computerized accident reporting form at the scene of the crash or elsewhere shortly thereafter using a department-issued laptop computer. Using the pop-up reminders for each data field, the appropriate codes are entered into the form by the officer. The intersection drawing process may be made easier by the use of templates for specific intersections. The report is transferred to the State accident database by the officer or a clerk back at the police station, often using a diskette.

As can be seen from the above scenarios, the data may be directly entered by the reporting officer, or the data may be several steps removed from that officer with resultant errors of interpretation (both of the officer's handwriting and of the officer's original intent).

The national databases are developed by slightly different processes. The Fatal Accident Reporting System (FARS) is a census of every fatal crash that occurs in the United States and Puerto Rico. Each year of the FARS database contains three files: the accident file, the vehicle file, and the person file. For the most recent year (1999), there are approximately 52 accident variables, 76 person variables, and 80 vehicle/driver variables coded for every fatal crash (some variables appear in more than one file). The data to be coded are collected primarily from police accident reports (PARs) with supplemental information obtained from hospital and ambulance records, the medical examiner's office, the State department of motor vehicles, and follow-up interviews where necessary. Where the State reporting form and its associated coding do not match the required FARS information, additional investigation, interpretation, or mapping may be required. However, FARS coders are trained to work with each State's PAR form.

The General Estimates System (GES) is another national accident database. It is developed through a sampling technique rather than a complete census. This sampling process results in an estimate of the number of crashes of various types. There are 60 primary sampling units (large central city, county surrounding a city, or group of counties) chosen to be representative of the country in terms of population distribution, traffic density, etc. Within these 60 primary sampling units, approximately 400 police jurisdictions are sampled. For the GES database, the data are coded directly from PARs into an electronic file. The data are automatically checked as they are entered into the file. Quality checks are performed on the completed data sets. As with the FARS, the coders working with the PARs may be required to do some interpretation or mapping of responses when coding the data. However, coders are trained to work with each State's PAR form.

The GES coding manual, which guides the GES coders in entering data from the State PARs into the GES databases, is 435 pages long. Each variable is described in detail along with the definitions associated with each code. Each variable also contains a series of consistency checks to make sure the data are logically correct. For example, if the crash were coded as occurring at noon, it would be inconsistent to have the light condition coded as dark.

There are several ways in which traffic accident report forms and their associated coding schemes could be improved, depending on the goals of the improvement process. (Concrete examples of suggested improvements are provided on the next several pages.) Several of these goals are presented below.

- Improve the police accident reporting form to better assist the investigating officer. The goal would be to make the reporting officer's job easier. This could have the additional advantages of improving departmental efficiency and inter-officer consistency.
- Improve the police accident reporting form to make accident reporting more accurate. This would require revisions to the forms and coding schemes to achieve more precision

in crash descriptions and possible contributing factors. This must be balanced against the goal of making the officer's job easier to perform. Greater precision often requires a greater investment of time.

- Improve the police accident reporting form to make accident databases more responsive to (usable by) research investigators (concrete examples provided later in this chapter). At present, the national databases are quite usable. However, there are categories that the research investigators invariably wish were included (usually specific to the project at hand). Compounding the problem is the fact that jurisdictions (generally States) change their accident reporting forms to capture information seen as currently relevant. When this happens, not all States make changes at the same time, and not all of them make the changes. For example, Florida recently (January, 2001) began collecting information on driver distraction in its accident reporting forms (*Miami Herald,* 2001). Pennsylvania is in the process of changing its PAR form to reflect the use of a cell phone prior to the crash (Guzzo, 2000).
- Improve the police accident reporting form to achieve standardization across jurisdictions (concrete examples provided later in this chapter). This would have several advantages. The forms could be redesigned to reflect coding needs at the national level, thus reducing errors in recoding information. The forms could be redesigned according to human factors principles to improve efficiency and reduce error. Coders who work with PARs from several States would have an easier time coding crash information and would require less training.

There are several problems with the current system of individual State PARs and State versus national coding systems. One of the major problems is that the same crash will often undergo several iterations of transcription that can lead to errors of interpretation, especially in the mapping of one coding system into another. The forms that are used are inconsistent across jurisdictions. The data lack the degree of precision desired by researchers who use them. Finally, the reporting officer typically has a heavy workload, especially in regard to paperwork. Any proposed changes should reflect an attempt to reduce (or at least not add substantially to) this workload.

Typical Current Accident Reporting Forms

A survey of PAR forms from several States, including Virginia, Minnesota, and Oklahoma, demonstrates that the typical PAR form is from one to three pages long. Virginia uses a one-page form. There are several boxes for coding crash variables along the left- and right-hand sides of the form and an overlay is required for completing the coding boxes. The Minnesota form is three pages long. The first page is the accident report itself and the next two pages are used for coding. Arrows on the coding pages are used to line up coding information with coding boxes on the accident report page. Oklahoma uses a two-page form. The coding is contained within the form so that additional sheets or overlays are not required.

Forms are generally crowded with boxes and graphical elements, often with a font size of 9 points or less. Forms generally request several types of information. Driver and other involved-person information is mostly alphanumeric (name, age, driver's license number, insurance, etc.). Injury information may be assigned codes. Vehicle information is generally alphanumeric. Accident information uses a combination of narrative, graphic, and assigned coding (weather, road geometry, point of impact, etc.). The information is arranged somewhat haphazardly (perhaps the layout is driven by the limited real estate available). The main impression of these forms is that a great deal of information is squeezed into very little space. Typical categories found on PARs and their associated coding schemes are presented in table 23.

Table 23. Data contained in a typical police accident reporting form.

Accident Information	Coding scheme
Time	Alphanumeric
Location	Alphanumeric
Name(s) and relevant information for driver(s)	Alphanumeric
Vehicle information (make, model, etc.)	Alphanumeric
Insurance information	Alphanumeric
Narrative description	Alphanumeric
Statute violation	Alphanumeric
Number of vehicles involved	Numeric
Number of persons killed or injured	Numeric
Accident diagram	Graphic
Driver/pedestrian condition	Multiple Choice/Check-off
Injury severity	Multiple Choice/Check-off
Injury type	Multiple Choice/Check-off
Occupant restraint information	Multiple Choice/Check-off
Chemical test (DUI, etc.)/alcohol involvement	Multiple Choice/Check-off
Position of occupant in vehicle	Multiple Choice/Check-off
Type of accident/pre-accident maneuver	Multiple Choice/Check-off
Traffic control devices	Multiple Choice/Check-off
Type of road/road geometry	Multiple Choice/Check-off
Object struck by vehicle	Multiple Choice/Check-off
Weather	Multiple Choice/Check-off
Light	Multiple Choice/Check-off
Locality type (rural, urban, etc.)	Multiple Choice/Check-off
Road surface/road condition	Multiple Choice/Check-off
Point of first contact on vehicle	Multiple Choice/Check-off
Vehicle condition	Multiple Choice/Check-off
Pedestrian action	Multiple Choice/Check-off
Vehicle type	Multiple Choice/Check-off
Vehicle damage severity	Multiple Choice/Check-off
Relationship to intersection	Multiple Choice/Check-off
Commercial vehicle information	Multiple Choice/Check-off
Unsafe action/contributing factors	Multiple Choice/Check-off

An example of coding scheme mapping, the GES database uses the following coding scheme for the damage area(s) of each vehicle involved in a sampled crash (note that up to five damage areas may be coded in GES):

0 = no damage

1 = front

2 = right side

3 = left side

4 = back

5 = top

6 = undercarriage

7 = all areas/damaged

9 = unknown damage areas

FARS uses a more precise scheme, and codes a single initial impact point as well as a single principal impact point:

00 = non-collision

01-12 = clock positions (12 is front center bumper, and numbers go around clockwise)

13 = top

14 = undercarriage

99 = unknown

Minnesota uses the following coding for the principal damage area of the vehicle(s):

0 = not applicable

1 = front

2 = right front

3 = right center

4 = right rear

5 = rear

6 = left rear

7 = left center

8 = left front

9 = top

10 = bottom

11 = multiple areas

99 = unknown damage areas

By contrast, Oklahoma codes the point of first contact on the vehicle by using a diagram with 12 points marked around the edges of the vehicle in a clockwise direction, similar to the FARS coding scheme (but offset slightly in orientation). There are check-off boxes for damage to the top and bottom of the vehicle. The officer is required to fill in 1 of the 12 numbers for each involved vehicle. Unlike the FARS, GES, and Minnesota forms, there are no codes for an unknown damage area or for no damage.

The Virginia PAR also uses a diagram, and the officer is asked to check off the points of impact. Whether this refers to initial impact or principal impact is unclear from the form. The officer is allowed to check off as many points as are applicable, which probably requires interpretive coding when only one code is allowed (as in FARS). There is no apparent coding for an unknown damage area or for no damage, and there does not appear to be a method for coding damage to the undercarriage. In this scheme, the check-off points are represented by the following numbers:

1 = front
2 = right front quarter panel
3 = right side doors
4 = right rear quarter panel
5 = rear
6 = left rear quarter panel
7 = left side doors
8 = left front quarter panel
9 = top

In attempting to classify the same crash using these different coding schemes, there will be more or less precision depending on the original coding scheme and the interpretation of how it should be applied to the current coding system. Note that there are also large differences in whether the initial impact point, the principal impact point, or both are to be coded. Some schemes allow for coding of multiple points and some only allow for one point. When data from various State PARs are input into a national database such as FARS or GES, there will be differences in how similar crashes are coded. This can result in apparent State differences in the frequency of certain types of crashes.

Nearly every data category listed in table 23 demonstrates the same degree of variability in coding scheme, level of precision, and definition, as does the point of impact variable. It seems likely that these divergent coding schemes result in some degree of error at each of the data coding levels.

Driver Error Project Results with Regard to Accident Database Coding

As part of the Task C effort of this project, investigating officer focus groups were held, and officers suggested improvements to the Virginia police accident report forms. Of the officer suggestions made during the focus groups, the following have implications for improvements to the national databases:

- Provide templates of basic intersections. This would allow for more consistent coding of accident scenarios in the national database.
- Use more meaningful codes (and make codes consistent across States). This would result in more accurate accident information from the bottom up.
- Eliminate unnecessary information. This would free up room on the database forms for new information fields of pressing interest, such as the driver error taxonomy.

Another important point obtained from the focus groups is that officers would like to have input into coding changes and infrastructure changes. As the front-line personnel who are driving the streets, investigating the crashes, and filling out the accident report forms on a daily basis, officers often detect the problems not seen by report form designers and highway engineers. This is a standard human-centered design approach and should be implemented as a design practice.

Task C also resulted in a taxonomy of principal contributing factors affecting driving performance. This taxonomy was derived from a database analysis and an examination of existing taxonomies. The categories of driving performance problems are related to human error, and the principal contributing factors help explain how these errors occur. An understanding of these contributing factors is important so that methods can be developed for mitigating human error in driving. Thus, an effort should be made to capture this information on driver error in a more precise and uniform fashion than is currently the case. This will be discussed in more depth in the next section of this report. The principal contributing factors and the associated driving performance problems are presented below.

Principal contributing factors

Inadequate knowledge, skills, training

Lack of understanding or misunderstanding of:

Traffic laws

Driving techniques

Vehicle kinematics, physics

Driver capabilities and limitations

Impairment

Fatigue and drowsiness

Use of drugs, alcohol

Health related:

Illness

Incorrect use of, failure to use, medication

Disability, uncorrected disability

Willful inappropriate behavior

Purposeful violation of traffic laws, regulations

Aggressive driving

Use of vehicle for improper purposes:

Intimidation

As a weapon

Infrastructure and environment

Problems with:

Traffic control devices

Roadway:

Alignment

Sight distances

Delineation

Weather and visibility

Any of these principal contributing factors may lead to a driving performance problem:

Driving performance problem

Failure to perceive or perceive correctly:

In general

Distraction

Inattention

Incorrect assumption

Incorrect cognitive processing

Failure to act

Incorrect action

In-depth knowledge of the prevalence of these principal contributing factors would have far-reaching ramifications. Specific solutions could be designed and implemented to address these factors. Crash data could then be tracked to assess the success or failure of these solutions. For example, for a problem with willful inappropriate behavior (such as running red lights), solutions might include better enforcement (both conventional and automatic ticketing), better education and training, and perhaps behavior modification techniques. Problems with driver proficiency could be addressed with better education and training, as well as better signing to overcome driver lack of knowledge (an example of such a sign would read "yield to pedestrians on right turn").

Adding the categories of principal contributing factors and driving performance problems to the PARs could have legal ramifications, however. In many cases, officers would be asked to attribute and/or surmise these factors. Some officers may be hesitant to attribute a crash to driver error for fear of liability. However, the current forms also require a certain amount of educated guesswork and, at present, the officers seem to be protected from legal action based on their reports. In ticketing the driver considered to be at fault, as is the case for many crashes, the officer is in effect already assigning a driver error to one of the involved drivers.

Recommendations for Changes

Recommendations for changes to the accident reporting system are presented below.

1. Develop a Uniform Coding Scheme That Will Suit the Needs of Both the State and the National Databases

As shown in the example for impact points, several methods are used to categorize crash variables. Development of a uniform coding scheme would result in more consistent data transferal with little or no need for the re-transcription that is now often necessary. Ideally, this development process would result in a single prototype PAR that could be adopted by all States. An effort such as this would require the full support of both State and national agencies. The GES coding manual describes how such an effort was undertaken by the National Governors Association (NGA):

> In 1987 the nation's Governors adopted a comprehensive motor carrier safety policy, which stated that a necessary first step toward improved motor carrier safety would be the uniform collection of information on truck and bus accidents. The NGA surveyed fifty states to assemble the latest police accident reports, and conducted case study field visits to four states to get a better understanding of data collection and reporting. After reviewing state truck and bus accident data collection efforts, the NGA drafted a set of uniform data elements. These data elements were pilot tested in several states and finalized (GES Coding Manual, NHTSA, 1998, p. 335).

These NGA variables are now included in the GES databases. Although this example concerns a limited subset of accident data, it does demonstrate that a nationwide effort is feasible. It is unclear which agency should take the lead role in developing a uniform coding scheme. The NGA may not be interested in taking the lead, because the effort would result in some expense to the States in training and computer programming if implemented. However, since the States would surely want to have input into the new coding scheme, the NGA may be interested in partnering with the lead agency (perhaps NHTSA or the National Safety Council).

2. Make Human Factors Improvements to Existing Forms and Computer Software

Although States and individual police departments are slowly making the transition to computerized accident report forms, the paper PAR is likely to be around for the foreseeable future. If a standard form is not adopted, then each State should make an effort to improve its forms. A survey of State forms demonstrates the following areas for improvement:

- Separate the information into logical groupings, keep each grouping in physical proximity on the form, and delineate and label each grouping clearly.[13]
- Where fonts are too small, increase the font size.
- Remove unnecessary information from the form.
- Include coding schemes on the form.
- Eliminate carbon copies, and use a copy machine to make necessary copies.
- Assess the codes themselves and make them more meaningful where possible. Alphanumeric codes may be easier to remember and may result in fewer initial coding errors (Weather: R for Rain, C for Clear, S for Snow, F for Fog, etc.). Computer programs can transcribe these codes into numeric codes if necessary for later processing. Keep coding practices consistent within the form.

For computerized PARs, human factors principles for the design of human-computer interfaces should be followed. Computers offer many advantages for completing PARs. Computers allow more flexibility in the entry and coding of information, and mistakes are easier to correct. Relevant information does not have to be re-entered for crashes involving more than two vehicles. Many of the drawing tools (such as intersection templates) can be pre-drawn and simply dragged into the diagram. Rather than entering codes, pop-up menus allow the officer to click on the

[13] Many of the guidelines presented in this section (e.g., grouping, font size) are recommended practice and can be found in any human factors text.

appropriate answer, and the computer program will then assign the correct code. Computerized PAR interfaces should be designed with officer usability testing.

3. Include Principal Contributing Factors and Driving Performance Problems on the PAR

Further improvements to existing accident report forms could be made by the addition of a principal contributing factors checklist (with possible ranking), including driving performance problems. This checklist could be based on the driver error taxonomy developed as part of this project and as discussed in the previous section. Such an addition would allow the collection of valuable driver error data to be used in more detail and more consistently than is now possible. A prototype of the suggested Principal Contributing Factors checklist is shown in figure 32.

Principal contributing factors that led to the crash:

(up to three, with most important ranked 1, least important ranked 3)

1. Inadequate knowledge, skills, training
   - 1.1. Lack of understanding or misunderstanding of:
     - 1.1.1. ____ Traffic laws
     - 1.1.2. ____ Driving techniques
     - 1.1.3. ____ Vehicle kinematics, physics
     - 1.1.4. ____ Driver capabilities and limitations
2. Impairment
   - 2.1. ____ Fatigue and drowsiness
   - 2.2. ____ Use of drugs, alcohol
   - 2.3. Health related:
     - 2.3.1. ____ Illness
     - 2.3.2. ____ Incorrect use of, failure to use, medication
     - 2.3.3. ____ Disability, uncorrected disability
3. Willful behavior
   - 3.1. ____ Purposeful violation of traffic laws, regulations
   - 3.2. ____ Aggressive driving
   - 3.3. Use of vehicle for improper purposes:
     - 3.3.1. ____ Intimidation
     - 3.3.2. ____ As a weapon
4. Infrastructure and environment problems
   - 4.1. ____ Traffic control devices
   - 4.2. Roadway:
     - 4.2.1. ____ Alignment
     - 4.2.2. ____ Sight distances
     - 4.2.3. ____ Delineation
   - 4.3. ____ Weather and visibility

Driving performance problem

(check one)

1. Failure to perceive or perceive correctly:
   - 1.1. ____ In general
   - 1.2. ____ Due to distraction
   - 1.3. ____ Due to inattention
2. ____ Incorrect assumption
3. ____ Incorrect cognitive processing
4. ____ Failure to act
5. ____ Incorrect action

Figure 32. Principal contributing factors and driving performance problem checklist for use on accident report forms.

Note that a large amount of real estate would be required to include the full driver error taxonomy on the accident report form. By use of a coding manual or accident report overlay, the space required could be reduced, as shown in figure 33. This reduced area design also makes the cause/effect relationship between the two crash variables more explicit.

Principal contributing factors (up to 3)

1. Most important Code:________
2. Intermediate importance Code:________
3. Least important Code:________

These factors resulted in an:

Ultimate driving performance problem

Code:__________

Figure 33. Principal contributing factors and driving performance problem accident report box to be used with overlay or coding manual.

An example of a completed accident report form is shown in figure 34 for a case in which a tired driver purposefully ran a red light. The police officer determines that the most important principal contributing factor was running the red light (coded 3.1) and the second most important factor was the driver's fatigue (coded 2.1), resulting in an incorrect action (driving performance problem; coded 5).

Principal contributing factors (up to 3)

1. Most important Code: 3.1
2. Intermediate importance Code: 2.1
3. Least important Code: ________

These factors resulted in an:

Ultimate driving performance problem

Code: 5

Figure 34. Sample principal contributing factors and driving performance problem accident report boxes as used with overlay or coding manual.

The coding scheme used in this example is somewhat arbitrary and was designed to show the hierarchical relationship between several of the contributing factors and driving performance problems. Other coding schemes could also be used. Note that the real estate problem discussed earlier is not as crucial for accident reports filled out on a computer. However, until every officer in the field within a particular State has access to a portable computer, paper forms will continue to be used. Thus, these recommendations are applicable to paper forms. Although real estate is not as great an issue with computerized forms, care must also be taken to design computerized form entry that is both efficient and user friendly (i.e., avoid the temptation to require the officer to provide a multitude of new information in the PAR simply because the volume of information required is not as obvious in a computerized system).

4. Eliminate Re-Transcription

There are two keys to having the accident data as coded at the scene of the crash be the same information that is used in the higher level (State and national) databases. One key is to have uniformity of coding, as discussed in Recommendation 1. The second key is to have a greater degree of computerization of the PARs. With these two elements in place, the coding would be done at the level of the initial accident report when the information is likely to be most accurate. Little or no re-transcription or mapping would be necessary at higher levels. The investigating officer's input and coding would go directly into the State and national databases. Even with uniform coding and standard PARs, a national training effort would be required to ensure consistent, accurate data with similar coding interpretations across jurisdictions.

5. Solicit Officer Suggestions for Remedies to Infrastructure and Driver Problems

As discussed, officers are at the front line when it comes to crashes. They constantly drive the same streets, see near misses, experience near misses themselves, and investigate crashes. When their opinions are solicited in a focus group environment, officers demonstrate a wealth of good suggestions for dealing with infrastructure and driver problems. A formalized method of soliciting this feedback on a regular basis and finding ways to implement officer suggestions should prove valuable at both the local and State levels.

One possibility for soliciting this feedback would be to include space in the narrative crash description for officer-suggested solutions to the infrastructure and driver contributing factors noted in the principal contributing factor and driving performance problem area(s) of the form. Since this feedback would be most useful to local agencies and officials, providing it in the narrative portion of the PAR would be quite effective. The suggestions would be collected and reviewed several times a year, and local agencies would have this information at their disposal when making decisions concerning infrastructure changes. Suggestions for solutions to driver-related problems could be collected at the State level as feedback for legislative groups and State agencies considering regulatory changes. Officer input and suggestions should also be solicited when redesigning PARs.

Summary

Several problems with the current system of individual State PARs and State versus national coding systems have been identified. One of the major problems is that the same crash will often undergo several levels of transcription that can lead to errors of interpretation, especially in the mapping of one coding system onto another. The forms that are used are inconsistent across jurisdictions (usually States). The data lack a certain degree of precision desired by researchers who use the national and State databases. Finally, the reporting officer typically has a heavy workload, especially in regard to paperwork.

Recommendations for addressing these problems are as follows:

1. Develop a uniform coding scheme that will suit the needs of both the State and the national databases, keeping in mind that the use of codes raises human factors issues of accuracy, training, and legibility (for paper forms).
2. Make human factors improvements to existing forms and computer software.
3. Include error principal contributing factors and driving performance problems on the police accident reporting form.
4. Eliminate re-transcription.
5. Solicit officer suggestions for remedies to infrastructure and driver problems and for improvements to PARs.

If these recommendations are implemented in part or in full at either the State or national level, the result would be more accurate, more precise, and more useful crash data. It should be noted in conclusion that the United States is not alone in grappling with crash data collection and coding issues. Neilson and Condon (2000) came to very similar conclusions about the quality of accident data in the United Kingdom, and advocated somewhat similar changes to the accident data collection process.

PART II. USE OF DRIVER ERROR MODELS IN SIMULATION

Background

How the Driver Error Work Might be Used in Driver Simulation Models

One of the goals of the Driver Error project was to develop driver error models that could be integrated into simulations. Accordingly, a set of critical incident probability occurrence models was developed in Task E (Wierwille et al., 2000). This part of the report serves to highlight how the technique used to develop these probability models might be used for generating data for simulations.

In describing how the probability models might be used, two simulation programs are highlighted. The first is the IHSDM and the second is INTEGRATION, a traffic simulation model. A brief description of each is presented below.

Interactive Highway Safety Design Model (IHSDM)

The IHSDM is a software program being developed by the FHWA that will assist traffic engineers, roadway designers, and other transportation professionals to evaluate roadway designs in terms of safety. The IHSDM will operate within a Computer Aided Drafting and Design (CADD) environment and will enable the user to create or modify the design of a roadway segment.

Figure 35 provides a schematic of IHSDM (figure from Kantowitz, Levison, Hughes, Taori, Palmer, Dingus, Hanowski, Lee, Mears, and Williges, 1997). An overview of IHSDM is provided online at http://www.tfhrc.gov/safety/ihsdm/ihsdm.htm. This website states that the "IHSDM will be a suite of evaluation tools for assessing the safety impacts associated with geometric design decisions. IHSDM's evaluation capabilities will help planners and designers maximize the safety benefits of highway projects within the constraints of cost, environmental and other considerations. A small increase in the safety cost effectiveness of individual highway projects, when accumulated across the tens of billions of dollars invested in highway improvements each year, can contribute significantly to FHWA's strategic safety objective of 'reducing the number of highway-related fatalities and serious injuries by 20 percent in 10 years.'"

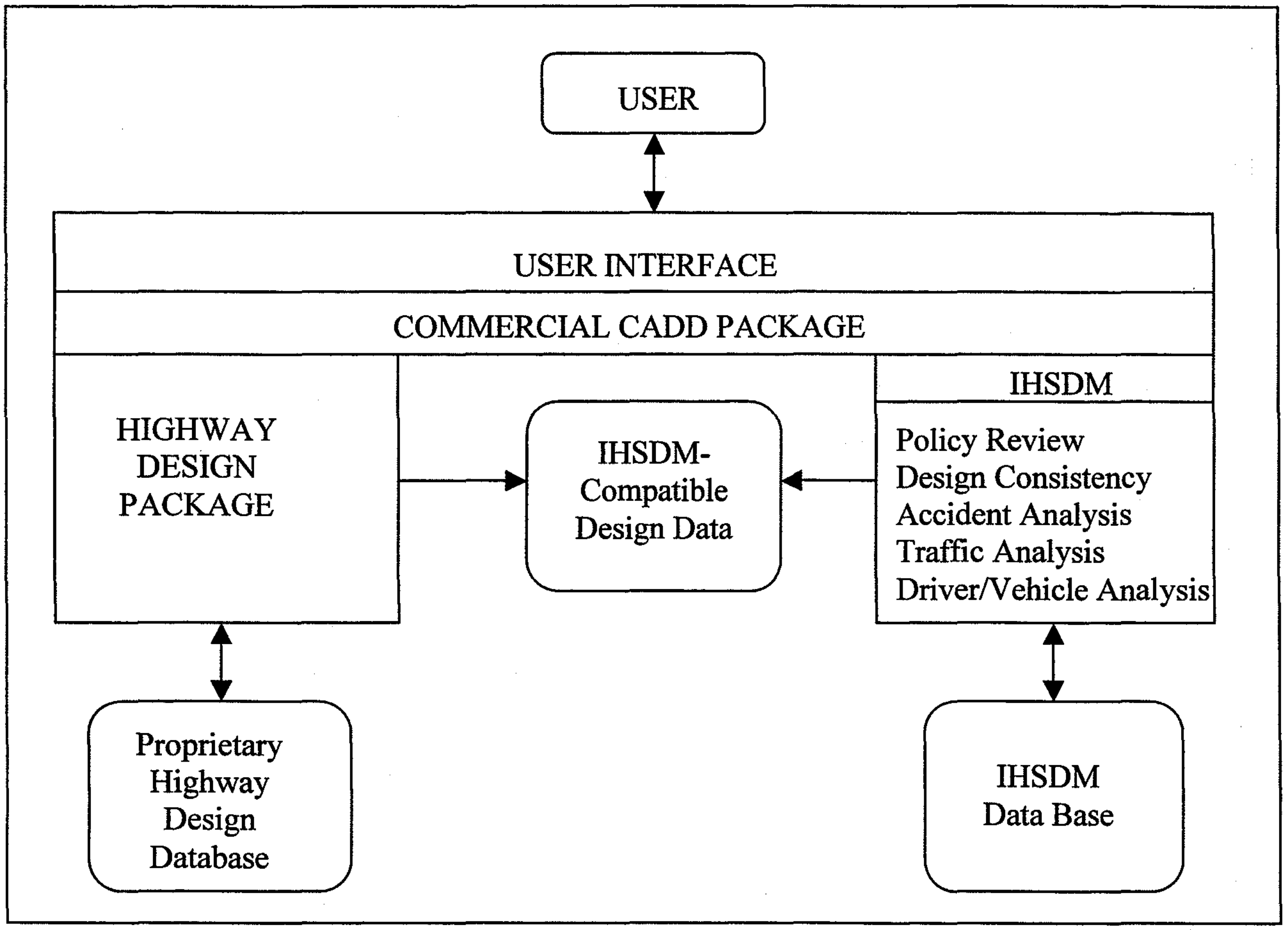


Figure 35. Schematic of IHSDM (from Kantowitz et al., 1997).

The probability models developed in Task E of the Driver Error project focus on "critical incidents" (i.e., near crashes) as a function of various infrastructure parameters. Probability models like these could be used in the IHSDM to determine the safety implications of particular geometric designs.

INTEGRATION Traffic Simulation Model

The INTEGRATION model is a trip-based "microscopic" traffic simulation model (e.g., Van Aerde and Rakha, 1999). The model is designed to trace individual vehicle movements (therefore, microscopic) from a vehicle's origin to its destination at a level of resolution of one status update every 1/10th of a second. The model provides a simulation framework in which a variety of traffic conditions can be tested. For example, Avgoustis (1999) developed a safety model that is used with INTEGRATION to test the benefits of traffic signal coordination. More specifically, this safety model uses regression coefficients based on data extracted from the GES database.

Briefly, the INTEGRATION simulation model has a number of development inputs that a user can control. For example, a user can specify "link" (i.e., roadway) characteristics such as number of lanes and roadway length, the presence of signals and signs, the signal timing plans (as in Avgoustis's [1999] safety model), the number/type of vehicles using the network, and incident descriptions. Once the parameters for the inputs have been specified, the simulation can be run. INTEGRATION provides a variety of outputs based on the input parameters. For example, summary data are generated that specify the number of vehicles in the network, the number of kilometers traveled, the number of wrong turns, the number of crashes, and the total delay time (note that these represent only a small sample of the set of outputs provided).

Probability models, like those developed for the current effort, could be used in INTEGRATION to explore the safety implications of various geometric designs (e.g., intersection configurations).

Application

The method of developing probability models from critical incident data was detailed earlier in this report (see Chapter VI). Though the probability values generated in this project may not themselves be appropriate for direct use in simulations, the technique used to generate these values can be of use to simulation programmers. Use of these techniques for the IHSDM and INTEGRATION are highlighted below.

Use in IHSDM

When complete, the IHSDM will consist of six analysis modules. Table 24 provides an overview of these modules.

Table 24. The six analysis modules to be included in the IHSDM.

Analysis Module	Overview
Crash Prediction Module	Will estimate the number and severity of crashes on specified roadway segments.
Design Consistency Module	Will provide information on the extent to which a roadway design conforms to drivers' expectations.
Driver/Vehicle Module	Will consist of a Driver Performance Model linked to a Vehicle Dynamics Model.
Intersection Diagnostic Review Module	Will use an expert system approach to evaluate intersection design alternatives.
Policy Review Module	Will verify compliance with highway design policies.
Traffic Analysis Module	Will use traffic simulation models to estimate the operational effects of road designs under current and projected traffic flows.

The crash probability models that were developed appear to be particularly relevant to the Crash Prediction Module. Referring to the IHSDM website, it is noted that "the Crash Prediction Module will estimate crash potential for a design alternative, including all roadway segments and intersections. Estimates will be quantitative and will include the number of crashes for a given roadway segment or intersection as well as the percentage of fatal and severe crashes. The module will allow the user to compare the number of crashes over a given time period for different design alternatives or perform sensitivity analyses on a single alternative (e.g., how is the frequency of crashes affected by lane/shoulder width, ADT and other important variables?)." Based on this description, it appears that crash probability models are needed for the Crash Prediction Module database. It is suggested that the technique used to generate the Driver Error models in the current project can be applied to developing models for IHSDM.

It should be stressed that the data collected for the current project were critical incidents and the locations where data were collected were "problem sites." Though crash estimates were made based on these data, it may not be appropriate to use the values themselves in IHSDM or INTEGRATION. However, the technique used to generate the values could be utilized with other data relevant to the particular application.

Use in INTEGRATION

In a manner similar to that used in IHSDM, it is suggested that the technique used to generate the crash probability models developed in the current project could be used for the INTEGRATION simulation. INTEGRATION allows a user to specify a variety of input parameters to develop a traffic network of interest. In this network building phase, parameters that match the infrastructures that were studied in the current effort (e.g., signalized complex intersection) could be specified. The safety model developed by Avgoustis (1999) explored the impact of traffic signal timing on crashes. The network input parameters specified the details of the traffic signals and their timing. Avgoustis conducted a search of the GES database to extract accident data. The data were used to develop regression coefficients that were tagged to the traffic signal/timing parameter. The approach is not unlike what might be accomplished using the crash probability models developed in the current project. That is, instead of traffic signal timing parameters, as studied by Avgoustis (1999), of interest would be geometric design parameters. And, instead of accident estimates derived from GES, probability models such as those using the technique developed here could be used. However, again, the caveat is put forth that the models developed in the current effort may not be suitable for directed use in INTEGRATION. However, the technique used to develop the models may be worthwhile. For example, critical incident data could be collected at a location that is representative of the design parameters being modeled. Crash estimates could be made based on the critical incident data, using the technique outlined, and appropriate probability models developed.

Summary

This part of the report has outlined how the technique used in developing model output from the driver error effort might be used in traffic simulations. Although the discussion in this section of the report focuses on the use of the developed crash probability models in IHSDM and INTEGRATION, it is suggested that the technique used in developing probability models could be adapted for use in other traffic simulations as well. It is likely that any simulation that allows the user to specify the geometric configuration of a roadway, and links this configuration to a crash probability model, would be a candidate.

PART III. CANDIDATE CHANGES FOR GUIDELINE DOCUMENTS

Background

Task F resulted in the identification and development of countermeasures for 43 infrastructure-related problems. In the majority of cases, the countermeasures developed were considered to be conventional and were already covered to some extent in standard reference materials such as MUTCD (FHWA, 2000) and the AASHTO (1994) policy guide. Thus, one of the major conclusions was that most of the infrastructure problems contributing to driver errors are a result of deviations from standard practice. Another finding was that virtually every problem site was unique. An effort was made to find common themes within the 43 problems and their countermeasures so that research recommendations might be drawn. Eight areas where future study are needed were developed:

- Visibility blockage caused by large vehicles,
- Pedestrian right-of-way violations,
- Left turns at signalized intersections,
- Right-of-way confusion at two-way stop-controlled intersection,
- Entrance and exit lane inadequacies,
- Private entrances and exits near intersections,
- Intersections in close proximity to one another, and
- Beginning and endpoint control of time-of-day directional lane usage.

The results suggest that direct development of candidate changes in standard reference materials would be premature. Either the countermeasures are already covered in reference materials or more research is required before specific recommendations can be provided. The findings of Task F left the research team in a dilemma. It would be difficult to supply candidate changes for reference materials, yet this is called for in the statement of work.

To develop possible candidate changes, the team re-examined all of the material generated during the project. Instead of looking only for formal graphical changes (that is, strictly infrastructure) the examination included concepts that might improve the reference documents by providing greater explanation or by sensitizing the user to issues that involve or contribute to human error.

This review yielded five areas where possible additions could be made to reference materials. These areas are the following:

- Generalization of the concept of human error to include the contributing factors taxonomy developed earlier,
- Visibility blockage by large vehicles,
- Stop bar placement to provide greater safety for pedestrians and to take other tradeoffs into account,
- Redundant regulatory signs emphasizing traffic conventions and rights-of-way (including pedestrian rights-of-way) at hazardous locations, and
- Specification of right of way at two-way stop signs.

These candidates are intended to improve or expand the perspective of the standard reference user and suggest consequences when certain designs are considered. They are presented in the following pages of this report. Each candidate statement has been written so that it can be directly inserted into the text. In other words, it is written in the style and format of the reference document.

Candidate Statements

Candidate 1.

To be considered for inclusion following the section on Error Due to Situation Demands, page 50, AASHTO policy guide. Earlier material in the section could be abridged because it is covered more comprehensively in this addition.

This addition is intended to provide a more general understanding of driver error by presenting the driver behavior taxonomy developed during the project. Such an addition provides a better understanding of the reasons for driver performance failures.

Candidate Statement:

Contributing Factors Taxonomy

A more comprehensive understanding of driver error may be obtained by generalizing the concept to include factors that contribute to driver performance failures. An approach that seems to work well is shown in figure 36. The fundamental concept underlying the taxonomy is that failures in driver performance, as shown on the right, are a result of a combination of contributing factors shown on the left. Four major categories of contributing factors have been identified. These are: 1) Inadequate knowledge, training, and skill, 2) Impairment, 3) Willful inappropriate behavior, and 4) Infrastructure and environment. These contributing factors help to explain in greater detail how mishaps occur. There may be one overriding factor in a given crash, or there may be more than one factor with each playing a role in the crash.

It should be the goal of the highway and traffic engineer to reduce the likelihood of or eliminate "infrastructure" as a contributing factor in crashes. Drivers should not be forced into situations that require them to make unsafe maneuvers or that cause confusion or that otherwise make safe driving difficult. Beyond this, the goal should be to make the driving environment as forgiving as possible so that when other contributing factors come into play, crash likelihood and severity are minimized.

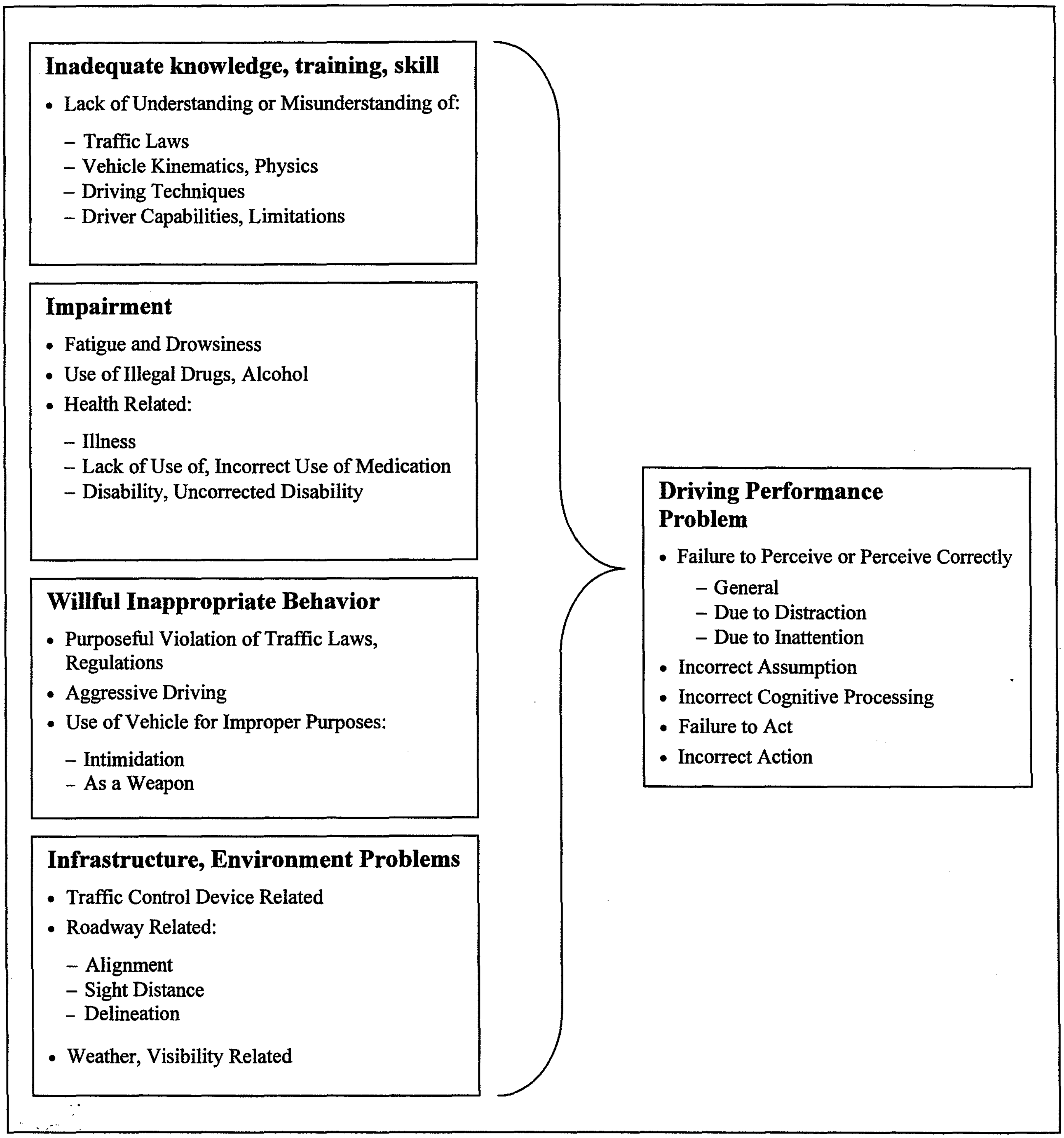


Figure 36. Taxonomy of contributing factors affecting driving performance.

Candidate 2.

To be considered for inclusion at the end of section 3B.16, Stop and Yield Lines, MUTCD.

This addition is intended to explain the complex tradeoffs that exist in stop bar (line) placement. In particular, the use of staggered stop bars for multiple lanes is introduced for the specific purpose of increasing the likelihood of detecting pedestrians in adjacent lanes of a multilane intersection. The general purpose is to ensure that the user of the manual does not place stop bars without full consideration of the consequences.

Candidate Statement:

At stop-controlled intersections in general, and specifically at two-way stop-controlled intersections, placement of stop bars should take into account multiple competing aspects. Sight distance of the intersecting roadway is one major consideration and pedestrian safety is another. If drivers are unable to see the cross traffic from the stop bar, they are forced to move past it before proceeding.

The decision regarding stop bar placement may represent a complex tradeoff of several factors including the following:

1. The need for visibility of cross traffic,
2. The avoidance of physical interference with cross traffic whether that traffic is turning or going straight,
3. The farther back a stop bar is placed, the greater is the gap required to safely enter and traverse the intersection,
4. Drivers may ignore stop bars that are placed too far back,
5. The requirement that pedestrians in crosswalks be visible from all stop bar lead vehicle positions (see sec. 3B.17), and
6. The requirement that lead vehicle positions must always be clear of crosswalks.

In some complex multilane intersections, the positions of the stop bars should change from lane to lane so that the considerations stated above may be optimized on a per lane basis. When there are vehicles in all other lanes, particular attention should be paid to ensuring sight distance of the crosswalk from every lead vehicle lane position. If possible, there should be no visual blockage of the crosswalk by adjacent vehicles.

Candidate 3.

To be considered for inclusion immediately following SIGHT DISTANCE, General Considerations section, page 696, AASHTO policy guide.

This addition is intended to caution the user of the problem of hidden vehicles, which is an important consideration in sight distance evaluation.

Candidate Statement:

The Hidden Vehicle Problem

In recent years there has been an increase in the disparity of vehicle sizes, owing to the popularity of vans, pickup trucks, and sport utility vehicles. Additionally, the numbers of local/short-haul and long-haul trucks have increased. In general, larger vehicles cause visual obstruction for drivers of smaller vehicles. It is not uncommon for a larger vehicle to completely obstruct the view of a smaller vehicle alongside, behind, or diagonally behind the larger vehicle. Certain relative velocities can make the detection of hidden vehicles impossible, even for alert and conscientious drivers.

In the evaluation of sight distances, account should be taken for the possibility of hidden vehicles when there are multiple lanes. In particular, drivers at two-way stop-controlled intersections and yield-controlled entrances into major roadways may have difficulty reacting to obstructed vehicles. To the extent that it is possible to do so, sight distance evaluation should take into account the hidden vehicle problem. Designs that ameliorate the problem are preferred. Such designs might include channelization, appropriate elevations to improve vantage points, and adjustment of approach angles. Where alignment and geometry do not provide adequate solutions, traffic signals may need to be included. Traffic signals have the advantage of ensuring unambiguous rights of way when the hidden vehicle problem cannot otherwise be solved.

Candidate 4.

To be considered for inclusion under Guidance in section 4C.01 of MUTCD. This candidate could be inserted between the second and third full paragraphs of page 4C-2.

This addition is intended to cover the hidden vehicle problem from the standpoint of replacing stop signs with a signal.

Candidate Statement:

Engineering judgment should also be used for intersections having multiple lanes or turning lanes. Drivers of vehicles on a minor intersecting roadway may be unable to view all lanes of the cross traffic because of vehicle obstruction. In recent years there has been an increase in the disparity of vehicle sizes, owing to the popularity of vans, pickup trucks, and sport utility vehicles. Additionally, the numbers of local/short-haul and long-haul trucks have increased. It is not uncommon for a larger vehicle to completely obstruct the view of a smaller vehicle alongside, behind, or diagonally behind the larger vehicle. Certain relative velocities can make the detection of hidden vehicles impossible, even for alert and conscientious drivers.

When hidden vehicle problems cannot be solved by other methods, a signal may have to be used. The signal has the advantage of ensuring unambiguous rights of way, whether or not all vehicles can be seen from the minor roadway.

Candidate 5.

To be considered for inclusion in section 2A.17, Overhead Sign Installations, MUTCD.

This addition is intended to make the user aware of situations where ground-mounted signs cannot be seen by drivers of smaller vehicles because of visual obstruction by larger vehicles. This problem is usually associated with multi-lane roadways having heavy traffic volumes.

Candidate Statement:

L. Visual Obstruction of Ground-Mounted Signs (caused by other vehicles)

(Note: because this candidate statement concerns ground-mounted signs, a suggestion is made that the statement be labeled as "L" to follow "K. Insufficient Space for Ground-Mounted Signs." If so, then the existing items L and M should be re-lettered as M and N.)

Candidate 6.

To be considered for inclusion at the end of section 2A.20, Position of Signs, MUTCD.

This addition is intended to inform the user of the possibility of sign visibility obstruction by larger vehicles.

Candidate Statement:

Regardless of the type of sign, consideration must be given to placement in such a way that visual blockage by intervening vehicles is minimized. In some cases, this may necessitate use of duplicate signs on opposite sides of the lanes or the use of overhead signs.

Candidate 7.

To be considered for inclusion under Regulatory Signs as section 2B.51 of MUTCD. The existing section 2B.51 would become 2B.52.

This addition is intended to indicate to the user that it may be necessary to remind drivers of existing traffic law and conventions. Drivers may sometimes disregard a known law or they may not know/remember the law. When consequences can be severe, such regulatory signs are appropriate.

Candidate Statement:

2B.51 Redundant Regulatory Signs Emphasizing Traffic Conventions and Rights-of-Way

With increased congestion has come the problem of increased violation of traffic laws and rights-of-way. These seem to occur for two reasons: willful inappropriate behavior and lack of knowledge on the part of drivers. In some cases, such violations can lead to collisions with other vehicles, pedestrians, or cyclists. Strictly speaking, warning signs should not be necessary when all other conventions of design are appropriately affected. Ordinarily, it can be assumed that drivers are properly trained and act within the law. However, there may be locations where it is desirable to warn drivers of the law. These warnings are intended to remind drivers and thus reduce the likelihood of collisions.

Examples of such warnings may include the following:

- Yield to pedestrians in crosswalks,
- Pedestrians have the right-of-way over turning traffic,
- Yield on green (ball)
  (for use with left turning traffic; see sign R10-12),
- No left turn from right lane
  (as also indicated by lane marking arrows or lane arrow signs), and
- Stop here on Red
  (to emphasize stopping at the stop bar; see sign R10-6).

These signs serve as a form of redundancy. They should be used sparingly to avoid clutter, but serve an important purpose when violations result in a high likelihood of a collision.

Candidate 8.

To be considered for inclusion between the first and second paragraphs of section 2B.51, Other Regulatory Signs, MUTCD. The intent is to inform the user of the problem at two-way stop-controlled intersections in which it is not clear which of the two vehicles on opposite sides at the two stop signs has the right-of-way.

Candidate Statement:

As an example of a warning sign that may be necessary, but is not specified in this manual, consider a two-way stop-controlled intersection. A vehicle approaches the stop sign in one direction and another vehicle approaches the stop sign on the other side coming from the opposite direction. If one vehicle intends to turn left and the other intends to go straight, a dilemma can occur. If the left-turning vehicle has arrived somewhat before the vehicle going straight, it is not clear who has the right-of-way. This type of situation can be resolved by a warning sign establishing a convention. Suggested warning sign: "Arrive at same time? Left turn yield to oncoming traffic." It could be posted below the stop sign on each side of the intersection. This example serves to illustrate the unusual circumstances under which an unconventional warning sign may be needed.

CHAPTER IX. SUMMARY OF PROJECT RESULTS

As can be seen, substantial work was undertaken to investigate, identify, and evaluate driver errors. The following provides a brief summary of the project results.

