Safe Streets, Livable Streets: A Positive Approach to Urban Roadside Design

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Eric Dumbaugh

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Safe Streets, Livable Streets:
A Positive Approach to Urban Roadside Design

Approved by:

Dr. Michael D. Meyer
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Adjo Amekudzi
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. David Sawicki
Department of City and Regional Planning
Georgia Institute of Technology

Michael Dobbins
Department of City and Regional Planning
Georgia Institute of Technology

Dr. Randall Guensler
School of Civil and Environmental Engineering
Georgia Institute of Technology

Date Approved: July 19, 2005

The danger in supplanting the real measure of safety (i.e., crash frequency and severity) by surrogates arises when the link between the two is conjectural, when the link remains unproven for long, and when the use of unproven surrogates becomes so habitual that the need to eventually speak in terms of crashes is forgotten.

- Ezra Hauer, 1999a

To Michael Meyer,

who has always provided

fail-safe guidance

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Transportation safety is a highly contentious issue in the design of cities and communities. While urban designers, architects and planners often encourage the use of aesthetic streetscape treatments to enhance the livability of urban streets, conventional transportation safety practice regards features such as street trees as fixed-object hazards, and strongly discourages their use. This dissertation examines the subject of urban roadside safety to better understand the safety impacts of livable streetscape treatments. It finds that there is little empirical evidence to support the assertion that livable streetscape treatments have a negative impact on a roadway's safety performance, and substantial evidence indicating that they will actually enhance safety. Instead, the more substantive barrier to their use is a design philosophy that discounts the important relationship between driver behavior and safety performance. This dissertation traces the origin and evolution of this philosophy, and proposes an alternative approach, termed "positive design," that better accounts for the existing empirical evidence on urban road safety, as well the dynamic relationships between road design, driver behavior and crash performance.

CHAPTER 1

INTRODUCTION

Streets and their sidewalks, the main public places of a city, are its most vital organs. Think of a city and what comes to mind? Its streets. If a city's streets look interesting, the city looks interesting; if they look dull, the city looks dull.

- J. Jacobs, 1962, p. 37

Urban areas present unique challenges to the roadway designer. Urban and regional stakeholders demand a transportation network that allows them to accomplish their travel objectives with a minimum amount of travel delay, and to have these travel demands met in a safe and reliable way. Correspondingly, the design and implementation of "safe and efficient" roadways has become a central organizing concept for many transportation agencies.

While safety and efficiency are important to the successful performance of urban roadways, many transportation professionals and urban stakeholders have become increasingly aware that the economic and developmental vitality of urban areas requires that transportation networks do more than just expedite traffic. Beyond simply acting as thoroughfares for motorists, urban streets often double as public recreational spaces for urban residents and visitors. Urban streets are places for people to shop, interact, socialize, and generally engage in the diverse array of social and recreational activities that, for many, are what makes urban living enjoyable (see Figure 1-1). In short:

> "streets are what constitute the outside for many urbanites; places to be when they are not indoors… Sociability is a large part of why cities exist and streets are a major if not the only *public* place for that sociability to develop." (A. Jacobs, 1993, p. 4)

Figure 1-1: The Social and Recreational Character of Urban Streets

In urban areas, streets comprise between 25% and 35% of all developed land, making public rights-of-way the largest single land use (A. Jacobs, 1993). As such, streets play an important, if not the primary, role in shaping the quality and character of urban living. While much of contemporary planning and engineering practice is oriented towards understanding and addressing the travel uses of streets, their role as a social and recreational amenity should not be discounted. As William Whyte discovered as part of his Street Life Project:

> It is often assumed that children play in the street because they lack playground space. But many children play in the streets because they like to. One of the best play areas we came across was a block on 101st street in East Harlem… The street itself was the play area. Adjoining stoops and fire escapes provided prime viewing across the street and were highly functional for mothers and older people. There were other factors too, and had we been more prescient, we could have saved ourselves a lot of time spent later looking at plazas (1980, p. 248).

Beyond these quality-of-life benefits, streets that are designed to support and sustain pedestrian activity have been increasingly linked to a host of highly-desirable social outcomes, including economic growth (Florida, 2002), improvements in air quality (Frank, Stone and Bachman, 2000) and increased physical fitness and health (Frank, Engelke and Schmid, 2003), to name only a few. For these reasons, as well as a host of others, many groups and individuals encourage the design of "livable" streets, or streets that seek to better integrate the broader needs of pedestrians and urban residents into a roadway's design.

There has been a great deal of work describing the characteristics of livable streets (see esp. Duany, Plater-Zyberk and Speck, 2000; Ewing, 1996; J. Jacobs, 1961; Nelessen, 1993), and there is general consensus on their components: livable streets, at a minimum, seek to enhance the pedestrian character of the street by both increasing its aesthetic appeal, as well as minimizing the negative impacts of automobile use on pedestrians. Of particular importance is the design of the roadside, which is the area between the vehicle travelway and edge of the right-of-way. In urban areas, the roadside is the location for most of the activities that characterize urban living, and often include sidewalks, benches, street cafes and indeed, most non-motorized activity. Correspondingly, livability advocates encourage the placement of street trees, landscaping, aesthetic street lights and other roadside features along the edge of the vehicle travelway to both increase a street's aesthetic appeal, as well as to physically buffer pedestrians from potentially hazardous oncoming traffic (see Figure 1-2).

Figure 1-2: Livable Street Treatments

Considering Traffic Safety

While most would agree that the inclusion of trees and other streetscape features enhances the aesthetic quality of a roadway, there is substantive disagreement about their safety effects. From the perspective of traffic safety, the trees, bollards, street lights and other roadside features depicted in the figure above are fixed-object hazards that can transform a minor navigational error on the part of a driver into a hazardous, and potentially fatal, fixed-object crash. When one considers the aggregate statistics on run-off-roadway crashes, there is indeed cause for concern. In 2002 alone, there were over 12,000 fatal crashes involving fixed objects, accounting for more than 30% of the total fatal crashes for that year (Data Source: Fatal Analysis Reporting System [FARS]).

Because of concerns about the potential hazard of a run-off-roadway event, conventional transportation design practice encourages the design of "forgiving" roadsides, or roadsides that will allow a vehicle to leave the travelway without encountering a fixed object. Typically, this is achieved by providing a "clear runout zone" adjacent to the travelway that is free of roadside objects, with a preferred width of 30 feet. In terms of how to best accomplish this goal, AASHTO's *Roadside Design Guide*, the central authority on the design of safe roadsides, states that:

> Through decades of experience and research, the application of the forgiving roadside concept has been refined to the point where roadside design is an integral part of transportation design criteria. Design options for reducing roadside obstacles, in order of preference, are as follows:
>
> 1. Remove the obstacle.

2. Redesign the obstacle so it can be safely traversed.
3. Relocate the obstacle to a point where it is less likely to be struck.
4. Reduce impact severity by using an appropriate breakaway device.
5. Shield the obstacle with a longitudinal traffic barrier design for redirection or use a crash cushion.
6. Delineate the obstacle if the above alternatives are not appropriate (2002a, p. 1-2).

Thus, while livability advocates encourage the use of “Trees. Big trees” (Whyte, 1980, p. 308) along the edge of the travelway, conventional design practice strongly discourages such roadside treatments, preferring instead to set roadside objects back as far as possible from the edge of the travelway, or, at a minimum, ensuring that objects located in the clear zone can be easily traversed by an errant vehicle. Figure 1-3, below shows illustrative examples of how conventional urban arterial engineering addresses the design of urban roadsides. These roadways use the minimum sidewalk specifications (4 ft) listed in the American Association of State Highway and Transportation Officials’ (AASHTO) *A Policy on the Geometric Design of Highways and Streets* (the “Green Book”), with landscaping, lighting and other roadside elements placed behind the edge of the right-of-way. This design economically uses the sidewalk as part of the roadway’s clear recovery zone, but at the expense of the comfort and livability of the street as a whole, and potentially the safety of pedestrians as well.

Figure 1-3: Roadside Design Practice and the Design of Pedestrian Facilities

The widespread adoption of such design practices have led livable street advocates to assert that “the real problem in the United States is lack of willingness to do anything that infringes on the prerogatives of motor vehicle users” (Pucher and Dijkstra, 2000, p. 15), and that “because pedestrian-friendly streets are not specified in the manuals, they are simply not possible, despite all evidence encouraging their use” (Duany, Plater-Zyberk & Speck, 2000, p. 70). In short, there is an inherent tension between the roadside design applications sought by livable streets advocates, and those promoted by conventional roadside design practice and guidance.