DEVELOPMENT OF A CONTRIBUTING FACTORS TAXONOMY

A new taxonomy of contributing factors was developed during the course of the current project. This taxonomy is presented in figure 36. One of the innovative features of this taxonomy is that it focuses on the causes of driver error. It provides an explanation of not only *what* happened, but *why* it happened. Many of the taxonomies outlined in the literature fail to promote an understanding of why an accident occurred. A second feature of this taxonomy is that it allows for a blending and ranking of factors. That is, an understanding can be gained with regard to multiple factors involved in the accident, and the relative importance of these factors. Finally, the taxonomy allows for the selection of a principal contributing factor, or the one factor that was most critical to the incident/crash occurrence. It should be noted that this taxonomy could be modified as needed. However, it was found that the taxonomy works well and is effective in its present state.

BENEFITS OF TREE DIAGRAMS

Tree diagrams were found to be very useful and effective tools for viewing incident/accident data and for structuring crash causal factors. Perhaps the most important feature of the tree diagram is that it provides an approach whereby the data can "drive" the structure. That is, the structure of the diagram can be set dependent on the detail available in an accident report/narrative. For example, both accident reports with minimal detail and accident narratives with a rich amount of detail can be accommodated. An example of this was presented earlier in figures 20 and 24. In the example shown in figure 20, the tree diagram can be used to identify what happened in the crash. Figure 24 illustrates that, with a detailed accident narrative, the researcher can explore more deeply why the crash occurred. As the data permit, the structure can be expanded and the errors characterized in greater detail. Completed tree diagrams can be considered taxonomies.

A final point on tree diagrams should be made with regard to histograms as a tool for plotting tree diagram data. As shown with the tree diagram/taxonomy examples presented previously, histograms can be used to display frequency data for a level of a tree diagram. An example of this approach is shown in figure 21.

IMPROVING ACCIDENT REPORT FORMS AND CODING SYSTEMS

One of the project goals was to make recommendations for improving the accident report forms that are completed by investigating police officers. Any given crash report may undergo several levels of transcription, each of which may result in errors. In addition, the forms are inconsistent across jurisdictions. The data recorded on the forms often lack the precision desired by researchers. To remedy these problems, a number of recommendations were made:

- Develop a uniform coding scheme that will suit the needs of both the State and the national databases.
- Make human factors improvements to existing forms and computer software.
- Include principal contributing factors and driver performance errors on the form.
- Eliminate re-transcription.
- Solicit officer suggestions for remedies to infrastructure and driver problems and for improvements to the accident reporting forms.

It is suggested that these recommendations would result in more accurate, more precise, and more useful crash data.

RECOMMENDED SITE EVALUATION METHODOLOGY

One of the goals of this project was to develop a protocol for determining solutions to site problems. The methodology that was developed was a variation and refinement of the Traffic Conflict Technique (TCT) method that had been developed previously. Briefly, the steps of the Site Evaluation Methodology that was developed consisted of:

1. Site Survey
2. Site Drive-Through
3. Site Diagram and Description
4. Videotape Surveillance
5. Data Collection
6. Data Reduction and Extraction

7. Incident Cluster Identification
8. Additional Analyses

By completing this protocol, it is suggested that traffic engineers would develop a clear understanding of the contributing factors associated with accidents/incidents, driver errors, and the relationship between driver errors and the infrastructure. Ultimately, this information could serve to aid in the development of countermeasures.

DEVELOPMENT OF IMPROVED SCALE FOR GRADING TRAFFIC EVENT SEVERITY

As outlined in table 11, a Traffic Event Rating Scale was developed. This scale represents an improvement over previously developed scales for grading the severity of traffic events. Perhaps the primary improvement over previous scales is that the scale is capable of differentiating crashes from critical incidents from lesser events. The new scale has several levels within each grade, which results in an 8-point scale. This scale was found to work well for site surveillance and allows for substantial discrimination for assessing the severity of various types of events.

DEVELOPMENT OF PROBABILITY MODELS FOR INCIDENTS AND CRASHES

Probability models were developed for both incidents and accidents. An interesting aspect of the probability models is that they follow a tree-structure form and result in summable taxonomies. This approach allows researchers working with simulations the flexibility to input data as a function of any of several levels of the taxonomy.

CLUSTERING AS A MEANS OF IDENTIFYING INFRASTRUCTURE PROBLEMS

An approach to identifying infrastructure problems was developed that involved identifying clusters of incidents. The premise of this approach is that clusters of incidents point to "troubled" areas within a site. Examination of the clusters may suggest infrastructure-related countermeasures to problems that might not, at first glance, appear to be related to the infrastructure.

THE IMPORTANCE OF FOLLOWING STANDARD PRACTICE

The primary reason for most of the errors involving infrastructure is the failure to follow the standard roadway design practices described in MUTCD (FHWA, 2000) and the AASHTO policy guide (1994). The primary finding from the site surveillance and countermeasure development effort was that following standard practice is important and that the failure to follow standards seems to be directly linked to incidents and crashes.

RECOMMENDED RESEARCH

Eight areas for future research were recommended:

1. Larger Vehicle Visibility Blockage Problem
2. Pedestrian Right-of-Way Violations
3. Left Turns at Signalized Intersections
4. Right-of-Way Confusion at Two-Way Stop-Controlled Intersection
5. Entrance and Exit Lane Inadequacies
6. Private Entrances and Exits Near Intersections
7. Intersections in Close Proximity to One Another
8. Beginning and Endpoint Control of Time-Of-Day Directional Lane Usage

RECOMMENDED CHANGES IN REFERENCE DOCUMENTS

In Chapter VIII, eight candidate changes were recommended for the AASHTO (1994) and MUTCD (FHWA, 2000) reference documents. For details of these changes, the reader should refer to the Chapter VIII text. Note that these eight candidate changes were related to five general areas (themes) that resulted from a careful review of the infrastructure-related driver errors that were captured in the site surveillance. As a review, the candidate changes involved the following areas:

- Generalization of the concept of human error to include the contributing factors taxonomy developed earlier,
- Visibility blockage by large vehicles,
- Stop bar placement to provide greater safety for pedestrians and to take other tradeoffs into account,

- Redundant regulatory signs emphasizing traffic conventions and rights-of-way (including pedestrian rights-of-way) at hazardous locations, and
- Specification of right of way at two-way stop signs.

SUMMARY STATEMENT

The work conducted in this project has resulted in a substantially better understanding of driver error, particularly with regard to contributing factors. For example, it was determined that it is necessary to generalize the concept of driver error to include factors such as "willful inappropriate behavior." This is an important and innovative conclusion since, as in other taxonomies, willful inappropriate behavior is considered an intended action and does not strictly fall within the concept of error. The research presented here has shown that willful inappropriate behavior is a factor in many errors.

It is important to highlight that the work that was conducted resulted in improved methods of data gathering, analysis, and classification. Newly developed taxonomies that used a tree diagram approach proved to be very useful in classifying the data collected in the site surveillance phase of the project.

Finally, one of the goals of this effort was to end up with results that are flexible, can be adapted to fit multiple situations, and are widely applicable. It is believed that this was accomplished. This goal can be represented by highlighting the newly developed contributing factors taxonomy that can be adjusted, modified, or further detailed, depending on the data and the researcher's needs. In addition, the tree structure approach to data classification was shown to be widely applicable using various database sources. As such, it is believed that the results of this research will be beneficial to a wide range of researchers in the transportation community.

REFERENCES

Almqvist, S., and Hyden, C. (1994a). Methods for assessing traffic safety in developing countries. *Building Issues 6*(1), 1-20.

Almqvist, S., and Hyden, C. (1994b). *Traffic safety assessment based on traffic conflicts: Field study in Kingston, Jamaica* (Technical Report, CODEN LUTVDC/[TVTT-7136]1-53). Lund, Sweden: Lund University, Department of Traffic Planning and Engineering.

American Association of State Highway and Transportation Officials (AASHTO). (1994) *A policy on geometric design of highways and streets; 1994*. Washington, D.C.: American Association of State Highway and Transportation Officials.

Avgoustis, A. A. (1999). Quantifying the safety impacts of intelligent transportation systems. Unpublished master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Ball, K., and Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors 33*(5), 583-595.

Chapanis, A. (1959). *Research techniques in human engineering*. Baltimore, MD: Johns Hopkins Press.

Dingus, T. A., Hetrick, S., and Mollenhauer, M. (1999). Empirical methods in support of crash avoidance model building and benefits estimation. *ITS Journal 5*, 93-125.

Dingus, T., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleischman, R. (June 1995). *TravTek evaluation task C3 camera car study*. Publ. No. FHWA-RD-94-076. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Edwards, D. S., and Hahn, C. P. (1980). A chance to happen. *Journal of Safety Research 12*(2), 59-67.

Federal Highway Administration (2000). *Manual on Uniform Traffic Control Devices (MUTCD)*. Washington, D.C.: Federal Highway Administration.

Garber, J. N., and Patel, S. T. (September, 1994). *Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones* (Report Number FHWA/VA-95-R4). Virginia Transportation Research Council for the Virginia Department of Transportation. Richmond, VA. Available on-line at http://www.bts.gov/ntl/DOCS/EC.html.

Guzzo, M. (2000). Calling all cars: Car phone users can't forget common sense rules of the road. Found online at *Bizjournals.com/Pittsburgh.* Accessed January 4, 2001 at http://www.bizjournals.com/pittsburgh/stories/2000/11/06/focus2.html.

Hankey, J. M., Wierwille, W. W., Cannell, W. J., Kieliszewski, C. A., Medina, A., Dingus, T. A., and Cooper, L. M. (1999). *Identification and evaluation of driver errors: Task C report; Driver error taxonomy development.* (Contract No. DTFH61-97-C-00051). Washington, DC: Federal Highway Administration.

Heinrich, H. W., Peterson, D., and Roos, N. (1980). *Industrial accident prevention.* New York: McGraw Hill.

Hollnagel, E. (1993). The phenotype of erroneous actions. *International Journal of Man-Machine Studies 38*, 1-32.

Indiana University Institute for Research in Public Safety (1977). *Tri-level study of the causes of traffic accidents* (Report No. DOT-HS-034-3-535). Springfield, VA: National Technical Information Service (Accession No. SRIS-750247R).

Kantowitz, B. H., Levison, W. H., Hughes, W., Taori, S., Palmer, J., Dingus, T. A., Hanowski, R., Lee, J. D., Mears, B., and Williges, R. (October 1, 1997). *Development of prototype driver models for highway design: Task A final project I work plan.* (DTFH61-96-R-00065). Seattle, WA: Battelle.

Miami Herald (2001). Cellphones to appear on car crash reports. AP byline. Published Thursday, January 4, 2001.

National Highway Transportation Safety Administration (NHTSA) (1998). *General Estimates System Coding Manual, 1998.* Washington, D.C.: National Highway Traffic Safety Administration.

Neilson, I., and Condon, R. (2000). Desirable improvements in road accident and related data. *PACTS Research Paper 1.* London, UK: Parliamentary Advisory Council for Transport Safety.

Norman, D. A. (1988). *The design of everyday things*. New York: Doubleday Currency.

Older, S.J., and Spicer, B.R. (1976). Traffic conflict—A development in accident research. *Human Factors 18*(4), 335-349.

Parker, M. R., Jr., and Zegeer, C. V. (January, 1989a). *Traffic conflict techniques for safety and operations; Engineers Guide.* Report No. FHWA-IP-88-026. McLean, VA: Federal Highway Administration.

Parker, M. R., Jr., and Zegeer, C. V. (January, 1989b). *Traffic conflict techniques for safety and operations; Observers Manual.* Report No. FHWA-IP-88-027. McLean, VA: Federal Highway Administration.

Rasmussen, J. (1980). What can be learned from human error reports? In K. D. Duncan, M. M. Gruneberg, and D. Wallis (Eds.), *Changes in working life* (pp. 97-113). New York: John Wiley and Sons.

Rasmussen, J. (1986). *Information processing and human machine interaction.* Amsterdam, Netherlands: North Holland Press.

Rasmussen, J., Pejtersen, A. M., and Goodstein, L. P. (1994). *Cognitive systems engineering.* New York: John Wiley and Sons.

Reason, J. T. (1990). *Human error.* New York: Cambridge University Press.

Roess, R. P., McShane, W. R., and Prassas, E. S. (1998). *Traffic engineering, second edition* (pp. 137-138). Upper Saddle River, NJ: Prentice Hall.

Rouse, W. B., and Rouse, S. H. (1983). Analysis and classification of human error. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-13*(4), 539-549.

Sabey, B. (1980). *Road Safety and Value of Money.* TRRL Supplementary Report SR 581, Transportation Research Board, UK.

Sanders, M. S., and McCormick, E. J. (1987). *Human factors in engineering design.* New York: McGraw-Hill Publishing Company.

Senders, J. W., and Moray, N. P. (1991). *Human error: Causes, prediction, and reduction.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Sheridan, T. B. (1981). Understanding human error and aiding human diagnostic behavior in nuclear power plants. In G. Salvendy (Ed.), *Human detection and diagnosis of system failures.* New York: Planum Press.

Svensson, A. (1998). *A method for analysing the traffic process in a safety perspective* (Doctoral Dissertation, CODEN LUTVDG/TVT-1018-174/1998). Lund, Sweden: Lund University, Department of Traffic Planning and Engineering.

Tijerina, L. (1996). A taxonomic analysis of crash contributing factors and prospects for ITS crash countermeasures. *Proceedings of the ITS America International Conference*. 185-193. Washington, D.C.: ITS America.

Treat, J. R. (1980). A study of precrash factors involved in traffic accidents. *The HSRI Research Review 10*(6)-*11*(1). Ann Arbor, MI: University of Michigan, Highway Safety Research Institute.

U.S. Dept. of Transportation, Federal Highway Administration (1988). *Manual of uniform traffic control devices for streets and highways; 1988 edition.* Washington, D.C.: U.S. Government Printing Office.

U.S. Dept. of Transportation, Federal Highway Administration (December, 2000). *Manual on uniform traffic control devices; Millennium edition.* Available on-line at http://mutcd.fhwa.dot.gov/kno-millennium.htm.

Van Aerd, M., and Rakha, H. (1999). Microsimulation of traffic with and without adaptive cruise control: Model logic. *Proceedings of the 1999 Annual Meeting of ITS America.* Washington, D.C.: ITS America.

Virginia Department of Transportation, (1996a). *HTRIS—Accident subsystem: Section critical rate report* (Report ID TAN8635-01). Available from Virginia Department of Transportation, 1401 East Broad Street, Richmond, VA 23219.

Virginia Department of Transportation, (1996b). *Intersection critical rate report.* Available from Virginia Department of Transportation, 1401 East Broad Street, Richmond, VA 23219.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd edition). New York: Harper Collins Publishers.

Wiegmann, D. A., and Shappell, S. A. (1997). *Workshop 6: A human factors approach to accident investigation.* Document presented at the 41st Annual Meeting of the Human Factors and Ergonomics Society.

Wierwille, W. W., Hanowski, R. J., Hellinga, B., Early, N., Kieliszewski, C., and Dingus, T. A. (1998). *Identification and evaluation of driver errors: Task A report; Information gathering in support of taxonomy development.* (Contract No. DTFH61-97-C-00051). Blacksburg, VA: Virginia Tech Transportation Institute.

Wierwille, W. W., Hanowski, R. J., Kieliszewski, C., and Medina, A. (2000). *Identification and evaluation of driver errors: Task F report; Development of infrastructure-related countermeasures for driver errors.* (Contract No. DTFH61-97-C-00051). Blacksburg, VA: Virginia Tech Transportation Institute.

Wierwille, W. W., Kieliszewski, C. A., Hanowski, R. J., Keisler, A. S., and Olsen, E. V. B. (July 2000). *Identification and evaluation of driver errors: Task E report, investigation of critical incidents.* Contract No. DTFH61-97-C-00051. Blacksburg, VA: Virginia Tech Transportation Institute.

Wierwille, W. W., and Tijerina, L. (1996). An analysis of driving accident narratives as a means of determining problems caused by in-vehicle visual allocation and visual workload. In A. G. Gale (Ed.), *Vision in vehicles - V* (pp. 70-86). Amsterdam, Netherlands: Elsevier Science Publishers.

APPENDIX A: REVIEW OF THE CRASH DATABASE ANALYSIS CONDUCTED IN SUPPORT OF TAXONOMY DEVELOPMENT

OVERVIEW

One primary goal of this project was to determine the way in which driver error impacts motor vehicle crashes. To achieve this goal, several crash taxonomies of driver error were developed. Several analytical approaches were used to develop these taxonomies. The analytical approach described in this section used data from Motor Vehicle Accident (MVA) databases.

As detailed in the Task C report for this project (Hankey, et al., 1999), MVA databases at both the national and State levels were analyzed to obtain a better understanding of driver error. The driver error data in these databases are usually based on the written report of a police officer at a crash scene, or on post-accident interviews of the drivers conducted by crash investigators. It was anticipated that the abundance of data contained in MVA databases would provide a foundation for the development of candidate taxonomies.

Two types of database search studies were conducted. The first type involved traditional accident database analysis. The second type analyzed a database that allows a keyword search of accident narratives. Before outlining the results of each of these studies, a brief description of each type of database (i.e., traditional and narrative) is presented.

NATURE OF TRADITIONAL CRASH DATABASES

To name only a few, traditional crash databases include the Fatality Analysis Reporting System (FARS), the Highway Safety Information System (HSIS), and the State Data Program (SDP). There are several characteristics of "traditional" databases:

- The traditional databases consist of data fields. The data fields may be searched for keywords, for example, crash types of interest.
- Traditional databases are very useful when appropriate fields are available. Not surprisingly, the success of a traditional database search hinges on selecting the appropriate keywords that allow the crash events of interest to be identified.
- By using the appropriate set of keywords, an analyst can identify crashes that fit keyword combinations. That is, by using keyword combinations, through Boolean logic, the

analyst can identify crashes that meet specific characteristics of interest (i.e., "rear-end" and "inattentive").

- Traditional databases allow for the determination of both relative distributions and values of occurrences. For example, an analyst can determine not only how the frequency of rear-end crashes has varied over the last 5 years (relative distribution), but also how many rear-end crashes there were in a specific year (absolute value).
- These databases do not generally permit highly detailed analyses to be conducted. The reason for this is that the data field structure (which uses pre-defined categories) and the minimal amount of qualifying information restrict the analyst from determining the underlying detailed factors involved in a crash. For example, an analyst may be interested in determining the details of cell-phone-related crashes. A traditional database would allow the analyst to determine the extent of the problem, whereby the analyst could enter "cell-phone" in a keyword search. However, the details of the crash set (such as whether the driver was talking, dialing, listening, or picking up the phone) may not be so easily determined.

NARRATIVE SEARCH APPROACH

What might be considered a "non-traditional" database search approach involves using narratives. Narratives are detailed, free-form descriptions of crashes that are written by investigating officers. These are included in most accident reporting forms, but must be coded (entered) into a database to be useful for narrative searches. The following are some of the features of the narrative search approach:

- It allows for a search using a keyword, as in traditional databases, when narratives are coded. Similarly, as in traditional database searches, narrative searches can be conducted using a uniform sampling strategy.
- Narrative searches allow for both relative distributions and absolute values, just as in a traditional database search. However, unlike a traditional approach, narrative searches can focus on more specific targets that are not included in the pre-defined categories.
- As discussed in Wierwille and Tijerina (1996), narrative searches can be combined with tree diagrams. The benefit of using tree diagrams is that they allow for a great amount of

detail when conducting an analysis. The amount of detail that can be achieved goes far beyond distributions (the limit for traditional database analysis).

- A narrative search using keywords produces a "directed search" on certain objectives. Using the cell-phone crash example outlined previously, narrative searches, as compared with searches of traditional databases, would more easily allow the analyst to determine the details of the crash such as the task the driver was engaged in during the crash (e.g., talking, listening).

The next section highlights some of the findings from the database studies that were conducted. First, the focus will be on the traditional database analyses that were conducted using the Pennsylvania State database and the FARS. This is followed by a discussion of two database analyses using the North Carolina State database; one analysis used the narrative (non-traditional) approach and the other used a traditional approach via the HSIS database.

HIGHLIGHTS OF RESULTS ASSOCIATED WITH DRIVER ERRORS

Only the highlights of the results from the database analyses are presented in this final report. The reader is directed to the Task C report (Hankey et al., 1999) for detailed analysis information including all results.

1. Traditional Database Analysis with Emphasis on Driver Error

Figure A1 provides an overview of the database analyses that were conducted using the traditional approach. At the highest level shown in figure A1, the databases are divided into (1) SDP databases and (2) national databases. Five SDP databases were analyzed: (1) California (CA), (2) Kansas (KS), (3) Maryland (MD), (4) Ohio (OH), and (5) Pennsylvania (PA). For the national databases, three databases were analyzed: (1) FARS, (2) National Automotive Sampling System/General Estimates System, NASS/GES, and (3) National Automotive Sampling System/Crashworthiness Data System, NASS/CDS. Based on the analysis of the five SDP databases and the three national databases, it was determined that the PA database (SDP) and the FARS database (national) provided the best information on driver errors and other contributing factors. The next section highlights the findings from the PA database analysis and the FARS database analysis.

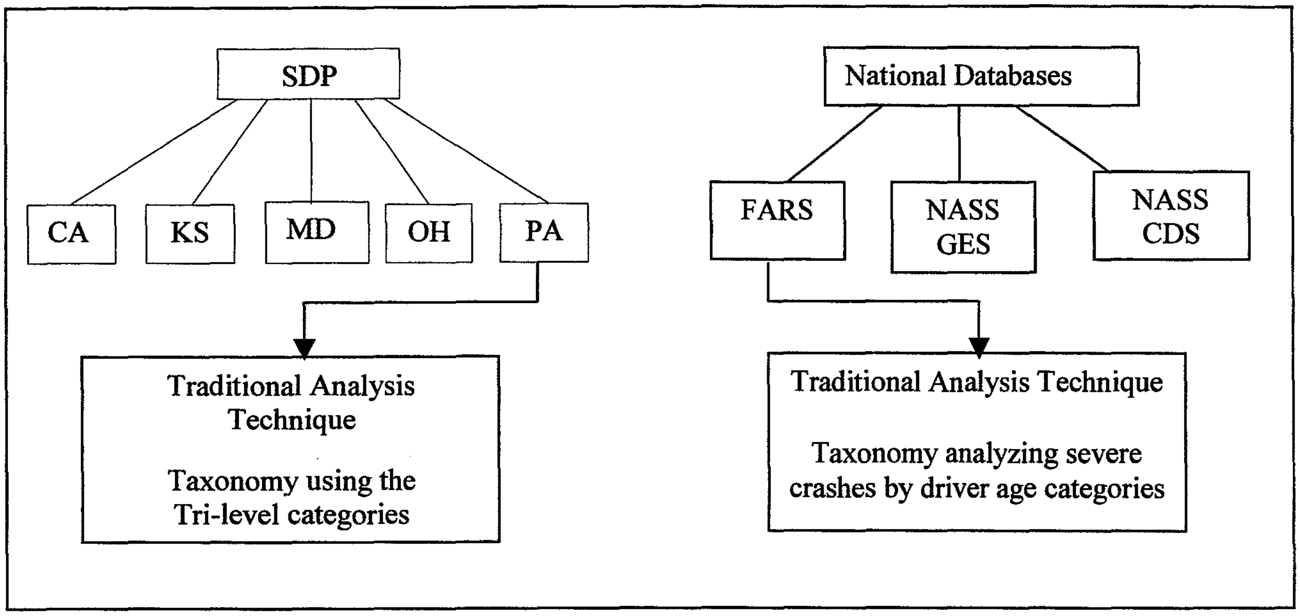


Figure A1. SDP and national database analyses overview.

1A. Pennsylvania Database Analysis

In conducting the database analysis with the Pennsylvania (PA) database, one of the objectives was to determine the contributing factors that should be considered "driver error" and which of these factors, can be significantly impacted by infrastructure. A second objective of this analysis was to determine what driver errors and contributing factors accounted for most of the crashes recorded in the database.

To meet these objectives, the 1995 and 1996 PA databases were combined and analyzed. The analysis approach was to use the "contributing factor" (CF) field listed in the database. As shown in table A1, data from a total of 279,730 crashes were collected in PA in 1995 and 1996. For these crashes, 431,004 occurrences of contributing factors were included in the database records. (Note that there could be multiple contributing factors for a given crash.) A one-way frequency analysis was conducted on these 431,004 occurrences for 170 possible contributing factors in the CF field. Examples of some factors that could be classified as driver error are shown in table A2. It should be noted that multiple cross tab analyses (to examine the interaction between field categories) were done between the CF field and infrastructure fields. These included intersection type, roadway type, and traffic control device (TCD). Unfortunately, these analyses did not yield any more information than could be derived from the one-way frequency analysis. The next section highlights a sample of the taxonomies that were developed based on the PA database analysis results.

Table A1. Number of crashes and contributing factors in the SDP PA database for 1995 and 1996.

Year	Accidents (Crashes)	Contributing Factors
1995	136,835	213,672
1996	142,895	217,332
Total	279,730	431,004

Table A2. Examples of possible factors in the CF field in the SDP PA database for 1995 and 1996.

Categories	
On-road distraction	Off-road distraction
Inside distraction - event in car	Adjusting radio, tape, or CD player
Adjusting vent, window, heater, etc.	Conversation with passenger
Using cellular phone	Other distraction (day-dreaming, etc.)
Assumed other driver had stop/yield sign	Assumed other driver would stop/yield
Assumed oncoming would move out of way	Assumed other vehicle was going to turn
Assumed there was no traffic on roadway	Assumed vehicle would fit under overpass
Other false assumption	Illegal U-turn
Illegal/careless right turn on red	Improper/careless turning
Improper or no signals while turning	Turned from wrong lane or position
Went straight ahead instead of turning	Failure to respond to flashing signal
Failure to respond to yield sign	Fail to respond to RR crossing controls
Fail to respond to officer, flag person	Failure to respond to school zone signal
Failure to respond to emergency vehicle	Failure to respond to other/unknown TCD
Ran red light trying to beat yellow	Ran red light/didn't see the signal
Ran red light/did not see change to red	Anticipated green light before change
Ran red light because brakes failed	Ran red light for other reasons
Ran red light for unknown reasons	Proceeding without clearance
Did not see stop sign	Did not stop, slowed down
Could not stop - no brakes	Did not/could not stop for other reasons
Did not stop for unknown reasons	Reacting to rock on the roadway
Reacting to tire recap on roadway	Reacting to dead animal on roadway
Reacting to spilled cargo from truck	Reacting to other obstacles on roadway
Tailgating	Failure to heed stopped school bus
Failure to heed pedestrian on roadway	Failure to heed stopped vehicle
Sudden slowing or stopping	Illegally stopped on roadway
Careless passing	Careless lane change
Passing in a no passing zone	Driving the wrong way on a one-way roadway
Careless or illegal backing on roadway	Driving on the wrong side of roadway
Driving in two lanes (same direction)	Making improper entrance to highway
Making an improper exit from highway	Careless parking/"un-parking" maneuver
Improper use of lights	Driving too close to center line
Cresting hills at center of roadway	Braking late at improper location
Over/under compensation at curve	Excessive acceleration
Other improper driving techniques	Over posted speed limit
Too fast for conditions - roadway design	Too fast for conditions (traffic, peds, etc.)

Taxonomy Development Using the Pennsylvania Database

The causal factors and subcategories used in the Indiana Tri-level Study (1977) were used as a framework for developing a taxonomy of the contributing factors in the CF field in the PA database. A sample of the operational definitions of the causal factors and subcategories used in the Indiana Tri-level Study is found in table A3; the complete set of operational definitions appears in Appendix 1 of the Task C report (Hankey et al., 1999). In many cases, the possible contributing factors matched the categories identified in the Indiana Tri-level Study. However, in other cases, it was difficult to place some of the factors within these categories using their operational definitions. For example, "Excessive speed" and "False assumption" can easily be distinguished from one another and the other decision error categories, while "Improper maneuver" and "Improper driving practice or technique" cannot be as easily distinguished from one another. The Indiana Tri-level Study authors stated that an improper maneuver applies "whenever a driver willfully chooses a vehicle path which is wrong..." and an improper driving technique or practice occurs "when a driver engages in the improper control of path or speed, in a manner that unduly increases the risk of an accident and involves practices which are (or might be) habitual to a particular driver..." The authors believe that the key difference between these categories is the driver's recognition of the risk (1977). For example, a driver making a right-hand turn from the left lane is taking a willful risk and as such is making an improper maneuver. A driver who rolls too far out into an intersection when waiting for a red light to turn green is using an improper driving technique. For some contributing factors, the distinction between these two groups was difficult to discern. However, the Indiana Tri-level Study operational definitions and the driver's understanding of the risk were used to determine how each factor was categorized. Note that some of the Indiana Tri-level Study category names were modified or new names were developed to provide better descriptions of the underlying contributing factor.

The next section provides a sample of some of the taxonomies (or distributions) that resulted from the PA database analysis. The sample results shown have been selected to highlight the "Driver error" and "Infrastructure" categories that are related to motor vehicle crashes.

Table A3. Sample of error operational definitions from the Indiana University Institute for Research in Public Safety, 1977, pp. 201-233.

Error Type	Operational Definition
Human Direct Causes	Refers to all human acts and failures to act in the minutes immediately preceding an accident, which increase the risk of collision beyond that which would have existed for a conscious driver driving at a reasonable standard of good defensive driving. Causes include recognition errors, decision errors, and performance errors.
Recognition Errors	Includes all situations where a conscious driver does not properly perceive, comprehend, and/or react to a situation requiring adjustment of speed or path of travel for safe completion of the driving task. Categories include: failure to observe, inattention, internal distraction, external distraction, inadequate or improper lookout, and other delays in recognition for other or unknown reasons.
Failure to Observe	Applies whenever a conscious driver for any reason fails to notice a sign that should have been visible to him/her, and as a result is involved in an incident.
Inattention	Applies when a driver has chosen to direct his/her attention elsewhere for some non-compelling reason. The category thus denotes an unnecessary wandering of the mind, or a state of being engrossed in thought in matters not of immediate importance to the driving task (preoccupation).
Excessive speed	Applies when a driver excessively increases the risk of a traffic incident by choosing to travel at too great a speed. Excessive speed is a speed greater than a person driving at a high but reasonable standard of good defensive driving practice would choose to travel under existing conditions, which is not necessarily the posted speed limit.
Inadequate or Improper Lookout	Applies whenever a driver is delayed in his/her recognition of information needed to safely accomplish the driving task because he/she encountered a situation requiring a distinct visual surveillance activity (for safe completion of the driving task). However, the driver either did not look, or did look but did so inadequately, and included are both cases where a driver "looks but does not see," and cases where a driver needed to look but did not even attempt to.
False Assumptions	Applies whenever a driver takes action based on a decision or opinion arrived at by assuming that to be true which is not true.
Improper Maneuver	Applies whenever a driver willfully chooses a vehicle path that is wrong, in the sense of being obviously calculated to generate an exceedingly high risk of collision (willful violation of a traffic law or rule).
Improper Driving Technique or Practices	Applies when a driver engages in the improper control or path, or speed in a manner that unduly increases the risk of accident-involvement. This includes practices that might be habitual to a particular driver, hence the risk involved is not fully appreciated.

Results and Discussion

The merging of the Indiana Tri-level Study categories and the primary contributing factors from the Pennsylvania database provided a view of what factors lead to crashes and what driver errors play a role. This information is shown in figure A2. Histograms based on the taxonomy are presented in this section to highlight the main points. Percentages will be used in the text so the reader can easily distinguish the relative occurrence of the contributing factors. However, the actual counts can be found in figure A2 and can be estimated from the ordinate axis on the histograms. In the following discussion, information gained through the officer focus groups and driver interviews (both discussed in detail in later sections) will be used to provide insight into specific contributing factors.

332342	Human Errors Direct Cause
52445	Environmental Causal Factors
34600	Human Conditions and States
10210	Vehicle Failure or Problems
1407	Other Contributing Factors

Total: 431004

Figure A2. Driver error and contributing factor taxonomy using the Pennsylvania (SDP) database.

As illustrated in figure A3, 77 percent of the contributing factors were classified as "Human error." The remaining 23 percent were accounted for by "Environmental causes" (12 percent), "Human conditions and states" (8 percent), "Vehicular failures/Problems" (2 percent), and "Other contributing factors." The "Other contributing factors" were factors that could not be classified. They accounted for less than 1 percent of the sample.

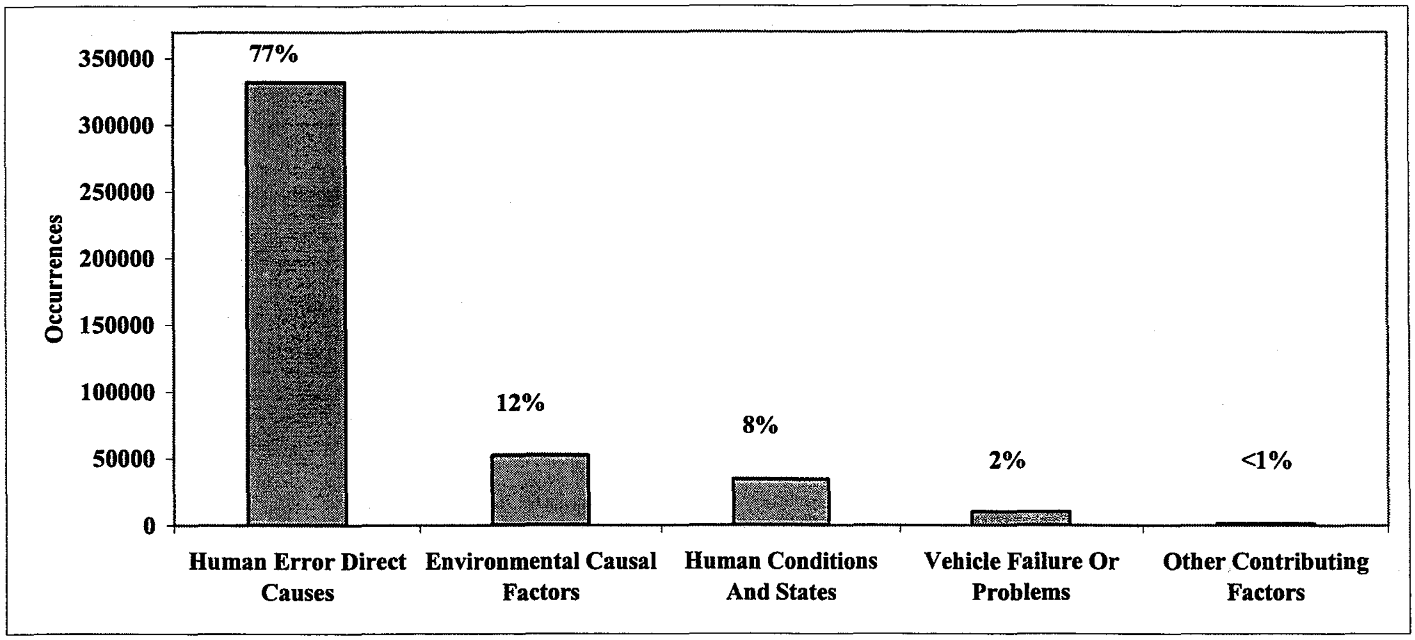


Figure A3. Contributing factors in the 1995 and 1996 Pennsylvania crashes.

Human Error Direct Causes. According to the Indiana Tri-Level Study (1977), "Human direct causes" can be divided into five categories. Two of these categories are non-errors where the driver did not perform because of physical incapacitation or intentionally crashing, such as a suicide attempt. The other three categories, "Recognition," "Decision," and "Performance," do represent human errors.

Decision Errors. In this study, "Decision errors" accounted for 47 percent of the contributing factors. It is important to note that decision errors are those errors where the driver receives the necessary information to drive correctly but chooses to take no action or takes an incorrect action. As shown in figure A4, "Improper maneuver" (22 percent), "Improper driving technique" (13 percent), and "Excessive speed" (11 percent) accounted for the bulk of the decision errors. Although several applicable contributing factors of false assumption were included in the PA database CF field, these contributing factors had relatively few occurrences, summing to less than 1 percent of the total number of contributing factors.

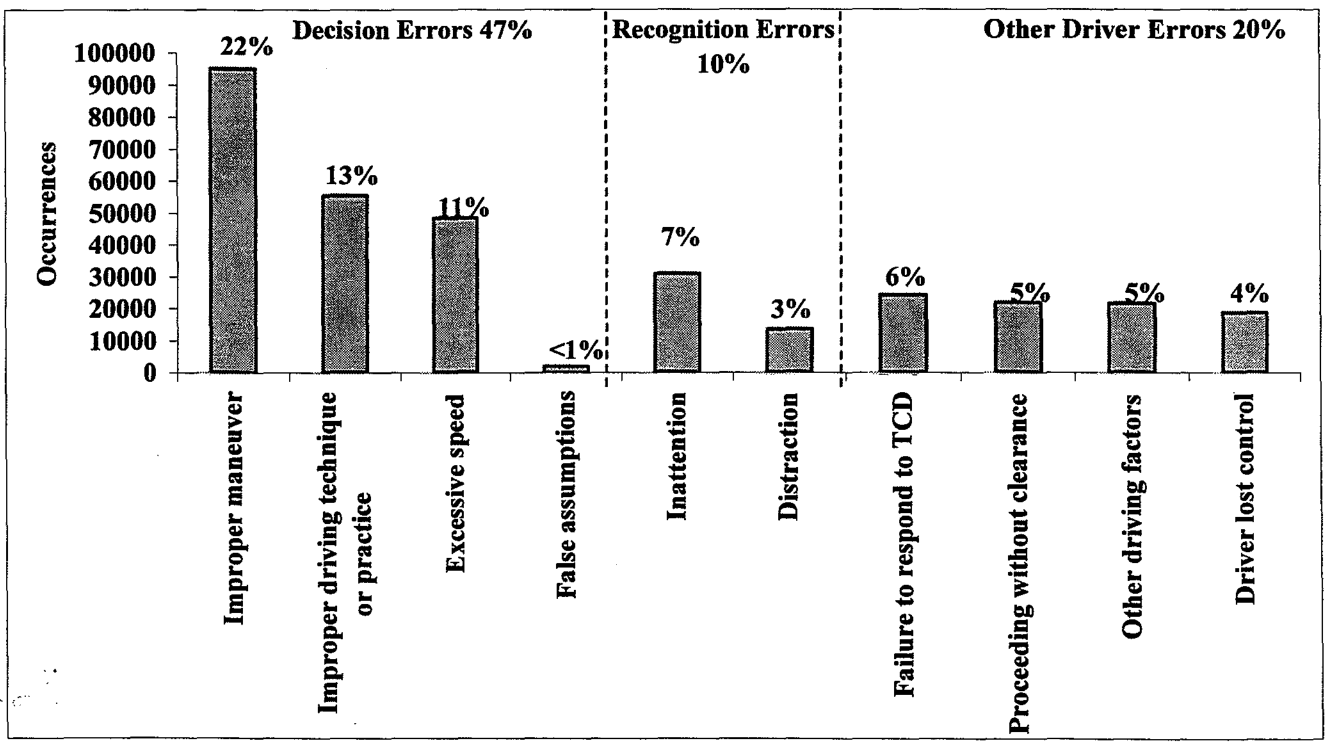


Figure A4. Driver errors in the 1995 and 1996 Pennsylvania crashes.

"Improper maneuvers" are those maneuvers in which the driver willfully performed a wrong maneuver. As shown in figure A5, "Improper maneuvers" can be further divided into "Improper or careless lane change, entrance, or exit" (8 percent), "Driving in the wrong lane" (8 percent), or "Illegal or improper turn" (6 percent).

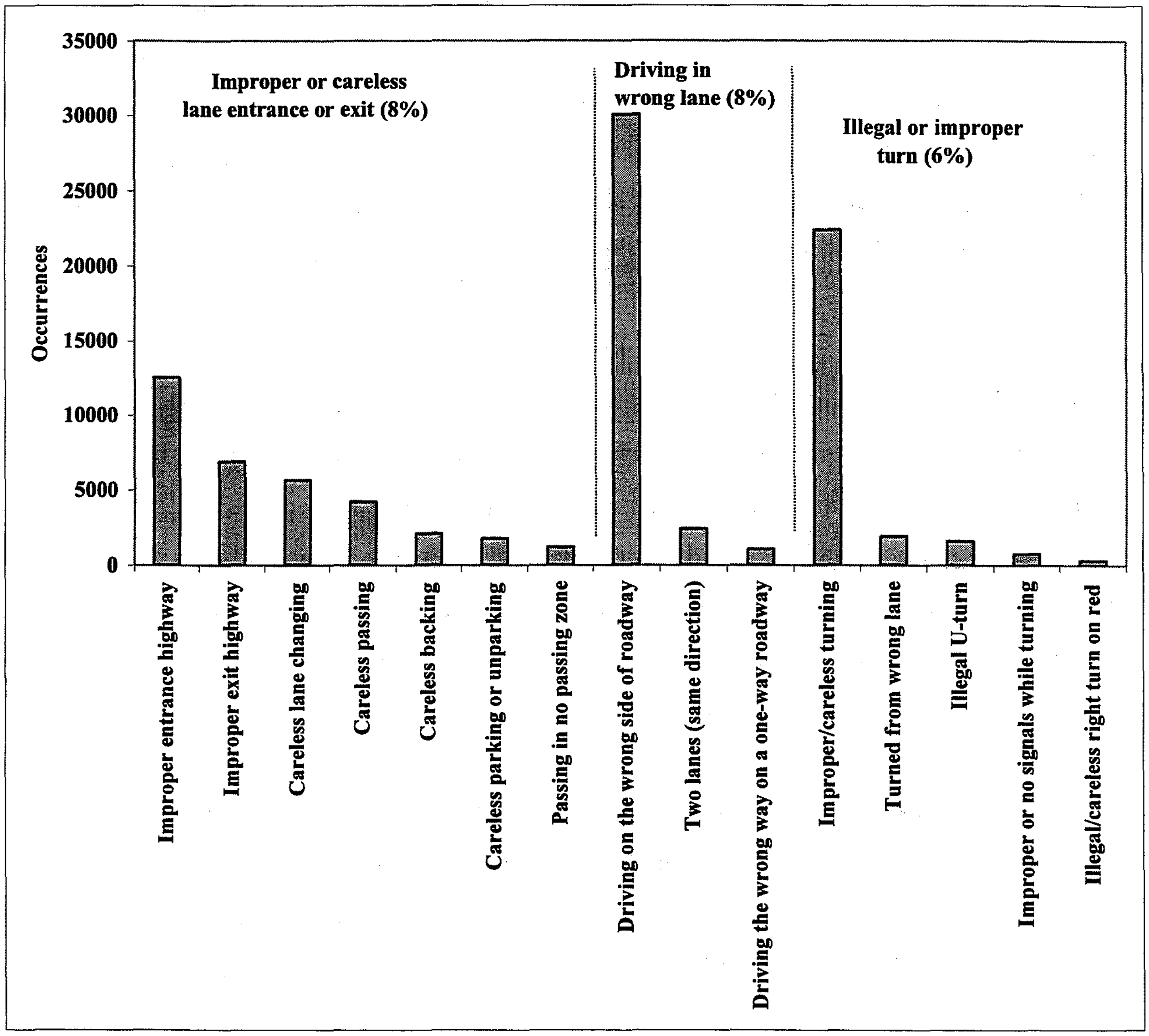


Figure A5. Improper maneuver categories.

"Improper or careless lane change, entrance, or exit" could be further separated into seven subcategories, with the top two being "Improper highway entrance" (2.9 percent) and "Improper highway exit" (1.5 percent) (figure A5). Crashes associated with these factors may be reduced through changes in infrastructure. Entering a highway requires drivers to merge with vehicles that are travelling at a high rate of speed. The design of highway on-ramps can greatly influence how drivers accomplish this maneuver. Ramps should be designed so that a driver has enough time to reach an adequate speed to merge, and also has good visibility of the adjacent lane into which the driver wishes to merge. One location with the most frequent crashes identified in our officer focus group session was a location where traffic was attempting to merge and did not have enough distance to reach an adequate merging speed. Exit ramp design was another problem that was discussed in our officer focus groups, and the officers also gave an example of an exit ramp that had caused many crashes. Officers thought the crashes on this ramp could be greatly mitigated by redesign, and believed that appropriate signing could help reduce the crashes. This specific ramp had a large number of single vehicle off-road crashes that were caused primarily by drivers underestimating the amount of curvature and attempting to travel around it too fast.

"Careless lane changing" and "Careless passing," two other subcategories under "Improper or careless lane change, entrance, or exit," accounted for more than 2 percent of the contributing factors (figure A5). It is probable that crashes associated with these factors are more likely due to drivers misjudging the speed/distance of other vehicles, improper scanning behavior prior to performing the maneuver, and not signaling an intention to change lanes or pass. Therefore, changing the infrastructure would probably minimally reduce these crashes. In-vehicle warning systems alerting a driver of an adjacent vehicle may help mitigate these types of crashes.

"Driving in the wrong lane" accounted for approximately 8 percent of the contributing factors, with the majority of these factors involving "Driving on the wrong side of the road" (7 percent) (figure A5). "Driving on the wrong side of the road" could be caused by multiple factors including infrastructure, drivers' impaired condition, and inattention. From an infrastructure standpoint, driving on the wrong side could be reduced by providing barriers such as medians or guardrails between the lanes of the roads. However, the cost and design feasibility would have to be determined on a case-by-case basis.

The final improper maneuver subcategory is "Performed an illegal or improper turn" (6 percent). Although it is likely that improper lookout and misjudging speed/distance were the factors most highly associated with these crashes, these crashes could be reduced through infrastructure changes. For example, incorporating a protected left turn into a problem intersection would reduce these types of crashes. Of course, incorporating the correct infrastructure "fix" into a system requires understanding all the factors in the system. For example, the officer focus group session described an intersection where a protected left turn was used part of the time, and an unprotected left turn was used during the remainder of the time (cycle). Officers believed a large number of crashes at that intersection were due to drivers believing they had a protected turn (i.e., a green arrow) when actually they had a yield-right-of-way left turn (i.e., green ball). In this case, using a protected left turn some of the time may have increased the number of left-turn-related crashes at this intersection.

"Improper driving technique" accounted for 13 percent of the contributing factors. Recall that the factors under "Improper driving technique" were more likely to be factors that drivers habitually committed. The factors or subcategories within improper driving technique or practice are illustrated in figure A6.

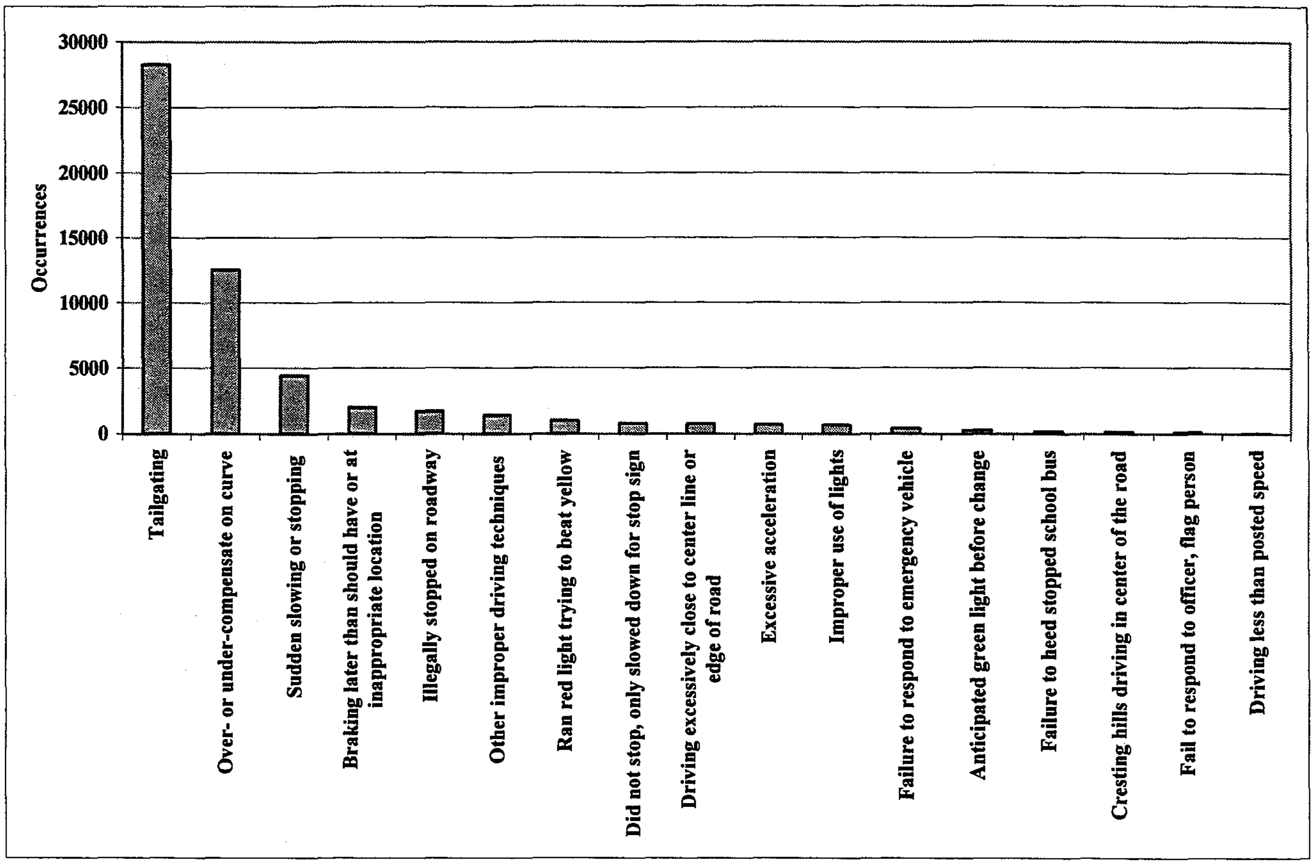


Figure A6. Improper driving technique or practice categories.

"Tailgating" (or following too closely) was by far the number one improper driving technique or practice, accounting for half of the occurrences in this category. "Tailgating" accounted for more than 6 percent of the factors contributing to the 1995 and 1996 Pennsylvania crashes. The underlying reasons for tailgating vary greatly. When discussing the problems of tailgating with the officers in the focus groups, they narrowed the cause primarily to driving aggressiveness, inattention, and not understanding the ability of the driver and the vehicle to "stop in time." An example of aggressive driving was tailgating in the left lane on an interstate to encourage the lead driver to move to the right lane. In this example, officers also felt that tailgating was due in part to drivers using the left lane as a travel lane and not a passing lane. Another example cited under aggressive driving was drivers following too closely to maintain relative position. When drivers leave an acceptable gap, other drivers slide into that gap, requiring the following driver to slow to leave another gap. This scenario keeps repeating itself until the following driver becomes frustrated and closes the gap. Initially, from the standpoint of infrastructure, increasing the number of lanes seems to be the only way to reduce the number of drivers tailgating. However, there are other more practical methods of reducing tailgating-related crashes from an infrastructure standpoint. Warning people of changes in transitory roadway conditions with signing (i.e., crash ahead), targeting infrastructure areas that force a change in speed on heavily traveled roads such as narrow lanes, or transitioning from three to two lanes could also reduce these types of crashes. Non-infrastructure methods to reduce these crashes include ensuring that drivers understand how long it takes to stop their vehicle, ensuring that they understand traffic laws such as using the left lane for passing only, and using in-vehicle warning systems for drivers following too closely.

"Over- and under-compensation in a curve" accounted for approximately 3 percent of the contributing factors in crashes. The officers in the focus groups believed that drivers in rural areas too often drive too fast around curves and cut across the centerline into the other lane. The driver interview portion of this report indicated that drivers felt that appropriate warning signs prior to a curve in rural areas would help reduce the crashes. Signing is a relatively inexpensive "fix" for some of the curve-related problems. In some curve areas, where drivers have a tendency to cut across the yellow lines, mirrors have been positioned so drivers can look for an oncoming vehicle. Barriers can be positioned between oncoming lanes to reduce head-on collisions on curves. Again, the best solution requires understanding all the roadway factors in a problem area.

"Sudden slowing or stopping" accounted for approximately 1 percent of the contributing factors, and braking at inappropriate locations was the next highest improper driving technique or practice. Although both of these contributing factors could be due in part to infrastructure, such as slowing to decipher confusing signs, this driver error may be best mitigated by ensuring that drivers realize that when slowing, they must also ensure that the following drivers have enough room to slow. Lead drivers must also signal their intentions early, such as tapping on the brake even though they are going to slow by down shifting (i.e., using the transmission to slow rather than the brake).

"Excessive speed" accounted for 11 percent of the contributing factors. As shown in figure A7, excessive speed could be further divided into seven categories. "Excessive speed for the weather conditions" was the contributing factor most often cited (3.5 percent). Officers in the focus group believed that drivers often did not vary their speed to accommodate poor weather conditions. According to the officers, some drivers expect to drive at the speed limit regardless of driving conditions. Some drivers may not know the impact that weather can have on the vehicle's handling and their own ability to see potential obstacles. Signing that adjusts the speed appropriately for changing roadway conditions may be a possible infrastructure solution. It also should be noted that some of the officers in the focus groups believed that drivers actually drive faster during inclement weather conditions because of the reduced likelihood of being ticketed for speeding.

As shown in figure A7, drivers were also likely to be driving over the speed limit when a crash occurred. The officers in the focus groups believed that there were many reasons why people drive over the speed limit. These ranged from aggressive driving to inattention. Approximately 1 percent of the contributing factors were at least in part due to driving too fast for the conditions (e.g., traffic, pedestrians). Both this 1 percent and the 0.9 percent due to driving too fast for the road design could possibly be improved by changes in infrastructure. However, not enough is known about the associated crashes to determine what changes could be made. The additional 1.6 percent of crashes that combined two of the excessive speed factors together may also be reduced through infrastructure changes.

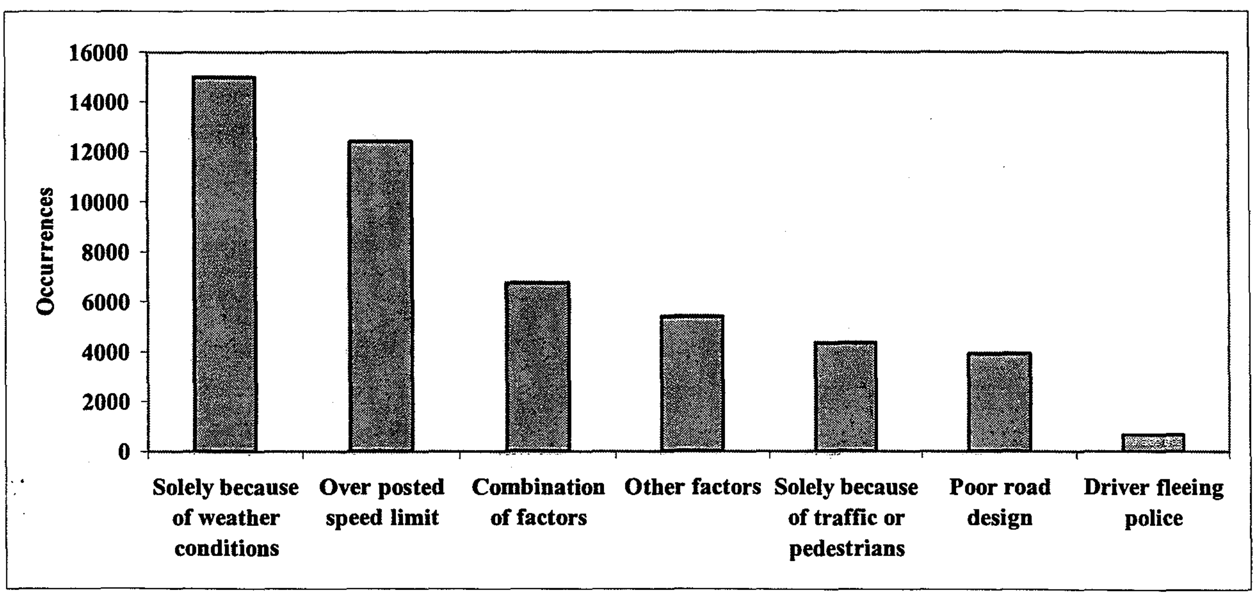


Figure A7. Excessive speed categories.

Other Human Errors. "Other human errors" accounted for 20 percent of the contributing factors (figure A4). Occurrences were placed in this category when it was thought an error had occurred but it did not fit into the decision or recognition categories. The "Other" category was further divided into the seven categories shown in Figure A8.

"Failure to respond to a TCD" accounted for 5.6 percent of the contributing factors. For example, running a red light or a stop sign for unknown reasons would fall into this category. Note that this category is not inclusive of all TCD-related errors; it only includes the TCD errors in which drivers failed to respond and there was not enough information to place the occurrence in a more meaningful category. For example, drivers failed to respond to a TCD in the category "Ran red light but did not see it change red," but this factor was better described as a recognition problem. Over the entire taxonomy, TCDs accounted for 7.5 percent of the contributing factors. This estimate does not include "Proceeding without clearance," which is discussed in detail later.

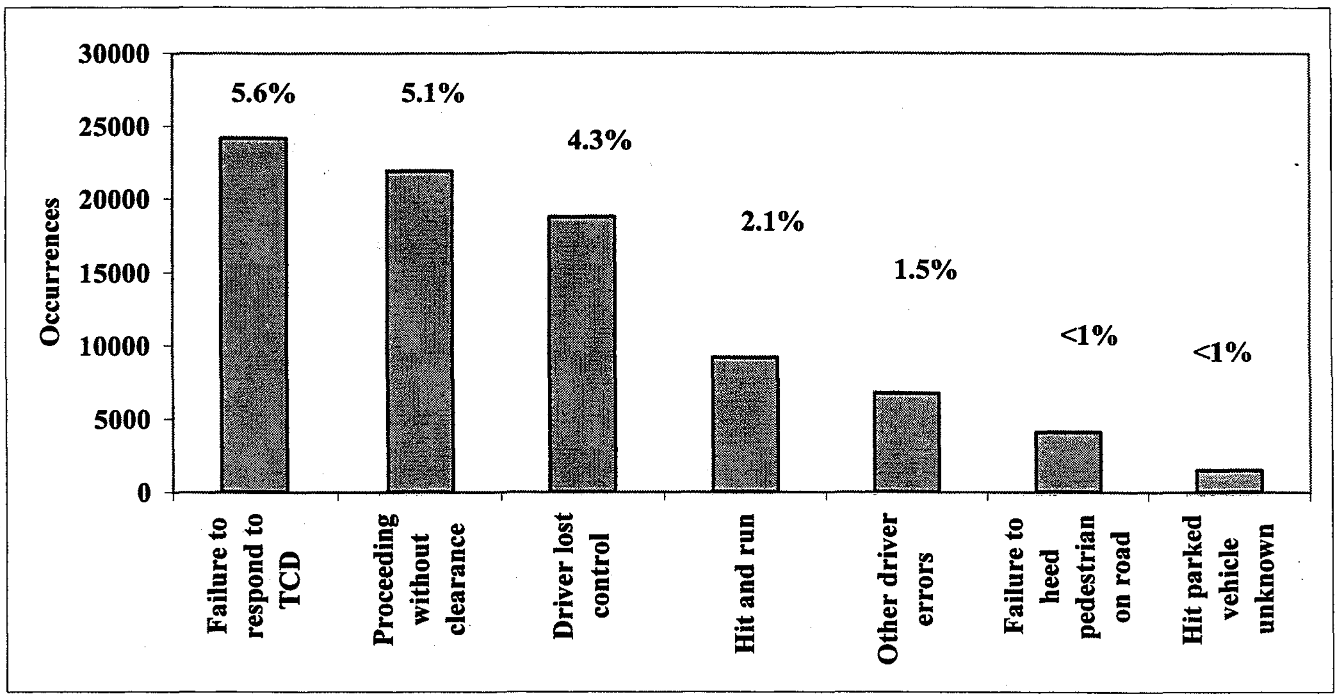


Figure A8. Other human error categories.

The TCDs and counts included in the "Failure to respond to a TCD" category are shown in figure A9. As has been shown in other analyses included in the report, traffic signals and stop signs are associated with the bulk of the TCD-associated crashes. The number of crashes associated with traffic signals and stop signs is actually higher since there are additional factors described in other places in this taxonomy that also include these TCDs (figure A2). Note that the main reason that the counts for these two TCDs are higher is that there are more of these devices than other TCDs. An attempt was made to obtain relative numbers of these devices in Pennsylvania. Unfortunately, there was no TCD asset management system available, so the relative numbers of these devices could not be determined.

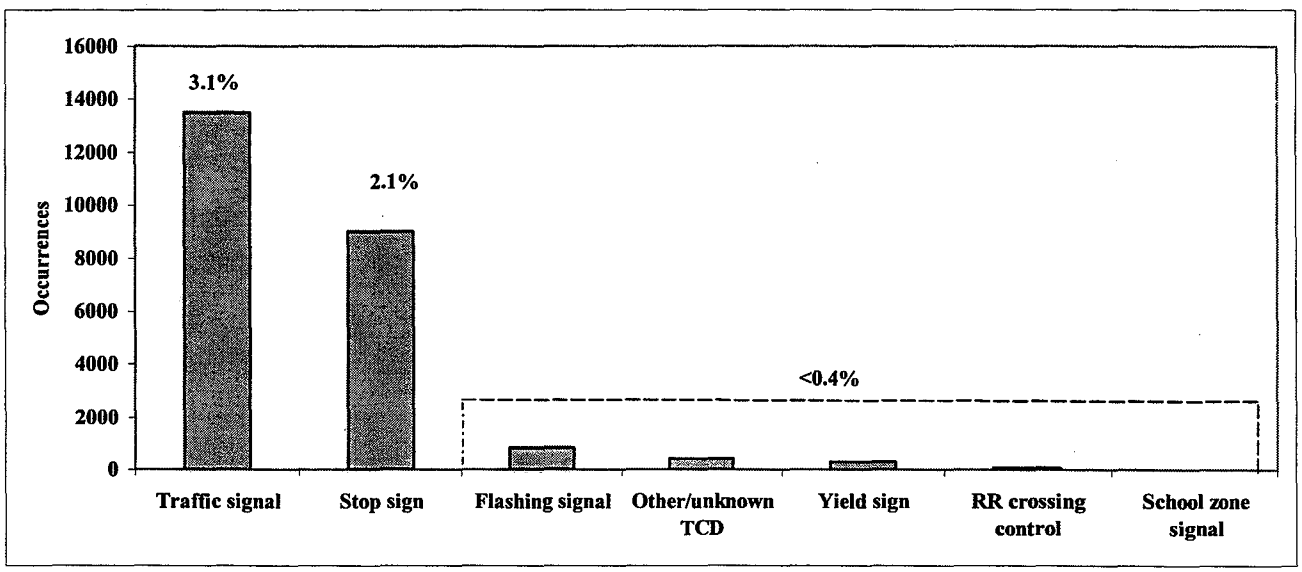


Figure A9. Failure to respond to TCD categories.

"Proceeding without clearance" accounted for 5.1 percent of the contributing factors. This category is interesting since it represents drivers who initially stopped, as directed by either a TCD, a flag person, or the roadway design (i.e., entering a main roadway from a private drive) and then proceeded prior to being given clearance. For example, these drivers stopped initially for a red traffic light, and then continued across the intersection prior to the light turning green. This example could be considered a willful act since drivers probably knew the light was still red when they attempted to cross. Stopping at a stop sign or stopping at the main road before proceeding from a driveway and then proceeding when the driver thought the roadway was clear would also fall into the "Proceeding without clearance" category. These examples could probably be better described as an error in judgment or improper lookout. It is unfortunate that this category cannot be separated further to understand the factors of which it is comprised.

"Driver lost control" accounted for 4.3 percent of the contributing crashes, and "Hit and run" accounted for 2.1 percent of the factors. The factors leading up to this loss of control or the hit and run are not known and, as a result, cannot be expanded upon further.

Recognition Errors. "Recognition errors" accounted for approximately 10 percent of the contributing factors (figure A4). "Recognition errors" were divided into "Inattention" (7 percent) and "Distraction" (3 percent). As illustrated in figure A10, "Inattention to a stopped vehicle" was the most frequent recognition error. This would include crashes where a lead vehicle attempting to make a left turn was stopped waiting for oncoming traffic. "Rear-ending a stopped lead vehicle" was also shown to be a large category in the North Carolina Narrative search. "Inattention to signs and signals" may have obvious infrastructure implications. Drivers in these cases either did not see the stop signs or traffic signals or, in the case of the traffic signal, did not see it turn red. Increasing the saliency of these devices may reduce related crashes. However, "Did not see the sign or signal" is probably a fairly common "untrue" excuse that some drivers used.

"Internal distractions" accounted for less than 2 percent of the contributing factors, and "External distractions" accounted for less than 1 percent. "On-the-road distractions" could have potential infrastructure causes, but the numbers of occurrences are fairly small. Perhaps the best way to reduce distractions is to alert drivers of a possible threat through a warning system.

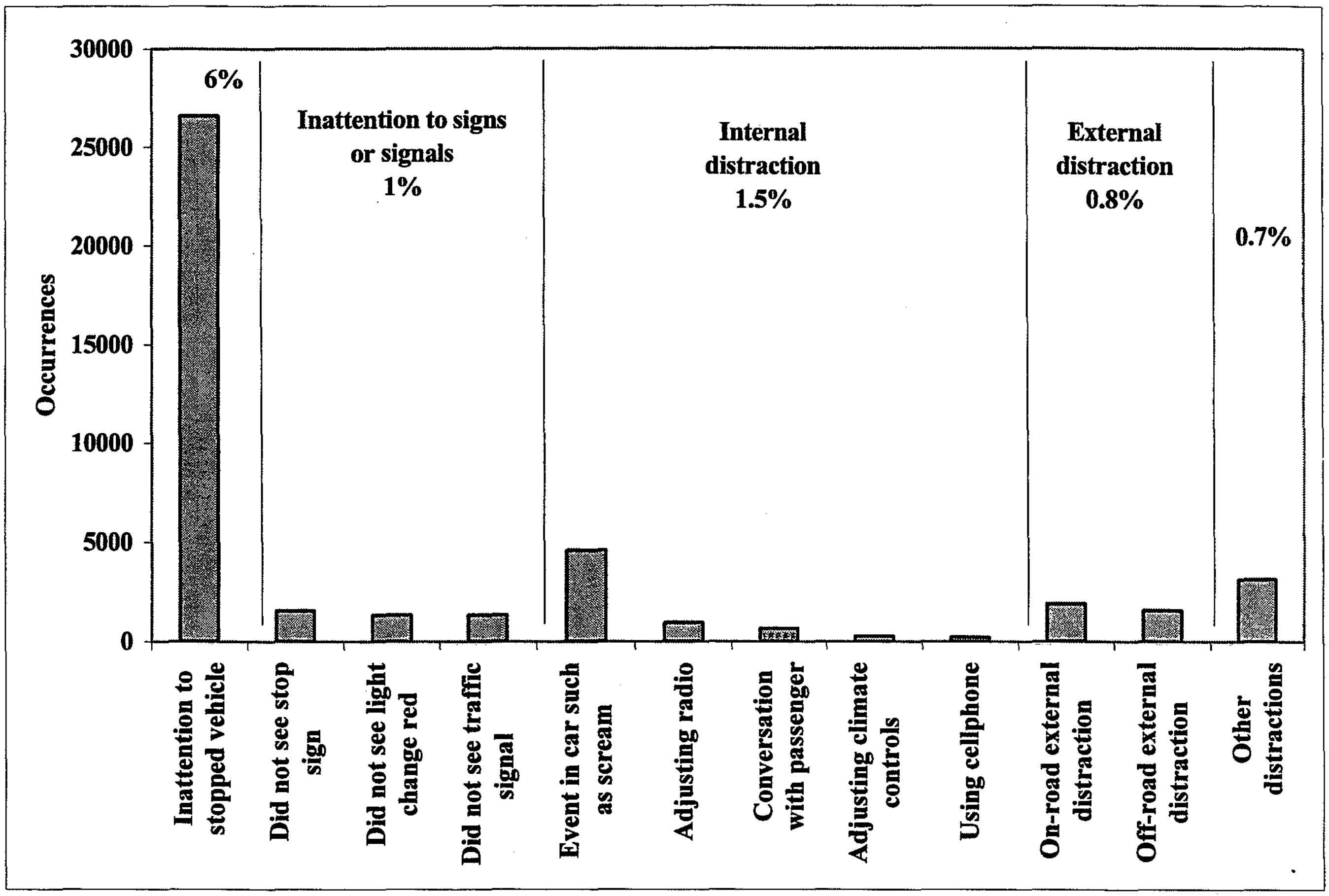


Figure A10. Recognition errors in the 1995 and 1996 Pennsylvania database.

Environmental Factors. "Environmental factors" accounted for approximately 12 percent of the contributing factors in the 1995 and 1996 database (figure A3). As shown in figure A11, some of those "Environmental factors" have obvious infrastructure implications. "Roadway structure problems" represented the largest environmental contributing factor. Figure A12 illustrates each of the subcategories that comprised the "Roadway structure problems" category. "Slippery pavement" accounts for most of the "Roadway structure problems." "Bleeding of the pavement" (a film of bituminous material on the pavement surface that creates a glass-like, reflecting surface) lowers the skid resistance. This example was identified as a problem at a specific intersection during one of the officer focus group sessions. The other categories that make up "Roadway structure problems" sum to less than 1 percent of the contributing factors (figure A12). However, we should not lose sight of the fact that these other roadway structure problems were a contributing factor 3,838 times.

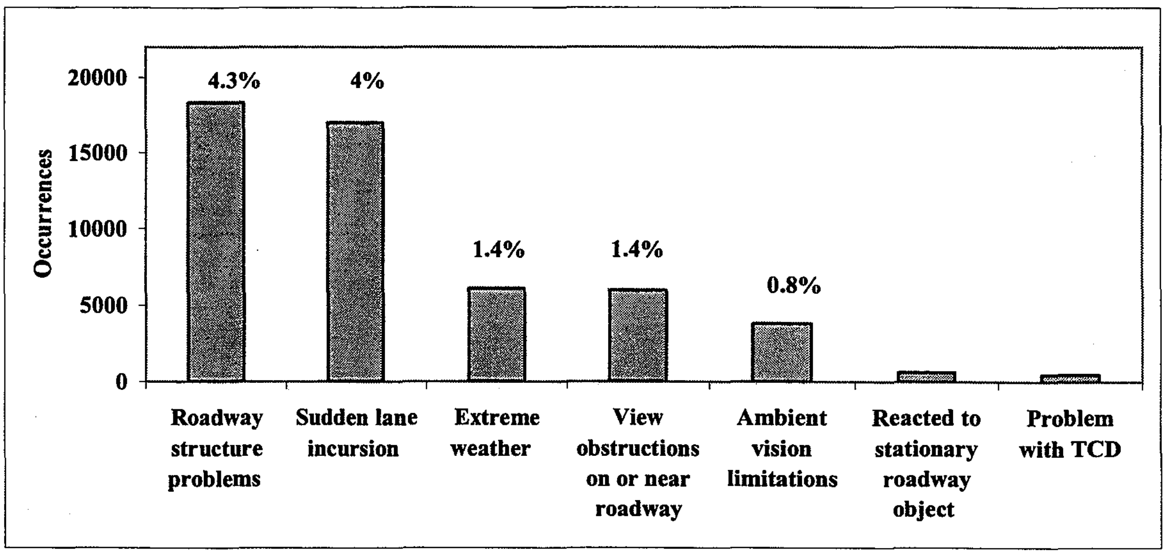


Figure A11. Environmental factors in the 1995 and 1996 Pennsylvania database.

“Sudden lane incursion” accounted for 4 percent of the contributing factors. Deer, other animals, and pedestrians were the most likely objects to suddenly move into the roadway. From an infrastructure standpoint and as mentioned previously, deer and other animals could be kept from the roadway with fences, thus minimizing the chances of this type of crash. Clearing the roadway easement of brush and trees in rural areas would help drivers see approaching animals earlier and perhaps reduce the number of related crashes. Clearing the easements of brush and trees would perhaps also reduce the “View obstructions on or near the roadway” that accounted for 1.4 percent of the contributing factors.

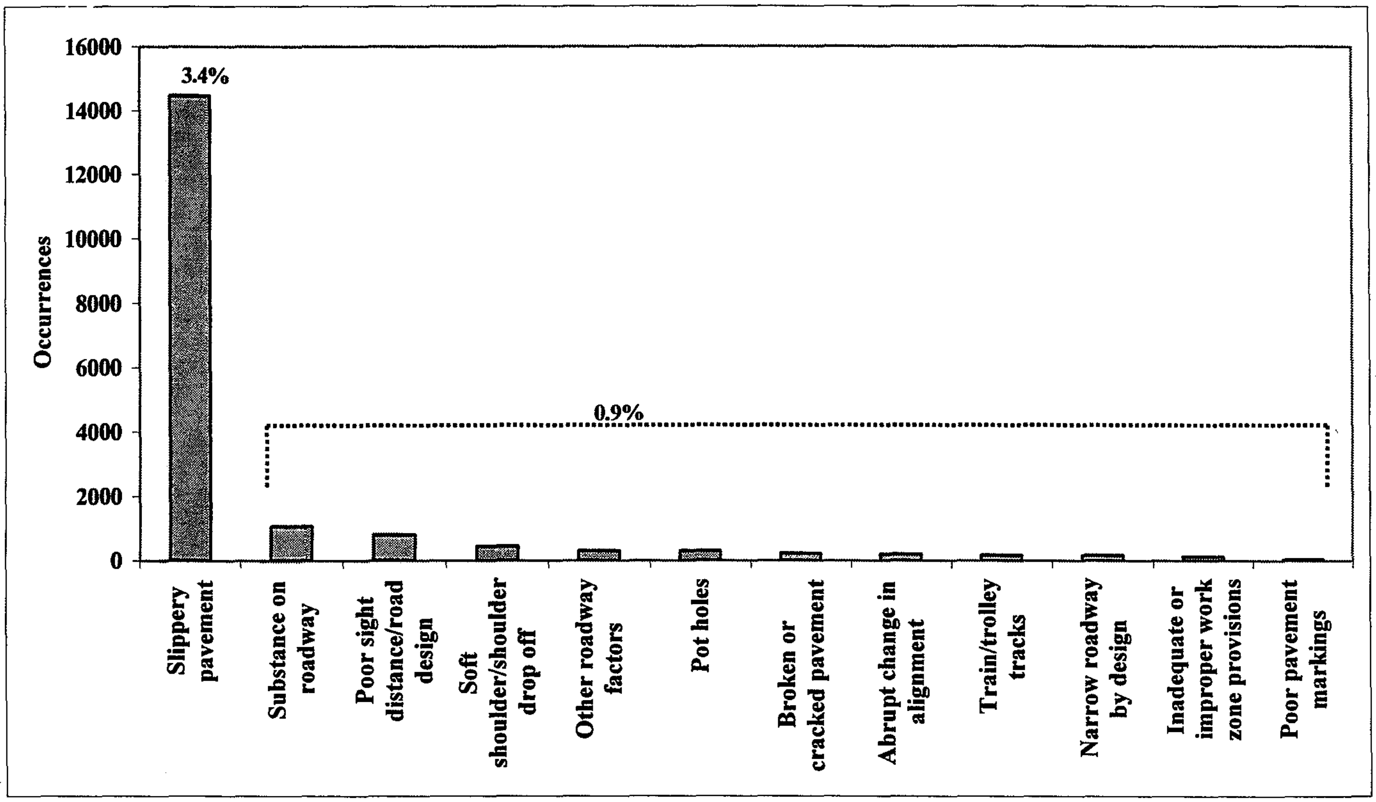
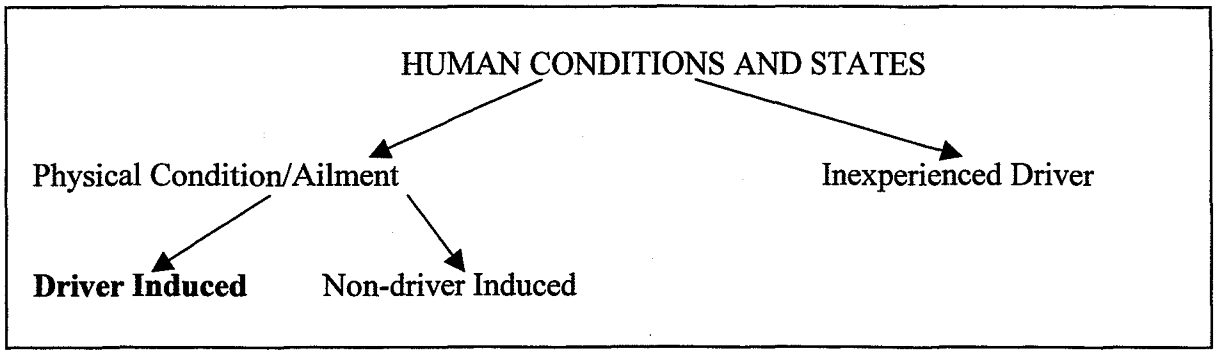


Figure A12. Road structure problems in the 1995 and 1996 Pennsylvania database.

Human Conditions and States. “Human conditions and states” accounted for approximately 8 percent of the contributing factors (figure A3). As illustrated in figure A13, “Human conditions and states” can be further separated into “Physical condition/ailment,” and then into “Driver-induced” and “Non-driver-induced” factors. “Driver induced” refers to those conditions or states that were the result of something over which the driver had control. For example, driving after consuming alcoholic beverages accounted for more than 5 percent of the contributing factors and was something over which the driver had control (figure A13). "Non-driver induced" refers to those conditions over which the driver had no control (e.g., a blackout or a heart attack while driving). Arguably, "Driver-induced" contributing factors could be considered willful acts or driver errors. That is, drivers who know they are making the choice to drive under an altered state or condition are, at the least, performing an error and perhaps performing a willful act. "Driver-induced" factors accounted for 6.9 of the 8 percent of human conditions and states, with driving under the influence of alcohol and being fatigued as the largest factors (figure A14).



Figur

e A13. Taxonomy for human conditions and states.

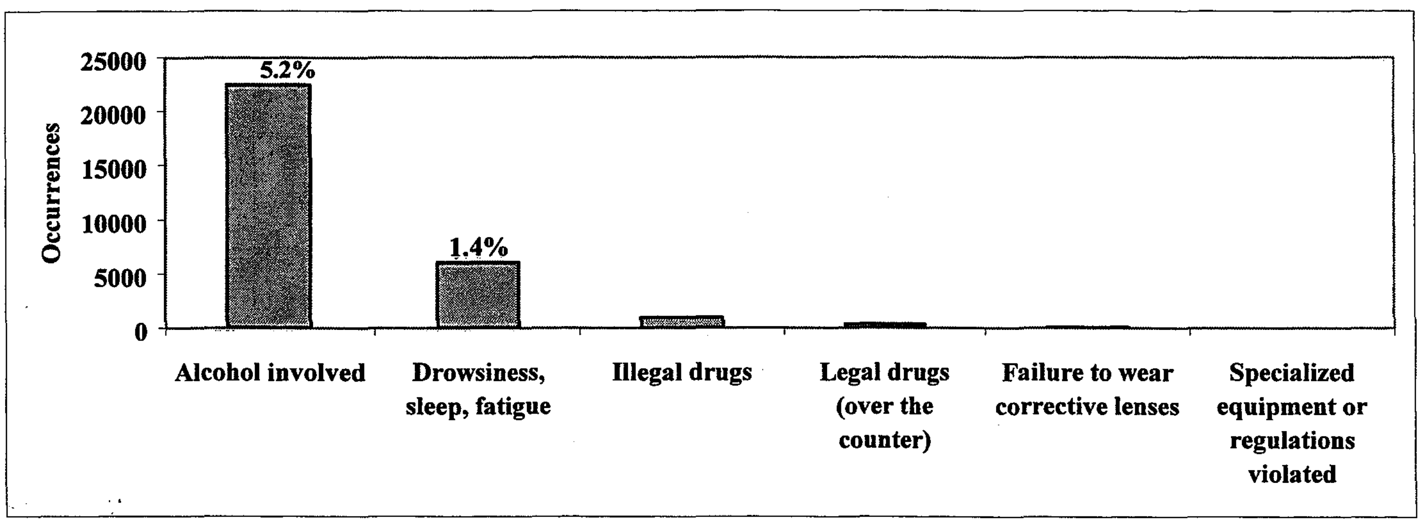


Figure A14. Driver-induced human conditions and states.

<u>Vehicle Failure and Problems</u>. "Vehicle failure and problems" accounted for approximately

2 percent of the contributing factors (figure A2). This causal factor in the Indiana Tri-level Study was defined in extreme detail. However, fewer categories can be used to capture the majority of these factors. Some of these categories should also be considered driver error. For example, driving with a dirty or frosty windshield is something that a driver knows reduces visibility and should be corrected prior to driving the vehicle. Drivers also know that driving with bald tires increases their chance of a blowout or losing control of the vehicle. Both of these examples could be classified as driver error. The "Vehicle problems and failure" categories that could be considered driver error are shown in table A3. Each of these factors could probably be addressed with routine maintenance.

Table A3. Vehicle failure and problem contributing factors that could be considered driver error.

Inadequate tire tread depth
Improper inflation/bald tires
Mismatch of tire types and/or sizes
Unsecured or shifting load
Improper towing
Overloaded
Dirty/frosty windshields
Defective defrosting
Defective wipers
Lighting problems
Inoperable headlamps
Inoperable taillights
Inoperable turn signal
Taillights and turn lights obscured by dirt, grime
Mis-aimed headlamps
Dirty, obscured headlamps

Conclusions From the PA Traditional Database Analysis

Although useful information was obtained using the Indiana Tri-level Study as a framework for this taxonomy, the numerous ambiguities, such as the differences between improper maneuvers and inadequate techniques or practices, make it difficult to use.

Understanding the underlying reason behind driver error is one key component to mitigating the problem, but this could not be fully determined through this traditional analysis. Drivers may exhibit the same driver error for varied reasons. For example, our analysis showed that "Following too closely/Tailgating" was a contributing factor 28,270 times in Pennsylvania during 1995 and 1996. A subsequent analysis showed that it was the primary contributing factor in 22,558 crashes out of the 279,730 crashes that occurred during the same time frame. That is, this was the factor that officers filling out the report form believed was the primary "causal" factor in more than 8 percent of these crashes. Attacking this problem could have a potentially large impact on the number of crashes. However, following too closely could be caused by aggressive driving, inattention, or drivers simply not understanding how long it takes for them to react and for their vehicles to stop. Each of these underlying reasons would require a different mitigation strategy. Aggressive driving may require greater presence of law enforcement, inattention may require an in-vehicle system to alert drivers when they are driving too closely, and lack of knowledge may require a public awareness campaign and an emphasis on vehicle kinematics in training. Although all these approaches and others could be used in a "shotgun" type approach in hopes of hitting the target(s), understanding the key reason(s) would help focus a mitigation strategy using the available resources to obtain the greatest crash reduction for the money.

"Human errors" accounted for the majority of the contributing factors in this database. Some of these errors could be eliminated through infrastructure changes. However, no obvious global infrastructure changes that would reduce human error were identified.

"Decision errors" accounted for the majority of the contributing factors (47 percent). These were errors where drivers correctly interpreted the information, but chose to perform an incorrect action or chose to perform no action. "Recognition errors" accounted for 10 percent of the contributing factors. These were the errors where the driver failed to recognize the threat. There was another 20 percent classified as "Other" driver errors that could not be classified as either decision or recognition errors. "Failure to avoid an obstacle on the road" accounted for a surprising 10 percent of the contributing factors and included "Hit a parked vehicle," "Hit a stopped vehicle," and "Hit a pedestrian or animal in the road."

Finally, table A4 lists nine driver errors that account for approximately two-thirds of all the contributing factors in the Pennsylvania database for 1995 and 1996. A subsequent analysis determined that these factors were also considered the primary contributing factor in more than two-thirds of the crashes. This section of the report described each of these factors and the applicable potential infrastructure changes that could reduce related crashes. Attacking any one of these factors could have a significant impact on the number of crashes on both Pennsylvania and U.S. roadways.

Table A4. Nine driver errors associated with crashes in Pennsylvania during 1995 and 1996.

	Driver Errors	Primary Contributing Factor
1	Excessive speed	8.7%
2	Improper or careless lane change, entrance, or exit	7.8%
3	Driving in wrong lane	4.9%
4	Traffic control device-related	7.8%
5	Driver-induced physical ailment	7.8%
6	Following too closely or tailgating	8.1%
7	Improper or illegal turn	7.8%
8	Inattention to a stopped vehicle	7.8%
9	Proceeding without clearance after stopping	7.2%
	Total	**67.9%**

1B. FARS Database Analysis

The second traditional database analysis was conducted using records from the FARS. There were two primary goals in analyzing the FARS database. First, as in the analysis of the PA database, it was believed that a taxonomy could be developed to provide insight into which driver error and contributing factors are most associated with fatal crashes. However, unlike the PA database analysis, the FARS analysis would provide results from data collected across the United States (not just in one State). The second goal of the FARS analysis was that it was to include the effects of driver age. More specifically, it was believed that a FARS analysis would indicate which errors younger, middle aged, and older drivers are most likely to commit.

Approach

To obtain a better understanding of which driver errors are associated with severe crashes, an analysis was conducted using the 1996 FARS database. In 1996, approximately 41,900 people died in roadway-related crashes in the United States. Of these 41,900, approximately 15 percent were pedestrians, cyclists, or other people not in a motor vehicle. Approximately 57,000 drivers were involved in these crashes. As shown in figure A15, younger drivers were involved in a large number of these crashes.

An analysis was conducted to determine if there was a difference in the types of errors that drivers of different ages made that led to these fatal crashes. As illustrated in table A5, "Related factors-driver level" includes categories that could be considered as a driver error or a contributing factor. A cross tab analysis was done between driver age and this "Related factors-driver level." All drivers involved in a fatal crash were considered regardless of whether an occupant of their vehicle was fatally injured. That is, an occupant in another vehicle or a non-occupant such as a pedestrian could have accounted for the fatality.

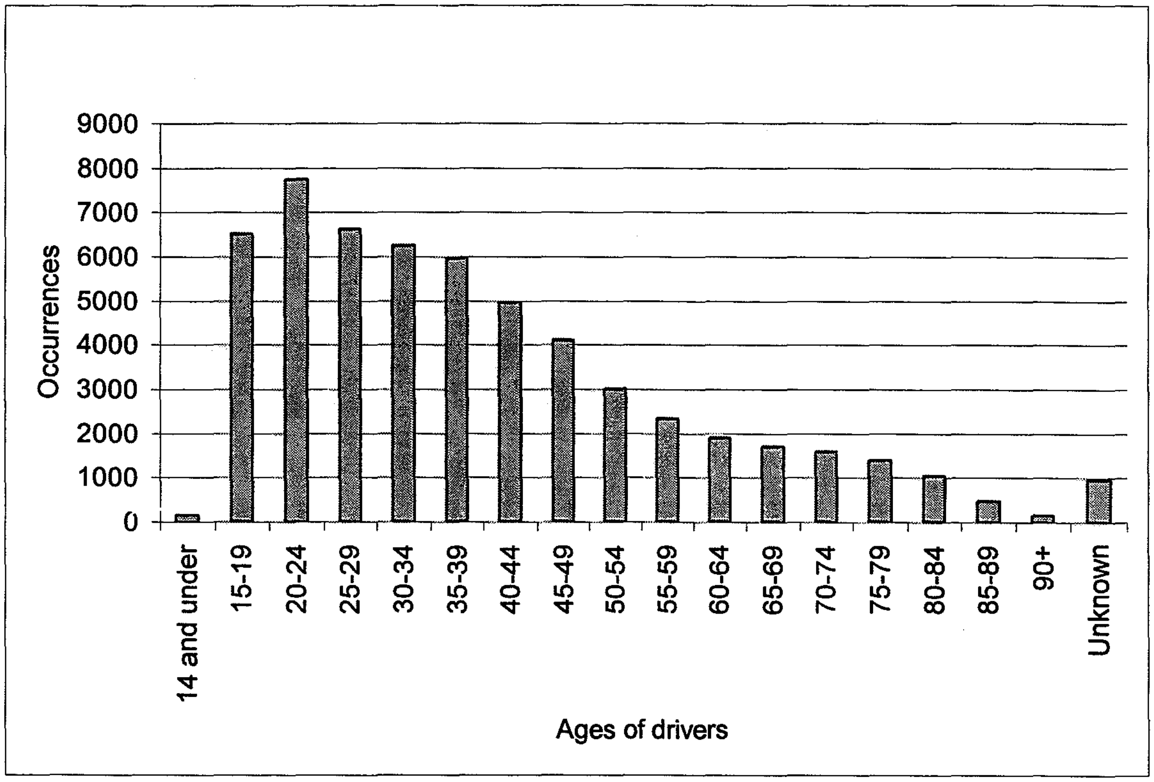


Figure A15. Ages of drivers involved in fatal crashes in 1996.

Table A5. Categories in the FARS database field "related factors-driver level."

Drowsy, Asleep	Pass Wrong Side	Building, Billboard
Ill, Blackout	Pass Insufficient Distance	Tree, Plants
Emotional	Erratic/Reckless	Moving Vehicle
Drugs-Medication	High Speed Chase	Parked Vehicle
Inattentive	Failure to Yield	Splash, Spray
Wheelchair	Failure to Obey	Inadequate Defroster
Previous Injury	Around Barrier	Inadequate Lights
Other Physical	Fail to Observe Warning	Obstruct Angles
Unknown	Fail to Signal	Improper Windshield
Mental Challenge	Driving too Fast	Other Obstruct
Fail to Take Drugs	Under Min Speed	Crosswind
On Prohibited Road	Wrong Lane Turn	Truck Wind
Invalid License	Other Improper Turn	Slippery Surface
Vehicle Unattended	Phys Rest Comply	Flat Tire
Improper Loading	Wrong Way	Debris in Road
Improper Towing	Wrong Side of Road	Rut in Road
Improper Lights	Operational Inexperience	Animal
W/O Required Equipment	Unfamiliar with Road	Vehicle in Road
Unlawful Noise	Stopping in Road	Phantom Vehicle
Improper Following	Low Tire Pressure	Pedestrian
Improper Lane Change	Locked Wheel	Water, Snow, Oil
Run Off Road/Lane	Over Correcting	Hit and Run
Driving Shoulder	On/Off Moving Vehicle	Homicide
Improper Entry/Exit	On/Off Stop Vehicle	Other Violation
Improper Start/Back	Weather	Cellular Phone
Open Vehicle Closure	Glare	Fax Machine
Prohibited Pass	Curve, Hill, etc.	2-Way Radio

Three age groups were selected: younger, medium, and older ranges (see table A6). These were nearly the same age ranges used in the driver interview portion of this report (discussed later). Table A6 shows the total number of drivers in each age group, the number of drivers who had no driver-related factor, and the number of drivers who had a driver-related factor. Approximately one-third of the crashes selected had no driver-related factor. In the way of further explanation, note in table A6 that the values in the second column result from the same data that appear in figure A15. For example, the value 14,279 is the sum of the first three bars of figure A15, the value 10,955 is the sum of the sixth and seventh bars, and the value 6,387 is the sum of the twelfth through seventeenth bars. Note that the percentages in the third column consider only the drivers included in the three age groups. Therefore, the percentages for each of the three age groups sum to 100 percent. Approximately one-third of the drivers selected were involved in crashes with no driver-related error. Therefore, 21,183 of the drivers selected had a driver-related factor. Of the drivers with a driver-related factor, approximately 50 percent were under 25 years of age, 29 percent were 35 to 45, and 22 percent were at least 65 years old. Thus, these percentages serve as a "baseline" to consider when further categorizing the results. Note that these percentages were calculated using only drivers within the three age groups who had a driver-related factor. Therefore, the percentages for the three groups also sum to 100 percent.

To aid in the understanding of driver error causes and contributing factors, the "Related Factors-Driver Level" classifications present in the FARS database were analyzed. These individual, low-level classifications were then combined into a taxonomy of driver errors and other contributing factors (presented in the Task C report, Hankey et al., 1999). As shown in figure A16, several categories within the taxonomy, including "Aggressive driving," "Ran-off road or failure to stay in lane" and "Improper lookout or misjudgment," had much higher frequencies of occurrence than some of the other categories in the taxonomy. Also, as shown in figure A16, there is some indication that age has a *specific* relationship to the occurrence of certain types of errors.

Table A6. Three age groups selected for analysis and the relative percentage of driver-related factors.

Selected Age	Total Number	Total Percent	No Driver-Related Factors	Driver-Related Factor	Percent of Driver-Related Factors
Less than 25	14,279	45%	3,767	10,512	49.6%
35-44	10,955	35%	4,912	6,043	28.5%
65 or older	6,387	20%	1,759	4,628	21.8%
Total	31,621	100%	10,438	21,183	99.9%

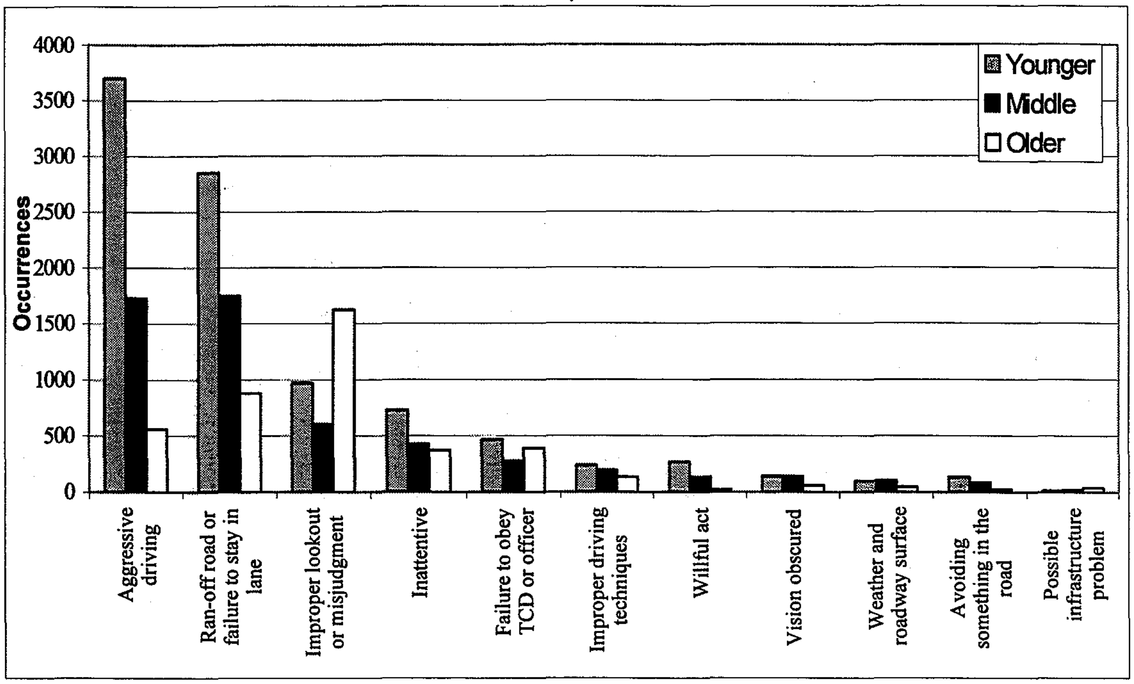


Figure A16. Driver error categories derived from the taxonomy "related factors - driver level" categorization in the FARS database.

To examine the age relationships in greater detail across the taxonomy, the frequency counts shown in figure A16 were converted to percentages by error type. The percentages of errors committed by age group are shown in figure A17. Several of the categories differ substantially from the average percentages of error represented by the total sample shown in table A6.