Context-Sensitive Solutions, Livable Streets, and Traffic Safety

Despite the criticisms of livable streets advocates, many within the transportation design profession have increasingly recognized the need to better integrate the design concerns of urban stakeholders into design practice. Context-sensitive solutions have emerged as an attempt to better incorporate the needs and concerns of project stakeholders into specific design solutions (FHWA, 1997; TRB, 2002). While this approach is commendable for its attempt to broaden the types of issues considered in the design process, context-sensitive solutions cannot address the fundamental safety issues surrounding the design of livable streets. Context-sensitive solutions “refer to an approach or process as much as… an outcome” (Transportation Research Board [TRB], 2002, p. 4). The problem that emerges is that the determination of whether a particular design solution is appropriately safe is ultimately a matter of professional engineering judgment, not a product of public involvement activities. Indeed, “one of the strongest, if unwritten, rules of scientific life is the prohibition of appeals to… the populace at large in matters scientific” (Kuhn, 1962, p. 168). Thus, despite the best intent of designers, context-sensitive solutions cannot resolve the impasse between urban advocates and design engineers regarding the placement of streetscape features adjacent to the travelway.

But what is the nature of this impasse? Is it not possible to design streets to enhance community livability while maintaining a substantive concern for the safety of motorists? Are there perhaps opportunities for doing so that have been overlooked? Given the increased emphasis placed on the design of roadsides to enhance community livability, as well as the need to more clearly understand the safety effects of urban roadside design applications more broadly, this dissertation examines the subject of roadside safety in urban environments.

Dissertation Overview

Because of the potential breadth of this research effort, it is important to begin by delineating what this study focuses on, and what it does not. Specifically, this study focuses on the design of *roadsides*, which is the area between the outside travel lane and the edge of the right-of-way. While this study will consider other related geometric elements that have an effect on roadside safety and livability, such as lane and median widths, this study is not principally oriented towards the design of those elements.

Second, this study is specifically interested in the design of roadsides in *urban* areas. A focus on urban areas necessitates a clear definition of what an “urban area” is. While such a definition would seem obvious on its surface, the professionally-adopted definition of an urban environment is vague. At present, the current definition of an urban area is established in the U.S. Code (Section 101, Title 23), which states:

> The term urban area means an urbanized area or, in the case of an urbanized area encompassing more than one State, that part of the urbanized area in each such State, or an urban place as designated by the Bureau of the Census having a population of five thousand or more and not within any urbanized area, within boundaries to be fixed by responsible State and local officials in cooperation with each other, subject to approval by the Secretary. Such boundaries shall, as a minimum, encompass the entire urban place designated by the Bureau of the Census.

This definition is inclusive of a wide range of physical environments, and includes design conditions that range from central business districts to the suburban hinterland (see Figure 1-4). Because the definition of “urban” as used in the literature on roadside design refers to this broad range of environments, the term “urban” in this research is likewise used inclusively unless otherwise noted.

Figure 1-4: Three Minor Arterials in “Urban” Areas

Next, this dissertation focuses specifically on those roadways where urban stakeholders often express the greatest concerns about livability issues – typically those roadways classified as minor arterials, collectors and local roadways. While highways, freeways and other high-speed, limited access roadways may have important effects in the overall livability of an urban area, these roads are typically reserved for high-speed motor vehicle travel exclusively and are not appropriate candidates for livable street treatments.

Finally, it is important to define concisely what is meant by safety. For this study, the term “safety” refers specifically to crashes and their corresponding injuries and fatalities. Defining safety in terms of crashes, injuries and fatalities provides a straightforward metric[1] by which to measure and evaluate a roadway’s safety performance. This study treats safety as a measurable design outcome, not a latent characteristic of a roadway. Thus, the relative level of safety for a roadway is determined not by whether it incorporates specific design treatments presumed to enhance safety, but instead on measurements of crashes, injuries and fatalities.

Research Approach and Data Sources

This research uses a variety of data sources to understand and analyze roadside safety. First, the literature and guidance on the subject of roadside design is a key data source. An early review of this literature revealed that there was a need to review it *critically*. The literature on which contemporary roadside design guidance and practice is based has focused largely on rural environments; there have been surprisingly few studies of roadside safety in urban environments. Further, much of the literature that has examined the subject of urban roadside safety does not support the design practices recommended in guidance documents such as the *Roadside Design Guide*. Thus, this literature is reviewed for not only what its authors have formally recommended, but also for the accuracy, validity, and generalizability of their conclusions.

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[1] An important issue is whether crashes are measured in absolute numbers – i.e., crash totals – or else in rates, which are the numbers of crashes and injuries per vehicle mile traveled. This issue will be discussed in greater detail in Chapters 4-6, which evaluate the safety performance of specific roadways.

Given the limited and contradictory empirical evidence on the safety performance of conventional roadside design practices in urban environments, it was important to re-examine the historical foundations of these practices to better understand the theoretical assumptions on safety that led to their widespread adoption. This approach is useful both for clarifying possible misconceptions regarding what is meant by a “safe” roadside, as well as for defining the theoretical assumptions that guide current practice in terms that can be empirically tested and validated.

Several data sources were used in the course of this research. First, Fatality Analysis Reporting System [FARS] and General Estimates System [GES] data were analyzed to understand the general characteristics of fixed-object crashes. Nevertheless, one of the major shortcomings of FARS and GES data is that they do not allow these crashes to be readily geo-located, thus preventing researchers from analyzing the specific characteristics of sites where crashes occurred. To overcome the limitations of FARS and GES data, crash data supplied by the Florida Department of Transportation for District 5 were also analyzed. Unlike FARS and GES data, these data provided information on the exact location of specific crash events, thereby permitting detailed site investigations. Using these data in conjunction with intensive site investigations and field analyses allowed this study to further examine the environmental factors that may influence a roadway’s safety performance across an urbanized metropolitan area, making this the first study to explicitly do so.

Dissertation Outline

This dissertation is comprised of three major sections. The first section (Chapters 1-3) introduces the topic of roadside safety in urban environments. This introductory chapter has briefly discussed the central issues surrounding the design of livable roadsides in urban environments. Chapter 2 examines FARS and GES data to describe the characteristics of roadside crashes in urban environments, followed by a detailed discussion of conventional roadside safety practice in Chapter 3.

The second section (Chapters 4-6) examines the theory and empirical evidence that drives roadside safety practice, paying particular attention to whether the existing empirical evidence supports the design practices recommended in current design guidance. Chapter 4 details existing empirical research on the subject of roadside safety, as well as its historical and theoretical underpinnings. After detailing the theoretical propositions that direct contemporary urban roadside design practice, Chapter 5 subjects them to a suite of empirical tests aimed at understanding their applicability to urban environments. Finally, Chapter 6 then seeks to move beyond hypothetical "best practices" to better understand the specific nature of roadside crashes in urban environments.

The third and final section of this research (Chapters 7-8) seeks to better develop practice of urban roadside design based on the empirical findings presented in Chapters 5 and 6. Chapter 7 outlines a new approach to addressing safety that better accounts for both the existing empirical evidence, as well as more recent developments in the areas of driver psychology and behavior. Chapter 8 concludes this study by providing a summary of the overall research effort and future research directions.

CHAPTER 2

ROADSIDE SAFETY IN URBAN ENVIRONMENTS

This chapter uses 2002 Fatality Analysis Reporting System [FARS] and General Estimates System [GES] data to provide an aggregate portrait of the current state of roadside safety. After discussing the advantages and disadvantages of the use of these data sources, it proceeds to describe the current state of roadside safety, both at an aggregate level, as well as for urban areas specifically.

About the Data – Sources and Limitations

The National Highway Transportation Safety Administration's [NHTSA] Fatal Analysis Reporting System [FARS] provides a 100% count of fatal crashes that occurred on US roadways, and is thus the most reliable source of national data on transportation-related crashes. Unfortunately, FARS data do not provide information on non-fatal crashes. Because information on injurious and property-damage only [PDO] crashes is essential for understanding a roadway's safety performance, this research also uses General Estimates System [GES] data to supplement the information provided in FARS.

The General Estimates System is an NHTSA-produced product that uses a sample of police-reported crashes to derive weighted estimates for fatal, injurious and PDO crashes at the national level.[2] While samples are useful for deriving an understanding of a broader population that cannot be surveyed in its entirety, an issue that emerges in the use of samples is whether or not they accurately reflect the actual characteristics of the sampled population. To evaluate the reliability of GES data, I compared GES estimates of fatalities in 2002 with the actual number of fatalities recorded in FARS. The difference was substantial. While FARS reports 38,500 fatal crashes in 2002, GES estimates report only about 26,000. The reason for this difference is unknown. Despite the possible inaccuracy of GES data, it is currently the only national source of data for injury and PDO crashes, and is consequently analyzed in this chapter. Nevertheless, readers are cautioned that results derived from GES data may under-report the actual numbers of injurious and PDO crashes.