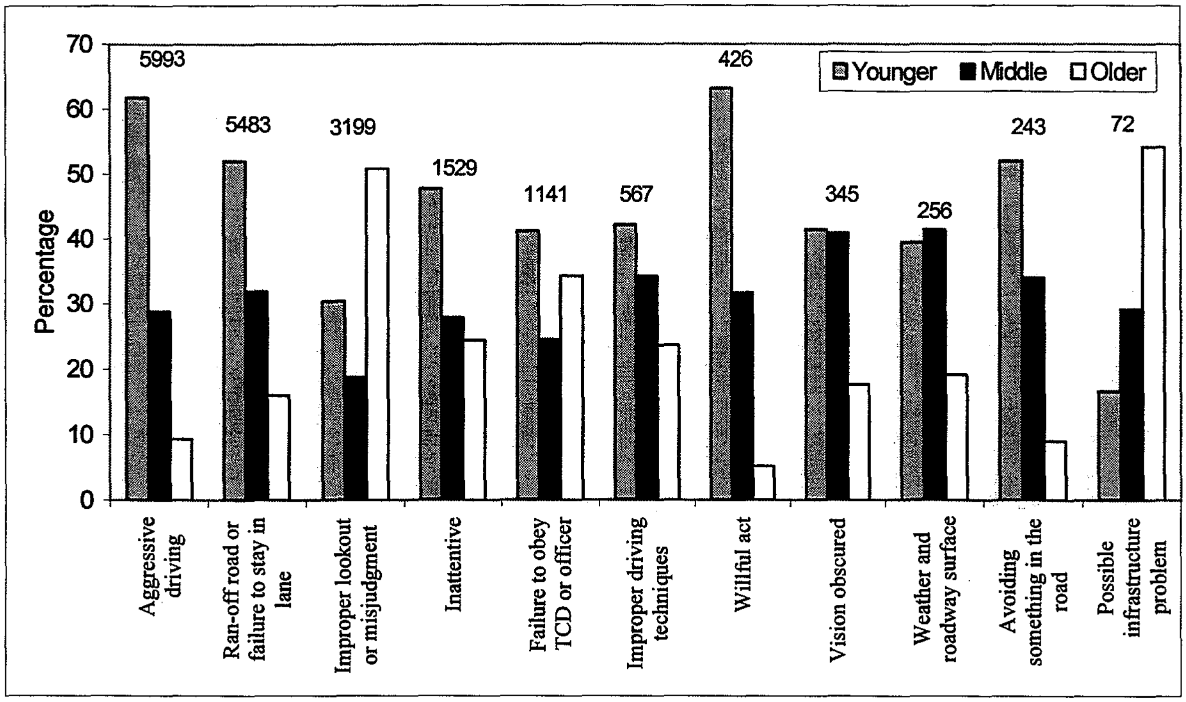


Figure A17. Percentage of errors committed by drivers of different age groups for each of the error categories in the taxonomy. (Total number of occurrences of each type of error is shown above the percentage distributions.)

Discussion

Aggressive Driving. The "Aggressive driving" category in the taxonomy was synthesized from the combination of categories in the FARS "Related factors-driver level." These categories could reasonably be associated with the tendency to drive aggressively, although this is not always the case. The categories that comprise "Aggressive driving," along with the counts for each category and each age within that category, are illustrated in figure A18.

"Aggressive driving" accounted for the largest number of fatal crashes in the taxonomy. As shown in figure A17, younger drivers appeared to commit more aggressive driving errors (62 percent) than would have been predicted by the expected frequencies (50 percent).[14] Many of

[14] Expected frequencies are defined as those in the right-hand column of table 11. In the case of aggressive driving errors, 62 percent exceeds 50 percent (actually 49.6 percent), indicating that these errors are over-represented in the younger age group, even after taking into account that younger drivers are involved in a larger proportion of fatal crashes.

the "sub-categories" listed deviated from the expected frequencies by age group for the younger drivers. Younger drivers were over-represented compared with their expected value of 50 percent in the subcategories "Driving too fast" (66 percent), "Erratic/Reckless" (54 percent), "Insufficient passing distance" (63 percent), "Prohibited pass" (70 percent), "Pass on the wrong side" (72 percent), "Hit and run" (60 percent), "Overcorrecting" (61 percent), and "High speed chase" (75 percent). Some of these errors can be characterized as mistakes stemming from inexperience, which led to errors in "Momentary decision judgment" in subcategories like "Passing distance," and an "Inappropriate control input" in subcategories like "Overcorrecting." Other errors can be characterized as errors in "Pre-meditated judgment." Many of these crashes could be the result of cases where the younger driver knowingly violated the law, such as in the cases of prohibited pass, passing on the wrong side, driving too fast, and high-speed chase. In regards to pre-meditated judgment, some cases could also be considered willful acts.

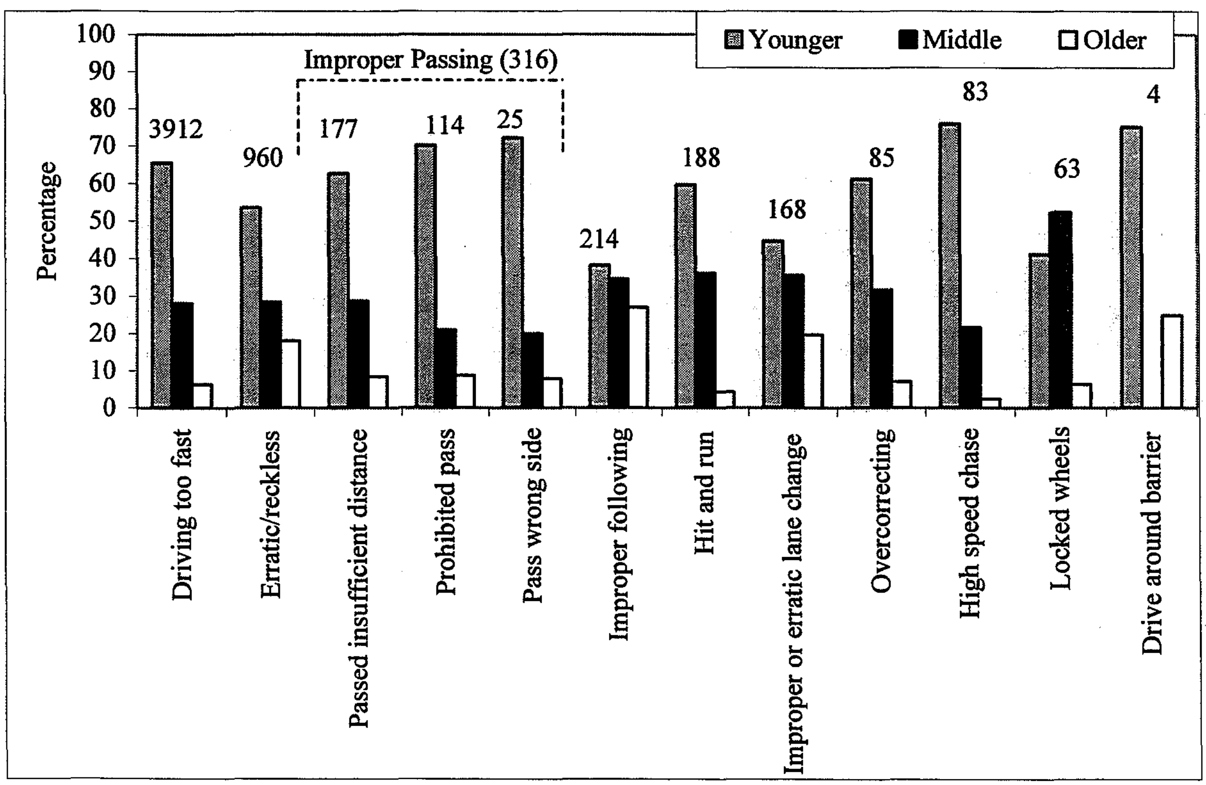


Figure A18. Number of errors for each aggressive driving subcategory and percent of drivers who committed them by age.

Not surprisingly, older drivers were less likely to perform "Aggressive driving" errors

(9 percent compared with an expected value of 22 percent). In fact, they were over-represented in only one subcategory for "Aggressive driving": "Improper following" (27 percent).

Run-off-Road or Failure to Stay in Lane. As shown in figure A16, the occurrence of fatal crashes resulting from "Failure to maintain position in the lane/Running off the road," was the second most frequent error in the taxonomy, with 5,483 occurrences. As shown in figure A17, this factor does not appear to have a large effect of age. Nevertheless, the oldest age group is somewhat under-represented as a population for this type of error (16 percent compared with an expected value of 22 percent). This effect could be due in part to older drivers being less likely to drive aggressively. Therefore, they are less likely to lose control of the vehicle and depart the road. As detailed in the Task C report (Hankey et al., 1999), fatigue is also more of a contributing factor with the younger age group than the expected value indicates.

Improper Lookout or Misjudgment. "Failure to yield right-of-way" (mostly at intersections), "Other improper turn," and "Improper start/back" were combined to create a category with 3,199 occurrences entitled "Improper lookout or misjudgment" in the taxonomy. In all three of these categories, the older driver group was greatly over-represented (53, 34, and 35 percent respectively, as compared with an expected value of 22 percent; figure A19). Particularly in the case of "Failure to yield right-of-way," it appears that older drivers are prone to misjudgments in speed and/or distance of approaching vehicles. It is interesting to note that younger drivers were under-represented in each of these categories.

Inattention. As shown in figure A16, the expected values in the "Inattentive" category mirror those of the percentage of fatal crashes for each of the three age groups. Since this was the fourth most frequent driver error (1,529 occurrences), inattention is an important problem for all age groups.

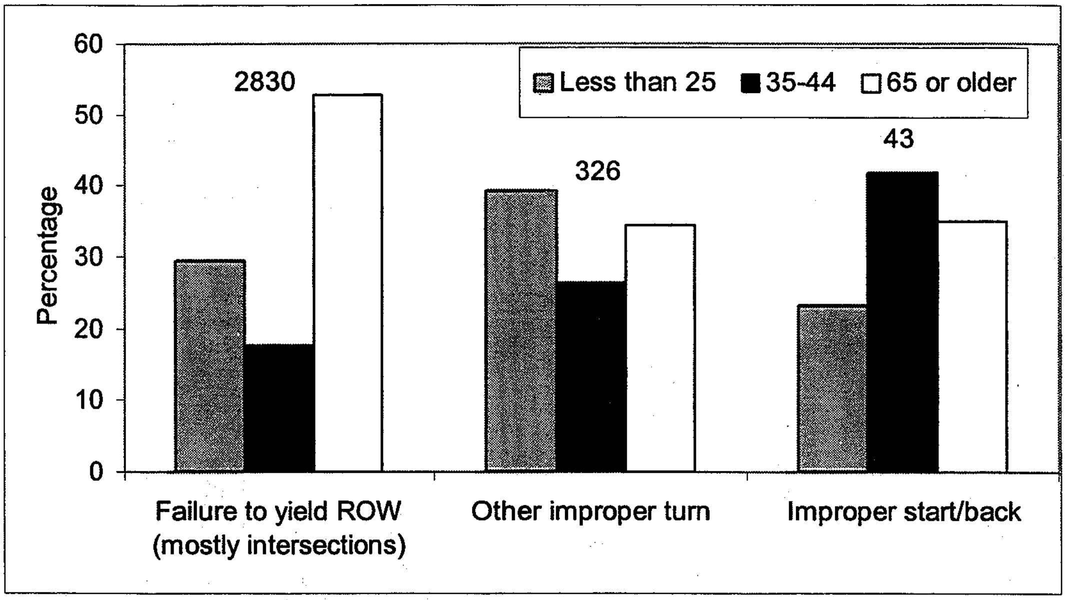


Figure A19. Number of errors for each improper lookout or misjudgment subcategory and percent of drivers who committed them by age.

Failure to Obey Traffic Control Device or Traffic Officer. "Failure to obey traffic control devices or traffic officers" accounted for 1,141 of the driver errors. As shown in figure A17, older drivers were over-represented in this category of fatal crashes (34 percent relative to an expected value of 22 percent). Several potential causal and contributing factors could explain this finding. Older drivers have been shown to have a decreased "useful field of view" (UFOV) relative to other drivers (Ball and Owsley, 1991). This means that older drivers do not see "signals" outside of the fovea as well as they once did. They may miss information in the periphery on occasion. Older drivers' possible failure to judge speed/distance accurately as described for the "Improper lookout or misjudgment" category may also be an important factor.

Driver Condition and Experience. The "Driver condition and experience" category was a combination of 10 subcategories of the "Related factors-driver level" that accounted for 1,085 occurrences. As shown in figure A20, fatigue accounted for approximately 60 percent of this category (692 occurrences). Younger drivers were more likely to be fatigued (55 percent) than their expected value (50 percent) indicated. In addition, younger drivers had higher "Operator inexperience" errors (82 percent), and "Unfamiliar with road" (70 percent) errors than the other groups. Older drivers were over-represented in the categories "Ill/Blackout" (74 percent) and "Other physical impairment" (80 percent).

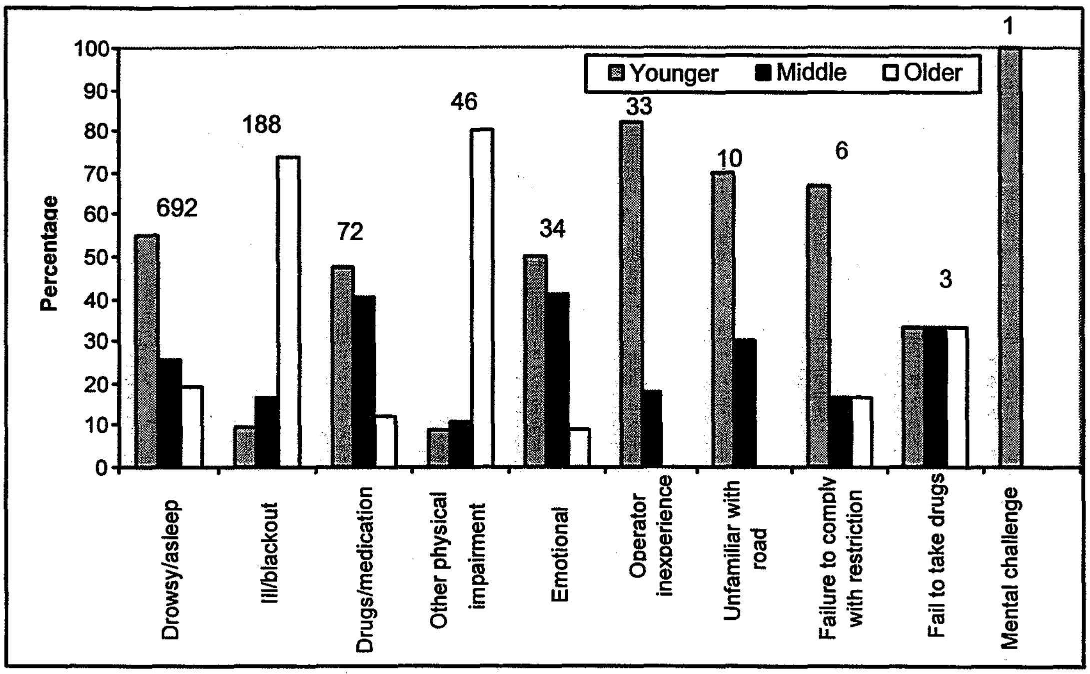


Figure A20. Number of errors for each driver condition and experience category and percentage of drivers who committed them by age.

Improper Driving Technique or Practice. "Improper driving technique or practice" comprised the following FARS subcategories: "Wrong side of the road," "Stopping in road," "Driving on shoulder or sidewalk," and "Under minimum speed limit." As shown in figure A17, middle-aged drivers account for more of these errors than expected (34 percent compared with an expected valued of 29 percent), and younger drivers had fewer of these errors than expected (43 percent compared with an expected valued of 50 percent). Each of these categories reflects behaviors that most drivers probably know are poor driving habits that could lead to crashes with pedestrians and other vehicles.

Willful Act. The FARS categories "Homicide" and "On prohibited road" make up this category. Younger drivers are over-represented in vehicular homicides (63 percent relative to an expected value of 50 percent).

Vision Obscured. Fifteen FARS subcategories make up the category "Vision obscured." A number of these categories had very low frequencies. It is interesting to note that middle-aged drivers were over-represented for this category (41 percent relative to an expected value of 29 percent). This finding is due primarily to a single subcategory, namely "Weather," where the middle age group accounts for 56 percent of the total.

Weather and Roadway Surface. The "Weather and roadway surface" category of the taxonomy (256 occurrences) consists of the FARS subcategories "Water/Snow/Oil," "Slippery surface," "Crosswind," and "Truck wind." As with the "Vision obscured" category, the middle-aged group is over-represented (41 percent relative to an expected value of 29 percent) in the "Weather and roadway surface" category as well.

Avoiding Something in the Road. "Avoiding something in the road" was a factor occurring 243 times. It contained the following FARS subcategories: "Vehicle in the road, "Animal, Phantom vehicle, Pedestrians, Debris in road," and "Rut in road." The middle-aged group is somewhat over-represented (34 percent relative to an expected frequency of 29 percent) for this category overall. This result is somewhat surprising since arguments could be made that younger and older drivers would be more likely to have trouble avoiding obstacles in the road (younger drivers because of lack of experience, and older drivers because of increased reaction times).

Possible Infrastructure Problems. Although, as shown in figure A16, this category has a low frequency relative to some of the other error categories (72 possible infrastructure problems), figure A17 shows that the older drivers are greatly over-represented in this category (54 percent relative to an expected value of 22 percent). This finding is consistent across the three FARS subcategories that make up this category, namely: "Improper exit/entry," "Wrong way on a one way," and "Turn from the wrong lane." If this finding were the result of unusual roadway/TCD designs, one might expect the younger drivers to be over-represented. Since it is the older drivers who commit more errors in these circumstances, they may be having difficulty in reading or processing guidance, advisory, or warning information at these locations.

Conclusions From the FARS Database Analysis

The cross tab analysis between driver-related factors and driver age provided several interesting findings. This analysis was for severe crashes where at least one person died. Therefore, eliminating some of these errors could have a direct impact on the number of driving-related fatalities as well as serious injuries and property damage.

Relevant driver-related factor subcategories were synthesized into a category entitled "Aggressive driving." This category accounted for 28 percent of all the driver-related factors analyzed for these age groups. Younger drivers were more likely to make these types of driver errors, whereas older drivers were less likely to make them. Efforts to mitigate younger driver crashes should emphasize reduction of aggressive driving "habits."

Older drivers were over-represented in categories of "Improper lookout and misjudgment," and "Failure to obey traffic control device or traffic officer." These two categories accounted for 20 percent of the driver-related factors and 43 percent of the older driver related factors. The subcategories that made up these categories were items such as "Failure to yield at an intersection." There appears to be a problem with older drivers judging the speed and distance of oncoming vehicles and seeing or obeying TCDs. This result has obvious infrastructure implications. The category "Possible infrastructure problems" also indicated that older drivers were affected more by the infrastructure than were other drivers. With our aging driving population, infrastructure may become an even more important factor in the future.

"Ran-off the road or failure to stay in lane" accounted for 26 percent of the driver-related factors. From an infrastructure standpoint, drivers could be protected from committing either of these errors by including barriers (e.g., guardrails, medians, etc) in the roadway system. However, a cost/benefit analysis would have to be done on a case-by-case basis to determine the feasibility of incorporating these barriers into a roadway system. Younger drivers were slightly more likely to commit this error than their expected value indicated, and older drivers were slightly less likely to commit this error. This difference could be a result of younger drivers' tendency to drive aggressively.

Middle-age drivers were over-represented in several of the categories. Together, these categories account for 6.6 percent of the driver errors and contributing factors. The categories were:

- Improper driving techniques such as stopping in the middle of the road,
- Vision obscured such as by the weather,
- Weather and roadway surface such as water/snow/oil on roadway, and
- Avoiding something in the road such as an animal.

This finding may be a result of exposure. Middle-aged drivers may be forced to drive under adverse conditions more than either older or younger drivers because of work and other commitments that require them to travel.

Conclusions Regarding the Traditional Database Analysis with Emphasis on Driver Error

Based on the results of the traditional database analyses using the PA database and the FARS database, it can be seen that the traditional approach provides a good indication of what happened during a crash event. However, it can also be seen from these results that this type of analysis is restricted and can only deal with the pre-specified categories found in the data fields. Analysts interested in information not included in the pre-specified categories are not able to work beyond this. That is, the structure of traditional database search approaches limit the analyst to data found in the data fields. The next section highlights the results of a non-traditional approach to database analysis that provides a means to delve deeper into the details of a crash.

2. Non-Traditional Database Analysis Using the North Carolina Narrative Accident Database

The analyses that were conducted on the North Carolina accident database are presented in this and next sections. A moderately comprehensive discussion of these analyses is presented in this final report, and the complete description can be found in the Task C report (Hankey et al., 1999).

The North Carolina Narrative Accident Database allows researchers to perform keyword searches on accident report narratives. The narratives originate from the written accident report provided by the attending police officer or from post-accident interviews conducted by accident investigators. Clerks at the Division of Motor Vehicles (DMV) in Raleigh, North Carolina, then type the narratives into the database. The Highway Safety Research Center (HSRC) of the University of North Carolina, Chapel Hill has developed a program to extract narratives based on whether they contain a given keyword or group of keywords.

Objective

The objective in using this database was to pinpoint categories or types of driver errors that contributed to motor-vehicle crashes and to evaluate any relationships between driver error and the infrastructure. For the purpose of this analysis, the infrastructure was defined as road geometry, TCDs, and roadway delineation. The data were analyzed to highlight relationships between this infrastructure and driver error. For example, motor vehicle crashes when merging may be associated both with failing to look left and with failure to comply with yield signs. It was hoped that this method would provide insights into driver error not available through traditional methods of accident database analysis.

Approach

A multi-step procedure was followed to extract and categorize the narratives. The 1994 database was selected for this analysis because it was found to be of ample size (more than 209,000 entries) and provided substantial crash event details in most of its records. Records without sufficient detail were not included in the analysis.

The database was searched using keywords (including keyword "stems"). Table A7 shows the lists used for each of the four searches. The four searches performed were Traffic Control Device-Related, Roadway Structure-Related, Roadway Delineation-Related, and Driver Reasons/Excuses-Related. In the first column, the word "flash" appears with an asterisk following it. This is a stem word, which could have any ending, such as flash, flashing, or flashed. Thus, narratives would be retrieved if they contained the word "flash." The four searches resulted in the number of narratives shown under the "count" columns of table A7. These numbers sum to values shown in the first numerical column of table A8, under "gross number of narratives."

Table A7. Keyword list and counts obtained for each area of interest.

Traffic Control Devices	Counts	Roadway Structure	Counts	Roadway Delineation	Counts	Reasons/ Excuses	Counts
Caution	30	Abut*	16	Barri*	207	Admit*	42
Flash*	219	Bridge	752	Center*	2,249	Because	668
Green	1,799	Bypass	81	Cone	63	Beli*	49
*Light	4,770	Corner	461	Construction	226	Decid*	122
Red	9,192	Crest	217	Cross*	6,567	Deni*	16
*Sign	4,115	Curve	2,827	Curb	787	Describ*	21
*Signal	43	Exit	739	Divid*	66	Due	2,151
Yellow	427	Fork	105	Ditch	4,919	Indicat*	117
Yield	1,776	Grade	85	Dropoff	0	Noti*	445
Zone	136	Hill	879	*Edge	224	Realiz*	403
		Inters	1,452	Flag	50	Reas*	526
		Lane*	1,607	Headon	78	Result of	83
		Overpass	29	Line*	1,747	Said	1,000
		Rail*	1,904	Marker*	30	Think	81
		*Ramp	742	*Median	1,001	Thought	699
		Sharp*	382	Merg*	1,327	Told	70
		Shoulder	3,138	Oncoming	619		
		Steep	130	Ranoff	103		
		Toll*	1	Reflec*	29		
		Underpass	18	Sight	18		
		*Wall	304				

Table A8. Keyword-retrieved narratives by search.

	Gross Number of Narratives	Number with Duplicates Removed	Final Sample Analyzed
Traffic Control Device-Related	22,507	16,047	1,008
Roadway Structure-Related	15,869	13,009	1,000
Roadway Delineation-Related	20,310	15,680	1,044
Reasons/Excuses-Related	6,493	6,094	997

Narratives containing two keywords were retrieved twice, those with three keywords were retrieved thrice, and so on. A procedure was therefore developed to remove duplicates, triplicates, etc. so that each narrative appeared only once. This resulted in the numbers (counts) shown in the second column of table A8.

The final column of table A8 shows the number of narratives read and classified for this report. It was decided that reading and classifying approximately 1,000 samples per keyword list would result in moderately stable proportions while also keeping labor efforts within bounds.

In addition to the keyword searches, a uniform sample search was performed. This search was conducted to provide representative proportions of various driver errors and the corresponding infrastructure elements involved. Thus, judgments could be made regarding the relative frequencies of occurrences of various types of crashes. Also, this search had the ability to pick up error types that might be missed by a keyword search.

For the uniform sample, HSRC first provided a sample of approximately 10,000 narratives. These were obtained by taking every 200th narrative. Once the data were received, they were again uniformly sampled, taking every tenth narrative, and resulted in a sample of 992 narratives.

Figure A21 depicts the five searches performed on the 1994 North Carolina narrative database. Three searches were intended to associate errors with infrastructure, the uniform sample was intended to provide proportions, and the reasons/excuses search was intended to provide information on common driver errors reported in the narratives.

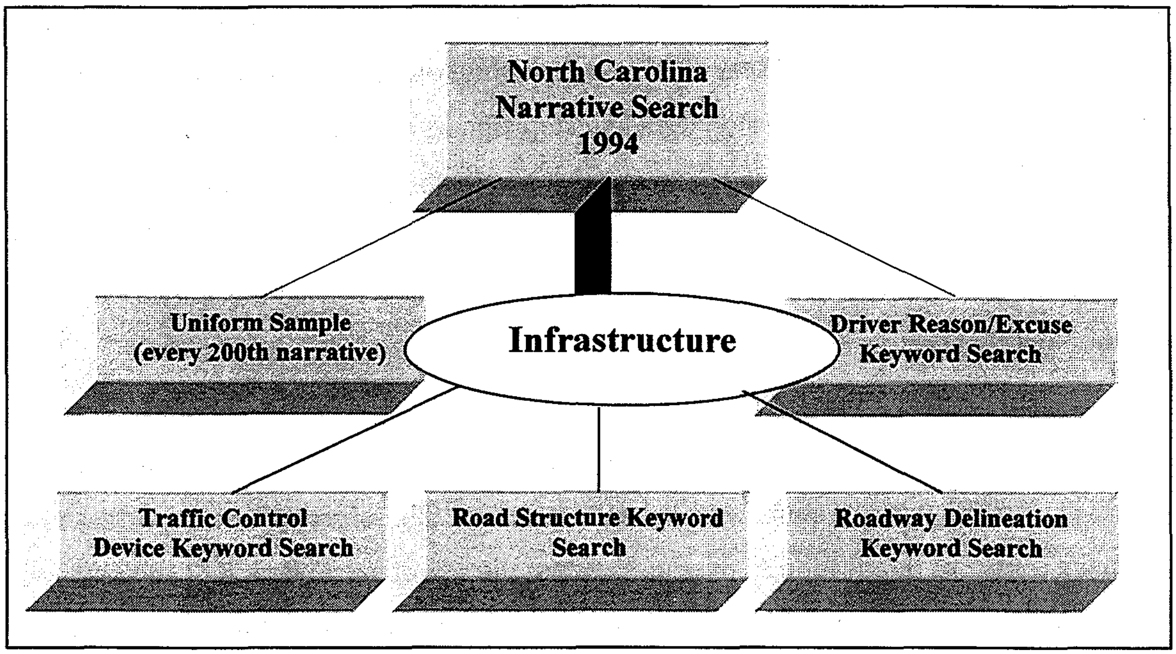


Figure A21. Five samples of NC MVA database narratives.

Once the five samples of approximately 1,000 narratives had been obtained, they were individually analyzed (narrative by narrative) and placed in a classification scheme. The classification scheme for each search was developed empirically and to some extent according to the objectives of the specific search. For example, the search on TCDs used several classifications involving signs and signals as major categories. On the other hand, the road structure search used several classifications such as curves, intersections, and ramps.

In all cases, the classifications were constructed as tree diagrams. Tree structures have the advantage of allowing any level of subclassification that the search data will support. Previous work involving accident taxonomies has achieved success using these structures (Treat, 1980; Wierwille and Tijerina, 1996). To develop the tree for each search, narratives were studied until patterns could be determined. For example, in the TCD search, it became clear that stoplights, stop signs, and other intersection crashes were prevalent. Thereafter, supplemental major categories were developed, and then each major category was further subdivided (split into branches) as needed. This procedure worked well and allowed the data to "drive" the tree.

Of course, there was an element of judgment in setting up the tree structure. Different classification schemes are possible. For example, stop light and stop sign crashes are usually of two types: "Failure to yield" and "Rear end." Conceivably, one could use these two latter categories as major categories with stop light and stop sign as second-order categories. In fact, this was done for the uniform sample taxonomy. However, for each search, only one classification scheme was developed: the one that seemed to best fit the data. Furthermore, no attempt was made to enforce uniformity across searches. It was believed that each search should have a structure that best fit the data for that search.

Duplication of narratives retrieved by keywords was eliminated in each final search sample. However, duplication was not eliminated *between* searches. Therefore, it was important to ascertain the degree of duplication or overlap between the searches. Figure A22 illustrates the number of duplicates between pairs of infrastructure searches. (Infrastructure searches were considered most likely to have duplicates.) Noting that there are approximately 1,000 narratives in each search, the histogram in figure A22 shows that the maximum duplication between searches is only 2.3 percent. Thus, any similarity of findings among the searches was not the result of the search technique that was used.

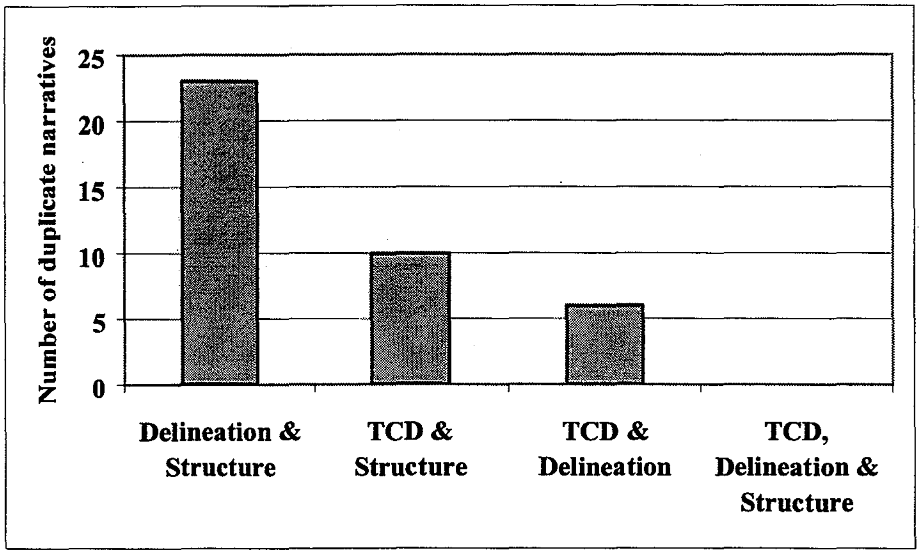


Figure A22. Numbers of narratives that appeared in two or more infrastructure searches.

All classification results were independently reviewed by a second researcher. This researcher's responsibility was to check for errors and to resolve questions as to where certain narratives might be placed (if they could be put in more than one place in the tree structure). In the analyses to be presented here, each given narrative is counted in only one place in the structure.

Results

The five sets of search results are presented in figures A23 through A27. Each search is presented consecutively, first by means of an overview histogram showing the major categories, and thereafter by means of the detailed taxonomy developed.

The taxonomies use a set of conventions that the reader needs to understand. These conventions will be described by using figures A23a and A23b as examples. Figure A23a is a histogram derived from the major (first-order) categories of the taxonomy. These categories are shown in figure A23b. The numbers in rectangles in figure A23b are the numbers of narratives classified under the first-order categories. These numbers are referred to as occurrences. The histogram in figure A23a uses slightly different wording in some cases, and combines first-order categories with corresponding numbers of occurrences.

The taxonomy continues in figure A23b. Each first-order category is bolded and appears against the left margin. Second-, third-, and fourth-order categories are progressively farther away from the left margin, have smaller type, and are not bolded. Note that the occurrences in the fourth-order categories add up to the occurrences in the third-order category under which they appear. For example, at the top of page 276, "General" (with 10 occurrences) and "View obstructed by another vehicle" (with 2 occurrences) sum to the 12 occurrences listed with the "Failed to see" third-order category. This process of summing continues from the third order to the second order and from the second order to the first order. Of course, the sum of the first order occurrences is the size of the database that was analyzed.

In some cases additional columns are used in the figures to minimize save space. Page 278 shows low-count first-order categories in a second column.

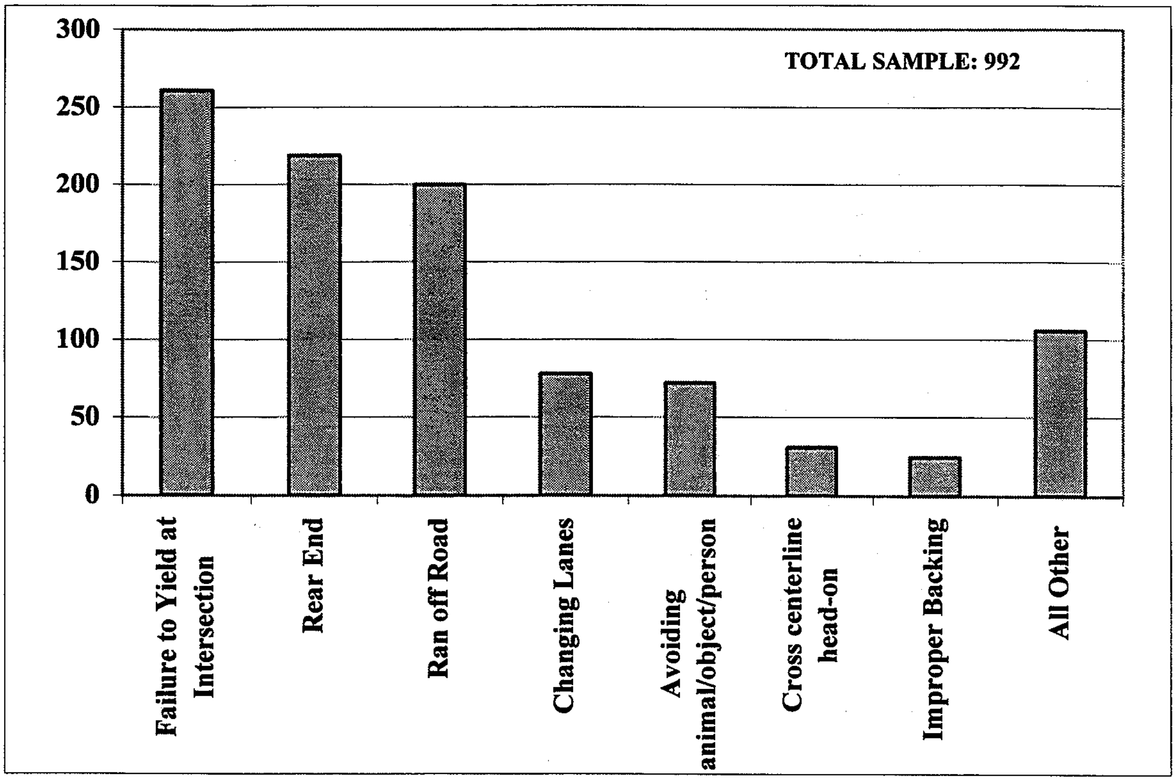


Figure A23a. Major categories for the uniform sample.

261	Failure to yield at intersection
219	Hit lead vehicle in rear
200	Ran off road
78	Changing lanes
72	Avoiding animal, object, person in roadway
31	Crossed center lane head-on
25	Improper backing
22	Other
20	Mechanical failure
17	Driver distracted
11	Driver physical condition
9	Driver misapplication of control
8	Making U-turn
6	Parking lot driving
5	Weather and roadway structure
3	False assumption
2	Driver did not see sign
2	Driver did not see vehicle because of weather
1	Made turn from wrong lane

Total: 992

Figure A23b. Uniform sample taxonomy.

- **261 Failure to yield at intersection**
  - 188 Intersecting roads
    - 71 Make left turn across path
      - 53 General
      - 12 Failed to see
        - 10 General
        - 2 View obstructed by another vehicle
      - 6 Stopped initally
    - 64 Perpendicular paths
      - 38 General
      - 12 Failed to see
      - 10 Pulled in front of oncoming vehicle to drive in the same direction
      - 4 Stopped initally
    - 22 Pulled in front or failed to yield right away
      - 15 General
      - 4 Didn't see
      - 3 Initally stopped
    - 15 Turned too tight or wide and side-swiped
      - 8 Turned too wide
      - 7 Turned too tight
    - 15 Waved through by other driver
    - 1 Fog obscured intersection
  - 37 Traffic signal
    - 22 Failed to stop at traffic signal
      - 19 General
      - 3 Failed to see signal
    - 12 Both had green light or started maneuver on green
    - 2 Saw a right on red turn and assumed had a green light
    - 1 Made an incorrect right on red turn
  - 36 Stop sign
    - 22 Ran stop sign
    - 10 General
    - 8 Ran stop sign and continued off road
    - 4 Failed to see stop sign
      - 3 General
      - 1 Sign obstructed by fog
  - 14 Stopped first then proceeded
    - 10 General
    - 4 Didn't see oncoming traffic

Figure A23b. Uniform sample taxonomy (continued).

- **219 Hit lead vehicle in rear**
  - 69 Multiple lead vehicles slow or stopped
    - 48 Lead vehicle stopped traffic
      - 21 General
      - 16 Attempted to stop
      - 11 Failed to reduce speed
    - 21 Lead vehicle slowing
      - 8 General
      - 8 Attempted to stop
      - 5 Failed to reduce speed
  - 65 Lead vehicle turning
    - 41 Lead vehicle turning left
      - 23 Stopped to make turn
        - 16 General
        - 7 Another vehicle stopped ahead
      - 9 Lead vehicle slowing to make turn
        - 7 General
        - 2 Another vehicle stopped ahead
      - 9 During the turn
    - 13 Turning direction unknown
      - 8 Lead vehicle stopped to make turn
        - 4 General
        - 4 Another vehicle stopped ahead
      - 4 Lead vehicle slowing to make turn
        - 3 General
        - 1 Another vehicle stopped ahead
      - 1 Lead vehicle making turn
    - 11 Lead vehicle turning right
      - 6 Lead vehicle making turn
        - 3 General
        - 3 Lead vehicle stopped before completing turn
      - 4 Lead vehicle slowing to make turn
      - 1 General
  - 29 Lead single vehicle stopped or slowing
    - 24 Lead vehicle stopped
      - 9 General
      - 9 Attempted to stop
      - 6 Failed to reduce speed
        - 3 Failed to see
        - 2 General
        - 1 Lead vehicle stopped to discharge passenger
    - 5 Lead vehicle slowing
      - 4 Attempted to stop
      - 1 General
  - 18 Rear-ended lead vehicle stopped or slowing for a traffic light
    - 14 Lead vehicle stopped for traffic light
      - 7 General
      - 5 Attempted to stop
      - 2 Failed to reduce speed
    - 4 Lead vehicle slowing for traffic light
      - 2 General
      - 2 Yellow light
  - 12 General
  - 9 Striking vehicle was intially stopped
    - 3 Moved forward into other vehicle
    - 3 Lead vehicle started forward and stopped
    - 2 Saw other traffic start to move
    - 1 Light turned green
  - 6 Lead vehicle stopped for construction, school bus, emergency vehicle
    - 3 Construction
    - 1 Emergency vehicle
    - 2 School bus
  - 5 Lead vehicle slowing to merge
  - 2 Intersection
  - 2 Failed to reduce speed
  - 2 Rear-ended at stop sign

- **200 Ran off road**
  - 55 Ran off right
    - 42 General
    - 9 Ice
    - 4 Rain
  - 31 Trying to negotiate curve
    - 22 General
    - 5 Ice
    - 4 Wet roadway
  - 24 Ran off left
    - 16 General
    - 5 Ice
    - 3 Rain
  - 22 Ran off one way, swerve back across to the other side
  - 17 Ran off road to avoid worse collision
  - 14 Ran off road, side unspecified
    - 10 General
    - 4 Ice
  - 12 Speeding
    - 10 General
    - 2 Wet roadway
  - 11 Attempted to turn
    - 9 General
    - 2 Wet Road
  - 7 Fleeing police
  - 4 Ramp
  - 3 Loose gravel on road

Figure A23b. Uniform sample taxonomy (continued).

- 78 Changing lanes
  - 21 Side-swiped other vehicle
  - 21 Attempting to avoid a slowed or stopped vehicle
    - 11 Other vehicle attempting to turn
    - 10 General
  - 11 Failed to see
    - 10 General
    - 1 Other vehicle obstructed view
  - 6 Attemping to change lanes as other vehicle passing
  - 5 Attempted to pass and lost control
  - 5 Attempting to change lanes to make a turn
  - 4 Merged in front of other vehicle
  - 3 Changing lanes to the same lane
  - 2 Changed lane had a slow or stopped vehicle
- 72 Avoiding animal, object, or person in roadway
  - 32 Deer
  - 13 Parked vehicle
  - 11 Pedestrian
  - 6 Domestic animal
  - 6 Struck object in road
  - 4 Bike or moped
- 31 Crossed center lane head-on
  - 13 General
  - 5 Traveling around a curve
  - 5 Lost control on wet roadway and crossed median
  - 4 Ran off roadway and travelled back across
  - 2 Attempting to pass
  - 1 Passing a stopped vehicle
  - 1 Vision obstructed
- 25 Improper backing
  - 12 Backed onto roadway
    - 7 General
    - 5 Didn't see oncoming vehicle
  - 8 Backed into parked vehicle or fixed object
  - 5 Backing to correct a poor maneuver
- 22 Other
- 20 Mechanical failure
  - 9 Tire problems
  - 7 Brakes failed
  - 4 Other mechanical
- 17 Driver distracted
  - 10 Internal
  - 7 External
- 11 Driver physical condition
  - 6 Driver fainted/blackout
  - 5 Driver fell asleep
- 9 Driver misapplication of control
- 8 Making U-turn
- 6 Parking lot driving
  - 4 General
  - 2 Backing accidents
- 5 Weather and roadway structure
  - 4 Bridge
    - 3 Icy
    - 1 Fog
  - 1 Grade
- 3 False assumption
- 2 Driver did not see sign
- 2 Driver did not see vehicle because of weather
- 1 Made turn from wrong lane

Figure A23b. Uniform sample taxonomy (continued).

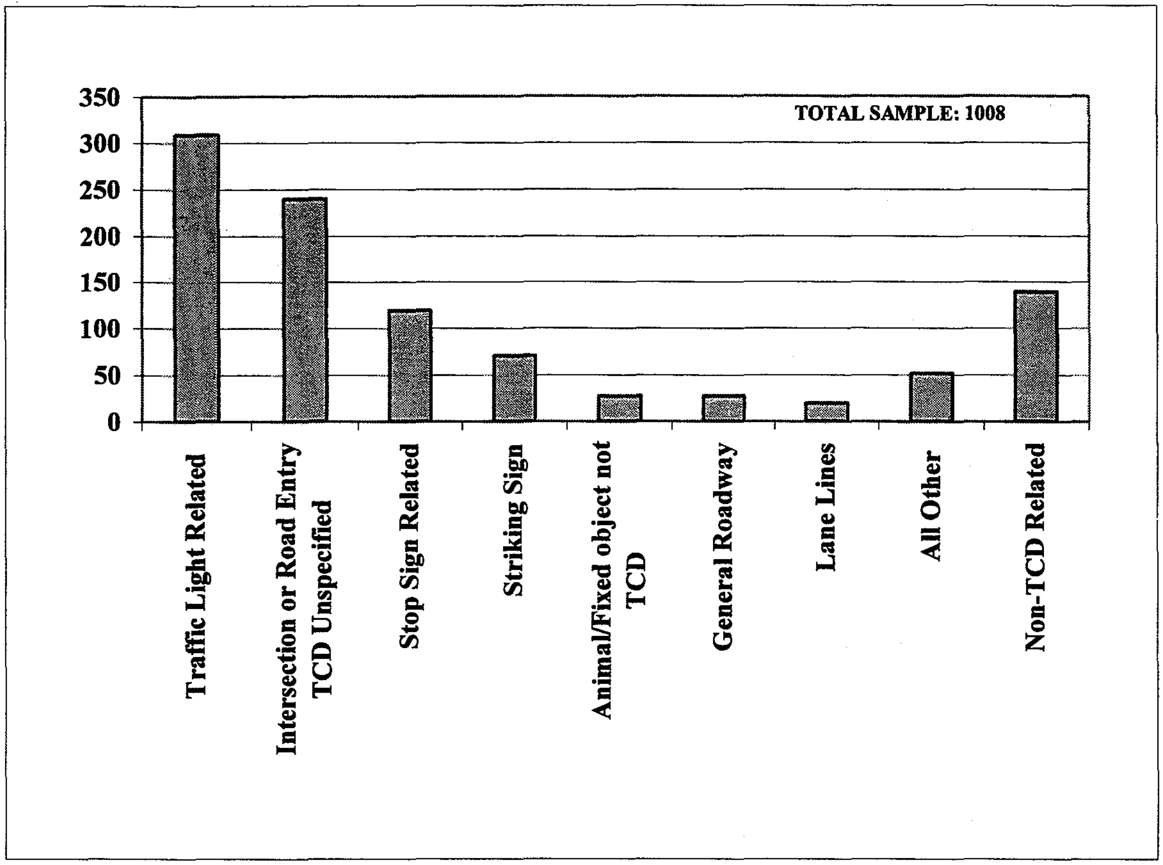


Figure A24a. Major categories for the TCD search.

309	Traffic light (conventional traffic signal)
240	Intersection or road entry; TCD, if any, unspecified
120	Stop sign
71	Striking traffic sign
28	Struck animal/fixed object (not a TCD)
28	General roadway, not intersection or unspecified as intersection
20	Lane lines
14	Flashing red, flashing yellow
9	Yield sign
4	Railroad crossing
2	Caution
26	Other

Total: 1008

Figure A24b. TCD taxonomy.

309 Traffic light (conventional traffic signal)

- 160 Ran red or yellow/red
  - 116 General
  - 19 Both drivers claim green
  - 6 Entered, not sure of color
  - 4 Entered before green
  - 4 Right turn on red
  - 3 Did not see light turn red
  - 2 Did not see light
  - 2 Distracted
  - 1 Skidded into intersection
  - 1 Assumed stop light was flashing red
  - 1 Incapacitated
  - 1 Car chase
- 120 Rear end
  - 71 With vehicle(s) stopped at light
    - 66 General
    - 2 Skidded
    - 2 Pedal misapplication
    - 1 Distracted
  - 22 After starting off on green
  - 17 As lead vehicle decelerates for red or yellow
  - 2 With vehicles stopped in intersection
    - 1 General
    - 1 Blinded by headlights
  - 2 With vehicle remaining stationary on change to green
    - 1 General
    - 1 Blinded by sun
  - 2 With vehicle in left-turn lane
  - 2 With vehicle stopped for emergency vehicles
  - 1 Evasive manuevers to avoid rear-ending results in another collision
  - 1 At on ramp road
- 12 Failure to yield
  - 9 Left turn at unprotected green
  - 1 Left turn on yellow
  - 1 Assumed left arrow was green
  - 1 Entered on green, but did not see residual vehicle
- 7 Backed
  - 3 At red
    - 2 General
    - 1 To trip sensor
  - 3 From side street or driveway into vehicle waiting at red
  - 2 Rolled back
- 4 Changed lanes in intersection
- 3 Malfunctioning signal
- 2 Wide turn
- 1 On green, went straight from left turn lane

Figure A24b. TCD taxonomy (continued).

240 Intersection or road entry; TCD, if any, unspecified

- 181 Failure to yield
  - 103 General (when entering or leaving roadway or intersection)
  - 42 While making a left turn
    - 39 Head on
    - 1 Side strike
    - 1 With vehicle making a right turn
    - 1 Sunlight glare
  - 32 On entering intersection
    - 19 General
    - 5 Did not see other vehicles
    - 3 Skidded
    - 1 Wrong assumption about other vehicle
    - 1 While making a right turn
    - 1 Claimed brake failure
    - 1 Alcohol involvement
    - 1 Distracted
  - 2 Struck pedestrian while turning
  - 1 Obstructed vision at intersection
  - 1 While making a U-turn
- 36 Rear end
  - 8 With vehicles thought to be moving forward
  - 8 With slowing vehicle
    - 3 General
    - 3 Making a turn
    - 1 Yielding to emergency vehicle
    - 1 Road rage
  - 8 With stopped vehicle
    - 5 Making a turn
    - 2 General
    - 1 Distracted
  - 5 With vehicle in intersection
    - 4 Distracted
    - 1 General

  - 4 Evasive maneuver to avoid, results in other collision
  - 2 Pedal misapplication
  - 1 Rolled forward
- 8 Turn signal
  - 4 Incorrect turn sign used
    - 2 Signaled right, turned left
    - 1 Signaled left, turned right
    - 1 Signaled turn, went straight
  - 3 Failure to use
    - 2 General
    - 1 Opposing vehicle speeding
  - 1 Not familiar with hand signals
- 7 Backing
  - 3 Rolled back
    - 2 General
    - 1 Pedal misapplication
  - 2 General
  - 2 Backed into roadway
    - 1 General
    - 1 Vision obscured
- 8 Other
  - 2 Passing
    - 1 Making a right turn, struck by vehicle passing on right
    - 1 Making a left turn, struck by vehicle passing on left
  - 2 Wide turn
  - 1 Illegal turn
  - 1 Vehicle with headlights off, not seen
  - 1 Lane change in or near intersection
  - 1 Head-on caused by failure to keep right in intersection

Figure A24b. TCD taxonomy (continued).

- **120 Stop sign**
  - 60 Ran stop sign
    - 44 General
    - 8 Did not see
      - 4 Distracted
      - 2 General
      - 1 New sign
      - 1 Unfamiliar area
    - 5 Skidded through
    - 3 Obscuration
      - 2 Fog
      - 1 Obstruction
  - 31 Failed to yield
    - 25 Failed to yield after stopping
      - 13 Did not see
      - 7 General
      - 5 While turning
    - 6 General
  - 23 Rear end
    - 18 With vehicle stopped at sign
    - 4 Stopped, but started up
    - 1 Movement to avoid
  - 6 Other
    - 4 Backed at sign
    - 2 Wide turn

- **71 Striking traffic sign**
  - 69 Ran off road
    - 36 General
    - 11 Weather
      - 7 Ice
      - 3 Wet pavement/hydroplaning
      - 1 Sun glare
    - 5 On curve or turn
    - 5 Speeding
    - 5 Evasive manuever
    - 3 Vehicle failure
      - 1 Steering
      - 1 Tire
      - 1 Loose towed vehicle
    - 3 Fell asleep
    - 1 After striking deer
  - 2 On road
    - 1 Struck traffic barrier sign
    - 1 Struck road construction sign

- **28 Struck animal/fixed object (not a TCD)**
  - 16 Utility pole/light pole/post/street sign
    - 6 General
    - 2 Distracted
    - 2 Evasive maneuver
    - 2 Incapacitated
    - 1 In curve
    - 1 Speeding
    - 1 Skidding
    - 1 Wet pavement/hydroplaning
  - 6 Tree
    - 2 In curve
    - 1 General
    - 1 Ice
    - 1 Evasive maneuver
    - 1 Bailed out of vehicle
  - 2 Deer in roadway
  - 1 Wire across roadway (overheight)
  - 1 Bridge deck (overheight)
  - 1 Construction zone barrier
  - 1 Guardrail

- **28 General roadway, not intersection or unspecified as intersection**
  - 20 Rear end
    - 6 General
    - 2 Speeding
    - 2 Pedal misapplication
    - 2 Backlights not working/not seen
    - 1 Deer
    - 1 Wet pavement/hydroplaning
    - 1 Unlit trailer
    - 1 With vehicles(s) slowing for construction
    - 1 Evasive manuever, hit guardrail
    - 1 With vehicle(s) stopped for traffic
    - 1 Distraction
    - 1 Fell asleep
  - 6 Ran off road
    - 2 Lost control
    - 1 On curve
    - 1 Headlight glare
    - 1 Speeding
    - 1 General
  - 1 Evasive maneuver to avoid vehicle with no headlights
  - 1 Sunlight glare

Figure A24b. TCD taxonomy (continued).

- 20 Lane lines
  - 14 Crossed yellow/double yellow
    - 6 Passing
      - 5 General
      - 1 Struck left turning vehicle
    - 3 General
    - 2 Lost control
    - 1 Distracted
    - 1 Struck pedestrian standing on yellow
  - 4 Failure to remain in line
    - 3 Turning vehicles(s)
    - 1 General
  - 2 Crossed centerline in no passing zone

- 26 Other
  - 13 Lane change general
  - 1 Crosswalk rear end
  - 2 With crossing pedestrians, signs unknown
  - 7 Illegal parking

- 14 Flashing red, flashing yellow
  - 7 Ran flashing red
  - 5 Failed to yield
    - 4 After stopping at flashing red
    - 1 At flashing yellow
  - 2 Rear end with vehicle stopped for flashing red
    - 1 At turn light
    - 1 At fire station

- 9 Yield sign
  - 7 Rear end
    - 3 Lead vehicle starts up but stops
    - 2 With slowing vehicle
    - 2 With stopped vehicle
  - 2 Failure to yield

- 4 Railroad crossing
  - 1 Rear end with vehicle stopped at gate
  - 3 Crossed tracks
    - 1 Signal unknown
    - 1 Flashing reds and bells activated
    - 1 Claimed brake failure

- 2 Caution
  - 2 Failure to heed (general)

Figure A24b. TCD taxonomy (continued).

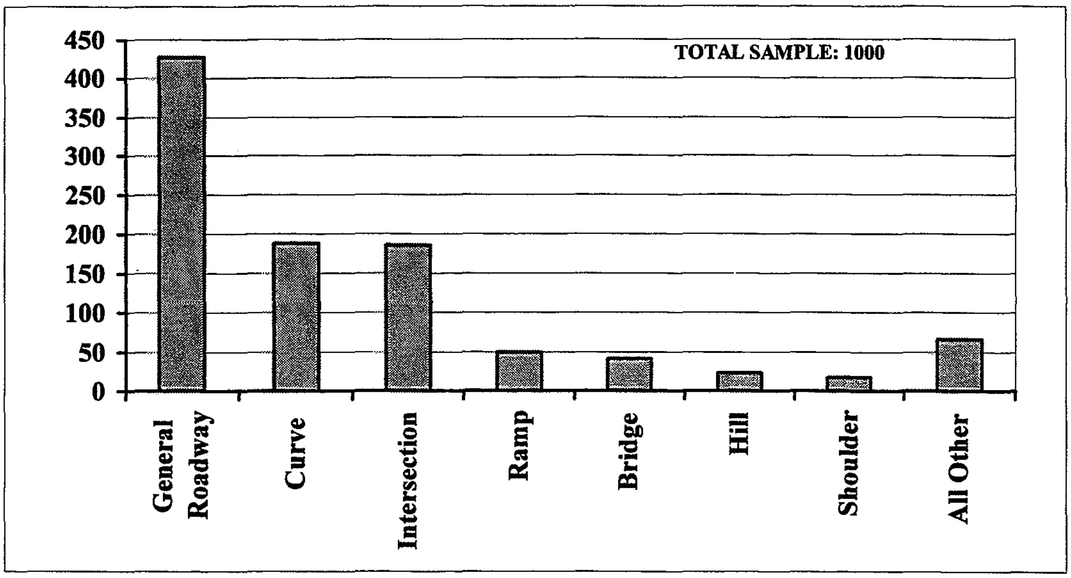


Figure A25a. Major categories for the roadway structure search.

428	General roadway
189	Curve
186	Intersection
50	Ramp
41	Bridge
23	Hill
17	Shoulder
15	Public vehicular area
11	Railroad
11	Driveway
10	Parking lot
9	Undeterminable
5	Grades
3	Bypass
1	Median
1	Work zone

Total: 1000

Figure A25b. Roadway structure taxonomy.

Other Human Errors. "Other human errors" accounted for 20 percent of the contributing factors (figure A4). Occurrences were placed in this category when it was thought an error had occurred but it did not fit into the decision or recognition categories. The "Other" category was further divided into the seven categories shown in Figure A8.

"Failure to respond to a TCD" accounted for 5.6 percent of the contributing factors. For example, running a red light or a stop sign for unknown reasons would fall into this category. Note that this category is not inclusive of all TCD-related errors; it only includes the TCD errors in which drivers failed to respond and there was not enough information to place the occurrence in a more meaningful category. For example, drivers failed to respond to a TCD in the category "Ran red light but did not see it change red," but this factor was better described as a recognition problem. Over the entire taxonomy, TCDs accounted for 7.5 percent of the contributing factors. This estimate does not include "Proceeding without clearance," which is discussed in detail later.

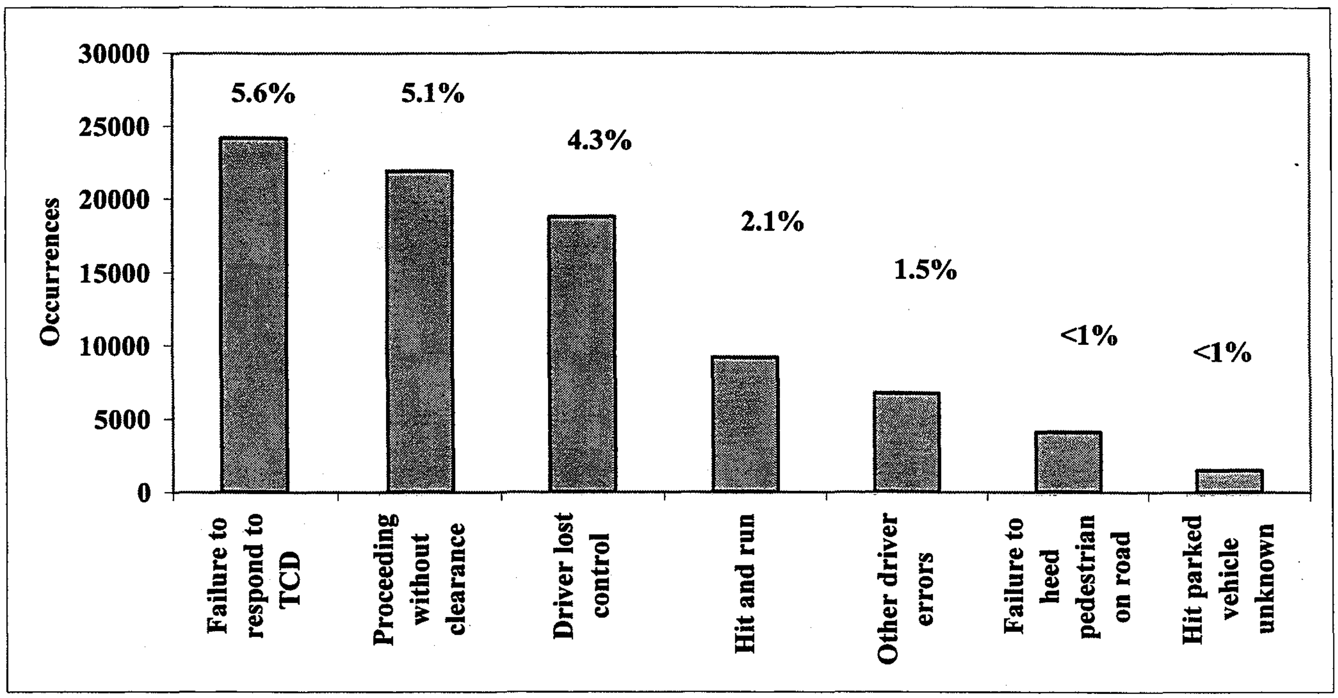


Figure A8. Other human error categories.

The TCDs and counts included in the "Failure to respond to a TCD" category are shown in figure A9. As has been shown in other analyses included in the report, traffic signals and stop signs are associated with the bulk of the TCD-associated crashes. The number of crashes associated with traffic signals and stop signs is actually higher since there are additional factors described in other places in this taxonomy that also include these TCDs (figure A2). Note that the main reason that the counts for these two TCDs are higher is that there are more of these devices than other TCDs. An attempt was made to obtain relative numbers of these devices in Pennsylvania. Unfortunately, there was no TCD asset management system available, so the relative numbers of these devices could not be determined.

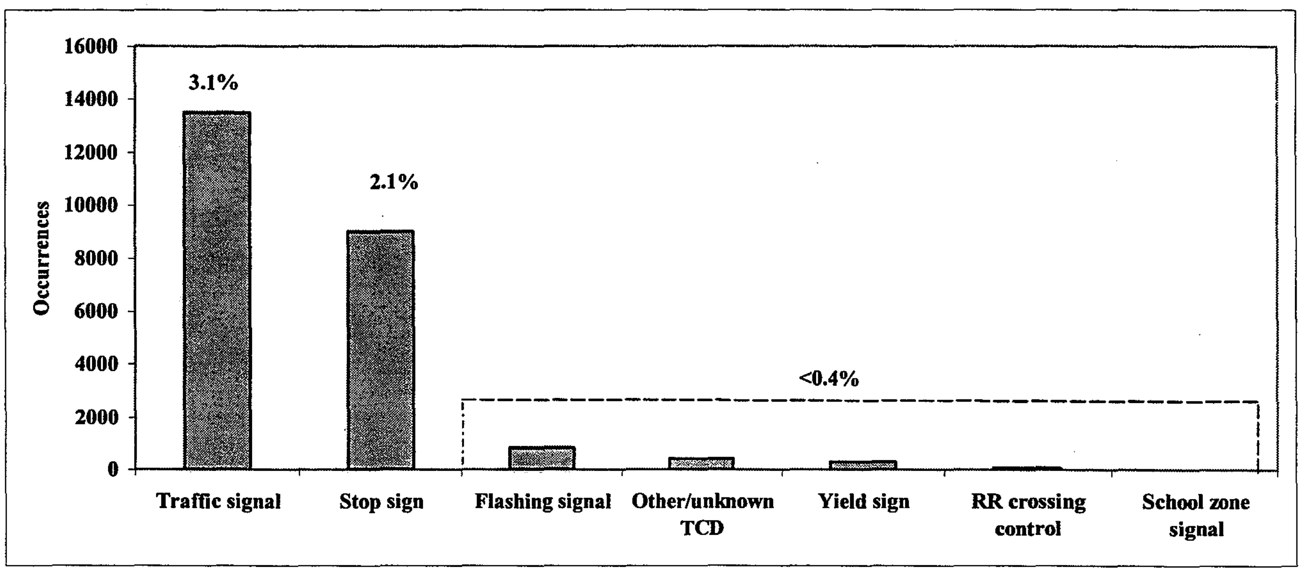


Figure A9. Failure to respond to TCD categories.

"Proceeding without clearance" accounted for 5.1 percent of the contributing factors. This category is interesting since it represents drivers who initially stopped, as directed by either a TCD, a flag person, or the roadway design (i.e., entering a main roadway from a private drive) and then proceeded prior to being given clearance. For example, these drivers stopped initially for a red traffic light, and then continued across the intersection prior to the light turning green. This example could be considered a willful act since drivers probably knew the light was still red when they attempted to cross. Stopping at a stop sign or stopping at the main road before proceeding from a driveway and then proceeding when the driver thought the roadway was clear would also fall into the "Proceeding without clearance" category. These examples could probably be better described as an error in judgment or improper lookout. It is unfortunate that this category cannot be separated further to understand the factors of which it is comprised.

"Driver lost control" accounted for 4.3 percent of the contributing crashes, and "Hit and run" accounted for 2.1 percent of the factors. The factors leading up to this loss of control or the hit and run are not known and, as a result, cannot be expanded upon further.

Recognition Errors. "Recognition errors" accounted for approximately 10 percent of the contributing factors (figure A4). "Recognition errors" were divided into "Inattention" (7 percent) and "Distraction" (3 percent). As illustrated in figure A10, "Inattention to a stopped vehicle" was the most frequent recognition error. This would include crashes where a lead vehicle attempting to make a left turn was stopped waiting for oncoming traffic. "Rear-ending a stopped lead vehicle" was also shown to be a large category in the North Carolina Narrative search. "Inattention to signs and signals" may have obvious infrastructure implications. Drivers in these cases either did not see the stop signs or traffic signals or, in the case of the traffic signal, did not see it turn red. Increasing the saliency of these devices may reduce related crashes. However, "Did not see the sign or signal" is probably a fairly common "untrue" excuse that some drivers used.

"Internal distractions" accounted for less than 2 percent of the contributing factors, and "External distractions" accounted for less than 1 percent. "On-the-road distractions" could have potential infrastructure causes, but the numbers of occurrences are fairly small. Perhaps the best way to reduce distractions is to alert drivers of a possible threat through a warning system.

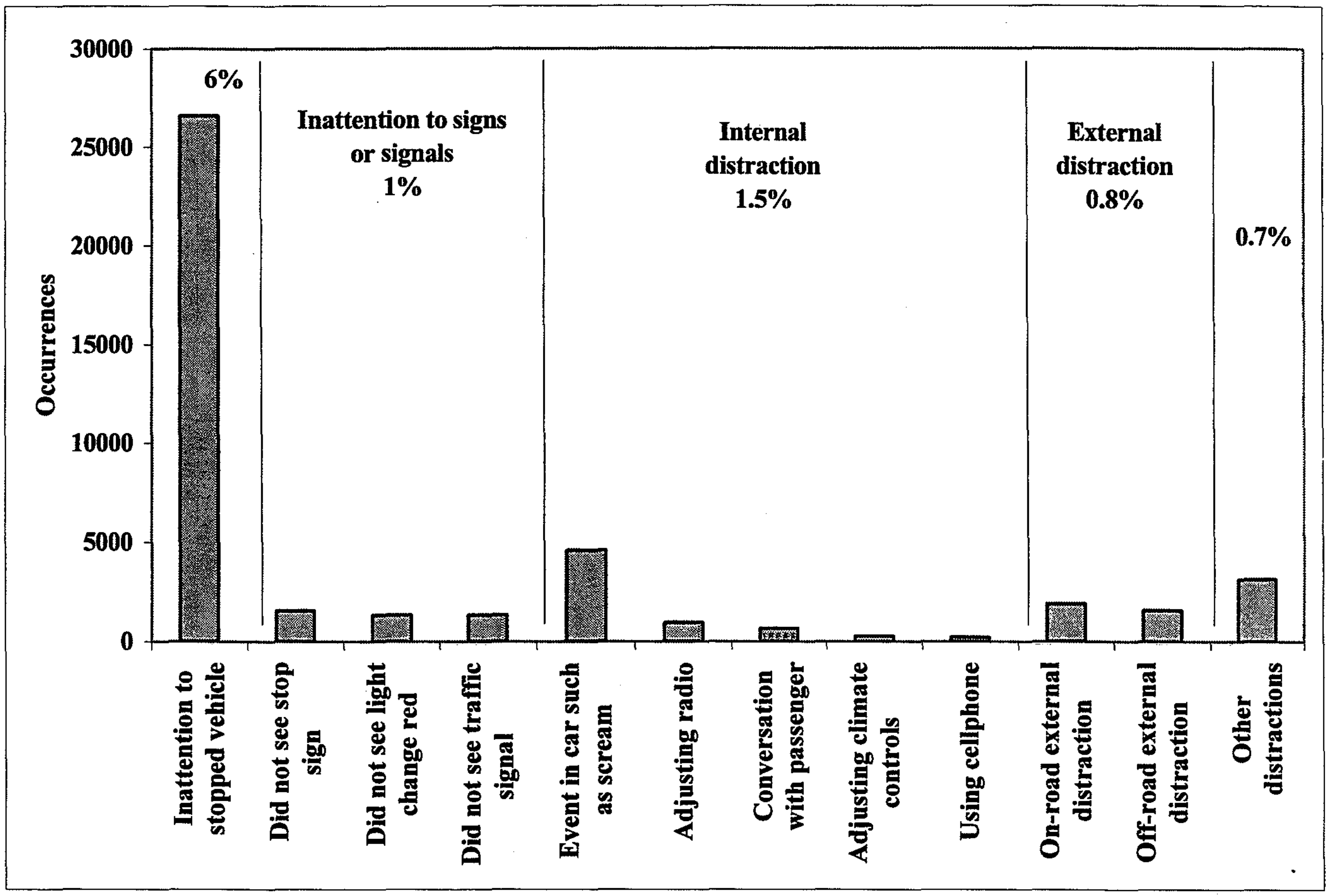


Figure A10. Recognition errors in the 1995 and 1996 Pennsylvania database.

Environmental Factors. "Environmental factors" accounted for approximately 12 percent of the contributing factors in the 1995 and 1996 database (figure A3). As shown in figure A11, some of those "Environmental factors" have obvious infrastructure implications. "Roadway structure problems" represented the largest environmental contributing factor. Figure A12 illustrates each of the subcategories that comprised the "Roadway structure problems" category. "Slippery pavement" accounts for most of the "Roadway structure problems." "Bleeding of the pavement" (a film of bituminous material on the pavement surface that creates a glass-like, reflecting surface) lowers the skid resistance. This example was identified as a problem at a specific intersection during one of the officer focus group sessions. The other categories that make up "Roadway structure problems" sum to less than 1 percent of the contributing factors (figure A12). However, we should not lose sight of the fact that these other roadway structure problems were a contributing factor 3,838 times.

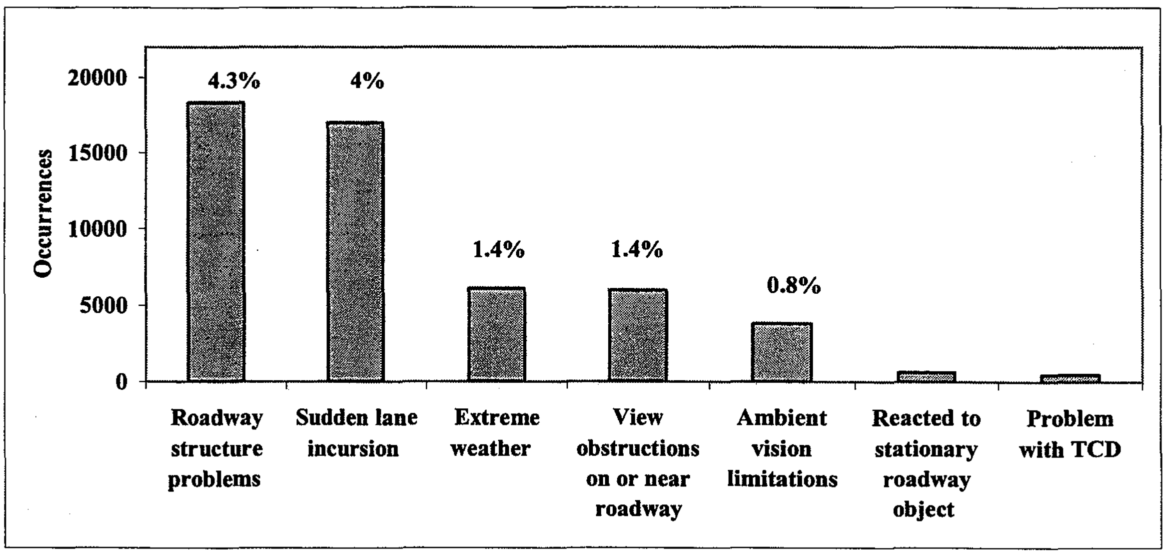


Figure A11. Environmental factors in the 1995 and 1996 Pennsylvania database.

"Sudden lane incursion" accounted for 4 percent of the contributing factors. Deer, other animals, and pedestrians were the most likely objects to suddenly move into the roadway. From an infrastructure standpoint and as mentioned previously, deer and other animals could be kept from the roadway with fences, thus minimizing the chances of this type of crash. Clearing the roadway easement of brush and trees in rural areas would help drivers see approaching animals earlier and perhaps reduce the number of related crashes. Clearing the easements of brush and trees would perhaps also reduce the "View obstructions on or near the roadway" that accounted for 1.4 percent of the contributing factors.

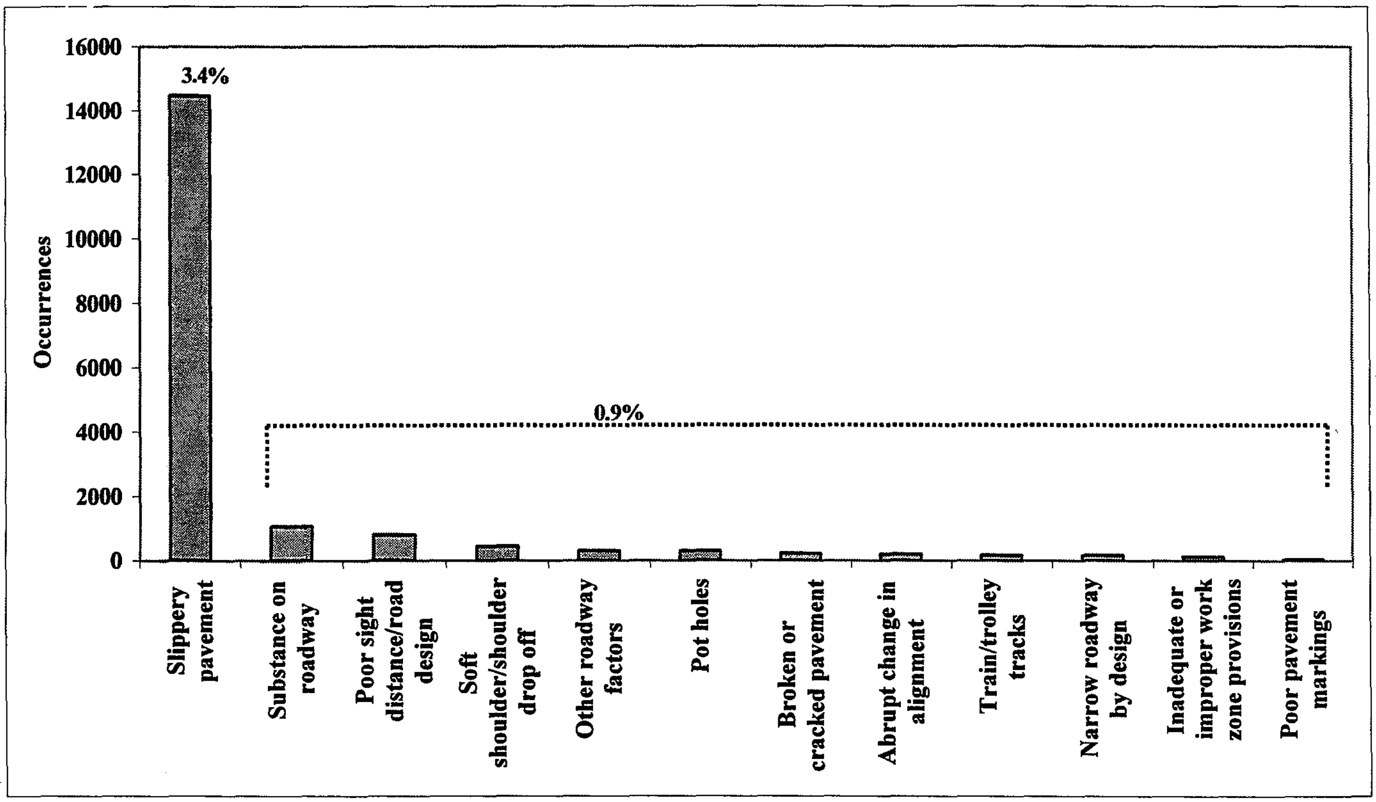
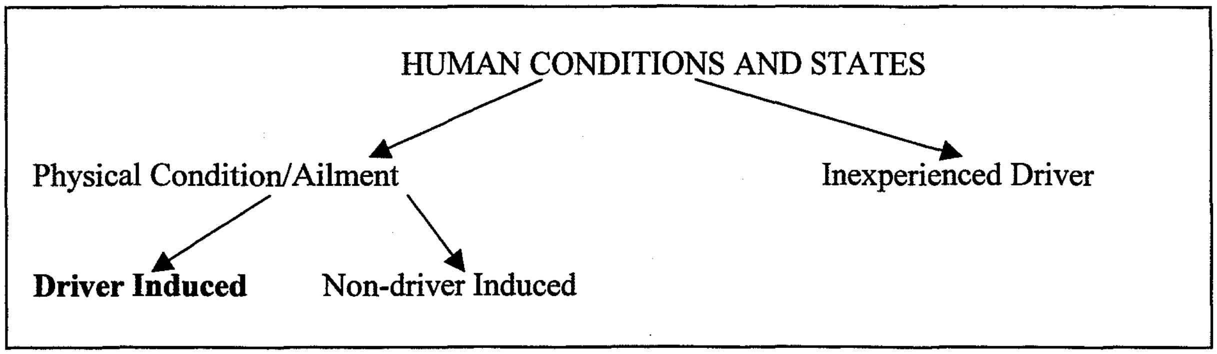


Figure A12. Road structure problems in the 1995 and 1996 Pennsylvania database.

Human Conditions and States. "Human conditions and states" accounted for approximately 8 percent of the contributing factors (figure A3). As illustrated in figure A13, "Human conditions and states" can be further separated into "Physical condition/ailment," and then into "Driver-induced" and "Non-driver-induced" factors. "Driver induced" refers to those conditions or states that were the result of something over which the driver had control. For example, driving after consuming alcoholic beverages accounted for more than 5 percent of the contributing factors and was something over which the driver had control (figure A13). "Non-driver induced" refers to those conditions over which the driver had no control (e.g., a blackout or a heart attack while driving). Arguably, "Driver-induced" contributing factors could be considered willful acts or driver errors. That is, drivers who know they are making the choice to drive under an altered state or condition are, at the least, performing an error and perhaps performing a willful act. "Driver-induced" factors accounted for 6.9 of the 8 percent of human conditions and states, with driving under the influence of alcohol and being fatigued as the largest factors (figure A14).



Figur

e A13. Taxonomy for human conditions and states.

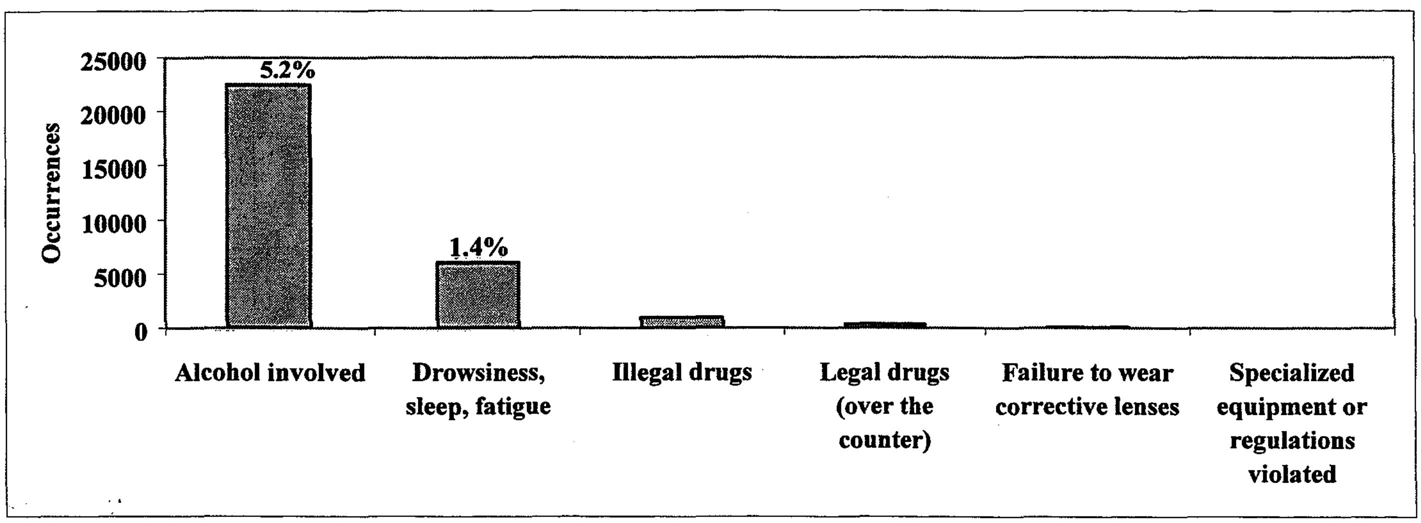


Figure A14. Driver-induced human conditions and states.

Vehicle Failure and Problems. "Vehicle failure and problems" accounted for approximately

2 percent of the contributing factors (figure A2). This causal factor in the Indiana Tri-level Study was defined in extreme detail. However, fewer categories can be used to capture the majority of these factors. Some of these categories should also be considered driver error. For example, driving with a dirty or frosty windshield is something that a driver knows reduces visibility and should be corrected prior to driving the vehicle. Drivers also know that driving with bald tires increases their chance of a blowout or losing control of the vehicle. Both of these examples could be classified as driver error. The "Vehicle problems and failure" categories that could be considered driver error are shown in table A3. Each of these factors could probably be addressed with routine maintenance.

Table A3. Vehicle failure and problem contributing factors that could be considered driver error.

Inadequate tire tread depth
Improper inflation/bald tires
Mismatch of tire types and/or sizes
Unsecured or shifting load
Improper towing
Overloaded
Dirty/frosty windshields
Defective defrosting
Defective wipers
Lighting problems
Inoperable headlamps
Inoperable taillights
Inoperable turn signal
Taillights and turn lights obscured by dirt, grime
Mis-aimed headlamps
Dirty, obscured headlamps

Conclusions From the PA Traditional Database Analysis

Although useful information was obtained using the Indiana Tri-level Study as a framework for this taxonomy, the numerous ambiguities, such as the differences between improper maneuvers and inadequate techniques or practices, make it difficult to use.

Understanding the underlying reason behind driver error is one key component to mitigating the problem, but this could not be fully determined through this traditional analysis. Drivers may exhibit the same driver error for varied reasons. For example, our analysis showed that "Following too closely/Tailgating" was a contributing factor 28,270 times in Pennsylvania during 1995 and 1996. A subsequent analysis showed that it was the primary contributing factor in 22,558 crashes out of the 279,730 crashes that occurred during the same time frame. That is, this was the factor that officers filling out the report form believed was the primary "causal" factor in more than 8 percent of these crashes. Attacking this problem could have a potentially large impact on the number of crashes. However, following too closely could be caused by aggressive driving, inattention, or drivers simply not understanding how long it takes for them to react and for their vehicles to stop. Each of these underlying reasons would require a different mitigation strategy. Aggressive driving may require greater presence of law enforcement, inattention may require an in-vehicle system to alert drivers when they are driving too closely, and lack of knowledge may require a public awareness campaign and an emphasis on vehicle kinematics in training. Although all these approaches and others could be used in a "shotgun" type approach in hopes of hitting the target(s), understanding the key reason(s) would help focus a mitigation strategy using the available resources to obtain the greatest crash reduction for the money.

"Human errors" accounted for the majority of the contributing factors in this database. Some of these errors could be eliminated through infrastructure changes. However, no obvious global infrastructure changes that would reduce human error were identified.

"Decision errors" accounted for the majority of the contributing factors (47 percent). These were errors where drivers correctly interpreted the information, but chose to perform an incorrect action or chose to perform no action. "Recognition errors" accounted for 10 percent of the contributing factors. These were the errors where the driver failed to recognize the threat. There was another 20 percent classified as "Other" driver errors that could not be classified as either decision or recognition errors. "Failure to avoid an obstacle on the road" accounted for a surprising 10 percent of the contributing factors and included "Hit a parked vehicle," "Hit a stopped vehicle," and "Hit a pedestrian or animal in the road."

Finally, table A4 lists nine driver errors that account for approximately two-thirds of all the contributing factors in the Pennsylvania database for 1995 and 1996. A subsequent analysis determined that these factors were also considered the primary contributing factor in more than two-thirds of the crashes. This section of the report described each of these factors and the applicable potential infrastructure changes that could reduce related crashes. Attacking any one of these factors could have a significant impact on the number of crashes on both Pennsylvania and U.S. roadways.

Table A4. Nine driver errors associated with crashes in Pennsylvania during 1995 and 1996.

	Driver Errors	Primary Contributing Factor
1	Excessive speed	8.7%
2	Improper or careless lane change, entrance, or exit	7.8%
3	Driving in wrong lane	4.9%
4	Traffic control device-related	7.8%
5	Driver-induced physical ailment	7.8%
6	Following too closely or tailgating	8.1%
7	Improper or illegal turn	7.8%
8	Inattention to a stopped vehicle	7.8%
9	Proceeding without clearance after stopping	7.2%
	Total	**67.9%**

1B. FARS Database Analysis

The second traditional database analysis was conducted using records from the FARS. There were two primary goals in analyzing the FARS database. First, as in the analysis of the PA database, it was believed that a taxonomy could be developed to provide insight into which driver error and contributing factors are most associated with fatal crashes. However, unlike the PA database analysis, the FARS analysis would provide results from data collected across the United States (not just in one State). The second goal of the FARS analysis was that it was to include the effects of driver age. More specifically, it was believed that a FARS analysis would indicate which errors younger, middle aged, and older drivers are most likely to commit.

Approach

To obtain a better understanding of which driver errors are associated with severe crashes, an analysis was conducted using the 1996 FARS database. In 1996, approximately 41,900 people died in roadway-related crashes in the United States. Of these 41,900, approximately 15 percent were pedestrians, cyclists, or other people not in a motor vehicle. Approximately 57,000 drivers were involved in these crashes. As shown in figure A15, younger drivers were involved in a large number of these crashes.

An analysis was conducted to determine if there was a difference in the types of errors that drivers of different ages made that led to these fatal crashes. As illustrated in table A5, "Related factors-driver level" includes categories that could be considered as a driver error or a contributing factor. A cross tab analysis was done between driver age and this "Related factors-driver level." All drivers involved in a fatal crash were considered regardless of whether an occupant of their vehicle was fatally injured. That is, an occupant in another vehicle or a non-occupant such as a pedestrian could have accounted for the fatality.

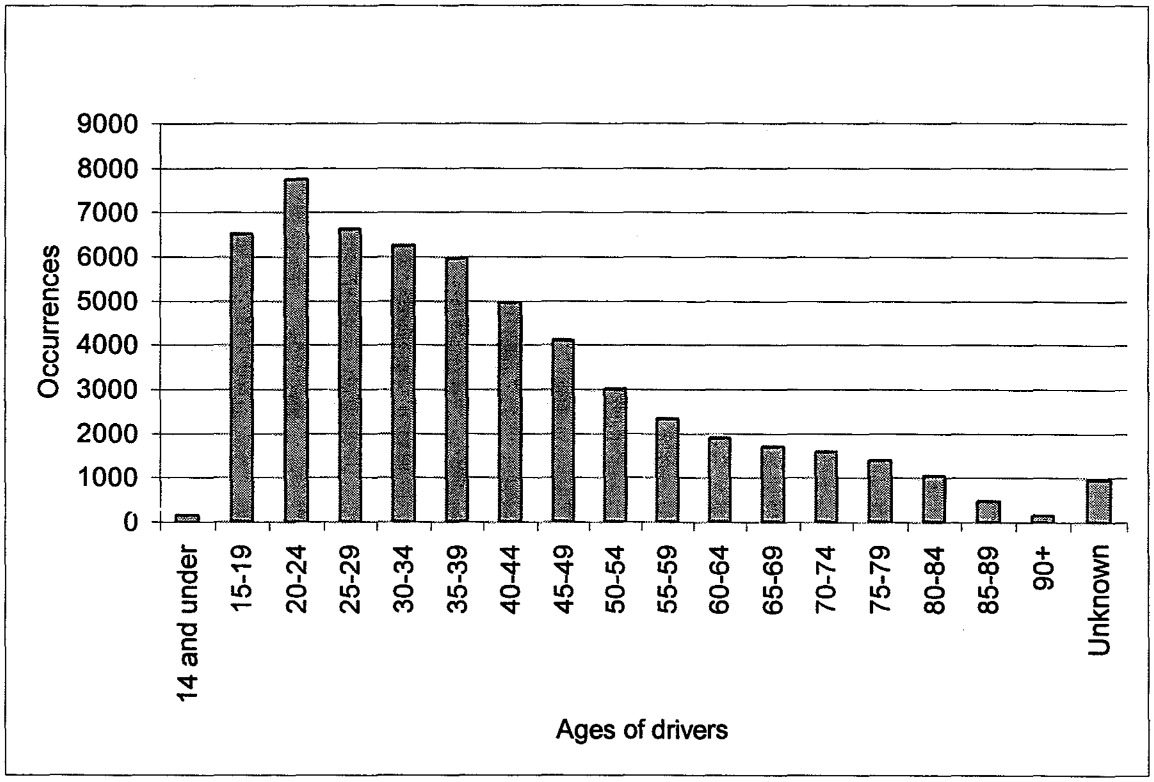


Figure A15. Ages of drivers involved in fatal crashes in 1996.

Table A5. Categories in the FARS database field "related factors-driver level."

Drowsy, Asleep	Pass Wrong Side	Building, Billboard
Ill, Blackout	Pass Insufficient Distance	Tree, Plants
Emotional	Erratic/Reckless	Moving Vehicle
Drugs-Medication	High Speed Chase	Parked Vehicle
Inattentive	Failure to Yield	Splash, Spray
Wheelchair	Failure to Obey	Inadequate Defroster
Previous Injury	Around Barrier	Inadequate Lights
Other Physical	Fail to Observe Warning	Obstruct Angles
Unknown	Fail to Signal	Improper Windshield
Mental Challenge	Driving too Fast	Other Obstruct
Fail to Take Drugs	Under Min Speed	Crosswind
On Prohibited Road	Wrong Lane Turn	Truck Wind
Invalid License	Other Improper Turn	Slippery Surface
Vehicle Unattended	Phys Rest Comply	Flat Tire
Improper Loading	Wrong Way	Debris in Road
Improper Towing	Wrong Side of Road	Rut in Road
Improper Lights	Operational Inexperience	Animal
W/O Required Equipment	Unfamiliar with Road	Vehicle in Road
Unlawful Noise	Stopping in Road	Phantom Vehicle
Improper Following	Low Tire Pressure	Pedestrian
Improper Lane Change	Locked Wheel	Water, Snow, Oil
Run Off Road/Lane	Over Correcting	Hit and Run
Driving Shoulder	On/Off Moving Vehicle	Homicide
Improper Entry/Exit	On/Off Stop Vehicle	Other Violation
Improper Start/Back	Weather	Cellular Phone
Open Vehicle Closure	Glare	Fax Machine
Prohibited Pass	Curve, Hill, etc.	2-Way Radio

Three age groups were selected: younger, medium, and older ranges (see table A6). These were nearly the same age ranges used in the driver interview portion of this report (discussed later). Table A6 shows the total number of drivers in each age group, the number of drivers who had no driver-related factor, and the number of drivers who had a driver-related factor. Approximately one-third of the crashes selected had no driver-related factor. In the way of further explanation, note in table A6 that the values in the second column result from the same data that appear in figure A15. For example, the value 14,279 is the sum of the first three bars of figure A15, the value 10,955 is the sum of the sixth and seventh bars, and the value 6,387 is the sum of the twelfth through seventeenth bars. Note that the percentages in the third column consider only the drivers included in the three age groups. Therefore, the percentages for each of the three age groups sum to 100 percent. Approximately one-third of the drivers selected were involved in crashes with no driver-related error. Therefore, 21,183 of the drivers selected had a driver-related factor. Of the drivers with a driver-related factor, approximately 50 percent were under 25 years of age, 29 percent were 35 to 45, and 22 percent were at least 65 years old. Thus, these percentages serve as a "baseline" to consider when further categorizing the results. Note that these percentages were calculated using only drivers within the three age groups who had a driver-related factor. Therefore, the percentages for the three groups also sum to 100 percent.

To aid in the understanding of driver error causes and contributing factors, the "Related Factors-Driver Level" classifications present in the FARS database were analyzed. These individual, low-level classifications were then combined into a taxonomy of driver errors and other contributing factors (presented in the Task C report, Hankey et al., 1999). As shown in figure A16, several categories within the taxonomy, including "Aggressive driving," "Ran-off road or failure to stay in lane" and "Improper lookout or misjudgment," had much higher frequencies of occurrence than some of the other categories in the taxonomy. Also, as shown in figure A16, there is some indication that age has a *specific* relationship to the occurrence of certain types of errors.

Table A6. Three age groups selected for analysis and the relative percentage of driver-related factors.

Selected Age	Total Number	Total Percent	No Driver-Related Factors	Driver-Related Factor	Percent of Driver-Related Factors
Less than 25	14,279	45%	3,767	10,512	49.6%
35-44	10,955	35%	4,912	6,043	28.5%
65 or older	6,387	20%	1,759	4,628	21.8%
Total	31,621	100%	10,438	21,183	99.9%

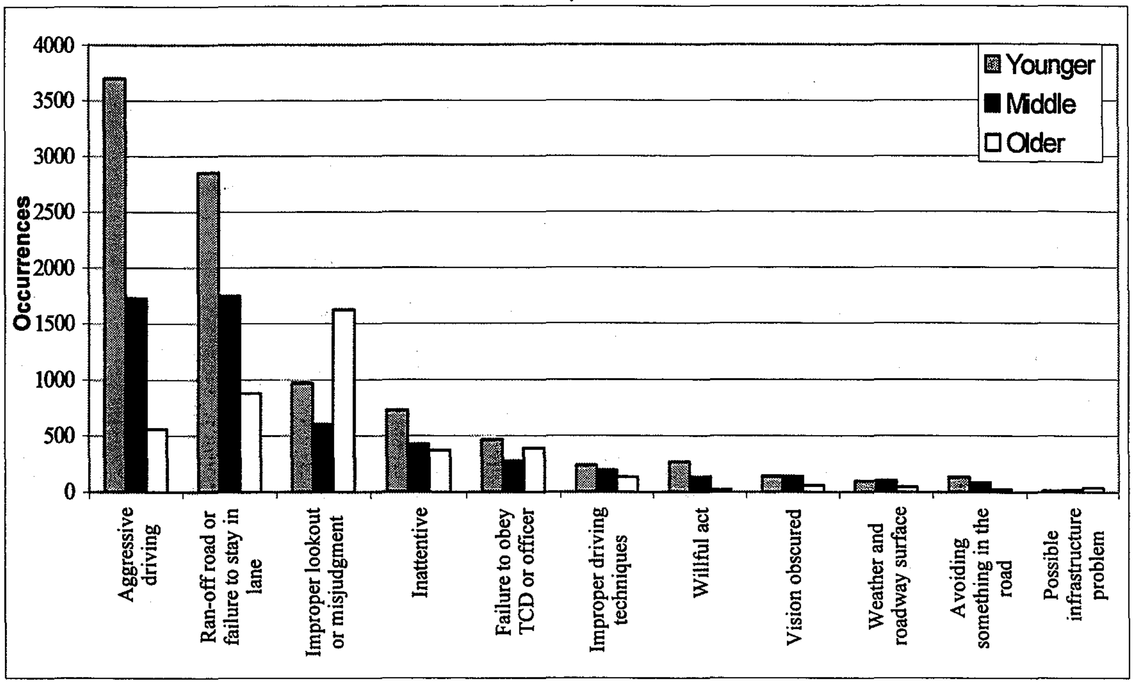


Figure A16. Driver error categories derived from the taxonomy "related factors - driver level" categorization in the FARS database.

To examine the age relationships in greater detail across the taxonomy, the frequency counts shown in figure A16 were converted to percentages by error type. The percentages of errors committed by age group are shown in figure A17. Several of the categories differ substantially from the average percentages of error represented by the total sample shown in table A6.