A second shortcoming of these two data sources is that their categories do not always overlap on variables of interest. While FARS data uses the urban and rural designations employed in conventional traffic engineering practice, GES data categorizes environments based on their population size, which may obscure the results. Thus, while urban areas in FARS are census-designated places with a population of 5,000 or more, urban areas in GES data are areas with a population of 25,000 or more. As a result, there is no information on injurious and PDO crashes in areas for areas with populations between 5,000 and 25,000.

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[2] The 2002 GES data used here were obtained by collecting police reports for 410 police jurisdictions in 60 locations through the United States. These data are then weighted to derive national estimates of fatal, injurious, and property-damage only crashes (NHTSA, 2002; 2004).

A third issue that prevents idealized comparisons is that GES data, unlike FARS data, does not provide information on a roadway's functional classification. Thus, while this study is specifically interested in roadways classified as minor arterials, collectors and local roads, such information is not available for non-fatal crashes. GES data only indicates whether or not a roadway is on the National Highway System, rather than providing a means for distinguishing freeway-type roadways from other roadway classes. Thus, all analysis of the safety performance of lower-speed roadways is limited to fatal crashes exclusively.

A fourth and somewhat less important issue is that specific field definitions do not always align between the data sources. For example, while utility and light poles are treated as independent fixed-object categories in FARS, they are categorized with sign posts in GES. To address categorical inconsistencies between the data sources, variable categories have been aggregated together to allow fatal (FARS), injurious and PDO crashes (GES) to be consistently analyzed.

Further, it must be acknowledged that all of this data is derived from police accident reports, and observations are necessarily limited to those crashes that were officially reported. Crashes that may have occurred, but which did not result in the filing of a police report, are not included in this analysis. Further, police reports may be subject to field coding and data entry errors, which may result in data inaccuracies. Nevertheless, until the methods for recording crash data are improved, any analysis of crash data are bound by these limitations.

For the following analysis, all data on fatal crashes come from FARS and should be regarded as highly reliable. Data on non-fatal injuries and PDO crashes are derived from GES data, and the data inaccuracies resulting from sampling error and non-aligning categorical definitions should be considered when interpreting GES-based statistics.

General Characteristics of Fixed-Object Crashes

Before examining the nature of roadside crashes specifically, it is useful to first consider the current state of traffic safety more generally. In 2002, there were roughly 6.3 million crashes, roughly 833,000 of which involved an injury, and 38,500 of which included a fatality. As shown in Table 2-1, multiple-vehicle crashes were the single largest crash type. Over 4,500,000 multiple vehicle crashes occurred in 2002, 500,000 of which involved at least one injury, and 16,000 of which were fatal. Fixed object crashes were the second largest crash category, with almost 1 million fixed-object crashes occurring, 200,000 of which were injurious, and 12,000 that were fatal.

Culverts, ditches and curbs were the roadside features most likely to be involved in a fixed object crash, followed by utility and light poles, trees and guardrails (see Figure 2-2). While fewer total tree crashes were reported, crashes involving trees are more likely to result in an injury or a fatality than the other object types. Indeed, more than a quarter of all fatal fixed-object crashes involve trees.

Table 2-1: Crashes by Crash Type and Severity, 2002

	No Injury	**Injury**	**Fatal (FARS)**	**Unknown**	**Total**
Motor Vehicle Collision	3,180,449 (76%)	498,789 (60%)	15,790 (41%)	986,844 (78%)	4,681,872 (74%)
Fixed Object	564,812 (14%)	190,469 (23%)	12,008 (31%)	178,514 (14%)	945,803 (15%)
Pedestrian/Bicyclist	7,332 (0%)	65,168 (8%)	5,157 (13%)	43,487 (3%)	121,144 (2%)
Overturn	42,578 (1%)	56,947 (7%)	4,308 (11%)	25,173 (2%)	129,006 (2%)
Other Causes	377,270 (9%)	21,671 (3%)	1,228 (3%)	31,117 (2%)	431,286 (7%)
Total	4,172,441 (100%)	833,044 (100%)	38,491 (100%)	1,265,135 (100%)	6,309,111 (100%)

Table 2-2: Fixed Object Crashes and Severities, 2002

Fixed Object	**No Injury**	**Injury**	**Fatal (FARS)**	**Unknown**	**Total**
Culvert/Ditch/Curb	123,097 (22%)	54,531 (29%)	2,402 (20%)	36,883 (21%)	216,913 (23%)
Utility/Light/Sign Poles	119,141 (21%)	35,637 (19%)	1,974 (16%)	37,346 (21%)	194,098 (21%)
Tree/Shrubbery	72,147 (13%)	37,431 (20%)	3,277 (27%)	26,932 (15%)	139,787 (15%)
Guardrail	66,186 (12%)	18,007 (9%)	1,099 (9%)	20,591 (12%)	105,883 (11%)
Building/Fence/Wall	52,151 (9%)	11,390 (6%)	669 (6%)	15,866 (9%)	80,076 (8%)
Embankment	28,555 (5%)	17,839 (9%)	1,312 (11%)	14,076 (8%)	61,782 (7%)
Bridge	11,632 (2%)	4,460 (2%)	398 (3%)	2,681 (2%)	19,171 (2%)
Other Fixed Object	91,903 (16%)	11,174 (6%)	877 (7%)	24,139 (14%)	128,093 (14%)
Total	564,812 (100%)	190,469 (100%)	12,008 (100%)	178,514 (100%)	945,803 (100%)

Roadway Class and Alignment

An area of specific interest to this study is whether fixed-object crashes are associated with particular roadway classes and alignments. While detailed information on a roadway's alignment is not provided by either FARS or GES, FARS does report whether a crash occurred on a straight or curved roadway section. A large percentage of these crashes (42%) occurred on curved sections, despite the fact that most roadway sections are straight (see Table 2-3).

Table 2-3: Fixed Object Crashes By Road Alignment, 2002

Fixed Object	Straight	Curved	Pct. Curved
Tree/Shrubbery	1735	1524	46.8%
Culvert/Ditch/Curb	1457	934	39.1%
Embankment	680	627	48.0%
Guardrail	610	485	44.3%
Utility/Light/Sign Poles	882	611	40.9%
Building/Fence/Wall	399	268	40.2%
Bridge	265	131	33.1%
Other Fixed Object	798	545	40.6%
Total[3]	6826	5125	42.9%

Non-Interstate arterials were the most dangerous roadway class, in terms of absolute numbers of fatalities, with 17,000 fatal crashes occurring in 2002. Interstate

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[3] Note: for 57 crashes, information on roadway alignment was not known. These crashes were not included in these tabulations.

roadways were the safest roadways, with 5,000 fatal crashes, while roughly 8,000 fatal crashes occurred on both collector and local roadways (see Table 2-4). Nevertheless, merely looking at absolute counts of crashes fails to account for exposure. To develop a more meaningful comparison of the relative hazard of these roadways, exposure rates, derived by dividing the number of fatal crashes by the number of vehicle miles traveled (VMT) for each of roadway class, are included in Table 2-5. After accounting for exposure, Interstates and other arterials perform similarly with respect to fatal fixed object crashes, with 23 and 29 fatal crashes per 100 million vehicle miles traveled (MVMT), respectively, while local roadways and collectors both have between 80 and 90 crashes per 100 MVMT.

Table 2-4: Fatal Crashes, by Crash Type and Roadway Class, 2002

	Fixed-Object	**Rollover**	**Other**	**Total**
Interstate	1,532	1,058	2,313	4,903
Other Arterial	3,940	1,247	11,987	17,174
Collector	3,261	1,094	3,933	8,288
Local	3,166	878	3,824	7,868
Unknown	109	31	118	258
Total	12,008	4,308	22,175	38,491

Table 2-5: Fatal Crashes Per 100 Million Vehicle Miles Traveled, by Crash Type and Road Class, 2002

	Fixed-Object	Rollover	Other	Total
Interstate	23	16	34	73
Other Arterial	29	9	89	128
Collector	80	27	96	203
Local	88	25	107	220
Total	43	15	80	138

Demographic Factors

While FARS does not provide information on the characteristics of at-fault drivers, it does provide basic demographic characteristics of the individuals involved in fatal fixed-object crashes. An examination of their demographic characteristics is revealing. Men are almost three times as likely to be killed in a fixed-object crash than women, with the number of males killed in fixed-object crashes exceeding that of women for all age groups except those aged 15 and younger, where the number of fatalities are approximately equal.