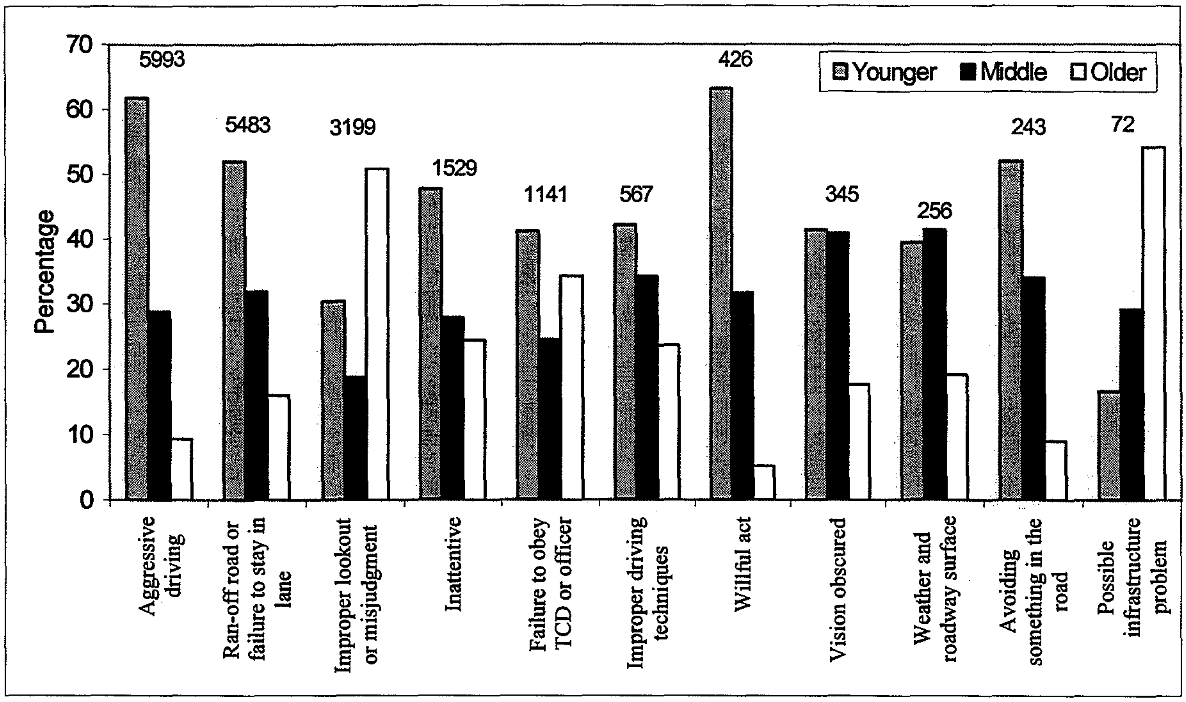


Figure A17. Percentage of errors committed by drivers of different age groups for each of the error categories in the taxonomy. (Total number of occurrences of each type of error is shown above the percentage distributions.)

Discussion

Aggressive Driving. The "Aggressive driving" category in the taxonomy was synthesized from the combination of categories in the FARS "Related factors-driver level." These categories could reasonably be associated with the tendency to drive aggressively, although this is not always the case. The categories that comprise "Aggressive driving," along with the counts for each category and each age within that category, are illustrated in figure A18.

"Aggressive driving" accounted for the largest number of fatal crashes in the taxonomy. As shown in figure A17, younger drivers appeared to commit more aggressive driving errors (62 percent) than would have been predicted by the expected frequencies (50 percent).[14] Many of

[14] Expected frequencies are defined as those in the right-hand column of table 11. In the case of aggressive driving errors, 62 percent exceeds 50 percent (actually 49.6 percent), indicating that these errors are over-represented in the younger age group, even after taking into account that younger drivers are involved in a larger proportion of fatal crashes.

the "sub-categories" listed deviated from the expected frequencies by age group for the younger drivers. Younger drivers were over-represented compared with their expected value of 50 percent in the subcategories "Driving too fast" (66 percent), "Erratic/Reckless" (54 percent), "Insufficient passing distance" (63 percent), "Prohibited pass" (70 percent), "Pass on the wrong side" (72 percent), "Hit and run" (60 percent), "Overcorrecting" (61 percent), and "High speed chase" (75 percent). Some of these errors can be characterized as mistakes stemming from inexperience, which led to errors in "Momentary decision judgment" in subcategories like "Passing distance," and an "Inappropriate control input" in subcategories like "Overcorrecting." Other errors can be characterized as errors in "Pre-meditated judgment." Many of these crashes could be the result of cases where the younger driver knowingly violated the law, such as in the cases of prohibited pass, passing on the wrong side, driving too fast, and high-speed chase. In regards to pre-meditated judgment, some cases could also be considered willful acts.

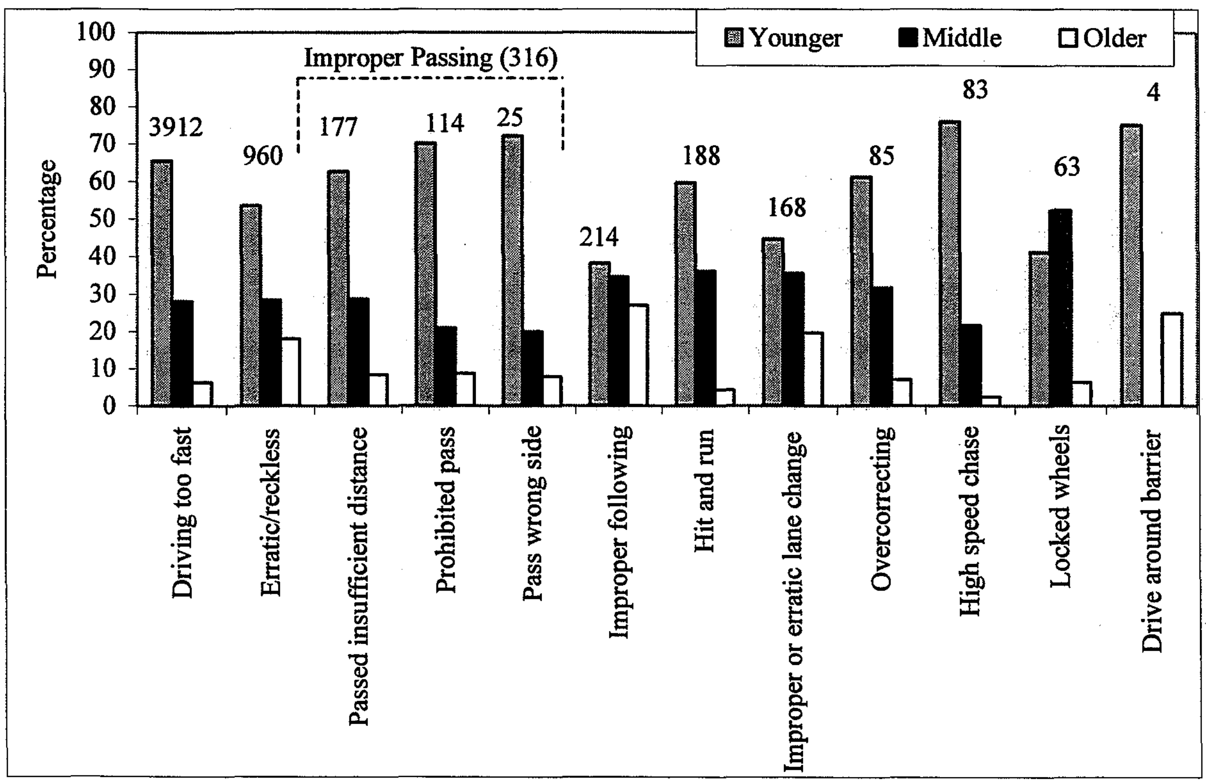


Figure A18. Number of errors for each aggressive driving subcategory and percent of drivers who committed them by age.

Not surprisingly, older drivers were less likely to perform "Aggressive driving" errors

(9 percent compared with an expected value of 22 percent). In fact, they were over-represented in only one subcategory for “Aggressive driving”: “Improper following” (27 percent).

Run-off-Road or Failure to Stay in Lane. As shown in figure A16, the occurrence of fatal crashes resulting from “Failure to maintain position in the lane/Running off the road,” was the second most frequent error in the taxonomy, with 5,483 occurrences. As shown in figure A17, this factor does not appear to have a large effect of age. Nevertheless, the oldest age group is somewhat under-represented as a population for this type of error (16 percent compared with an expected value of 22 percent). This effect could be due in part to older drivers being less likely to drive aggressively. Therefore, they are less likely to lose control of the vehicle and depart the road. As detailed in the Task C report (Hankey et al., 1999), fatigue is also more of a contributing factor with the younger age group than the expected value indicates.

Improper Lookout or Misjudgment. “Failure to yield right-of-way” (mostly at intersections), “Other improper turn,” and “Improper start/back” were combined to create a category with 3,199 occurrences entitled “Improper lookout or misjudgment” in the taxonomy. In all three of these categories, the older driver group was greatly over-represented (53, 34, and 35 percent respectively, as compared with an expected value of 22 percent; figure A19). Particularly in the case of “Failure to yield right-of-way,” it appears that older drivers are prone to misjudgments in speed and/or distance of approaching vehicles. It is interesting to note that younger drivers were under-represented in each of these categories.

Inattention. As shown in figure A16, the expected values in the “Inattentive” category mirror those of the percentage of fatal crashes for each of the three age groups. Since this was the fourth most frequent driver error (1,529 occurrences), inattention is an important problem for all age groups.

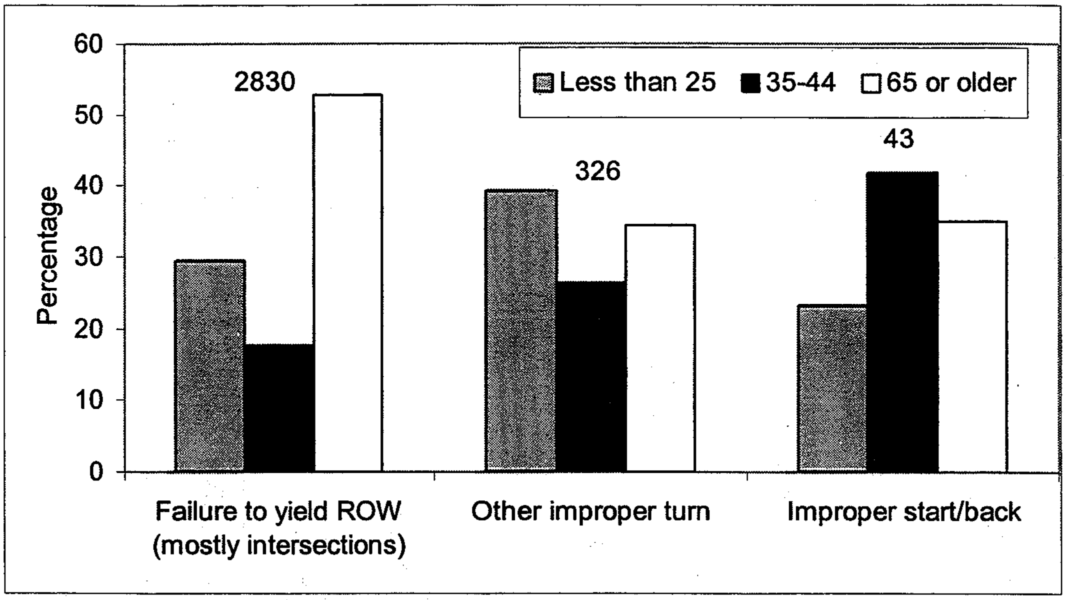


Figure A19. Number of errors for each improper lookout or misjudgment subcategory and percent of drivers who committed them by age.

Failure to Obey Traffic Control Device or Traffic Officer. "Failure to obey traffic control devices or traffic officers" accounted for 1,141 of the driver errors. As shown in figure A17, older drivers were over-represented in this category of fatal crashes (34 percent relative to an expected value of 22 percent). Several potential causal and contributing factors could explain this finding. Older drivers have been shown to have a decreased "useful field of view" (UFOV) relative to other drivers (Ball and Owsley, 1991). This means that older drivers do not see "signals" outside of the fovea as well as they once did. They may miss information in the periphery on occasion. Older drivers' possible failure to judge speed/distance accurately as described for the "Improper lookout or misjudgment" category may also be an important factor.

Driver Condition and Experience. The "Driver condition and experience" category was a combination of 10 subcategories of the "Related factors-driver level" that accounted for 1,085 occurrences. As shown in figure A20, fatigue accounted for approximately 60 percent of this category (692 occurrences). Younger drivers were more likely to be fatigued (55 percent) than their expected value (50 percent) indicated. In addition, younger drivers had higher "Operator inexperience" errors (82 percent), and "Unfamiliar with road" (70 percent) errors than the other groups. Older drivers were over-represented in the categories "Ill/Blackout" (74 percent) and "Other physical impairment" (80 percent).

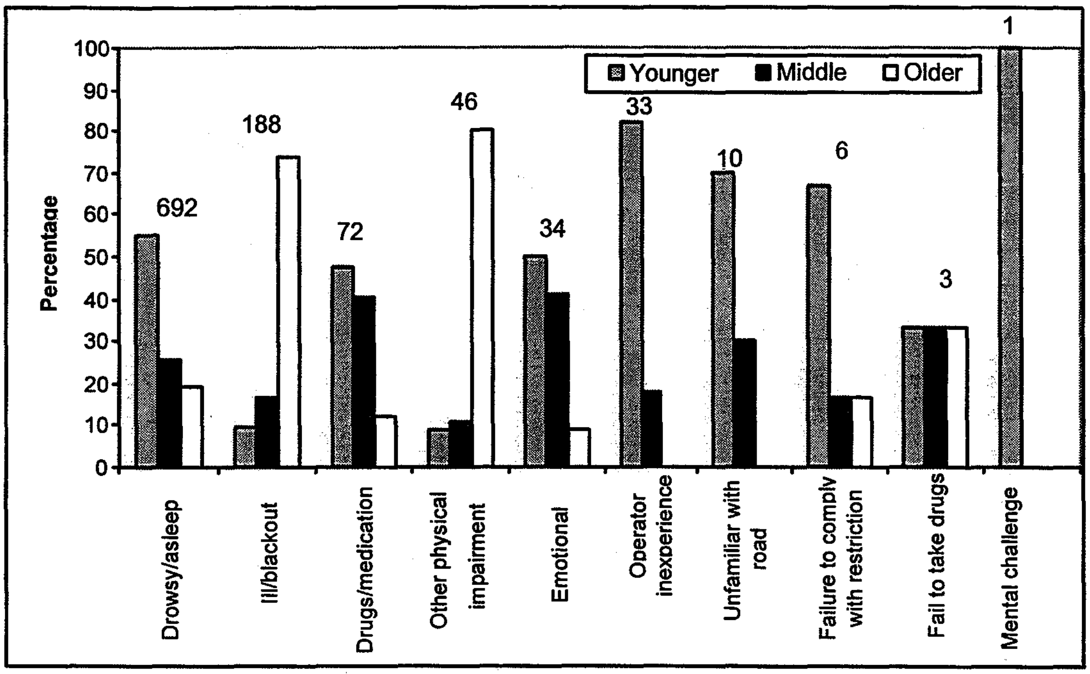


Figure A20. Number of errors for each driver condition and experience category and percentage of drivers who committed them by age.

Improper Driving Technique or Practice. "Improper driving technique or practice" comprised the following FARS subcategories: "Wrong side of the road," "Stopping in road," "Driving on shoulder or sidewalk," and "Under minimum speed limit." As shown in figure A17, middle-aged drivers account for more of these errors than expected (34 percent compared with an expected valued of 29 percent), and younger drivers had fewer of these errors than expected (43 percent compared with an expected valued of 50 percent). Each of these categories reflects behaviors that most drivers probably know are poor driving habits that could lead to crashes with pedestrians and other vehicles.

Willful Act. The FARS categories "Homicide" and "On prohibited road" make up this category. Younger drivers are over-represented in vehicular homicides (63 percent relative to an expected value of 50 percent).

Vision Obscured. Fifteen FARS subcategories make up the category "Vision obscured." A number of these categories had very low frequencies. It is interesting to note that middle-aged drivers were over-represented for this category (41 percent relative to an expected value of 29 percent). This finding is due primarily to a single subcategory, namely "Weather," where the middle age group accounts for 56 percent of the total.

Weather and Roadway Surface. The "Weather and roadway surface" category of the taxonomy (256 occurrences) consists of the FARS subcategories "Water/Snow/Oil," "Slippery surface," "Crosswind," and "Truck wind." As with the "Vision obscured" category, the middle-aged group is over-represented (41 percent relative to an expected value of 29 percent) in the "Weather and roadway surface" category as well.

Avoiding Something in the Road. "Avoiding something in the road" was a factor occurring 243 times. It contained the following FARS subcategories: "Vehicle in the road, "Animal, Phantom vehicle, Pedestrians, Debris in road," and "Rut in road." The middle-aged group is somewhat over-represented (34 percent relative to an expected frequency of 29 percent) for this category overall. This result is somewhat surprising since arguments could be made that younger and older drivers would be more likely to have trouble avoiding obstacles in the road (younger drivers because of lack of experience, and older drivers because of increased reaction times).

Possible Infrastructure Problems. Although, as shown in figure A16, this category has a low frequency relative to some of the other error categories (72 possible infrastructure problems), figure A17 shows that the older drivers are greatly over-represented in this category (54 percent relative to an expected value of 22 percent). This finding is consistent across the three FARS subcategories that make up this category, namely: "Improper exit/entry," "Wrong way on a one way," and "Turn from the wrong lane." If this finding were the result of unusual roadway/TCD designs, one might expect the younger drivers to be over-represented. Since it is the older drivers who commit more errors in these circumstances, they may be having difficulty in reading or processing guidance, advisory, or warning information at these locations.

Conclusions From the FARS Database Analysis

The cross tab analysis between driver-related factors and driver age provided several interesting findings. This analysis was for severe crashes where at least one person died. Therefore, eliminating some of these errors could have a direct impact on the number of driving-related fatalities as well as serious injuries and property damage.

Relevant driver-related factor subcategories were synthesized into a category entitled "Aggressive driving." This category accounted for 28 percent of all the driver-related factors analyzed for these age groups. Younger drivers were more likely to make these types of driver errors, whereas older drivers were less likely to make them. Efforts to mitigate younger driver crashes should emphasize reduction of aggressive driving "habits."

Older drivers were over-represented in categories of "Improper lookout and misjudgment," and "Failure to obey traffic control device or traffic officer." These two categories accounted for 20 percent of the driver-related factors and 43 percent of the older driver related factors. The subcategories that made up these categories were items such as "Failure to yield at an intersection." There appears to be a problem with older drivers judging the speed and distance of oncoming vehicles and seeing or obeying TCDs. This result has obvious infrastructure implications. The category "Possible infrastructure problems" also indicated that older drivers were affected more by the infrastructure than were other drivers. With our aging driving population, infrastructure may become an even more important factor in the future.

"Ran-off the road or failure to stay in lane" accounted for 26 percent of the driver-related factors. From an infrastructure standpoint, drivers could be protected from committing either of these errors by including barriers (e.g., guardrails, medians, etc) in the roadway system. However, a cost/benefit analysis would have to be done on a case-by-case basis to determine the feasibility of incorporating these barriers into a roadway system. Younger drivers were slightly more likely to commit this error than their expected value indicated, and older drivers were slightly less likely to commit this error. This difference could be a result of younger drivers' tendency to drive aggressively.

Middle-age drivers were over-represented in several of the categories. Together, these categories account for 6.6 percent of the driver errors and contributing factors. The categories were:

- Improper driving techniques such as stopping in the middle of the road,
- Vision obscured such as by the weather,
- Weather and roadway surface such as water/snow/oil on roadway, and
- Avoiding something in the road such as an animal.

This finding may be a result of exposure. Middle-aged drivers may be forced to drive under adverse conditions more than either older or younger drivers because of work and other commitments that require them to travel.

Conclusions Regarding the Traditional Database Analysis with Emphasis on Driver Error

Based on the results of the traditional database analyses using the PA database and the FARS database, it can be seen that the traditional approach provides a good indication of what happened during a crash event. However, it can also be seen from these results that this type of analysis is restricted and can only deal with the pre-specified categories found in the data fields. Analysts interested in information not included in the pre-specified categories are not able to work beyond this. That is, the structure of traditional database search approaches limit the analyst to data found in the data fields. The next section highlights the results of a non-traditional approach to database analysis that provides a means to delve deeper into the details of a crash.

2. Non-Traditional Database Analysis Using the North Carolina Narrative Accident Database

The analyses that were conducted on the North Carolina accident database are presented in this and next sections. A moderately comprehensive discussion of these analyses is presented in this final report, and the complete description can be found in the Task C report (Hankey et al., 1999).

The North Carolina Narrative Accident Database allows researchers to perform keyword searches on accident report narratives. The narratives originate from the written accident report provided by the attending police officer or from post-accident interviews conducted by accident investigators. Clerks at the Division of Motor Vehicles (DMV) in Raleigh, North Carolina, then type the narratives into the database. The Highway Safety Research Center (HSRC) of the University of North Carolina, Chapel Hill has developed a program to extract narratives based on whether they contain a given keyword or group of keywords.

Objective

The objective in using this database was to pinpoint categories or types of driver errors that contributed to motor-vehicle crashes and to evaluate any relationships between driver error and the infrastructure. For the purpose of this analysis, the infrastructure was defined as road geometry, TCDs, and roadway delineation. The data were analyzed to highlight relationships between this infrastructure and driver error. For example, motor vehicle crashes when merging may be associated both with failing to look left and with failure to comply with yield signs. It was hoped that this method would provide insights into driver error not available through traditional methods of accident database analysis.

Approach

A multi-step procedure was followed to extract and categorize the narratives. The 1994 database was selected for this analysis because it was found to be of ample size (more than 209,000 entries) and provided substantial crash event details in most of its records. Records without sufficient detail were not included in the analysis.

The database was searched using keywords (including keyword "stems"). Table A7 shows the lists used for each of the four searches. The four searches performed were Traffic Control Device-Related, Roadway Structure-Related, Roadway Delineation-Related, and Driver Reasons/Excuses-Related. In the first column, the word "flash" appears with an asterisk following it. This is a stem word, which could have any ending, such as flash, flashing, or flashed. Thus, narratives would be retrieved if they contained the word "flash." The four searches resulted in the number of narratives shown under the "count" columns of table A7. These numbers sum to values shown in the first numerical column of table A8, under "gross number of narratives."

Table A7. Keyword list and counts obtained for each area of interest.

Traffic Control Devices	Counts	Roadway Structure	Counts	Roadway Delineation	Counts	Reasons/ Excuses	Counts
Caution	30	Abut*	16	Barri*	207	Admit*	42
Flash*	219	Bridge	752	Center*	2,249	Because	668
Green	1,799	Bypass	81	Cone	63	Beli*	49
*Light	4,770	Corner	461	Construction	226	Decid*	122
Red	9,192	Crest	217	Cross*	6,567	Deni*	16
*Sign	4,115	Curve	2,827	Curb	787	Describ*	21
*Signal	43	Exit	739	Divid*	66	Due	2,151
Yellow	427	Fork	105	Ditch	4,919	Indicat*	117
Yield	1,776	Grade	85	Dropoff	0	Noti*	445
Zone	136	Hill	879	*Edge	224	Realiz*	403
		Inters	1,452	Flag	50	Reas*	526
		Lane*	1,607	Headon	78	Result of	83
		Overpass	29	Line*	1,747	Said	1,000
		Rail*	1,904	Marker*	30	Think	81
		*Ramp	742	*Median	1,001	Thought	699
		Sharp*	382	Merg*	1,327	Told	70
		Shoulder	3,138	Oncoming	619		
		Steep	130	Ranoff	103		
		Toll*	1	Reflec*	29		
		Underpass	18	Sight	18		
		*Wall	304				

Table A8. Keyword-retrieved narratives by search.

	Gross Number of Narratives	Number with Duplicates Removed	Final Sample Analyzed
Traffic Control Device-Related	22,507	16,047	1,008
Roadway Structure-Related	15,869	13,009	1,000
Roadway Delineation-Related	20,310	15,680	1,044
Reasons/Excuses-Related	6,493	6,094	997

Narratives containing two keywords were retrieved twice, those with three keywords were retrieved thrice, and so on. A procedure was therefore developed to remove duplicates, triplicates, etc. so that each narrative appeared only once. This resulted in the numbers (counts) shown in the second column of table A8.

The final column of table A8 shows the number of narratives read and classified for this report. It was decided that reading and classifying approximately 1,000 samples per keyword list would result in moderately stable proportions while also keeping labor efforts within bounds.

In addition to the keyword searches, a uniform sample search was performed. This search was conducted to provide representative proportions of various driver errors and the corresponding infrastructure elements involved. Thus, judgments could be made regarding the relative frequencies of occurrences of various types of crashes. Also, this search had the ability to pick up error types that might be missed by a keyword search.

For the uniform sample, HSRC first provided a sample of approximately 10,000 narratives. These were obtained by taking every 200th narrative. Once the data were received, they were again uniformly sampled, taking every tenth narrative, and resulted in a sample of 992 narratives.

Figure A21 depicts the five searches performed on the 1994 North Carolina narrative database. Three searches were intended to associate errors with infrastructure, the uniform sample was intended to provide proportions, and the reasons/excuses search was intended to provide information on common driver errors reported in the narratives.

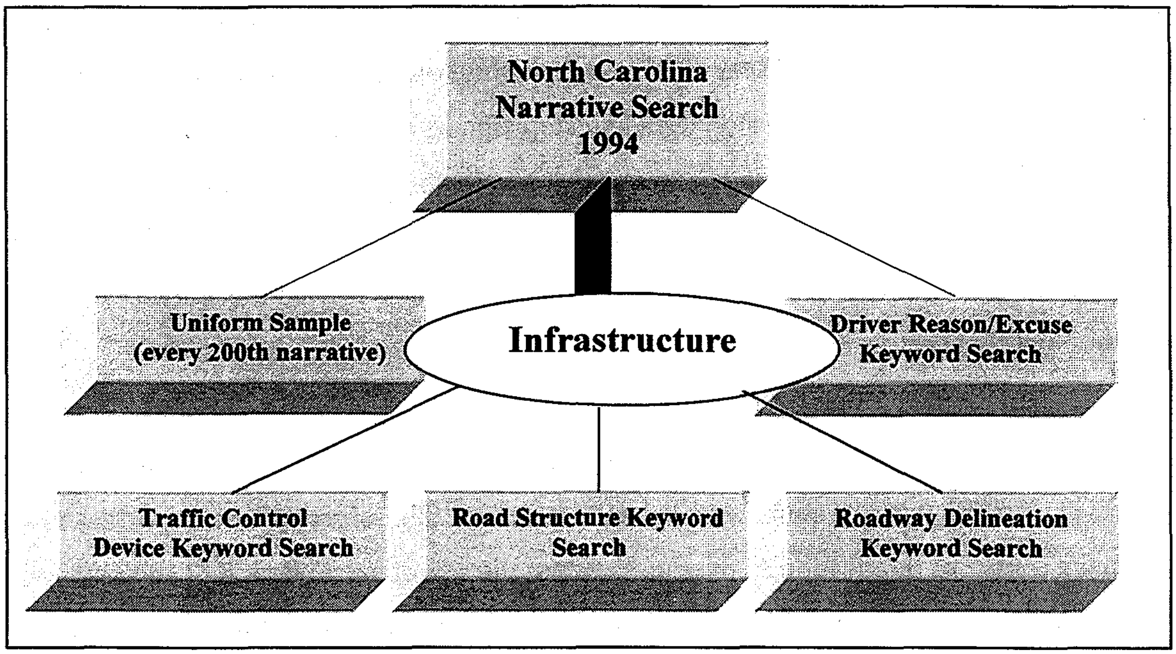


Figure A21. Five samples of NC MVA database narratives.

Once the five samples of approximately 1,000 narratives had been obtained, they were individually analyzed (narrative by narrative) and placed in a classification scheme. The classification scheme for each search was developed empirically and to some extent according to the objectives of the specific search. For example, the search on TCDs used several classifications involving signs and signals as major categories. On the other hand, the road structure search used several classifications such as curves, intersections, and ramps.

In all cases, the classifications were constructed as tree diagrams. Tree structures have the advantage of allowing any level of subclassification that the search data will support. Previous work involving accident taxonomies has achieved success using these structures (Treat, 1980; Wierwille and Tijerina, 1996). To develop the tree for each search, narratives were studied until patterns could be determined. For example, in the TCD search, it became clear that stoplights, stop signs, and other intersection crashes were prevalent. Thereafter, supplemental major categories were developed, and then each major category was further subdivided (split into branches) as needed. This procedure worked well and allowed the data to "drive" the tree.

Of course, there was an element of judgment in setting up the tree structure. Different classification schemes are possible. For example, stop light and stop sign crashes are usually of two types: "Failure to yield" and "Rear end." Conceivably, one could use these two latter categories as major categories with stop light and stop sign as second-order categories. In fact, this was done for the uniform sample taxonomy. However, for each search, only one classification scheme was developed: the one that seemed to best fit the data. Furthermore, no attempt was made to enforce uniformity across searches. It was believed that each search should have a structure that best fit the data for that search.

Duplication of narratives retrieved by keywords was eliminated in each final search sample. However, duplication was not eliminated *between* searches. Therefore, it was important to ascertain the degree of duplication or overlap between the searches. Figure A22 illustrates the number of duplicates between pairs of infrastructure searches. (Infrastructure searches were considered most likely to have duplicates.) Noting that there are approximately 1,000 narratives in each search, the histogram in figure A22 shows that the maximum duplication between searches is only 2.3 percent. Thus, any similarity of findings among the searches was not the result of the search technique that was used.

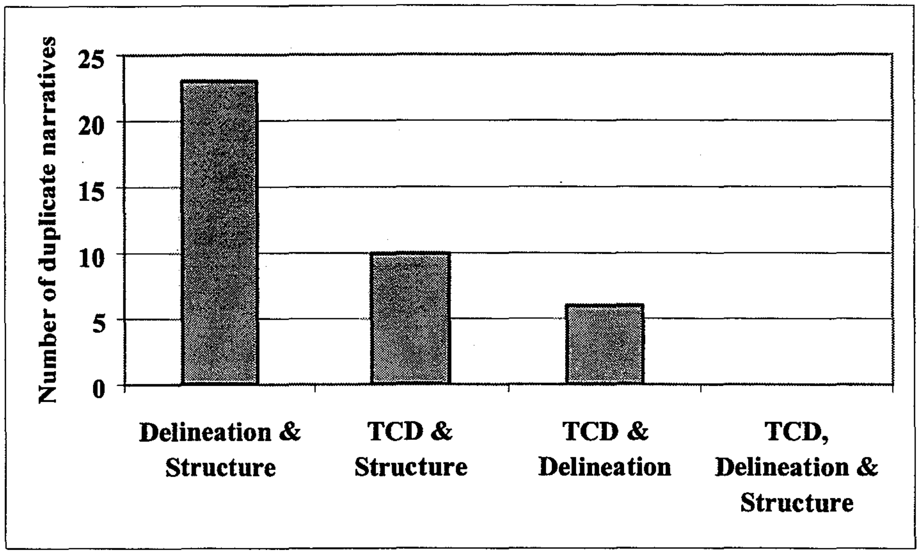


Figure A22. Numbers of narratives that appeared in two or more infrastructure searches.

All classification results were independently reviewed by a second researcher. This researcher's responsibility was to check for errors and to resolve questions as to where certain narratives might be placed (if they could be put in more than one place in the tree structure). In the analyses to be presented here, each given narrative is counted in only one place in the structure.

Results

The five sets of search results are presented in figures A23 through A27. Each search is presented consecutively, first by means of an overview histogram showing the major categories, and thereafter by means of the detailed taxonomy developed.

The taxonomies use a set of conventions that the reader needs to understand. These conventions will be described by using figures A23a and A23b as examples. Figure A23a is a histogram derived from the major (first-order) categories of the taxonomy. These categories are shown in figure A23b. The numbers in rectangles in figure A23b are the numbers of narratives classified under the first-order categories. These numbers are referred to as occurrences. The histogram in figure A23a uses slightly different wording in some cases, and combines first-order categories with corresponding numbers of occurrences.

The taxonomy continues in figure A23b. Each first-order category is bolded and appears against the left margin. Second-, third-, and fourth-order categories are progressively farther away from the left margin, have smaller type, and are not bolded. Note that the occurrences in the fourth-order categories add up to the occurrences in the third-order category under which they appear. For example, at the top of page 276, "General" (with 10 occurrences) and "View obstructed by another vehicle" (with 2 occurrences) sum to the 12 occurrences listed with the "Failed to see" third-order category. This process of summing continues from the third order to the second order and from the second order to the first order. Of course, the sum of the first order occurrences is the size of the database that was analyzed.

In some cases additional columns are used in the figures to minimize save space. Page 278 shows low-count first-order categories in a second column.

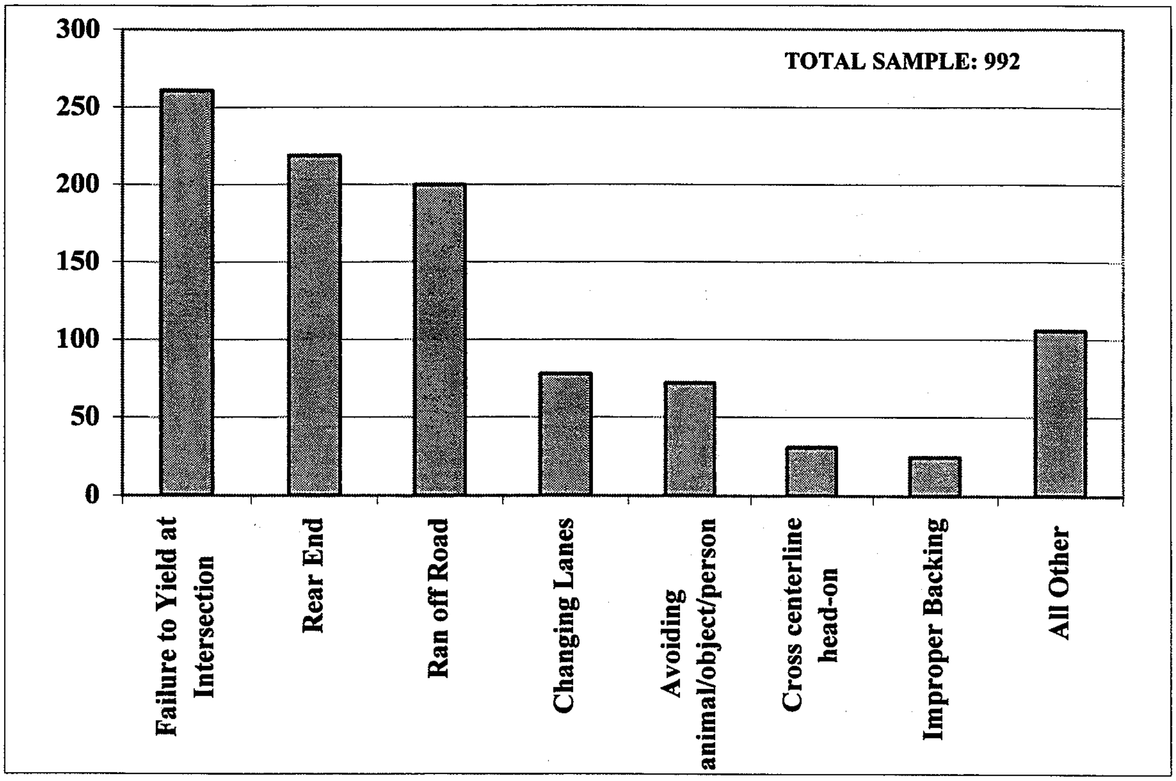


Figure A23a. Major categories for the uniform sample.

261	Failure to yield at intersection
219	Hit lead vehicle in rear
200	Ran off road
78	Changing lanes
72	Avoiding animal, object, person in roadway
31	Crossed center lane head-on
25	Improper backing
22	Other
20	Mechanical failure
17	Driver distracted
11	Driver physical condition
9	Driver misapplication of control
8	Making U-turn
6	Parking lot driving
5	Weather and roadway structure
3	False assumption
2	Driver did not see sign
2	Driver did not see vehicle because of weather
1	Made turn from wrong lane

Total: 992

Figure A23b. Uniform sample taxonomy.

261 Failure to yield at intersection

- 188 Intersecting roads
  - 71 Make left turn across path
    - 53 General
    - 12 Failed to see
      - 10 General
      - 2 View obstructed by another vehicle
    - 6 Stopped initally
  - 64 Perpendicular paths
    - 38 General
    - 12 Failed to see
    - 10 Pulled in front of oncoming vehicle to drive in the same direction
    - 4 Stopped initally
  - 22 Pulled in front or failed to yield right away
    - 15 General
    - 4 Didn't see
    - 3 Initally stopped
  - 15 Turned too tight or wide and side-swiped
    - 8 Turned too wide
    - 7 Turned too tight
  - 15 Waved through by other driver
  - 1 Fog obscured intersection
- 37 Traffic signal
  - 22 Failed to stop at traffic signal
    - 19 General
    - 3 Failed to see signal
  - 12 Both had green light or started maneuver on green
  - 2 Saw a right on red turn and assumed had a green light
  - 1 Made an incorrect right on red turn
- 36 Stop sign
  - 22 Ran stop sign
  - 10 General
  - 8 Ran stop sign and continued off road
  - 4 Failed to see stop sign
    - 3 General
    - 1 Sign obstructed by fog
- 14 Stopped first then proceeded
  - 10 General
  - 4 Didn't see oncoming traffic

Figure A23b. Uniform sample taxonomy (continued).

- **219 Hit lead vehicle in rear**
  - 69 Multiple lead vehicles slow or stopped
    - 48 Lead vehicle stopped traffic
      - 21 General
      - 16 Attempted to stop
      - 11 Failed to reduce speed
    - 21 Lead vehicle slowing
      - 8 General
      - 8 Attempted to stop
      - 5 Failed to reduce speed
  - 65 Lead vehicle turning
    - 41 Lead vehicle turning left
      - 23 Stopped to make turn
        - 16 General
        - 7 Another vehicle stopped ahead
      - 9 Lead vehicle slowing to make turn
        - 7 General
        - 2 Another vehicle stopped ahead
      - 9 During the turn
    - 13 Turning direction unknown
      - 8 Lead vehicle stopped to make turn
        - 4 General
        - 4 Another vehicle stopped ahead
      - 4 Lead vehicle slowing to make turn
        - 3 General
        - 1 Another vehicle stopped ahead
      - 1 Lead vehicle making turn
    - 11 Lead vehicle turning right
      - 6 Lead vehicle making turn
        - 3 General
        - 3 Lead vehicle stopped before completing turn
      - 4 Lead vehicle slowing to make turn
      - 1 General
  - 29 Lead single vehicle stopped or slowing
    - 24 Lead vehicle stopped
      - 9 General
      - 9 Attempted to stop
      - 6 Failed to reduce speed
        - 3 Failed to see
        - 2 General
        - 1 Lead vehicle stopped to discharge passenger
    - 5 Lead vehicle slowing
      - 4 Attempted to stop
      - 1 General
  - 18 Rear-ended lead vehicle stopped or slowing for a traffic light
    - 14 Lead vehicle stopped for traffic light
      - 7 General
      - 5 Attempted to stop
      - 2 Failed to reduce speed
    - 4 Lead vehicle slowing for traffic light
      - 2 General
      - 2 Yellow light
  - 12 General
  - 9 Striking vehicle was intially stopped
    - 3 Moved forward into other vehicle
    - 3 Lead vehicle started forward and stopped
    - 2 Saw other traffic start to move
    - 1 Light turned green
  - 6 Lead vehicle stopped for construction, school bus, emergency vehicle
    - 3 Construction
    - 1 Emergency vehicle
    - 2 School bus
  - 5 Lead vehicle slowing to merge
  - 2 Intersection
  - 2 Failed to reduce speed
  - 2 Rear-ended at stop sign

- **200 Ran off road**
  - 55 Ran off right
    - 42 General
    - 9 Ice
    - 4 Rain
  - 31 Trying to negotiate curve
    - 22 General
    - 5 Ice
    - 4 Wet roadway
  - 24 Ran off left
    - 16 General
    - 5 Ice
    - 3 Rain
  - 22 Ran off one way, swerve back across to the other side
  - 17 Ran off road to avoid worse collision
  - 14 Ran off road, side unspecified
    - 10 General
    - 4 Ice
  - 12 Speeding
    - 10 General
    - 2 Wet roadway
  - 11 Attempted to turn
    - 9 General
    - 2 Wet Road
  - 7 Fleeing police
  - 4 Ramp
  - 3 Loose gravel on road

Figure A23b. Uniform sample taxonomy (continued).

- **78 Changing lanes**
  - 21 Side-swiped other vehicle
  - 21 Attempting to avoid a slowed or stopped vehicle
    - 11 Other vehicle attempting to turn
    - 10 General
  - 11 Failed to see
    - 10 General
    - 1 Other vehicle obstructed view
  - 6 Attemping to change lanes as other vehicle passing
  - 5 Attempted to pass and lost control
  - 5 Attempting to change lanes to make a turn
  - 4 Merged in front of other vehicle
  - 3 Changing lanes to the same lane
  - 2 Changed lane had a slow or stopped vehicle

- **72 Avoiding animal, object, or person in roadway**
  - 32 Deer
  - 13 Parked vehicle
  - 11 Pedestrian
  - 6 Domestic animal
  - 6 Struck object in road
  - 4 Bike or moped

- **31 Crossed center lane head-on**
  - 13 General
  - 5 Traveling around a curve
  - 5 Lost control on wet roadway and crossed median
  - 4 Ran off roadway and travelled back across
  - 2 Attempting to pass
  - 1 Passing a stopped vehicle
  - 1 Vision obstructed

- **25 Improper backing**
  - 12 Backed onto roadway
    - 7 General
    - 5 Didn't see oncoming vehicle
  - 8 Backed into parked vehicle or fixed object
  - 5 Backing to correct a poor maneuver

- **22 Other**

- **20 Mechanical failure**
  - 9 Tire problems
  - 7 Brakes failed
  - 4 Other mechanical

- **17 Driver distracted**
  - 10 Internal
  - 7 External

- **11 Driver physical condition**
  - 6 Driver fainted/blackout
  - 5 Driver fell asleep

- **9 Driver misapplication of control**
- **8 Making U-turn**
- **6 Parking lot driving**
  - 4 General
  - 2 Backing accidents

- **5 Weather and roadway structure**
  - 4 Bridge
    - 3 Icy
    - 1 Fog
  - 1 Grade

- **3 False assumption**
- **2 Driver did not see sign**
- **2 Driver did not see vehicle because of weather**
- **1 Made turn from wrong lane**

Figure A23b. Uniform sample taxonomy (continued).

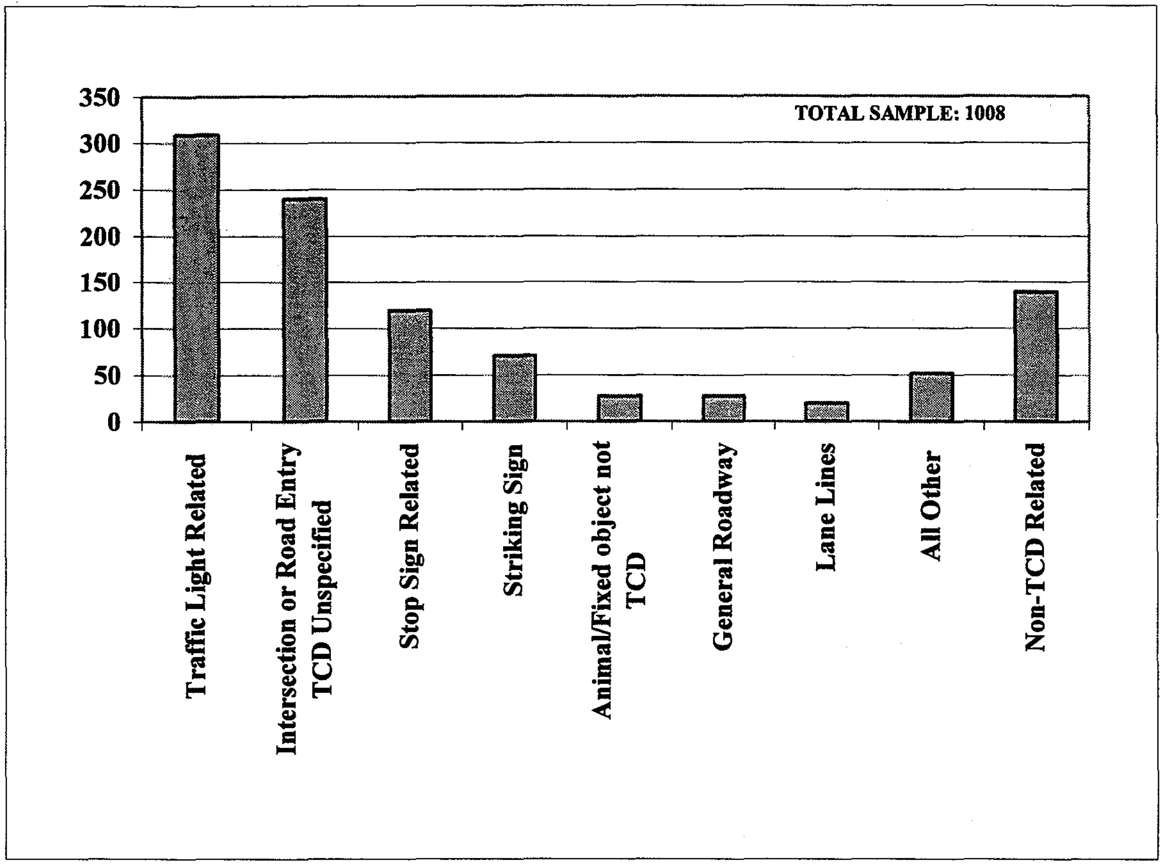


Figure A24a. Major categories for the TCD search.

309	Traffic light (conventional traffic signal)
240	Intersection or road entry; TCD, if any, unspecified
120	Stop sign
71	Striking traffic sign
28	Struck animal/fixed object (not a TCD)
28	General roadway, not intersection or unspecified as intersection
20	Lane lines
14	Flashing red, flashing yellow
9	Yield sign
4	Railroad crossing
2	Caution
26	Other

Total: 1008

Figure A24b. TCD taxonomy.

309 Traffic light (conventional traffic signal)

- 160 Ran red or yellow/red
  - 116 General
  - 19 Both drivers claim green
  - 6 Entered, not sure of color
  - 4 Entered before green
  - 4 Right turn on red
  - 3 Did not see light turn red
  - 2 Did not see light
  - 2 Distracted
  - 1 Skidded into intersection
  - 1 Assumed stop light was flashing red
  - 1 Incapacitated
  - 1 Car chase
- 120 Rear end
  - 71 With vehicle(s) stopped at light
    - 66 General
    - 2 Skidded
    - 2 Pedal misapplication
    - 1 Distracted
  - 22 After starting off on green
  - 17 As lead vehicle decelerates for red or yellow
  - 2 With vehicles stopped in intersection
    - 1 General
    - 1 Blinded by headlights
  - 2 With vehicle remaining stationary on change to green
    - 1 General
    - 1 Blinded by sun
  - 2 With vehicle in left-turn lane
  - 2 With vehicle stopped for emergency vehicles
  - 1 Evasive manuevers to avoid rear-ending results in another collision
  - 1 At on ramp road
- 12 Failure to yield
  - 9 Left turn at unprotected green
  - 1 Left turn on yellow
  - 1 Assumed left arrow was green
  - 1 Entered on green, but did not see residual vehicle
- 7 Backed
  - 3 At red
    - 2 General
    - 1 To trip sensor
  - 3 From side street or driveway into vehicle waiting at red
  - 2 Rolled back
- 4 Changed lanes in intersection
- 3 Malfunctioning signal
- 2 Wide turn
- 1 On green, went straight from left turn lane

Figure A24b. TCD taxonomy (continued).