Younger drivers are disproportionately involved in fatal fixed-object crashes. 40% of total fixed-object fatalities involve individuals between the ages 16 and 25, with males in this age group accounting for roughly a third of the total fatal crashes. The number of fixed object crashes for each age group declines until the 70 and older category, at which point fatalities increase for both males and females (see Figure 2-1).

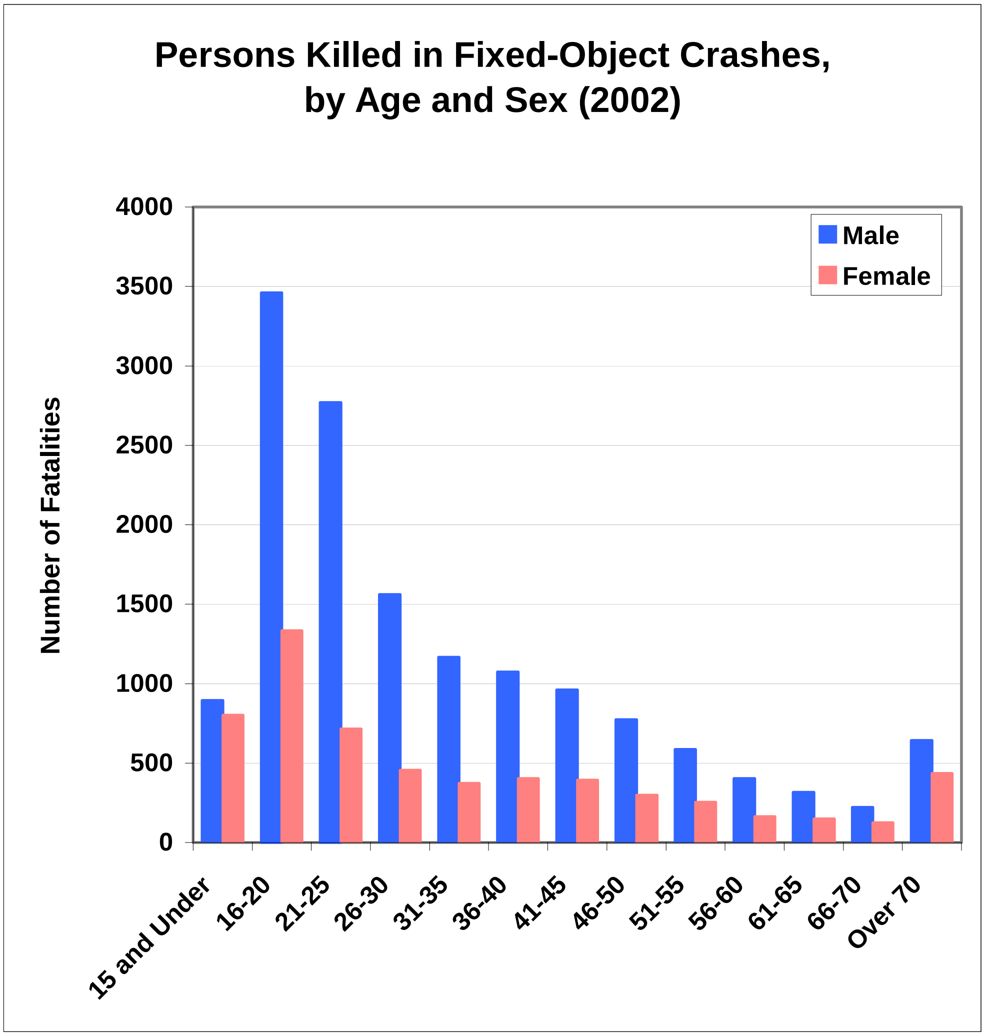

Figure 2-1: Persons Killed in Fixed Object Crashes, by Age and Sex, 2002

That there is an increase in fixed-object fatalities for the 70 and older group is not surprising. Aging is associated with a well-documented decline in perceptual and motor abilities, both of which result in a decline in one’s ability to operate a motor vehicle (Dewar, 2002a; Simoes and Marin-Lamellet, 2002). The reasons why younger drivers are disproportionately involved in fatal crashes are less clear. A common explanation is that younger drivers tend to overestimate their driving ability and are more likely to engage in high-risk driving behavior than are older drivers (Basch et al., 1987; Dewar, 2002a; Fuller, 2002; Jonah, 1997). A lack of driving experience, and thus a latent inability to recognize the actual hazards associated with specific behaviors, is further used to explain the over-involvement of young drivers in crashes (Gregersen, 1997; Groeger, 2000; Groeger, 2002; Delhomme and Meyer, 1997).

The over-involvement of men in fatal fixed-object crashes is also not entirely clear. Part of the reason may be that men tend to travel greater distances than women, are more likely to drive under higher-risk conditions (rush hour, late at night, and under adverse weather), and are more likely to drive while intoxicated (Dewar, 2002b). The differences may also be attributable in part to differences in driving styles. Women are more likely than males to provide adequate headways between vehicles, as well as to avoid higher-speed, rural travel (Polus et. al, 1988).

Alcohol and Fixed-Object Crashes

Alcohol use has been shown to result in declines in perceptual abilities, motor skills, information processing, and reaction times (Muskowitz, 1988). Driving while under the influence of alcohol is commonly cited as a major cause of crashes and injuries, and it appears to play a role in fatal fixed object crashes as well. For crashes where alcohol use on the part of the driver was known, 48% of those killed in fixed-object crashes were riding in a vehicle where the driver was under the influence of alcohol.[4] Alcohol was more likely to be a contributing factor in fatal fixed-object crashes for males than females. 54% of males killed in fixed-object crashes were in a vehicle operated by a driver under the influence of alcohol, compared to only 30% of females (see Table 2-6).

Table 2-6: Police Reported Alcohol-Involvement in Fatal Fixed-Object Crashes, 2002

	Known Alcohol Involvement			**Reported Alcohol Involvement**		
Alcohol Involvement	Male	Female	Total	Male	Female	Total
No (Alcohol Not Involved)	2862 (46%)	1343 (70%)	4205 (52%)	2862 (23%)	1343 (29%)	4205 (25%)
Yes (Alcohol Involved)	3364 (54%)	563 (30%)	3927 (48%)	3364 (27%)	563 (12%)	3927 (23%)
Total Reported	6226 (100%)	1906 (100%)	8132 (100%)			
Not Reported/Unknown				6079 (49%)	2755 (59%)	8834 (52%)
Total				12305 (100%)	4661 (100%)	16966 (100%)

While this information of often used to impute alcohol involvement rates for all crashes (NHTSA, 2002), one should be cautious about attempting to generalize based on this information. Information on whether the driver was under the influence of alcohol is not reported for more than half of all fixed-object crashes, and there is no reliable means for determining the reasons for these omissions. While this might be attributable to mere

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[4] FARS data reports alcohol involvement in a fatal crash based on the persons killed in a crash, not for the crashes themselves. Correspondingly, the total of persons killed in fatal fixed-object crashes (16,966) exceeds the number of total fixed-object crashes (12,008).

omissions on the part of the recording officer, it is equally likely that the officer did not suspect that alcohol was a factor, and chose not to conduct an alcohol test. In either event, this is mere speculation; all that can be stated with certainty is that alcohol was a known factor in 23% of fixed-object fatalities, and can be definitively ruled out as a factor for an additional 25%. Alcohol involvement for the remaining 52% of these crashes is not known.

Comparing Fixed-Object Crashes in Urban and Rural Environments

While such aggregate statistics are useful for developing a general sense of the nature of fixed-object crashes, this study is interested in the roadside safety performance of urban areas specifically. As shown in table 2-7, fixed-object crashes are more likely to occur in urban areas, but are less likely to involve an injury or a fatality. Indeed, while the absolute number of fixed-object crashes was 20% higher for urban areas, twice as many fatal fixed-object crashes occurred in rural environments than in urban ones. Further, these statistics only report total crashes; once one accounts for exposure (based on the vehicle miles traveled in each environment) rural areas are consistently more likely to experience a fixed-object crash than are urban areas (see Table 2-8).

Table 2-7: Fixed Object Crashes in Urban and Rural Areas, 2002

	Urban	**Rural**
Fatal	4,112	7,874
Injury	95,350	95,118
PDO	320,794	244,016
Total[5]	420,256	347,008

Table 2-8: Fixed Object Crashes per 100 Million Vehicle Miles Traveled in Urban and Rural Areas, 2002

	Urban	**Rural**
Fatal	25	71
Injury	569	861
PDO	1,914	2,208
Total	2,507	3,140

That rural fixed-object crashes tend to be more severe is not particularly surprising; rural travel is generally characterized by lower levels of congestion and higher overall traffic speeds, and increased speed logically results in increased crash severity. While this explains increases in severity, it does not explain the increased frequency. Part of the explanation may be attributable to the nature of rural travel. Unlike urban travel, rural travel is characterized by longer trip distances in relatively homogeneous environments, the combination of which can result in a condition cognitive psychologists refer to as “highway hypnosis.” When placed in highly predictable environments with little environmental stimuli, drivers tend to automatize the driving task and reduce visual

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[5] These totals only include crashes where data on environmental context were provided.

search and processing (Dewer, 2002c; Roge et. al, 2002; Steyvers 1993). This state results in a reduction in the driver's attentiveness to external stimuli and reduced reaction times, the combination of which would seem to explain the increased likelihood of fixed-object crashes in rural areas.

Fixed-Object Crashes on Low-Speed Urban Roadways

The relative hazard of rural areas is even more pronounced when one examines lower-speed roadways specifically. For roadways classified as minor arterials, collectors and local roads, rural areas are more likely to involve a fatal fixed-object crash than their urban counterparts, even before accounting for exposure (see Table 2-9).[6] In absolute terms, all types of fatal crashes except those involving pedestrians are more common in rural environments. Likewise, all individual categories of fixed-object crashes occur more frequently in rural environments than in urban ones (see Table 2-10).

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[6] The Bureau of Transportation Statistics, which provides data on vehicle miles traveled at the national level, does not distinguish between principal and minor arterials. Nevertheless, they do distinguish between collectors and locals, allowing exposure rates for fixed-object crashes to be developed for these road classes. For rural collector roadways, there are 110 fixed object-related fatalities per 100 MVMT, and 160 per 100 MVMT miles traveled for rural local roads. Comparatively, there are 30 fixed-object fatalities per 100 MVMT on urban collectors, and 40 per 100 MVMT on urban local roadways. The difference is a factor of four.

Table 2-9: Fatal Crashes on Low-Speed Roadways

	Urban				Rural			
	Minor Arterial	Collector	Local	Total	Minor Arterial	Collector	Local	Total
Motor Vehicle Collision	1,335 (44%)	410 (39%)	1,099 (34%)	2844 (39%)	2,005 (52%)	2,614 (36%)	1,073 (23%)	5692 (36%)
Ped/Bike	802 (27%)	221 (21%)	853 (26%)	1876 (26%)	245 (6%)	442 (6%)	339 (7%)	1026 (7%)
Overturn	103 (3%)	49 (5%)	148 (5%)	300 (4%)	427 (14%)	1,045 (14%)	730 (16%)	2202 (14%)
Fixed Object	696 (23%)	354 (33%)	1,007 (31%)	2057 (28%)	1,096 (28%)	2,907 (40%)	2,159 (47%)	6162 (39%)
Other	66 (2%)	30 (3%)	156 (5%)	252 (3%)	104 (3%)	216 (3%)	304 (7%)	624 (4%)
Total	3,002 (100%)	1,064 (100%)	3,263 (100%)	7329 (100%)	3,877 (100%)	7,224 (100%)	4,605 (100%)	15706 (100%)

Summary: Considering the Characteristics of Fixed-Object Crashes

While fixed-object crashes accounted for only 15% of the total crashes in 2002, they accounted for almost a quarter of the total injury crashes, and roughly a third of all fatal crashes. Thus, while fixed-object crashes may not be the most common crash type, they are very likely to involve an injury or a fatality. Ditches, culverts and curbs are the objects most likely to be involved in a fixed-object crash, although trees are the fixed object associated with the greatest number of fatal fixed object crashes.

Males are almost three times as likely as females to be involved in a fatal fixed-object crash, and drivers between the ages of 16 and 25 account for 40% of the total fatalities. Alcohol is often a factor in fixed-object crashes, with almost a quarter of all fixed-object fatalities involving a driver under the influence of alcohol. Since alcohol use is not reported for more than half of these crashes, it is highly possible the alcohol may be involved in a much larger percentage of these crashes.

Table 2-10: Fatal Fixed Object Crashes on Low-Speed Roadways

	Urban				**Rural**			
	Minor Arterial	Collector	Local	Total	Minor Arterial	Collector	Local	Total
Tree/Shrubbery	165 (24%)	99 (28%)	296 (29%)	560 (27%)	299 (27%)	929 (32%)	818 (38%)	2046 (33%)
Utility/Light/Sign Pole	170 (24%)	102 (29%)	231 (23%)	503 (24%)	182 (17%)	408 (14%)	264 (12%)	854 (14%)
Culvert/Ditch/Curb	185 (27%)	78 (22%)	208 (21%)	471 (23%)	204 (19%)	593 (20%)	419 (19%)	1216 (20%)
Embankment	27 (4%)	15 (4%)	46 (5%)	88 (4%)	168 (15%)	445 (15%)	277 (13%)	890 (14%)
Guardrail	52 (7%)	11 (3%)	39 (4%)	102 (5%)	102 (9%)	142 (5%)	67 (3%)	311 (5%)
Building/Fence/Wall	28 (4%)	16 (5%)	89 (9%)	133 (6%)	49 (4%)	163 (6%)	141 (7%)	353 (6%)
Bridge	15 (2%)	7 (2%)	29 (3%)	51 (2%)	29 (3%)	77 (3%)	64 (3%)	170 (3%)
Other Fixed Object	54 (8%)	26 (7%)	69 (7%)	149 (7%)	63 (6%)	150 (5%)	109 (5%)	322 (5%)
Total	696 (100%)	354 (100%)	1007 (100%)	2057 (100%)	1096 (100%)	2907 (100%)	2159 (100%)	6162 (100%)

Fixed-object crashes are most likely to occur on roadways classified as either a collector or a local roadway, and a large percentage (43%) of fatal fixed-object crashes occur along a curve. In absolute terms, fatal fixed-object crashes were less likely to occur on Interstates than on other roadway classes. When one distinguishes between urban and rural environments, however, several notable differences emerge. First, while urban areas are associated with higher total numbers of fixed-object crashes, they are less likely to involve an injury or a fatality than fixed-object crashes in rural environments. Once one accounts for exposure, rural roadways experience a higher total incidence of fixed-object crashes, and are much more likely to involve an injury or a fatality.

Urban roadways designated as minor arterials, collectors and local roadways are much less likely to experience a fatal fixed-object crash than are their rural counterparts. This may be attributable to a variety of factors, including lower design speeds, higher levels of congestion (and thus lower operating speeds), as well as differences in the nature of rural and urban travel. Urban travel tends to be characterized by shorter, intra-regional trips on roadways that are often familiar to the road user. Conversely, rural roadways serve longer trips, greater volumes of inter-regional travel, and greater volumes of truck and freight-related travel. Given that these travel characteristics differ, it is perhaps unsurprising that their safety performance should differ as well.

CHAPTER 3

ROADSIDE SAFETY: STATE-OF-THE-PRACTICE

The previous chapter detailed the general characteristics of fixed-object crashes. It found that young male drivers were over-represented in fixed object crashes, that a disproportionate share of fixed-object crashes were associated with curved roadway alignments and that, in general, urban environments were less likely to experience a fixed-object crash than rural environments, particularly for lower-speed roadways such as minor arterials, collectors and local roads. Further, while ditches, culverts and curbs were the objects most likely to be associated with a fixed-object crash, trees involved the greatest numbers of fixed-object fatalities. This chapter details the design strategies currently used to address these crashes.

Recommended practices on the design of safe roadsides are well established in contemporary design guidance. Beyond guidance documents such as AASHTO's *A Policy on the Geometric Design of Highway and Streets* (henceforth the "Green Book") (2001) and the *Roadside Design Guide* (2002), recommendations on the design of safe roadsides are further enumerated in supplemental guidance, such as the AASHTO *Highway Safety Design and Operations Guide* (1997), as well as in more recent TRB publications targeted at implementing AASHTO's Highway Safety Plan (2004a; 2004b). Further, there is a host of professional literature on the subject of roadside safety. As a point of departure for this research effort, this chapter synthesizes this broad literature to understand the current state-of-the-practice regarding the design of safe roadsides.