240 Intersection or road entry; TCD, if any, unspecified

- 181 Failure to yield
  - 103 General (when entering or leaving roadway or intersection)
  - 42 While making a left turn
    - 39 Head on
    - 1 Side strike
    - 1 With vehicle making a right turn
    - 1 Sunlight glare
  - 32 On entering intersection
    - 19 General
    - 5 Did not see other vehicles
    - 3 Skidded
    - 1 Wrong assumption about other vehicle
    - 1 While making a right turn
    - 1 Claimed brake failure
    - 1 Alcohol involvement
    - 1 Distracted
  - 2 Struck pedestrian while turning
  - 1 Obstructed vision at intersection
  - 1 While making a U-turn
- 36 Rear end
  - 8 With vehicles thought to be moving forward
  - 8 With slowing vehicle
    - 3 General
    - 3 Making a turn
    - 1 Yielding to emergency vehicle
    - 1 Road rage
  - 8 With stopped vehicle
    - 5 Making a turn
    - 2 General
    - 1 Distracted
  - 5 With vehicle in intersection
    - 4 Distracted
    - 1 General

  - 4 Evasive maneuver to avoid, results in other collision
  - 2 Pedal misapplication
  - 1 Rolled forward
- 8 Turn signal
  - 4 Incorrect turn sign used
    - 2 Signaled right, turned left
    - 1 Signaled left, turned right
    - 1 Signaled turn, went straight
  - 3 Failure to use
    - 2 General
    - 1 Opposing vehicle speeding
  - 1 Not familiar with hand signals
- 7 Backing
  - 3 Rolled back
    - 2 General
    - 1 Pedal misapplication
  - 2 General
  - 2 Backed into roadway
    - 1 General
    - 1 Vision obscured
- 8 Other
  - 2 Passing
    - 1 Making a right turn, struck by vehicle passing on right
    - 1 Making a left turn, struck by vehicle passing on left
  - 2 Wide turn
  - 1 Illegal turn
  - 1 Vehicle with headlights off, not seen
  - 1 Lane change in or near intersection
  - 1 Head-on caused by failure to keep right in intersection

Figure A24b. TCD taxonomy (continued).

- **120 Stop sign**
  - 60 Ran stop sign
    - 44 General
    - 8 Did not see
      - 4 Distracted
      - 2 General
      - 1 New sign
      - 1 Unfamiliar area
    - 5 Skidded through
    - 3 Obscuration
      - 2 Fog
      - 1 Obstruction
  - 31 Failed to yield
    - 25 Failed to yield after stopping
      - 13 Did not see
      - 7 General
      - 5 While turning
    - 6 General
  - 23 Rear end
    - 18 With vehicle stopped at sign
    - 4 Stopped, but started up
    - 1 Movement to avoid
  - 6 Other
    - 4 Backed at sign
    - 2 Wide turn

- **71 Striking traffic sign**
  - 69 Ran off road
    - 36 General
    - 11 Weather
      - 7 Ice
      - 3 Wet pavement/hydroplaning
      - 1 Sun glare
    - 5 On curve or turn
    - 5 Speeding
    - 5 Evasive manuever
    - 3 Vehicle failure
      - 1 Steering
      - 1 Tire
      - 1 Loose towed vehicle
    - 3 Fell asleep
    - 1 After striking deer
  - 2 On road
    - 1 Struck traffic barrier sign
    - 1 Struck road construction sign

- **28 Struck animal/fixed object (not a TCD)**
  - 16 Utility pole/light pole/post/street sign
    - 6 General
    - 2 Distracted
    - 2 Evasive maneuver
    - 2 Incapacitated
    - 1 In curve
    - 1 Speeding
    - 1 Skidding
    - 1 Wet pavement/hydroplaning
  - 6 Tree
    - 2 In curve
    - 1 General
    - 1 Ice
    - 1 Evasive maneuver
    - 1 Bailed out of vehicle
  - 2 Deer in roadway
  - 1 Wire across roadway (overheight)
  - 1 Bridge deck (overheight)
  - 1 Construction zone barrier
  - 1 Guardrail

- **28 General roadway, not intersection or unspecified as intersection**
  - 20 Rear end
    - 6 General
    - 2 Speeding
    - 2 Pedal misapplication
    - 2 Backlights not working/not seen
    - 1 Deer
    - 1 Wet pavement/hydroplaning
    - 1 Unlit trailer
    - 1 With vehicles(s) slowing for construction
    - 1 Evasive manuever, hit guardrail
    - 1 With vehicle(s) stopped for traffic
    - 1 Distraction
    - 1 Fell asleep
  - 6 Ran off road
    - 2 Lost control
    - 1 On curve
    - 1 Headlight glare
    - 1 Speeding
    - 1 General
  - 1 Evasive maneuver to avoid vehicle with no headlights
  - 1 Sunlight glare

Figure A24b. TCD taxonomy (continued).

- **20 Lane lines**
  - 14 Crossed yellow/double yellow
    - 6 Passing
      - 5 General
      - 1 Struck left turning vehicle
    - 3 General
    - 2 Lost control
    - 1 Distracted
    - 1 Struck pedestrian standing on yellow
  - 4 Failure to remain in line
    - 3 Turning vehicles(s)
    - 1 General
  - 2 Crossed centerline in no passing zone

- **26 Other**
  - 13 Lane change general
  - 1 Crosswalk rear end
  - 2 With crossing pedestrians, signs unknown
  - 7 Illegal parking

- **14 Flashing red, flashing yellow**
  - 7 Ran flashing red
  - 5 Failed to yield
    - 4 After stopping at flashing red
    - 1 At flashing yellow
  - 2 Rear end with vehicle stopped for flashing red
    - 1 At turn light
    - 1 At fire station

- **9 Yield sign**
  - 7 Rear end
    - 3 Lead vehicle starts up but stops
    - 2 With slowing vehicle
    - 2 With stopped vehicle
  - 2 Failure to yield

- **4 Railroad crossing**
  - 1 Rear end with vehicle stopped at gate
  - 3 Crossed tracks
    - 1 Signal unknown
    - 1 Flashing reds and bells activated
    - 1 Claimed brake failure

- **2 Caution**
  - 2 Failure to heed (general)

Figure A24b. TCD taxonomy (continued).

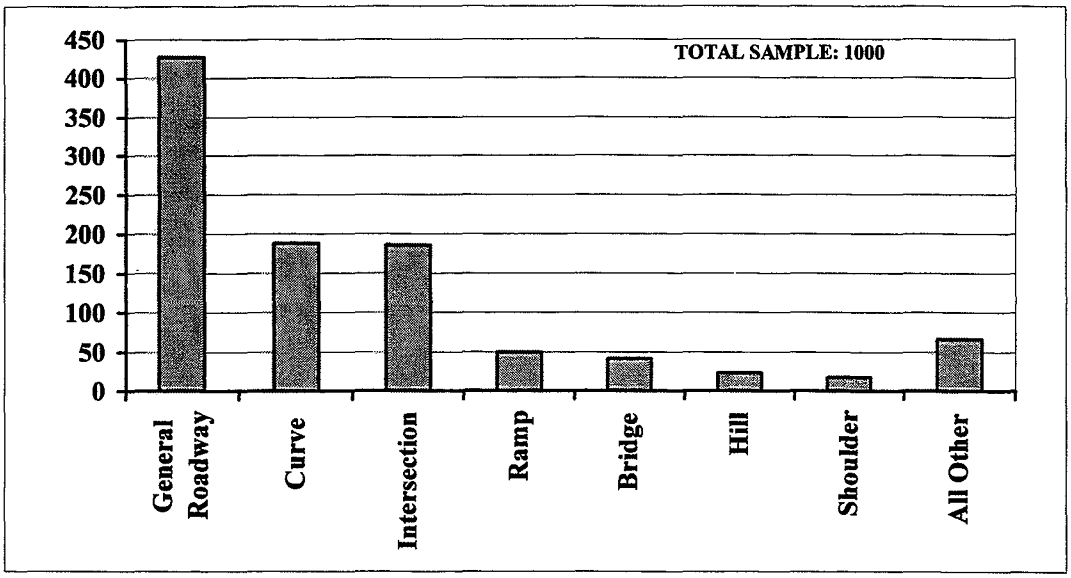


Figure A25a. Major categories for the roadway structure search.

428	General roadway
189	Curve
186	Intersection
50	Ramp
41	Bridge
23	Hill
17	Shoulder
15	Public vehicular area
11	Railroad
11	Driveway
10	Parking lot
9	Undeterminable
5	Grades
3	Bypass
1	Median
1	Work zone

Total: 1000

Figure A25b. Roadway structure taxonomy.

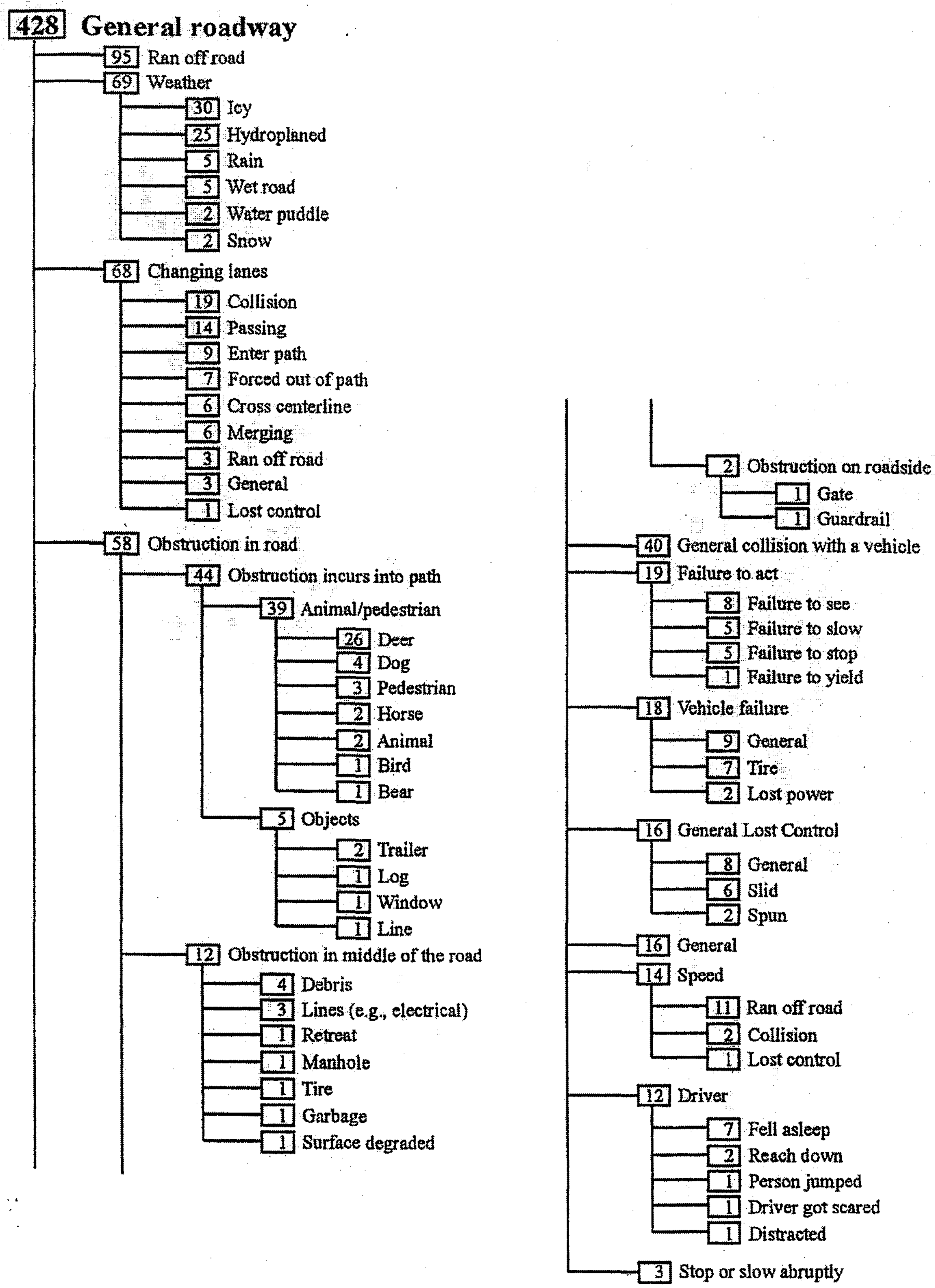


Figure A25b. Roadway structure taxonomy (continued).

- 189 **Curve**
  - 52 Speeding
    - 30 Ran off road
    - 8 General
    - 5 Skid
    - 2 Collision
  - 49 Ran off road
  - 22 Weather
    - 15 Icy
    - 4 Wet road
    - 2 Rain
    - 1 Hydroplaned
  - 12 Lost control
    - 6 General
    - 6 Skid
  - 11 Collision
  - 9 Sharp curve
  - 8 Change lanes (not a consequence of ran off road)
    - 4 Cross centerlane
    - 3 Pass
    - 1 Enter path
  - 5 Driver physical state
    - 3 Black out
    - 2 Fell asleep
  - 7 Failed action
    - 3 Failure to negotiate
    - 2 Failure to stop
    - 1 Failure to yield
    - 1 Failure to slow
  - 4 Vehicle failure
    - 2 Tire
    - 1 Steering wheel
    - 1 Trailer came loose
  - 3 Objects
    - 2 Living
    - 1 Sign
  - 3 Forced out of the road to avoid a car
  - 2 General
  - 2 Driver distracted

- 186 **Intersection**
  - 43 Turning
    - 30 Left turn
      - 18 General
      - 6 Failure to yield
      - 3 Failure to stop
      - 3 Failure to see
    - 7 Right turn
      - 6 General
      - 1 Failure to see
    - 6 Turn
      - 4 General
      - 1 Failure to see
      - 1 Failure to stop
  - 30 General
  - 29 Running red light
    - 25 General
    - 3 Both claimed green
    - 1 Thought the light was green
  - 16 Failure to stop
  - 15 Changing lanes
    - 12 Enter path
    - 3 General
  - 11 Failed to see
  - 9 Stop sign
    - 4 Failure to yield
    - 3 Failure to see
    - 2 General
  - 6 Running stop sign
  - 6 Failure to yield
  - 4 Object
    - 1 Utility pole
    - 1 Traffic island
    - 1 Loose gravel
    - 1 Curb corner
  - 4 Vehicle failure
    - 4 Brakes
  - 3 Speed or accelerating
  - 3 Weather
  - 2 Failure to slow
  - 2 Unsafe movement
  - 2 Braking
  - 1 Driver distraction

Figure A25b. Roadway structure taxonomy (continued).

- [50] **Ramp**
  - [21] Entrance or exit
    - [8] Failed action
      - [5] Failure to stop
      - [2] Failure to yield
      - [1] Failure to slow
    - [7] General
    - [2] Another vehicle entered path
    - [1] Assume vehicle started
    - [1] Vehicle failure
    - [1] Weather
    - [1] Braked abruptly
  - [18] Exit ramp
    - [14] General
    - [3] Failed action
      - [1] Failure to exit
      - [1] Failure to slow
      - [1] Failure to yield
    - [1] Red light running
  - [9] Entrance ramp
    - [7] General
    - [2] Failed action
      - [1] Failure to see
      - [1] Failure to stop
  - [2] Ramp/curve
- [41] **Bridge**
  - [13] Weather
    - [12] Icy
    - [1] Hydroplaned
  - [7] Ran off road
  - [6] Skid
  - [5] Lost control
  - [4] Underpass
    - [3] General
    - [1] Did not realize
  - [2] Driver
    - [1] Reach for papers
    - [1] Distracted
  - [1] Failure to see vehicle stopped
  - [1] Speeding
  - [1] Attempting to change lanes
  - [1] Forced out of path
- [23] **Hill**
  - [5] Intersection
    - [2] General
    - [1] Unable to stop
    - [1] Failure to see
    - [1] Blinded by sunglasses
  - [4] Weather
  - [4] Changing lanes
  - [3] Speed
  - [2] Object
  - [2] General
  - [1] Limited sight distance
  - [1] Vehicle failure
  - [1] Unable to stop
- [17] **Shoulder**
  - [12] Vehicle stopped
  - [3] General
  - [2] Reentering the road
- [15] **Public vehicular area**
  - [6] General
  - [4] Failure to see
  - [3] Failure to yield
  - [1] Object
  - [1] Failure to see
- [11] **Railroad**
  - [2] Underpass
    - [1] Failure to observe
    - [1] Other
  - [2] Rear end
  - [2] Struck railroad gate
  - [1] Failure to stop
  - [1] Vehicle failure
  - [1] Collision with train
  - [1] Ran off road
  - [1] Other
- [11] **Driveway**
  - [8] Private
  - [3] Public
- [10] **Parking lot**
  - [3] Turning
  - [2] Failure to see
  - [2] Exited/arrived at the same time
  - [2] Enter path
  - [1] Thought road was clear
- [9] **Undeterminable**
- [5] **Grades**
  - [4] Down
  - [1] Steep
- [3] **Bypass**
- [1] **Median**
- [1] **Work zone**

Figure A25b. Roadway structure taxonomy (continued).

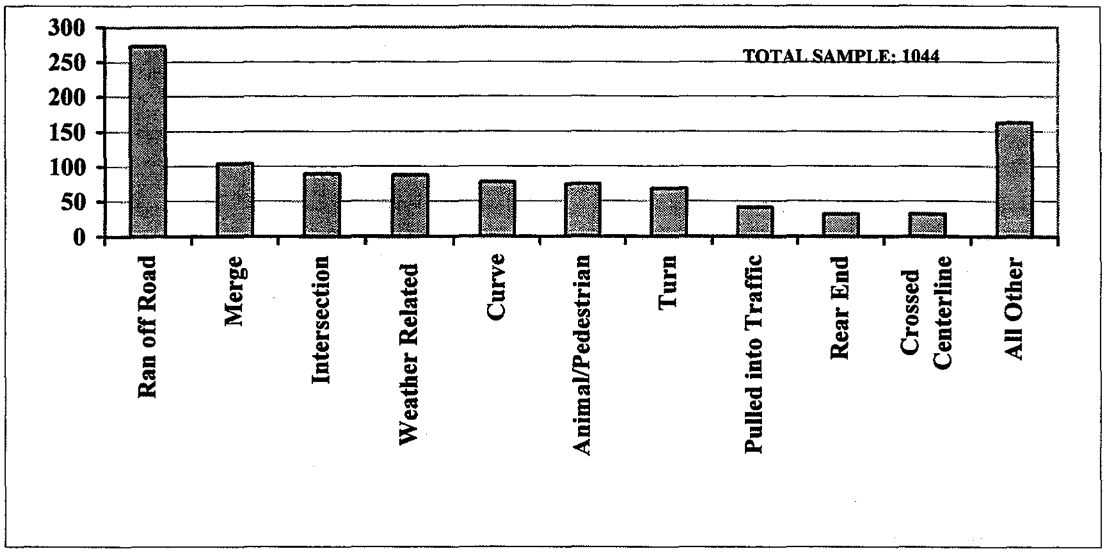


Figure A26a. Major categories for the roadway delineation search.

273	Ran off road
104	Merge
90	Intersection
88	Weather
78	Curve
75	Animal/pedestrian
68	Turn
41	Pulled into traffic
32	Hit rear
32	Crossed center line
31	Unknown
23	Speed
17	Construction
16	Fail to see
12	Pulling trailer
11	Mechanical problems
10	Two-car collision
9	Road features
8	Backed up
8	Cross over street
4	Object in the road
4	Three-car collision
3	Forced off road
2	Telephone lines fell on vehicle
2	Foot slipped off brake
1	Top of hill with sun reflection
1	Shock
1	No lights

Total: 1044

Figure A26b. Roadway delineation taxonomy.

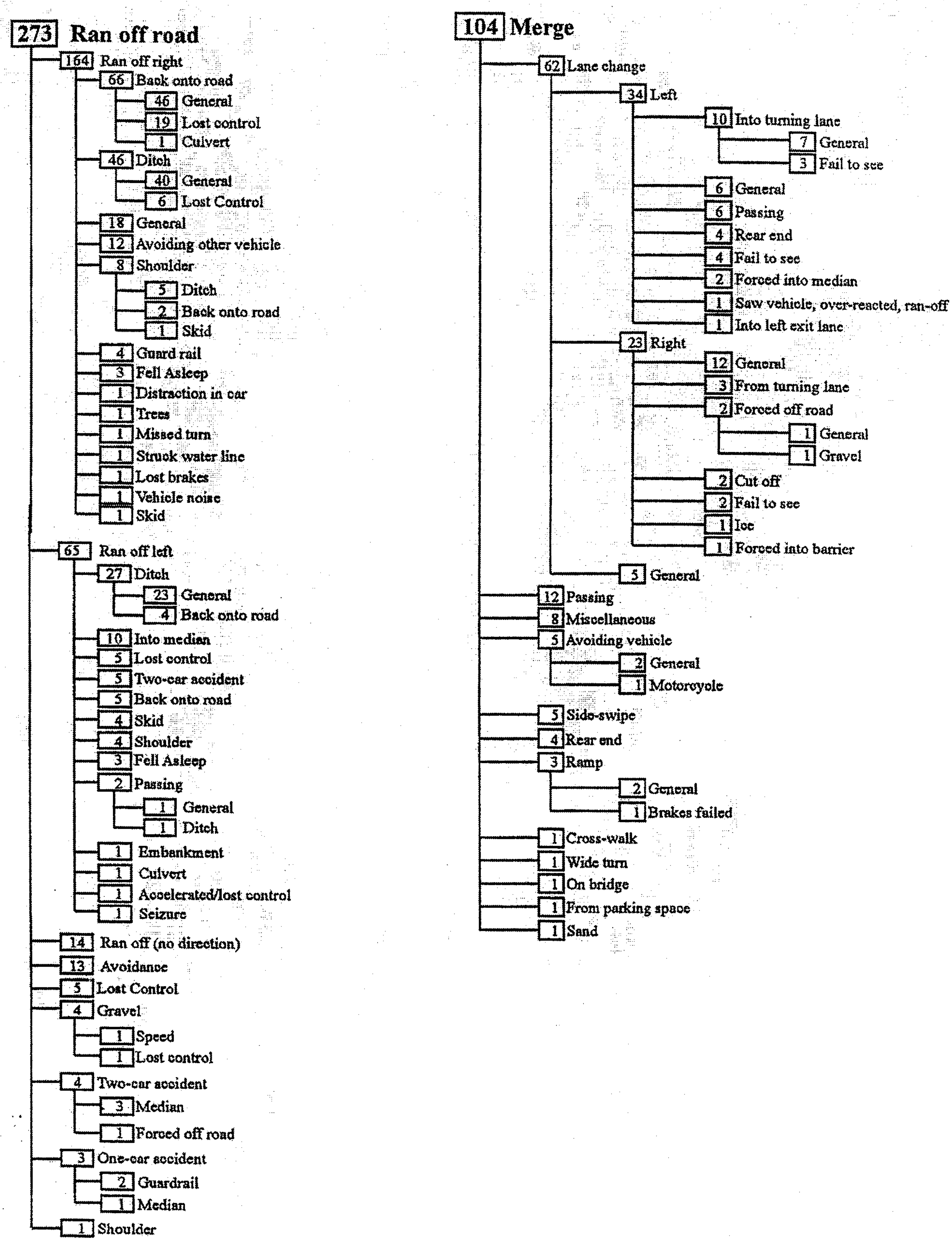


Figure A26b. Roadway delineation taxonomy (continued).

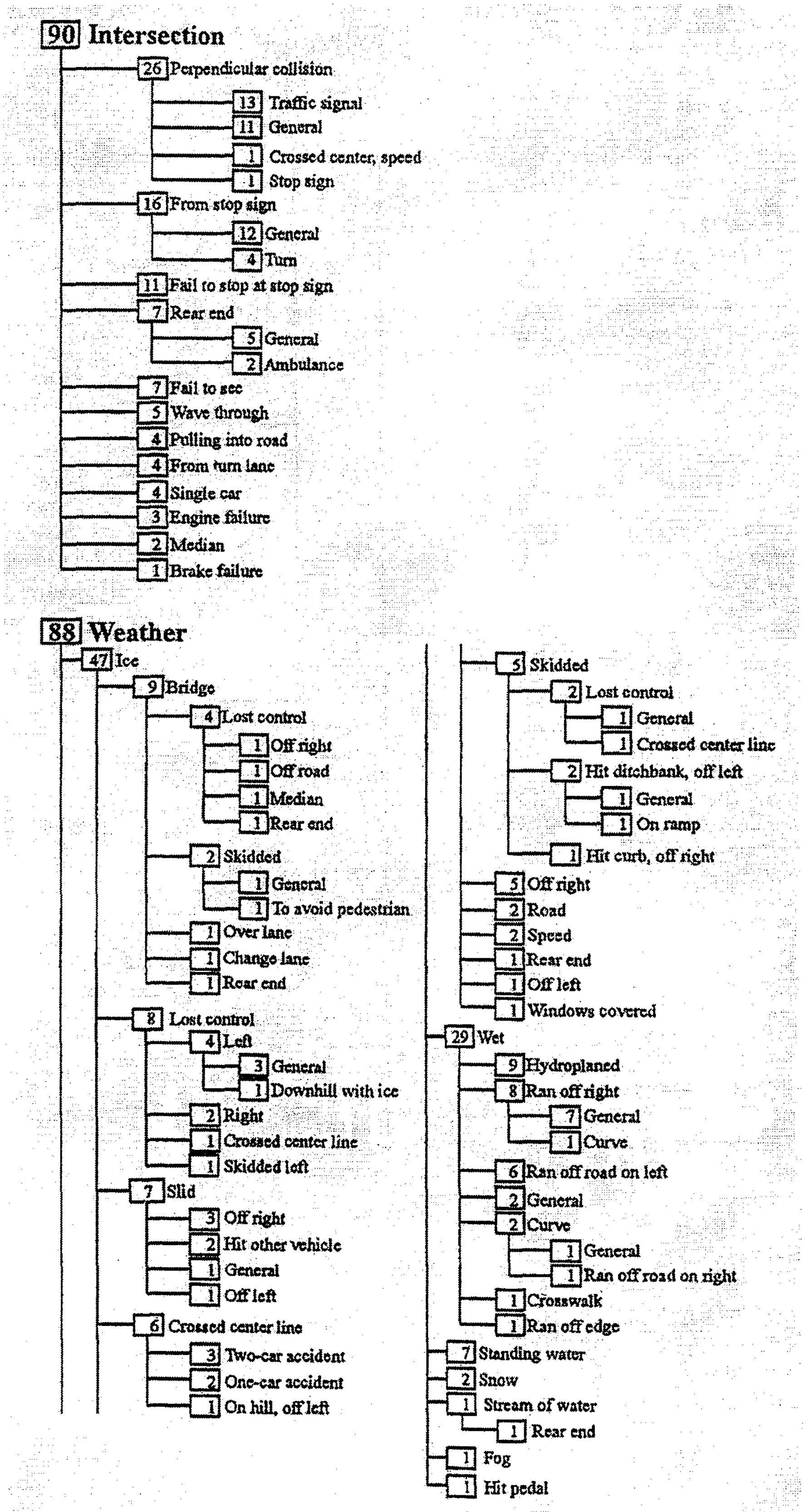


Figure A26b. Roadway delineation taxonomy (continued).

- 78 Curve
  - 23 Ran off right
    - 21 General
    - 1 Fell asleep
    - 1 Speed, alcohol/drugs
  - 18 Cross center line
    - 10 Two-car
      - 7 General
      - 2 Speed
      - 1 Blinded by headlights, went off left
    - 8 One-car
      - 4 Lost control, off left
      - 2 General
      - 2 Speed
  - 9 Speed
    - 4 Off right
    - 4 Off left
    - 1 General
  - 8 Ran off left
    - 7 General
    - 1 Speed
  - 6 Fail to make curve
    - 5 General
    - 1 Steering wheel locked up
  - 6 Ran off road
  - 4 Ice
    - 2 Off left
    - 2 Off right
      - 1 General
      - 1 Speed
  - 2 Gravel
  - 1 Stalled
  - 1 Looked down

- 75 Animal/pedestrian
  - 43 Deer
    - 42 General
    - 1 Multi-car
  - 12 Dog
    - 10 General
    - 2 Rear end
  - 11 Pedestrians
    - 10 General
    - 1 Sun?
  - 6 Other animals
  - 2 Bike
  - 1 Motorcycle with animal

- 68 Turn
  - 34 Left turn
    - 17 General
    - 9 Missed road
    - 7 Fail to see vehicle
    - 1 From outside lane
    - 1 After stopping for pedestrian
  - 12 Wide turn
    - 5 General
    - 4 Hit stopped vehicle
    - 3 Crossed center line
  - 8 Right turn
  - 9 At median
    - 4 Pulled into path
    - 3 Struck in rear
    - 2 Hit rear
  - 2 Across intersection
  - 2 Ramp turn
  - 1 Miscellaneous

- 41 Pulled into traffic
  - 25 General
  - 6 Fail to yield
  - 2 Median
    - 1 General
    - 1 Pulled out to see around trees in median

- 32 Hit rear
  - 15 Waiting for traffic
    - 12 General
    - 3 Traffic light
  - 8 General
  - 5 Slowing
  - 3 Sudden braking
  - 1 Cut off

- 32 Crossed center line
  - 28 Two-car
    - 26 General
    - 1 Sneezed
    - 1 Forced off road
  - 1 Left passing lane
  - 1 Stopped to turn
  - 1 High beams on
  - 1 Downhill with ice

Figure A26b. Roadway delineation taxonomy (continued).

- **31 Unknown**
- **23 Speed**
  - 19 Ran off road
    - 11 Right
      - 9 General
      - 2 Crossed center line
    - 8 Left
      - 7 General
      - 1 Alcohol
  - 1 Alcohol
  - 1 Skidded across center lane
  - 1 Motorcycle
  - 1 Ramp
- **17 Construction**
  - 9 Road construction
    - 4 Flagman
    - 3 General
    - 1 Barrier
    - 1 No lane markings at night in rain
  - 2 Slowing for stopped vehicle
    - 1 General
    - 1 Rear end
  - 2 Water equipment
  - 2 Barrel
  - 1 Off roadway
  - 1 Cones
- **16 Fail to see**
  - 5 Vehicle blocked view
  - 3 Attempted to cross
  - 2 Backed up traffic
  - 2 General
  - 1 From yield sign
  - 1 Secondary navigator
  - 1 From exit ramp
  - 1 From parking lot
- **12 Pulling trailer**
- **11 Mechanical problems**
  - 4 Brakes
  - 4 Tire blow out
  - 2 Wheel came off
  - 1 Steering problem
- **10 Two-car collision**
- **9 Road features**
  - 5 Rail road tracks
  - 4 Curb
- **8 Backed up**
- **8 Cross over street**
- **4 Object in the road**
  - 1 Bump in road
  - 1 Rock
  - 1 Metal bar
  - 1 Tree
- **4 Three-car collision**
- **3 Forced off**
- **2 Telephone lines fell on vehicle**
- **2 Foot slipped off brake**
- **1 Top of hill with sun reflection**
- **1 Shock**
- **1 No lights**

Figure A26b. Roadway delineation taxonomy (continued).

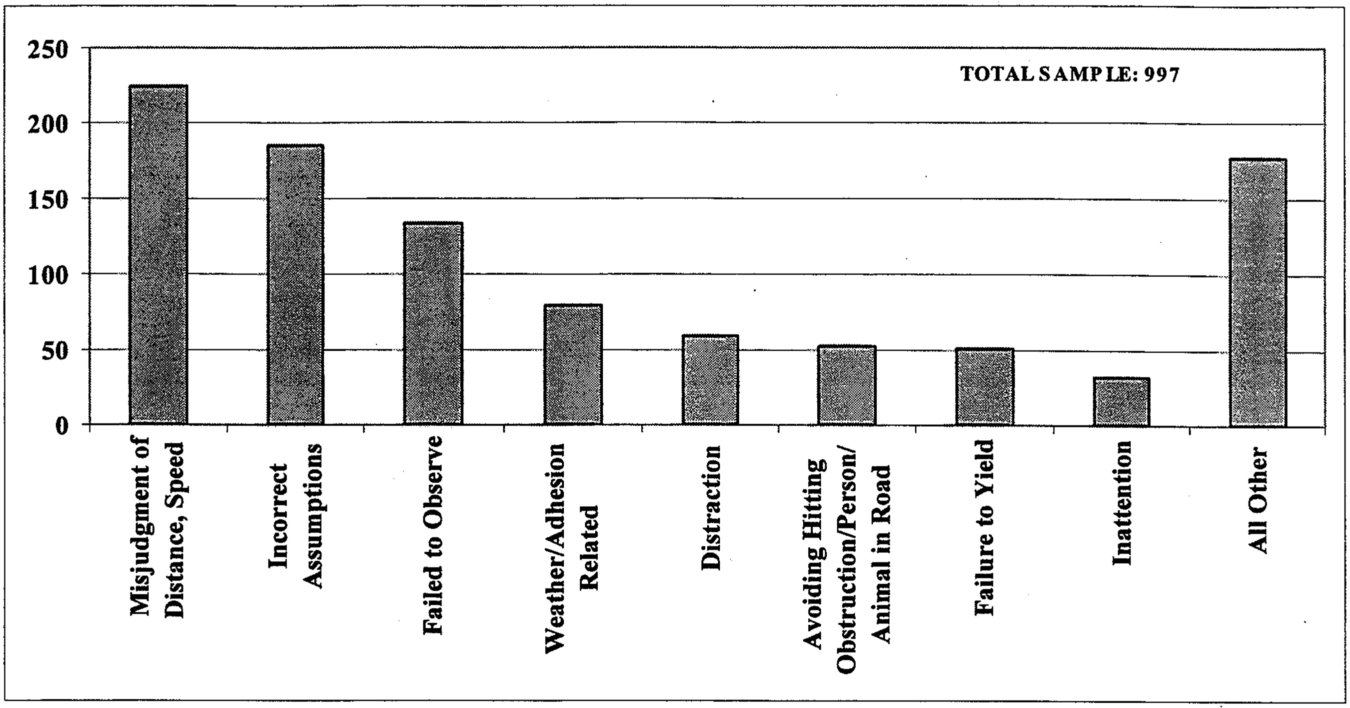


Figure A27a. Major categories for the reasons/excuses search.

224	Misjudgment of distance/speed
185	Incorrect assumptions
134	Failed to observe
80	Weather/adhesion related
60	Distraction
53	Avoiding/hitting obstruction in road
51	Failure to yield/stop
39	Undetermined
33	Inattention
29	Vehicle failure
23	Indecisiveness
21	Avoiding vehicle
21	Willful acts
15	Driver incapacitation
13	Other
9	Lost control for no reason
7	Misapplication of pedals

Total: 997

Figure A27b. Reason/excuses taxonomy.

224 Misjudgment of distance/speed

- 121 Vehicle ahead stopped unexpectedly due to traffic ahead
  - 94 General
  - 8 Vehicle ahead stopped suddenly due to accident
  - 8 Unusual circumstances led to car ahead stopping unexpectedly
  - 4 Vehicle ahead stopped suddenly
  - 3 Vehicle ahead reckless driving
  - 2 Vehicle ahead stopped suddenly for government car
  - 2 Vehicle ahead stopped for construction
- 34 Unexpected (rate of) slowing
  - 14 General
  - 14 Due to traffic
  - 2 Due to accident ahead
  - 1 Due to construction
  - 1 Due to animal in road
  - 1 To turn?
  - 1 No indication given
- 13 Misjudged traffic light
  - 8 Thought could make it through the intersection before the light changed
  - 4 Wasn't safe to stop for traffic lights
  - 1 Didn't stop in time for lights
- 20 Thought could perform maneuver in time
- 13 Changing lanes
  - 6 Thought had enough room
  - 1 Misjudged speed of car in adjacent lane
  - 1 Incomplete lane change prior to lead car stopping for stop sign
  - 1 Incomplete lane change prior to lead car stopping for traffic light
  - 4 No reason given for collision
- 9 Navigating a curve or turn
- 7 Merging
- 4 Rolled too far out into intersection
- 1 Turned in front of cars, no reason given
- 1 Thought he/she had completed the pass
- 1 Turning in front of oncoming cars

185 Incorrect assumptions

- 51 Thought lead car was going to proceed from stop
  - 16 General
  - 15 Through green traffic signal
  - 5 Through turn
  - 5 Through stop sign
  - 4 Through yield sign
  - 3 Through intersection
  - 2 With adjacent lane of traffic
  - 1 After waiting for another car to turn
- 34 Misperception of traffic lights
  - 24 Thought light was green
  - 3 Thought left turn light was also for driving straight ahead
  - 3 Thought straight ahead light was also for left-turning vehicles
  - 3 Thought light was yellow
  - 1 Thought other vehicle had red light
- 22 Expected other vehicle to turn in opposite direction
  - 18 General
  - 4 Turning car made a wide turn
  - 1 Had correct signal but presumed otherwise
- 18 Unexpected reactions of others to road signs/control devices
  - 7 Vehicle ahead stopped unexpectedly for a red light
  - 6 No additional reason or information given
  - 2 Vehicle ahead stopped unexpectedly due to stop sign
  - 2 Vehicle stopped unexpectedly for a yellow light
  - 1 Vehicle ahead stopped unexpectedly for end of road
- 18 Thought car turning, not going straight on
  - 15 General
  - 3 Other vehicle had turn signal on early
- 12 Assumed car would continue straight but stopped unexpectedly to turn
- 8 Confusing visual cues
  - 4 Vehicle ahead had no brake lights
  - 2 Had the wrong signal on
  - 1 Used no signal
  - 1 Had indicator lights on too long
- 8 Thought lead car was in motion
- 5 Road structure
  - 1 Thought all lanes in highway one way
  - 1 Thought there were two south-bound lanes so tried to pass
  - 1 Turned from center lane thinking it was turn lane
  - 1 Thought he/she had right of way
  - 1 Thought it was a 4-way intersection
- 2 Thought car was in park
- 2 Thought car would slow to let him/her into roadway
- 1 Own car accelerated more quickly than anticipated
- 1 Thought car stationary, not turning
- 1 Thought car going to turn so attempted pass
- 1 Did not anticipate yield sign

Figure A27b. Reason/excuses taxonomy (continued).

- 134 **Failed to observe**
  - 55 General
  - 28 Another vehicle obstructing
    - 8 Turning vehicle
    - 7 By parked vehicle
    - 5 By stopped vehicles motioning driver out
    - 4 General
    - 3 Vehicle in next lane
    - 1 By stopped traffic in intended lane of travel
  - 17 Perceived road as clear
    - 11 Thought it was clear
    - 3 Thought oncoming lane was clear
    - 2 Thought it was clear to turn right on red
    - 1 Thought car was in outside lane
    - 1 Thought car in outside lane, had only one headlight operational
  - 13 Structural obstructions
    - 6 Curve in which a stationary car was hidden from view
    - 3 Hillcrest
    - 2 Trees
    - 1 Street lights and bushes
    - 1 View obstructed by traffic lights
  - 10 Sun in eyes
  - 6 Failed to see red light
  - 3 Didn't see pedestrian
  - 1 Failed to see stop sign

- 80 **Weather/adhesion related**
  - 39 Wet
  - 25 Ice
  - 10 Rain
  - 4 Weather (general)
  - 2 Weather and speeding

- 60 **Distraction**
  - 32 External distraction
    - 9 Looking left
    - 9 Looking behind (rear view mirror)
    - 8 Looking elsewhere
    - 6 Looking at another car
  - 28 Internal distraction
    - 10 Looking down
    - 5 Picking something up
    - 3 Passenger
    - 2 Putting tape in radio
    - 2 Talking on phone
    - 1 Reading a bill
    - 1 Eating a hotdog
    - 1 Sneezed
    - 1 Glasses fell off face
    - 1 Taking glasses off
    - 1 Bee flew through window

- 53 **Avoiding/hitting obstruction in road**
  - 24 Parked vehicle
  - 13 Person
  - 7 Animal
  - 6 Object
  - 3 Disabled vehicle in road

- 51 **Failure to yield/stop**
  - 15 Failing to yield for traffic light
  - 14 Ran a red light
  - 12 Failed to stop general
  - 8 Failed to yield general
  - 2 Ran a stop sign

- 39 **Undetermined**

- 33 **Inattention**
  - 27 General
  - 3 Other
  - 1 Concentrating on potential maneuver
  - 1 Did not notice color of traffic light
  - 1 Did not realize on a one-way street and moved into adjacent traffic to left

- 29 **Vehicle failure**

- 23 **Indecisiveness**
  - 9 Reversed instead of performing maneuver
    - 5 Decided not to turn
    - 2 In left lane decided to turn right
    - 2 Decided to change lanes
  - 5 Stopped midway through a turn
  - 2 Start and stop at intersection
  - 2 Turned right from left lane
  - 1 Went straight ahead in turn lane instead of turning
  - 1 Indecisive, turned into adjacent car
  - 1 Merging
  - 1 Vehicle pulled out very slowly into oncoming traffic
  - 1 General

Figure A27b. Reason/excuses taxonomy (continued).

- 21 Avoiding vehicle
  - 12 No other reason or explanation
  - 1 Construction and traffic on curve
  - 1 Following closer than realized and rear-ended vehicle in front
  - 1 Entering intersection
  - 1 Wide vehicle
  - 4 Attempting maneuver quickly
  - 1 Vehicle ahead ran out of ramp (trying to avoid)
- 21 Willful acts
  - 9 Illegal
    - 2 Made an illegal U-turn
    - 2 Passing on double yellow lines
    - 2 Drove over centerline, forced off road
    - 1 Illegal left turn
    - 1 Car ahead stopped to turn from wrong lane
    - 1 Turned left on red
  - 8 Risky
    - 4 Reckless driving
    - 1 Navigating curve while over center line
    - 1 Overtaking on hill
    - 1 Admitted to following too closely
    - 1 Passing oversized load
  - 4 Speeding
- 15 Driver incapacitation
  - 7 Sleep
  - 6 Physical incapacitation
  - 2 Drink/drugs
- 13 Other
  - 3 Faulty control devices
  - 2 No reason
  - 1 Headlights not on
  - 1 Passenger told him it was clear
  - 1 Driver motioned car to go left
  - 1 Other
  - 1 Soft shoulder
  - 1 Turning left
  - 1 Object hit windscreen
  - 1 Trying to pass
- 9 Lost control for no reason
- 7 Misapplication of pedals
  - 5 Foot slipping off brake
  - 1 Hit gas pedal instead of brake
  - 1 Floor mat wedged under accelerator

Figure A27b. Reason/excuses taxonomy (continued).

Uniform Sample Taxonomy

The primary purpose of this sample was to provide information on the relative number of occurrences of various types of crashes and associated errors. The histogram of figure A23a provides an overview. It shows that "Failure to yield at intersections" accounted for more than one-fourth of all crashes. Within this category, major contributors were "Left-turn-related," "Traffic light-related," and "Stop sign-related," as shown in Figure a23b. An additional contributor was "Failure to see, see correctly, or observe."

Figure A23a also shows that more than one-fifth of all crashes involved rear-ending. "Rear-ending" occurred for a variety of reasons and at a variety of locations. These crashes usually are a result of "Inattention," "Following too closely," or otherwise "Failing to detect a slowing or stopped vehicle."

"Run off road" was another category that resulted in more than one-fifth of all crashes. More detailed categories under "Run off road" include "Weather related," "Excessive speed," and "Curve related."

Additional categories accounting for more than 7 percent (each) of all crashes were "Lane-change related" and "Obstacle/animal/person avoidance." It should be noted that centerline crossing resulted in an additional 3 percent, which could also be considered part of the "Failure to stay in lane/change lanes properly" category.

In general, the uniform search taxonomy demonstrates that there are major clusters in crashes, some of which are location-specific and some of which are type-specific.

Traffic Control Device (TCD) Taxonomy

This search was directed toward uncovering the interactions between TCDs and crashes/errors. Figure A24a provides a histogram summary of the major categories, and figure A24b provides the detailed taxonomy. As can be seen, more than 30 percent of all crashes occurred at or around traffic signals. In addition, some of the crashes included in the second most frequent category (i.e. "Intersection or road entry TCD unspecified") could be assumed to have occurred at signalized intersections, even though the type of TCD was not specified in the narrative. Thus, the number of crashes around traffic signals was actually higher than 30 percent.

Twelve percent of the narratives were associated with stop sign crashes and, surprisingly, 7 percent involved striking traffic signs. In the latter case, most involved roadway departure, that is, run-off-road crashes.

Also, it was surprising how few of the crashes involved flashing red, flashing yellow, yield, railroad crossing, and caution signs and signals. Combined, they accounted for fewer than 3 percent of all crashes. Of course, the numbers of such signs and signals is small compared with the numbers of stoplights and stop signs.

Within the TCD search, further analysis shows that at least 20 percent of the crashes are rear-end related, and that running lights/signs combined with failure to yield accounts for a gigantic 45 percent of the crashes.

Roadway Structure Taxonomy

This search was directed toward uncovering the interactions between structural aspects (bridges, curves, crests) of the roadway system and crashes/errors. Figure A25a shows the summary histogram for this search, and figure A25b shows the detailed taxonomy. The histogram shows that 42 percent of the narratives were generally "In-roadway" crashes, that is, not at intersections, not specified as being at curves, etc. Within this category, "Run-off-road," "Weather," "Lane changing," and "Obstructions" were principal contributors. Nineteen percent of the crashes were at curves, and another 19 percent were at intersections. "Excessive speed," "General running off road," "Weather," and "Loss of control" contributed to curve crashes. The intersection crashes are apportioned in a manner similar to the TCD taxonomy. Five percent of the crashes occurred at or near entry and exit ramps, 4 percent occurred at or near bridges, and 2 percent occurred on or near hills.

Roadway Delineation Taxonomy

This search was devised to uncover crashes associated with demarcation, delineation, and other non-sign/signal-related guidance devices. Results appear in figures A26a and A26b.

This search emphasized both normal and special situation delineation. In the special case, items such as barriers, barricades, traffic cones, and flags associated with construction and rerouting for crashes were included.

This search produced results similar to those seen in the previous searches. Twenty-six percent of the crashes were "Run-off-road" with a variety of causes. "Running off on the right" was 2.5 times more common than "Running off to the left."

Merge crashes accounted for 10 percent of all crashes, the majority of which were lane-change related. "Intersections" accounted for more than 8 percent of crashes in this search, as did "Weather-related causes." "Curves" and "Collisions with animals/pedestrians" each accounted for more than 7 percent. This search did not net large numbers of crashes associated with special situations such as construction.

Reasons/Excuses Taxonomy

This search was somewhat distinct from the others in that it was directed toward driver reasons, excuses, and other explanations as to what occurred or why a crash occurred. This search was less closely tied to the infrastructure and more closely tied to subjective impressions. The taxonomy itself was also patterned around reasons, excuses, and other explanations. Therefore, it is also closer to the concept of errors per se than the other taxonomies.

In this taxonomy, as shown in the histogram summary of figure A27a, more than 22 percent of the crashes were associated with misjudgment of distance or speed, and more than 18 percent were associated with incorrect assumptions. A variety of contributing factors fall under each of these major categories, as shown in figure A27b, the detailed taxonomy.

Failure to observe accounted for more than 13 percent of the crashes, and weather accounted for 8 percent. Failure to observe indicates that, in some cases, drivers were not able to see hazards because of obstructions. Driver distraction accounted for 6 percent of crashes.

It should be noted that the excuses/reasons/explanations are quite varied when one examines the smaller branches of the taxonomies in figure A27b. Nevertheless, there are several emerging patterns. One pattern is "Inattention," where drivers did not pay close enough attention to the driving situation.

Another pattern is "Excessive speed for the conditions." The category labeled "Misjudgment of distance or speed" is similar to this category. The category "Incorrect assumptions" suggests that drivers often drove without being certain of clear paths, rights-of-way, maneuverability, and stopping distances. "Failure to yield" in many cases can be attributed to improper understanding of traffic laws and conventions. Thus, while the reasons/excuses taxonomy provides excellent error information, care must be taken to properly interpret the real underlying error.

Conclusions Resulting From the Narrative Searches

The results of the narrative searches can be classified under three major headings: those associated with specific locations and infrastructure elements, those associated with crash type and general environment, and those associated with driver error type. Table A9 provides an overview of the major contributing factors under each heading. A discussion of each of these three areas can be found in the Task C report. Presented below are the conclusions from the infrastructure and driver error areas.

Table A9. Major crash contributory factors appearing in the narrative searches.