Considered holistically, the literature on roadside safety establishes three general strategies (AASHTO, 1997; AASHTO, 2001; AASHTO, 2002a; Cirillo and Opiela, 1999; Scott, 2000; Transportation Research Board, 2003a; Transportation Research Board, 2003b; Transportation Research Board, 2004). First, the ideal scenario is to **prevent vehicles from leaving the travelway**, thereby eliminating the roadside crash and thus the injuries and fatalities that may result from them. The second strategy is based on the premise that since it is impossible to prevent run-off-roadway events,[7] designers should strive to ensure that roadsides are “forgiving” – that is, that a roadside should be designed to **eliminate the hazard associated with a run-off-the road event**, should one occur. Under current practice, the ideal is to provide a 30 ft “clear recovery zone” adjacent to the roadside to allow errant vehicles to come to a controlled stop prior to encountering a fixed-object.

Nevertheless, under many situations, a clear runout zone is impossible or impractical to provide. In urban areas, right-of-way is often limited by existing development, preventing the possibility of providing an adequate clear runout zone. In other cases, fiscal constraints may prevent the provision of a clear runout zone. With limited budgets for acquisition and improvements, transportation agencies must allocate their resources towards those projects that best benefit the public interest. Thus, while the

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[7] The origin and empirical basis of this assumption is detailed in Chapter 4.

provision of a clear runout zone may be desirable from a safety perspective, the relative risk posed by fixed-object crashes for a specific segment of a roadway may not warrant the expenditure of money for right-of-way clearance and acquisition when compared against other competing agency objectives. Under these circumstances, design practice recommends strategies targeted at **minimizing the severity of a run-off-roadway crashes**, typically by ensuring that any object located in the runout zone is traversable by motor vehicles. The sections below detail each of these three strategies, as well as the specific practices used to implement them.

Strategy 1: Keep Vehicles From Leaving the Travelway

The logic behind keeping vehicles on the travelway is simple: if a vehicle doesn't leave the travelway, it will not be involved in a roadside crash. Unlike identifying appropriate clear zone widths or determining the crash effectiveness of impact cushions, however, these strategies are often oriented towards the behavior of the driver.[8] The design of runout zones and impact cushions can be determined using the laws of physics; strategies aimed at keeping the driver on the roadway are targeted at modifying the behavior of the driver are reliant upon psychology and social science. The problem that emerges is that, beyond the limited descriptive information provided in Chapter 2, there

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[8] A potential exception to this is the use of guardrails, which keep the vehicle on the travelway by providing a physical barrier that prevents vehicles from encroaching on the roadside. Nevertheless, since roughly 11% of all fixed-object crashes involve guardrails, these features are better described as strategies intended to *minimize the severity of a crash*, rather than a strategy that keeps the vehicle on the travelway, since guardrails themselves constitute a fixed object hazard. Correspondingly, guardrails are included as part of the third strategy listed in this chapter.

is little substantive understanding of the behavioral factors that result in a run-off-roadway event. Indeed, the *Roadside Design Guide's* treatment of this subject is so brief as to be included here in its entirety:

> There are many reasons why a vehicle will leave the pavement and encroach on the roadside, including:
>
> - driver fatigue or inattention
> - excessive speed
> - driving under the influence of drugs or alcohol
> - crash avoidance
> - roadway conditions such as ice, snow or rain
> - vehicle component failure
> - poor visibility (p. 1-2)

Currently, there are three practices aimed at keeping vehicles on the roadway: straightening curves,[9] denoting hazards through the use of signs and pavement markings, and applying rumble strips to a roadway's shoulder (TRB 2003a; TRB, 2003b). Each of these practices is briefly detailed below.

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[9] The reason for an emphasis on curve elimination is attributable to the nature of existing crash data. Secondary sources of crash data used in most safety analyses, such as FARS, provide limited information on a roadway's geometric design characteristics other than recording whether or not a curve was present. As researchers have largely chosen to use these readily-available data sources, rather than physically collecting data on a roadway's geometric design characteristics, a heightened emphasis has been placed on curves since it is the only geometric design variable included in readily-available secondary data sources.

Practice 1.1: Straightening Curves

As noted previously, as well as in other works on roadside safety (Bryer, 1993; TRB, 2003a; TRB 2004b; Turner and Mansfield, 1990; United States Department of Transportation [USDOT] 1987), curved roadway alignments are disproportionately represented in fixed object crashes. As a result, design practice encourages straightening curves, where possible, although the high cost of curve realignment strategies is widely recognized (Bissell, 1999; Institute of Transportation Engineers [ITE], 2002; Krammes, 1999;TRB 2003a; TRB 2003b).

Practice 1.2: Increase the Driver's Awareness of Hazards through Signing and Marking Applications

Because of the high cost of realigning the horizontal curvature of a roadway, roadside safety practice is often instead oriented toward delineating potentially hazardous objects and environments. The objective of this approach is to increase the driver's awareness of an oncoming curve or other hazard, typically through the use of posted advisory speeds, pavement markings, chevrons, and other advance warning signs (Bissell, 1999; FHWA, 1990; Krammes, 1999; ITE, 2002; TRB, 2003a; TRB, 2003b). While such practices make sense, on an intuitive level, the inconsistency of posted advisory speed practices (Chowdhury et. al., 1998), and indeed, the inconsistency of posted speed limit practices in general (Fitzpatrick et. al., 2003; Fitzpatrick et. al., 1996; Kubilins, 2000; Tarris et al., 2000), have led many drivers to disregard signs. While it is tempting to attribute this to recklessness and irresponsible driver behavior, there is growing evidence that suggests that even conscientious drivers have difficulty obeying safety information displayed through sign applications. Al-Madani and Al-Janahi (2002) found that drivers only comprehend about half of the signs placed along a roadway. Further, even when drivers are attempting to adhere posted speed limits, they naturally increase their operating speed to a roadway's design speed when their attention is diverted from actively monitoring their speedometer (Recarte and Nunes, 2002). Overall, this suggests that signs and pavement markings may have only a moderate effect in preventing run-off-roadway events.

Practice 1.3: Use Rumble Strips to Alert the Driver to a Run-Off-Roadway Event

The third practice recommended for preventing run-off-roadway events is the use of rumble strips along the shoulder of a roadway. Rumble strips are grooves placed into the roadway aimed at alerting the driver of potentially hazardous conditions. While rumble strips do not result in reduced speeds (Ewing, 1999), they cause a vehicle to vibrate and make noise when a vehicle crosses over them, thereby signaling to the driver that he or she is leaving the travelway. While in many conditions the sound made by a vehicle crossing rumble strips does not exceed a roadway's ambient sound (FHWA, 2000) the vibration they produce appears to be successful at alerting the driver that they are leaving the travelway. Indeed, several recent studies of the effectiveness of rumble strips found that can decrease the number of run-off-road crashes from between 30 and 85 percent (TRB, 2003b; FHWA, 2002).

While shoulder based-rumble strips have proven effective in reducing run-off-road crashes on Interstates and freeways, their applicability to lower-speed roadways may be limited. The appropriate use of rumble strips to alert the driver of a run-off-roadway event requires a paved shoulder adjacent to the travelway. While this condition is readily met on Interstates, freeways and rural arterials, urban roadways are often curbed and lack shoulders, thus limiting the use of rumble strips as a safety countermeasure.

Further, even when shoulders are available on urban roads, they are regularly used to accommodate bicyclists (AASHTO, 1999), a factor that raises questions about the appropriateness of rumble strip treatments. Rumble strips are not only physically unpleasant for bicyclists, they can also lead to the loss of control of the bicycle (Moeur, 1999). Thus, rumble strip applications may be contextually inappropriate in environments when bicycle use is either expected or encouraged.

Strategy 2: Eliminate the Hazard Associated With a Run-Off-Roadway Event

The majority of the guidance on roadside safety is focused on the idea that safety can be best ensured by designing roadways to be safe for run-off-roadway events, should they occur (American Association of State Highway Officials [AASHO], 1967, AASHO, 1974; AASHTO, 2001; AASHTO, 2002a; TRB, 2003a: TRB, 2003b; USDOT, 1987). As stated in the *Roadside Design Guide* “regardless of the reason for a vehicle leaving the roadway, a roadside environment free of fixed objects with stable, flattened slopes enhances the opportunity for reducing crash severity.” (AASHTO, 2002a, p. 1-2).

Correspondingly, current design guidance emphasizes the importance of ensuring that all roadsides are safe for vehicles that leave the travelway. To accomplish this objective, two key practices are recommended. The first is to provide a clear runout zone adjacent to the travelway, and the second is to ensure that ditches, slopes and curbs are designed to accommodate a run-off-roadway event.

Practice 2.1: Provide a Clear Runout Zone Adjacent to the Travelway

Current practice calls for the establishment of a clear runout zone adjacent to the travelway that will permit vehicles to come to a controlled stop prior to encountering a fixed object. The preferred width for a clear recovery zone is 30’, with adjustments for sideslope (AASHTO, 2002a, TRB, 2003b). While 30 feet is regarded as desirable, it is viewed as a preferred design *minimum*, with the most recent guidance stating: “The wider the clear zone, the safer it will be” (TRB, 2003b p. V-43). Clear zones can entail a combination of a paved shoulder and an unpaved area adjacent to the travelway that is free of roadside obstacles, although the design preference is for a paved shoulder. Under conventional practice, clear zones are typically some combination of the two (see Figure 3-1).

Figure 3-1: Illustrative Clear Zones

Practice 2.2: Design Accommodating Slopes, Ditches and Curbs

A second issue in the design of roadsides is to design slopes, ditches and curbs to accommodate run-off-roadway events. Much of the guidance is principally concerned with the influence of these features on rollover crashes. 11% of all fatal crashes involve a rollover event (see Table 2-1), and the largest number of rollovers occurs after a vehicle strikes an embankment or ditch (TRB, 2003b; Viner, 1995). The principal cause of rollover crashes is a vehicle “tripping” on an element in the roadside, such as a ditch or an embankment. To prevent vehicle tripping, design guidance recommends softening pavement “drop offs” (i.e., the point where the paved and unpaved portions of the roadway meet) and reducing the slope of shoulders and ditches.

Nevertheless, such considerations relate more to the design of rural roadways than to urban ones. First, rollovers tend to be primarily a rural problem; in 2002, for example, there were 3,500 fatal rollover crashes in rural areas, compared to 800 for urban areas, only 300 of which occurred on roadways classified as minor arterials, collectors or local roadways. Accounting for exposure (based on VMT), rollovers were 6.5 times more likely to occur in a rural environment than an urban one (source: FARS).

Second, urban areas have greater concentrations of roadside development, and a corresponding increase in impervious surface areas. As a result, curb and gutter applications are typically used to address stormwater runoff (see Figure 3-2), and concerns surrounding the use of curbing differ markedly from the design of slopes and ditches. Thus, this section is concerned largely with the design of curbs, rather than with the design of slopes and ditches.

Figure 3-2: Two Strategies for Dealing with Stormwater

The concerns surrounding curbs are twofold. First, conventional curb applications have relatively little ability to redirect an errant vehicle back into the travelway, particularly at higher speeds (Wezeker and Nkunga, 2003). As a result, the *Roadside Design Guide* states that:

> One common misconception is that a curb with a 0.5 m [1.5 ft] offset behind it satisfies the clear roadside concept. Realistically, curbs have limited redirectional capabilities and only at low speeds, approximately 40 km/h [25 mph] or lower. Consequently, the designer must strive for a wider clear zone that is reflective of the off-peak operating speed (85th percentile) or design speed, whichever is greater… serious consideration should be given to providing a full width paved shoulder[10] and offsetting any curbing to the back of the shoulder (AASHTO, 2002a, p. 10-2)

Shoulder treatments between the travelway and the curb can take the form of either a dedicated, marked shoulder or a wide outside travel lane (see Figure 2-3). The design guidance recommends a height of 4 inches for a vertical curb [1V:1H], and 6 inches for sloping curbs [1V:2H], and that curbs should be offset from 1 to 2 feet from the edge of the travelway (AASHTO, 2001).[11] A second concern in the design of curbing is that "an out of control vehicle may… become airborne as a result of an impact with a curb"

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[10] A full width shoulder is 10 ft in areas with little or no truck traffic, and 12 ft otherwise (AASHTO, 2001).

[11] Nevertheless, it must be observed that a curb will redirect an errant vehicle when the curb height exceeds the radius of a vehicle's tire.

(AASHTO, 2001, p. 324). To address this concern, vertical curbs are discouraged for roadways with speeds greater than 45 mph.

Figure 3-3: Wide Outside Lane and Dedicated Shoulder

Strategy 3: Minimize the Severity of Unpreventable Crashes

While the provision of a clear runout zone is the preferred practice for addressing roadside safety, in many cases it may not be practical to provide one. In urban areas, for example, there is often limited right-of-way available for the establishment of a clear runout zone due to the density and location of roadside development. To address these deficiencies, two practices are recommended: the first is to design roadside features to be traversable by errant vehicles, and the second is to shield objects that cannot be made traversable through the use of guardrails or other protective devices.

Practice 3.1: Ensure Roadside Objects are Traversable by Errant Vehicles

This practice begins by testing roadside features for their crash-worthiness, either by physically replicating a crash at specially-designated crash test sites, or by using computer applications, such as LS-DYNA, to simulate the crash. *NCHRP 350* (TRB, 1993) provides detailed specifications on the methods for testing an object's crash performance, including variables such as the design vehicle, angle of impact, soil conditions and other factors, and ongoing research continues to update these test procedures (see, for example, Mak and Bligh, 2002a; 2002b).

The current standard for breakaway hardware, as contained in the *Roadside Design Guide* and *NCHRP 350*, is that breakaway features function omni-directionally to ensure that the feature is traversable from any angle of impact. To prevent vehicle snags, the stub height, after breakaway, should not exceed 4 inches.

While breakaway features may minimize the severity of the initial impact, the dislocation of the breakaway feature from its base may create a secondary impact as the post falls on the vehicle. Thus, breakaway poles and similar features must be designed to prevent intrusion on the passenger compartment of the vehicle, either by minimizing the weight and load of such features, or by providing a secondary hinge, at least 7 ft above the ground, that permits the vehicle to pass safely beneath the post upon impact. The current edition of the *Roadside Design Guide* (AASHTO, 2002) provides detailed specifications for these devices.

Of particular importance to this study, however, is the treatment of trees located adjacent to the travelway in the "pedestrian buffer zone." In general, trees with a caliper width greater than 4 inches are regarded as being fixed-object hazard, and design practice discourages the placement of trees that exceed this width in the clear zone (USDOT, 1987, Turner & Mansfield, 1990; AASHTO, 2002a, TRB, 2003a, TRB, 2003b).

Practice 3.2: Shield Hazardous Objects

Where the roadside cannot be made clear of obstructions, or where slopes adjacent to the travelway are hazardous, the objects and/or roadside should be shielded using guardrails. While guardrails themselves constitute a major fixed-object hazard (9% of all injurious and fatal fixed-object crashes involve guardrails), the benefits of shielding objects appear to outweigh their hazards in certain conditions, such as when a steep slope is adjacent to the travelway (Michie and Bronstad, 1995). Thus, design guidance encourages shielding roadside objects or features using guardrails and other barrier treatments when the roadside cannot be made traversable. Like the design of traversable hardware, guardrails are subject to *NCHRP 350* tests prior to field application, and detailed design specifications for these features are included in the *Roadside Design Guide* (AASHTO, 2002).

Roadside Design Guidance: A Summary

Roadside safety practice is currently focused on three key strategies. The first is to prevent vehicles from leaving the travelway. While this is the strategy that will have the most profound impact on eliminating injuries and deaths associated with run-off-roadway events, it is currently the least developed. At present, design strategies aimed at preventing run-off-roadway events are largely limited to the use of signs and pavement markings to identify hazardous conditions or the use of rumble strips to alert the driver that (s)he is leaving the travelway. To date there is little understanding of the pre-crash behaviors that result in run-off-roadway events, or how to design roadways to prevent these behaviors from occurring. As such, this would appear to be an important opportunity for enhancing roadside safety, and one that will be discussed in subsequent chapters.

The second strategy is to minimize the hazard associated with a run-off-roadway event. The logic behind this approach is that since many run-off-roadway events cannot be prevented, the design objective should be to minimize the consequences of leaving the travelway. For this reason, contemporary roadside design practice encourages the provision of roadside that is free from hazardous slopes or fixed objects.

The third and final strategy is applicable when a clear roadside cannot be provided. In this case, design practice recommends that all objects in the clear recovery area be traversable by errant vehicles or shielded through the use of guardrails. Of the three strategies, this is the most thoroughly developed, with roadside features being subject to extensive crash testing prior to their application in the field.

When one considers the guidance on roadside safety holistically, however, two key design considerations are absent from the recommended practices. First, there is little discussion on how to integrate these design practices into urban environments. As stated by the *Roadside Design Guide*:

> the principles and guidelines for roadside design presented in… this Guide discuss roadside safety considerations for rural highways, Interstates and freeways, where speeds are generally higher, approaching or exceeding 80 km/h [50 mph], and vehicles are operating under free-flow conditions (AASHTO, 2002, p. 10-1).