Infrastructure Related	Crash Type/Environment Related	Driver Error Related
Intersection/Road Entry	Rear End	Failure to Yield ROW
-Stop Light		
Running Red/Yellow-Red	During Left Turn	Misjudgment of
-Stop Sign		Distance/Speed
Running Sign	Weather Related	
Collision after Stop		Incorrect Assumption
-Left Turn	With Animal/Object/Pedestrian	
-Rear End		Failure to See or Perceive
	Merge/Lane Change	Correctly
Roadway Departure		
(Run off road)		Distraction/Inattention
-General		
Left/Right		
-On Curve		
Left/Right		
Merge/Lane Change		

<u>Conclusions in Regard to Location and Infrastructure</u>

Several of the taxonomies demonstrate that intersections and road entrances are prone to crashes. Part of this problem is that there are a great number of intersections, and vehicles passing through them can easily end up in conflict with one another. When conflicts occur, there will be a dissipation of vehicle kinetic energy, resulting in collision damage and possible injuries or deaths.

Both signalized and stop-controlled intersections are heavily represented in the crash taxonomies. While both forms of traffic control are highly effective, they are not foolproof. Because of the large number of opportunities for conflicts, it is not surprising that collisions do occasionally occur. Even occasional occurrences will result in a large number of crashes because of the large number of intersections.

In regard to intersection crashes, a great number are a result of red light and stop sign running. In most cases, running occurs as a result of driver error, but it can also occur as a result of a willful act. In particular, passing through an intersection after the light has turned red can be a willful act.

Left-turn crashes are also common at intersections. In some cases, drivers do not understand that they do not have the right-of-way, particularly at unprotected green lights or at stop controlled intersections. In other cases, speed misjudgment or lack of detection of an oncoming vehicle results in a left-turn collision.

Finally, in regard to intersections, there are huge numbers of rear-end collisions. These occur both just prior to entering intersections and also within intersections. One common class is collision with a vehicle stopped for the light or sign. Another common class is collision with a vehicle starting off late or slowly after stopping. Yet another class is collision with a vehicle that is waiting to turn left in the intersection.

Roadway departure to the right is approximately 2.5 times more likely to occur than departure to the left. This result is explainable by the fact that in the United States, we usually travel on the right. Thus, with all other aspects being equal, a deviation to the right is more likely to result in leaving the roadway. Other aspects contributing to this imbalance include road crown biasing the vehicle to move to the right, the availability of a shoulder immediately to the right for use in evasive maneuvers, and the usual desire to avoid head-on collisions caused by going to the left. Roadway departures have many contributing factors including inattention, excessive speed, weather, evasive maneuvers and, to a lesser extent, incapacitation and vehicle failure.

The final major category of infrastructure-related crashes is merge/lane change maneuvers. Passing can also be included in this category as well. While merge/lane change crashes are not as prevalent as intersection and roadway departure crashes, they nevertheless contribute substantially to the narratives reviewed. These crashes occur for a variety of reasons including not detecting a conflict with another vehicle, excessive speed on the part of another vehicle, improper technique in determining appropriate gap, improper visual scan, and vehicle in blind spot. These reasons overlap one another in most cases.

Conclusions in Regard to Driver Errors

Several common classes of driver errors appear in the accident narrative databases. These are listed in the right column of table A9.

"Failure to yield right-of-way" is the most common reason cited in the narratives. Theoretically, it could be stated that if no driver ever violated a right-of-way, the number of crashes would be greatly reduced. The right-of-way concept is a result of having traffic paths that cross or conflict. Whenever such a potential conflict occurs, there must be a clear understanding of who has the right to proceed and who by law must yield. As traffic volumes increase, there are corresponding increases in potential numbers of conflicts, making understanding of rights-of-way even more important.

Rights-of-way may be violated for many reasons including lack of knowledge, willful acts, speeding, weather, and lack of detection of a vehicle or pedestrian having the right-of-way. Examples of lack of knowledge include making a left turn from a left-turn lane with an unprotected green (with oncoming traffic), and making a left turn not knowing that pedestrians crossing in parallel have the right-of-way. Examples of willful acts include purposely entering an intersection after the light has turned red, and purposely merging by forcing vehicles in the travel lane to take evasive action. Speeding may result in a right-of-way violation by causing an inability to stop or stop in time at an intersection. Weather may similarly cause an inability to stop or stop in time. Not seeing a stop sign or perceiving a traffic signal as green when it is red are examples of lack of correct detection that result in right-of-way violations.

Another major category of errors involves misjudgment of distance or speed. The "Reasons/Excuses" taxonomy shows that 22 percent of all crashes involve this type of error. Underestimating stopping distance for a given speed is a typical example in this category. Another example is traveling at high speed near the entrance of an intersection, thereby making it necessary to proceed late in the yellow-light phase of the traffic signal.

Closely associated with misjudgment of distance/speed is the category of "Incorrect assumptions." These are quite common and are usually cited as "the driver thought . . ." or something similar. A typical crash in this category is a rear-end collision with a vehicle stopped after change to green or proceeding slowly after change to green; in this case, the following driver "thought" the lead vehicle would accelerate. Note that the "Reasons/Excuses" taxonomy attributed more than 18 percent of all crashes to incorrect assumptions. If the "Misjudgment of distance/speed" and "Incorrect assumption" categories are combined, they account for more than 40 percent of all reasons/excuses for crashes.

The last two categories of major importance in the driver-error-related classification are "Failure to see or perceive correctly," and "Distraction/Inattention." Reasons for such failures include "Inadequate scanning," "Distraction/Inattention," "Obstruction," "Improper sign or signal placement," "Glare," "Inadequate illumination or contrast," and "Visual impairment." Unless drivers remain alert and attentive to the driving task, they increase their likelihood of becoming involved in crashes attributed to these categories.

General Conclusions Associated with the Narrative Searches

The narrative searches have been successful in providing information on where crashes are most likely to occur, the types of crashes that are most frequent, and the types of errors that are most prevalent. The searches clearly show that the perspective from which the narratives are drawn, as determined by the keyword list used, has an effect on the resulting taxonomies. Nevertheless, common threads among the taxonomies suggest general conclusions. Table A9 provides a list of factors with dominant themes and, as such, provides an outline of the conclusions drawn. These factors have already been discussed in this conclusion section and need not be repeated here. What is important to note is that the narrative searches provide a wealth of information on how to set up field data-collection procedures to capture driver errors since infrastructure, crash type, and error type are all taken into account.

3. Traditional Database Analysis Using the North Carolina HSIS Accident Database

The HSIS is a multi-State accident database system that is supported by FHWA in cooperation with various State agencies in the participating States. HSIS is intended to be used by researchers for purposes consistent with information gathering on highway crashes and with the development of countermeasures and infrastructure improvements.

For the Driver Error study, three States were initially selected for HSIS database analysis because they represented different geographical regions of the United States: North Carolina, Michigan, and Washington. However, because the taxonomy development study of Task C was already much larger than originally proposed, only the North Carolina HSIS data were analyzed. The other two sets of search results were set aside, but kept available for future analysis.

Objective

The use of *narrative* searches as documented in the previous section of this report is considered to be a somewhat unconventional approach to accident analysis. That approach depends on the technique of extracting narratives and then classifying them. HSIS, on the other hand, is an accident database constructed on conventional principles. While HSIS has many possible uses, for the taxonomy development of Task C (Hankey et al., 1999), it was decided to use the database as a means of checking the validity of the *narrative* approach. The fundamental idea was to determine whether HSIS results were similar to narrative results in those cases where comparisons could be made. To make such comparisons, only the North Carolina HSIS database was used. The year 1996 was selected because it was the most recent year for which comprehensive data were available. The *narrative* search was performed on the 1994 database. If reasonable correspondence could be found between the two sets of results, then the narrative approach could be considered valid.

Approach

The HSRC at the University of North Carolina, Chapel Hill, was under contract to FHWA to maintain and update the HSIS. Personnel at the HSRC were contacted to:

1) Help determine what data should be extracted for the purpose of the Task C report, and
2) Extract data from the HSIS database and transfer the data in an SAS-readable format to the Virginia Tech Transportation Institute (VTTI).

After analyzing the available HSIS documentation and after discussions with HSRC personnel, fields were selected in the Accident file, Vehicle file, and Roadway file for extraction by HSRC. The fields extracted by HSRC and their associated files are shown in table A10.

Table A10. Files and fields selected from the 1996 HSIS North Carolina database.

Accident File	Vehicle File	Road Inventory File
acc_date	action	aadt
acctype	contrib1-5	func_cls
hour	crossmed	improve1
light	drv_age	lshl_typ
loc_type	drv_sex	lshldwid
means	impactsp	med_type
month	maneuver	medwid
numvehs	miscact1	no_lanes
pedflag	mostharm	rshl_typ
plotqual	object1	rshldwid
rd_char1	physcond	rururb
rd_conf	rd2objst	spd_limt
rd_def	spdlim	spec_st
rdsurf	trvl_spd	st_mile1
severity	vision	surf_typ
time		surf_wid
trf_cntl		terrain
trf_oper		
trf_vis		
weather		

After transfer of the data to VTTI, one-way frequency analyses were performed on each of the fields in table A10. From these analyses, the fields shown in table A11 were selected as the most useful for error taxonomy development and narrative technique validation.

Table A11. Fields deemed most useful after one-way frequency analysis.

Accident File	Vehicle File
acctype	contrib1-5
loc_type	maneuver
means	mostharm
rd_def	physcond
rdsur	vision
trf_cntl	

There were 135,858 crashes included in this analysis of the HSIS 1996 North Carolina database. In these crashes, 237,828 vehicles were involved. Thus, the Accident file contained 138,858 entries, and the Vehicle file contained 237,828 entries. None of the Roadway file fields was found useful for purposes of the current analyses.

Results

The 11 fields shown in table A11 were classified by subcategories, rank ordered (in terms of number of occurrences), and plotted. Figures A28 through A38 show the resulting histograms. In the plots, certain conventions were used. In some accident reports, the field was left blank or incomplete by the investigating officer. In other cases, "no specific factor" was indicated. The numbers of entries for which there was no information or no specific information were subtracted from the total number of entries. These values appear above the "bars" in the graphs. Note that the maximum possible values would be 135,858 for the Accident file levels, and 237,828 for the Vehicle file levels. In other words, the heights of the bars sum to the values shown above the bars. Also included on each graph is a percentage indicating the ratio of the sum of occurrences to the database size (either 135,858 or 237,828) multiplied by 100.

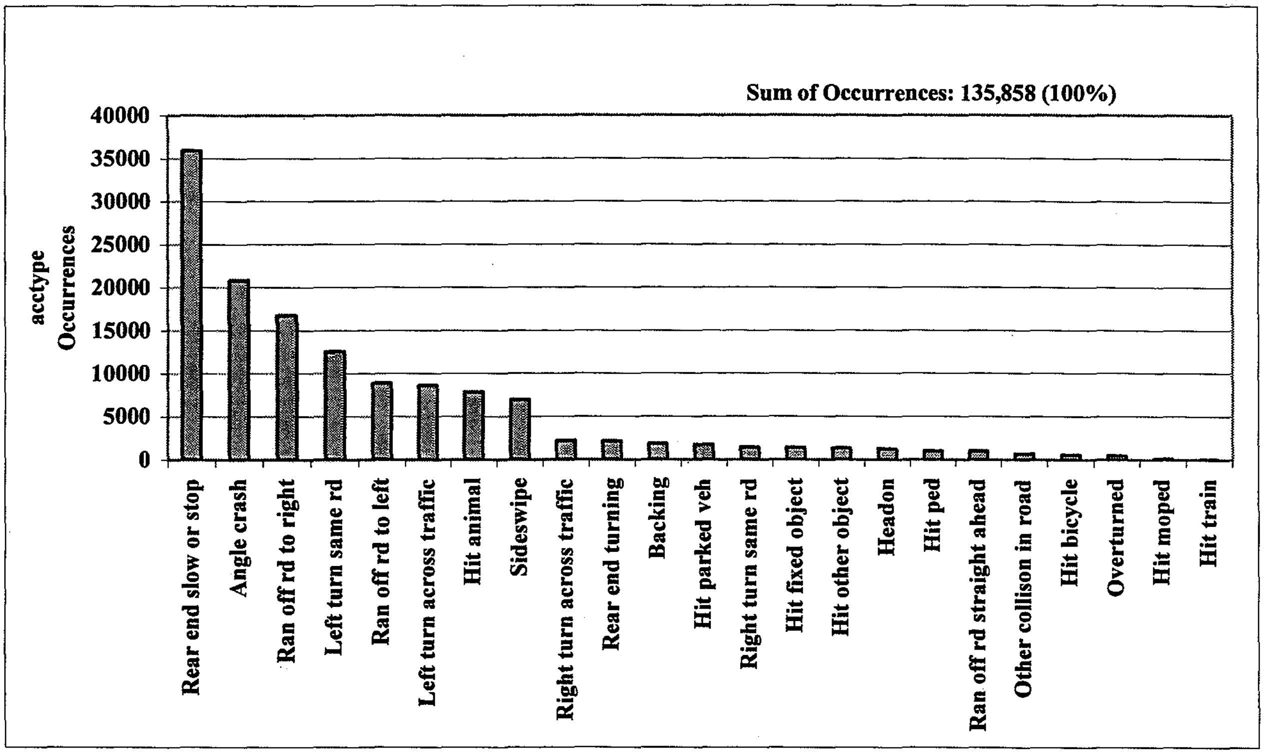


Figure A28. First harmful event occurrences in the NC HSIS Accident File.

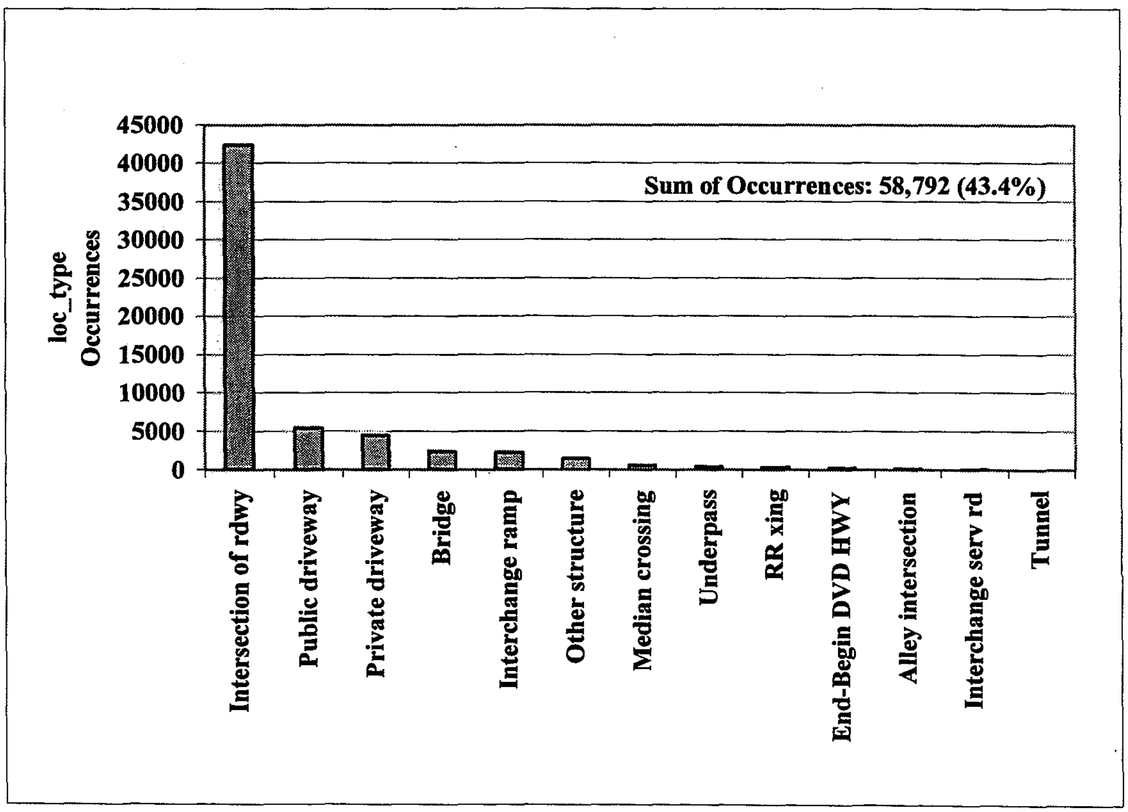


Figure A29. Accident location occurrences in the NC HSIS Accident File.

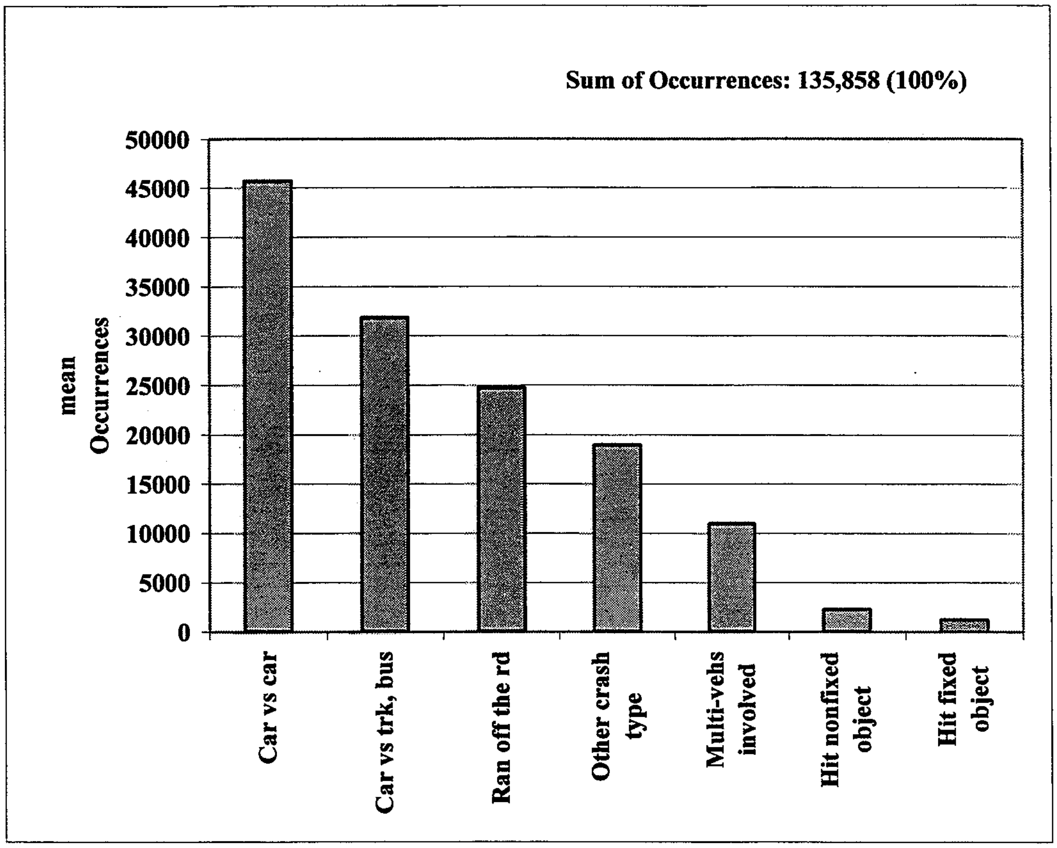


Figure A30. Means of involvement occurrences in the NC HSIS Accident File.

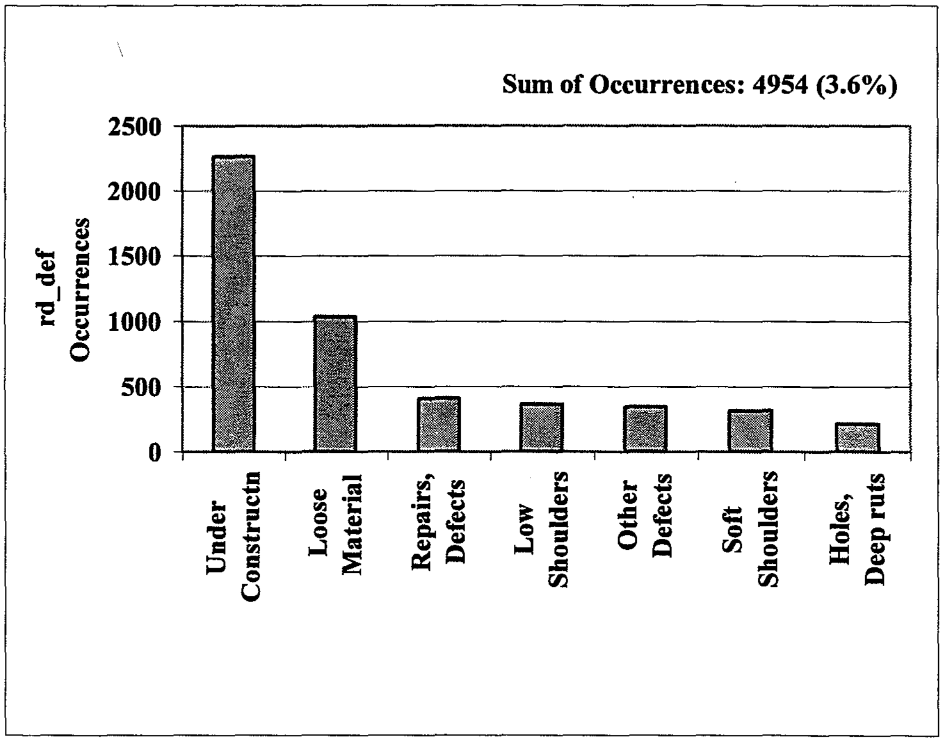


Figure A31. Road defect/under construction occurrences in the NC HSIS Accident File.

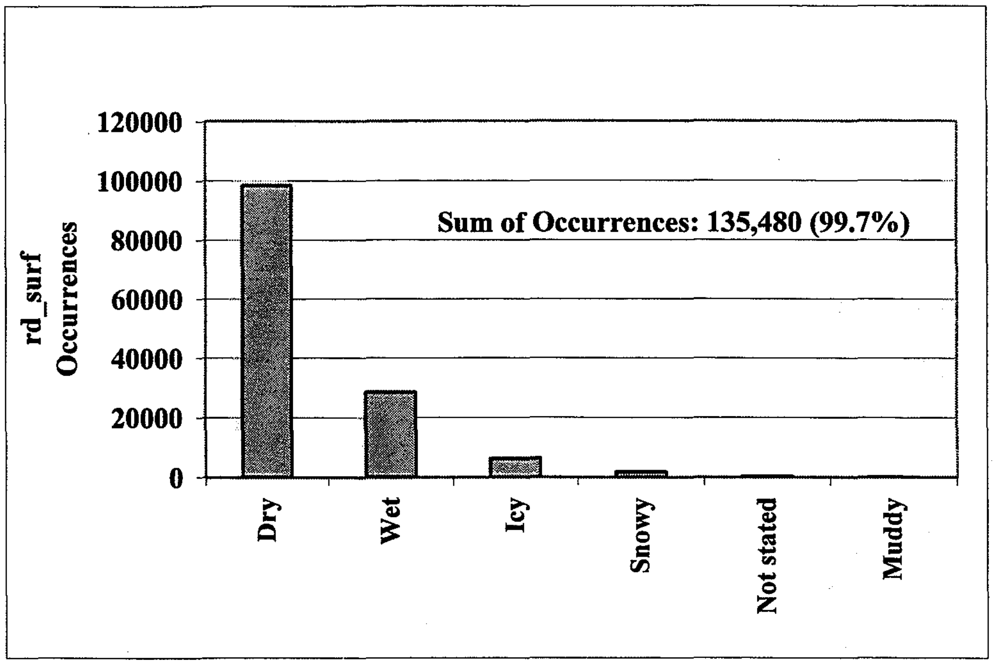


Figure A32. Road surface condition occurrences in the NC HSIS Accident File.

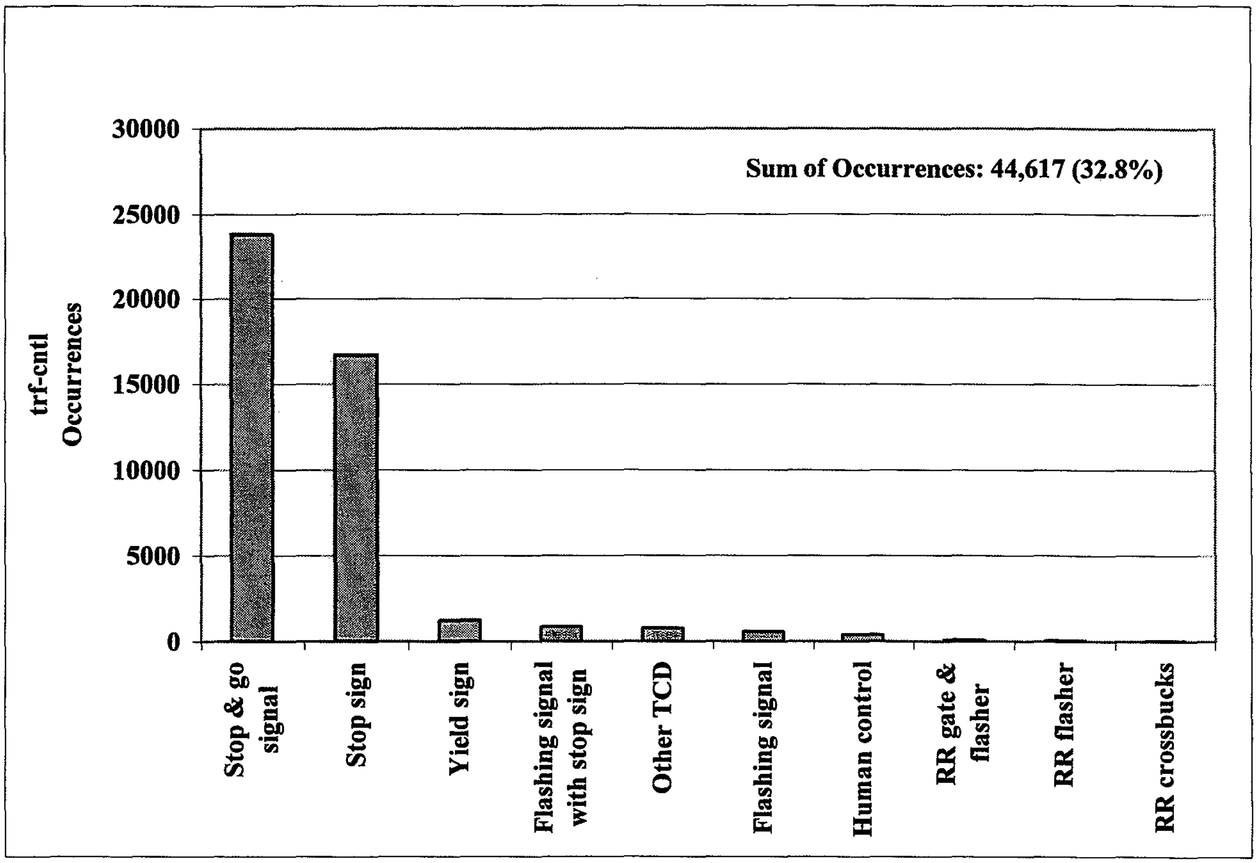


Figure A33. Traffic control type occurrences in the NC HSIS Accident File.

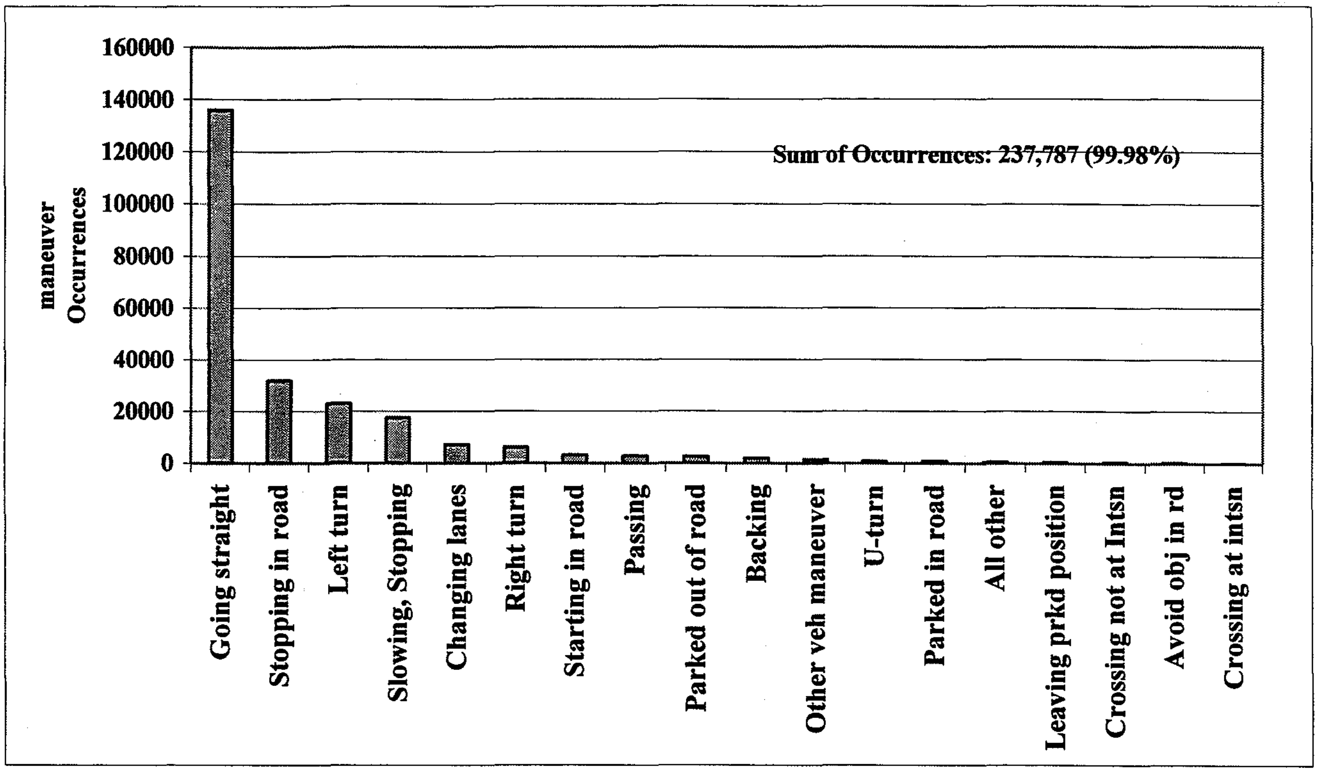


Figure A34. Violation/first-listed contributing factor occurrences in the NC HSIS Vehicle File.

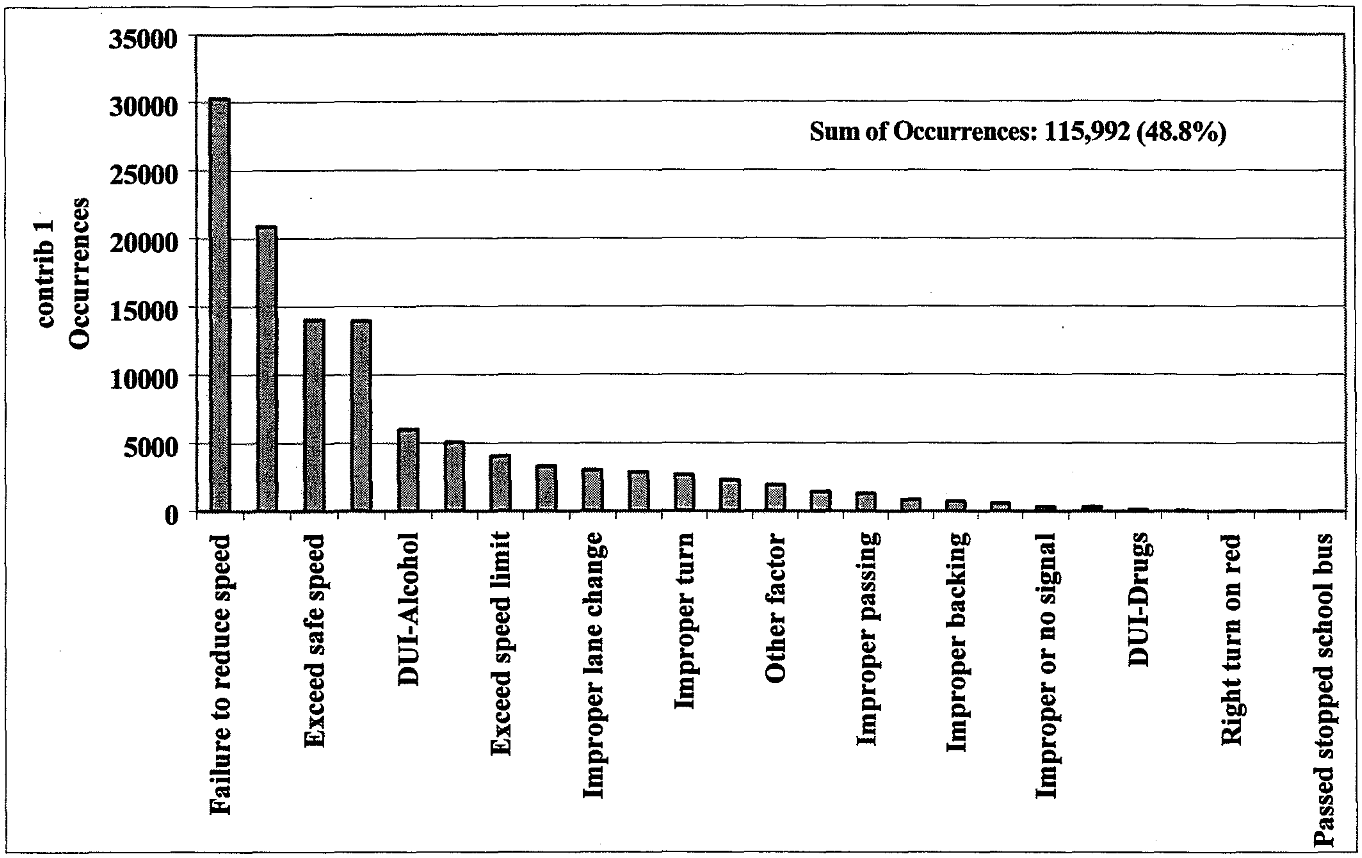


Figure A35. Vehicle maneuver/pedestrian action occurrences in the NC HSIS Vehicle File.

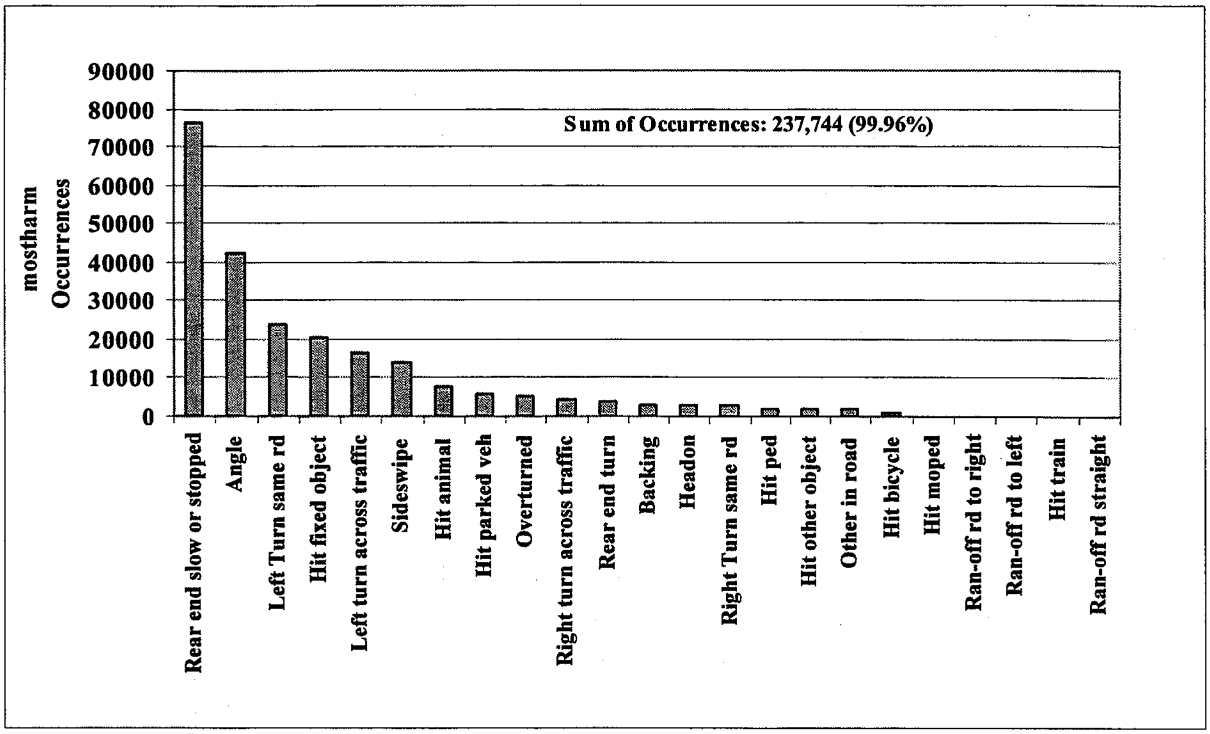


Figure A36. Most harmful event occurrences in the NC HSIS Vehicle File.

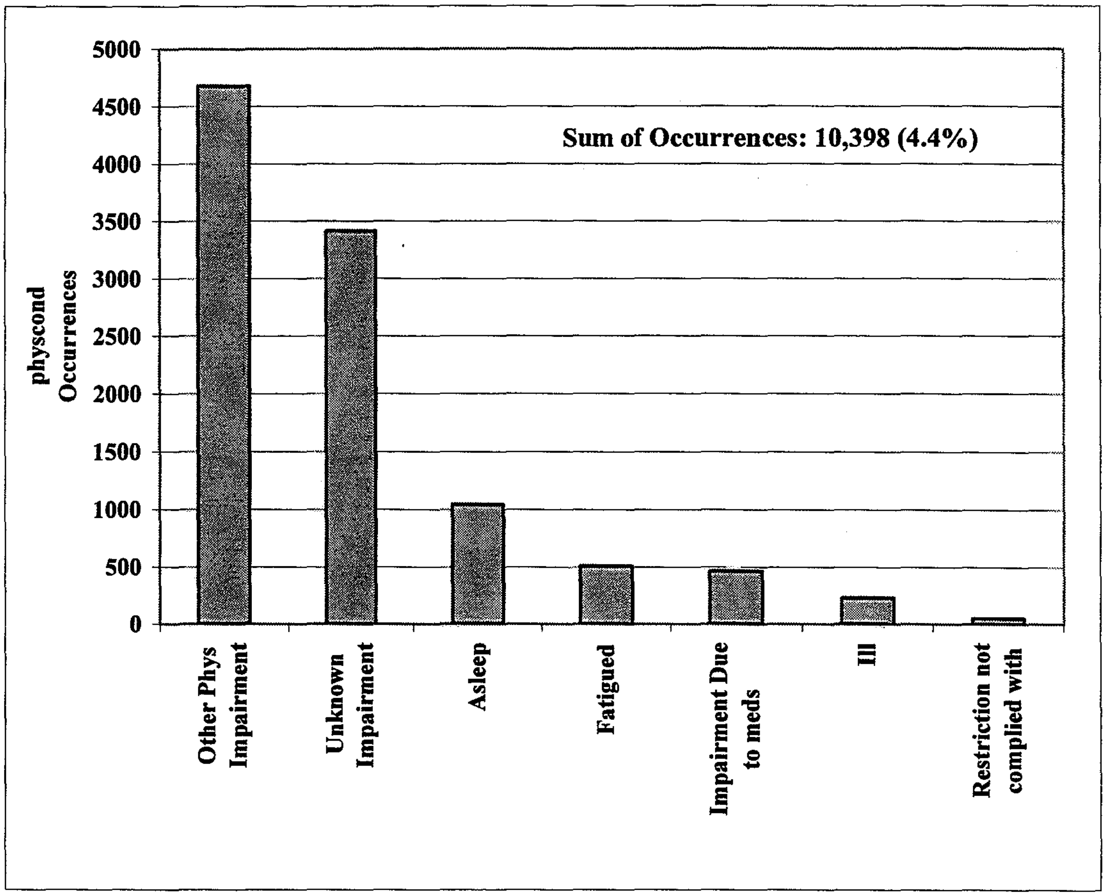


Figure A37. Physical condition of driver occurrences.

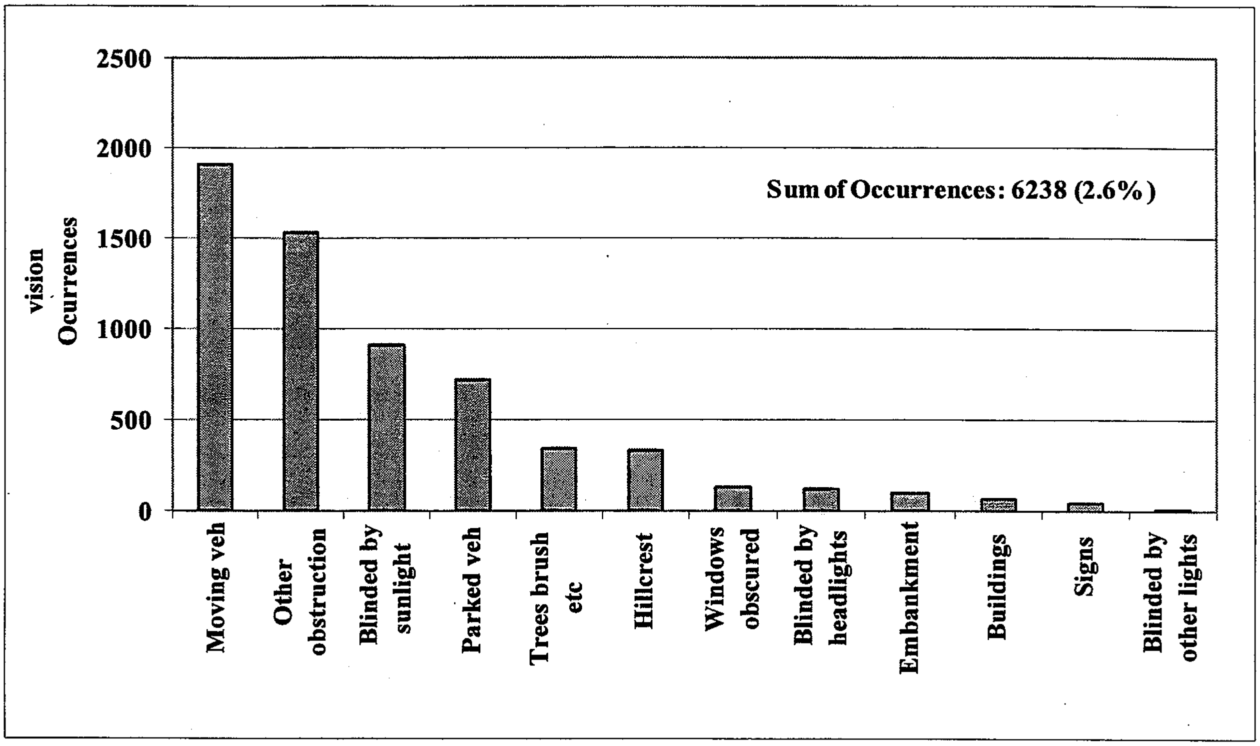


Figure A38. Vision obstruction occurrences in the NC HSIS Vehicle File.

Discussion

As indicated, the main objective in analyzing the North Carolina HSIS database was to determine the degree of correspondence between it and the narrative searches for purposes of validation. Therefore, while the HSIS results do stand on their own, most of the discussion will involve comparisons between the two approaches. Comparisons are provided by topic.

Intersection Crashes. One of the major findings of the narrative study was that a very large proportion of crashes occur at intersections and other places where one road meets another. Figures A23a, A24a, and A25a show large proportions of intersection crashes. In the HSIS analysis, figures A29 and A33 show this same result. In figure A29, in particular, at least 31 percent of all crashes are shown to occur at intersections.

Crashes at Traffic Signals and Stop Signs. Closely related to intersections are TCDs that would normally be found at intersections. Figure A24a of the narrative search shows that a large proportion of crashes occur at traffic lights and stop signs. These results correspond well to HSIS results, particularly those in figure A33. It should be noted that both types of searches show that crashes at traffic signals are more prevalent than crashes at stop controls.

Rear-end Crashes. Rear-end crashes were very prominent in the narrative search results, as exemplified by figure A23a and figure A27b (under misjudgment of speed and distance). In the HSIS search, figures A28 and A36 show rear-end crashes as the largest single category, while figure A35 (under stopping in road) provides additional verification. Once again, correspondence between the two sets of searches is excellent.

Additional Crash Types Exhibiting Correspondence. For the sake of brevity, additional categories showing correspondence are listed in table A12. In general, these additional selected categories exhibit correspondence that ranges from fair to excellent.

Table A12. Table of additional comparisons.

Crash Type	Appearing in Narrative Search Figure(s)	Appearing in HSIS Search Figure(s)	Degree of Correspondence	Notes
Run Off Road	6a, 9a	11, 13, 19	Excellent	Analyses can be categorized into left and right departures
Turning	6a, 9a, 10a	11, 19	Fair to Good	"Failure to yield" in narratives often corresponds to turns
On Curve	8a, 9a	17	Fair	HSIS accounts for curves indirectly via other categories
Avoiding Animal, Object, Person	6a, 7a, 9a, 10a	11, 18, 19	Good	HSIS separates objects, animals, and pedestrians
Backing	6a	11, 17, 18, 19	Good	Backing appears in several taxonomies of narrative searches
Merge/Pass/Lane Change	6a, 7a, 8a, 9a	12, 17, 18	Good	Ramp crashes are often merge crashes
Weather-Related	9a, 10a	15	Good	Weather-related factors appear in several of the narrative taxonomies

Elements of the Narrative Searches Not Covered by HSIS Searches. Several unique elements appear in the narrative search that do not appear in the HSIS database. Some of the more important elements are discussed here. "Failure to yield" appears in many of the histograms and taxonomies of the narrative searches, but it does not appear in the HSIS searches. This suggests that, for whatever reason, the accident reporting forms do not (did not) include "Failure to yield" as a field or category, at least for the levels examined in this study. Obviously, "Failure to yield" is a relatively general term, but it is "driver error centered." Therefore, it is not surprising that in reading the narratives, researchers studying such errors would use such a phrase. The "Reasons/Excuses" histogram and corresponding taxonomy of the narrative searches (figures A27a and A27b, respectively) contain several terms that are not found in the HSIS database. These terms include "Misjudgment of distance/speed," "Incorrect assumptions," "Failed to observe," "Distraction," and "Inattention." These are terms related more to the type of error that was committed than to what happened. Thus, insofar as driver error determination is concerned, the narrative searches provide useful and unique elements.

Elements of the HSIS Searches Not Covered by the Narrative Searches. The HSIS provides information elements that are not explicit in the narrative searches. Examples are those appearing in the histograms of figures A37 and A38. Figure A37 provides detailed information on the physical condition or possible impairment of the driver, and figure A38 provides detailed information on visual obstructions. Both histograms could be useful in determining reasons for crashes that are not necessarily covered by driver error per se.

The HSIS database has additional features that were not fully utilized in the current study. For example, HSIS can provide comprehensive location and infrastructure information including route, and distance and direction to a reference point such as an intersection, bridge, or city boundary. This type of information is potentially valuable in helping to understand how crashes occur.

Conclusions

In general, the HSIS database searches performed on the 1996 North Carolina database compare favorably with the narrative searches performed on the 1994 North Carolina database. This correspondence, which is relatively broad, suggests that if HSIS provides valid data, then so does the narrative approach.

Assuming the validity of the narrative searches, what are the unique aspects of these searches that make the investment of time and effort worthwhile? It does indeed appear that the narrative searches are capable of providing somewhat better information on driver error-related issues. This, in turn, fits well with the tree diagram methodology that was used (Wierwille and Tijerina, 1996). From the analyses that were conducted, it seems that tree diagrams provide a useful taxonomic structure because major factors can be detailed and subdivided into minor factors. In turn, these minor factors can be further subdivided. This type of structure allows an analyst to develop a clear understanding of not only the magnitude of factors associated with a crash type, for example, but also the relationship between factors. Unfortunately, traditional database searches do not lend themselves as neatly into a tree taxonomic structure. The details associated with crash records are not as accessible via traditional database searches as they are with the non-traditional narrative approach.

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