Despite this important caveat, these principles are assumed to be applicable to all design contexts. As stated in AASHTO's *Highway Safety Design and Operations Guide*: "for all types of highway[12] projects, clear zones should be determined or identified and forgiving roadsides established" (1997, p. 14).

Next, and perhaps most surprisingly, there is almost no information on how to design roadsides to accommodate pedestrian and bicycle activity. Other than noting that shoulders may be used by bicyclists and pedestrians (TRB, 2003b), pedestrian and bicyclist issues are almost entirely absent from roadside design guidance, despite the obvious fact that the roadside is where most pedestrian and bicyclist activity occurs.

In conclusion, the guidance on roadside safety indicates that the provision of a clear zones and forgiving roadside features will enhance a roadway's safety, regardless of a roadway's functional class or environmental context. Nevertheless, there is little information that will allow one to determine the degree to which safety will be enhanced through the implementation of roadside safety principles in urban environments. To better gauge the applicability of these practices in an urban context, the next chapter of

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[12] In conventional engineering parlance, all roadways are referred to as "highways." High-speed limited access roadways are referred to as "freeways"

this dissertation examines the empirical and historical basis of contemporary roadside design practice.

CHAPTER 4

THE PASSIVE SAFETY PARADIGM

The positive coefficient on shoulder widths is troubling; one normally expects a wider shoulder to be a safety feature.

- Ivan, Pasupathy and Ossenbruggen, 1999

The previous chapters of this dissertation discussed the basic characteristics of fixed-object crashes, as well as how contemporary design practice seeks to address them. Specifically, contemporary roadside design encourages the provision of a “forgiving” roadside, which entails providing a roadside that is free of fixed-object hazards, or, at a minimum, by ensuring that any roadside object placed adjacent to the right-of-way is traversable by errant vehicles. While such an approach would seem to go a long way towards minimizing the severity of run-off-roadway events, it results in design treatments that are viewed with hostility by many urban advocates (see Figure 1-3). Rather than embracing clear zone principles, livability advocates instead encourage the placement of trees and other roadside features in a “pedestrian buffer zone” between the sidewalk and the vehicle travelway, an approach that obviously violates the basic tenets of conventional roadside safety practice. As such, design practices aimed at enhancing livability are often incompatible with those intended to address the safety of run-off-roadway events (see Figure 4-1).

Figure 4-1: Safe or Livable? Two Competing Design Objectives

Yet a key question remains: are livable street treatments less safe, in terms of crash frequency and severity, than more conventional roadside design applications? This chapter begins the second section of this dissertation, which examines the empirical basis for the contemporary approach to addressing roadside safety in urban environments. It begins by summarizing the findings of empirical studies that have examined the crash frequency and severity. Crash impact studies, which examine the “crashworthiness” of vehicles and roadside features through hypothetical crash conditions (either on specific testing grounds of through computer applications such as LS-DYNA) are excluded from analysis. Instead, what is sought is an understanding of how roadside safety practices influence the frequency and severity of crashes that occur in *real-world* operating conditions, as well as how these have (or have not) influenced the development of roadside design guidance.

The Empirical Evidence on Geometric Design and Roadside Safety

Much of the early literature on roadside safety is primarily descriptive in nature. Perhaps the earliest study on run-off-roadway events examined median encroachment rates[13] for a 25-mile section of a highway in Illinois, finding that encroachment rates were roughly 0.75 per 100 vehicle kilometers traveled (Hutchinson and Kennedy, 1967). Foody and Long (1974) measured the location of roadside crashes, reporting that 37% of fixed-object crashes occurred between 6 and 12 feet from the edge the traveled way, and that 81% occurred within 20 feet. Hall et. al., (1976) examined utility pole crashes, and found that most utility pole crashes occurred along curves and within 11.5 feet of the travelway. Zeigler (1986) examined tree-related crashes in rural Michigan and found that 85% occurred within 30 ft of the travelway. Turner and Mansfield (1990) replicated Zeigler's study for the City of Huntsville, Alabama, and found that the majority of trees involved in crashes had a caliper width of 12 inches or greater, that 60% were located along a horizontal curve, and that 80% occurred within 20 feet of the travelway.

These early descriptive studies generally conclude by recommending the elimination of roadside objects located within 30 feet of the vehicle travelway and along

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[13] While this dissertation is not specifically interested in median design, Hutchinson and Kennedy's study played a profound role in shaping contemporary roadside design guidance and, as such, is included here. I will revisit this study later in this chapter.

curves. While these studies are useful for understanding the general characteristics of roadside crashes, such analyses do not lead to the conclusion that eliminating roadside objects with any or even all of the described characteristics will have any effect on a roadway's crash performance. Such conclusions can only be made by analyzing the comparative safety performance of roadways with clear runout zones, and those without, or else by conducting detailed before-after analyses at locations where roadside features have been either placed in a roadway's clear zone, or else removed from it.

In one of the earliest studies to conduct such an analysis, Zegeer, Deen and Mayes (1981) examined the safety performance of a variety of lane and shoulder widths[14] on two-lane rural highways. The authors found that crash rates decreased as shoulder widths increased, but only until shoulders reached a width of between 7 and 9 feet. The authors found that crash rates *increased* as shoulders exceeded 9 feet, suggesting a "U" shaped relationship between shoulder widths and crash rates.

The authors observed the same phenomenon for lane widths as well, with crash rates decreasing until lanes reached a width of 11 feet, and increasing as lane widths approached and exceeded the more common 12-foot standard. The authors further examined crash rates for roadways with a combination of lane and shoulder widths. Of these, the safest roadways, with less than half the crash rates of any other lane and shoulder width combination, were roadways with 11-foot lanes and 9-foot shoulders.

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[14] Because of the difficulty in obtaining data on clear zone widths (Lee and Mannering, 1999), most authors use shoulder widths as a proxy. Indeed, most of the studies reviewed in this chapter do so.

Finally, the authors examined the relationship between average annual daily traffic (AADT) and crash rates. While crash rates for multiple-vehicle crashes, measured as crashes per million vehicle miles traveled (MVMT), remained relatively constant for all levels of AADT, single vehicle crashes dropped dramatically once traffic volumes exceeded 500 AADT. These findings are consistent with the descriptive statistics reported in Chapter, 2, which found that urban areas, which tend to have heavier traffic volumes than rural areas, also have lower fixed-object crash rates.

Benekohal and Lee (1991) conducted before-after analyses of 17 “3R” (resurfacing, restoration and reconstruction) projects located on two-lane rural highways in Illinois that improved lanes and shoulders and eliminated roadside objects such as trees. The authors used a quasi-experimental design to examine the changes in two crash categories, single vehicle fixed-object crashes, as well as a crash category defined as “related crashes,” which included single vehicle fixed-object crashes, as well as overturn, head-on and sideswipe crashes. Each of the 17 projects was compared against control sites consisting of sections of the same roadway either immediately in advance of the improved site, or immediately following it.[15] When all 17 sites were considered collectively and compared against the crash performance of the control groups, these projects showed a net reduction in both single vehicle fixed-object crashes and related crashes, with t statistics of –1.195 and –1.745, respectively.[16]

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[15] The authors do not provide the criteria used in determining which section of the roadway was used as the control site.

[16] For n=17, the critical value for t at the 95% confidence level is 1.746 (one-tailed) and 2.120 (two-tailed).

When the projects are considered individually, however, their safety benefits are much less clear. Only 7 of these 17 projects actually resulted in a reduction in fixed-object crashes; 4 reported no change, and 6 showed *increases* in fixed-object crashes. For related crashes, 10 projects resulted in crash reductions, two reported no change, and five resulted in an increase in related crashes. In short, these results suggest that the safety benefits of these projects are inconclusive.

Ivan, Pasupathy and Ossenbruggen (1999) modeled single and multiple-vehicle crashes on two-lane rural roadways in Connecticut as a function of a roadway's level-of-service (LOS) and its geometric characteristics. Lower levels-of-service (i.e., increased congestion) were found to be associated with a statistically-significant reduction in the number of single-vehicle crashes. For multiple-vehicle crashes, LOS had a mixed effect, with LOS C and D entering with negative coefficients, depending on how the model was specified,[17] but failed to enter significantly in any of the authors' model runs. In general, however, the authors found that increased levels of congestion are associated with a decrease in single-vehicle crashes, while it seemed to have no discernable effect on multiple-vehicle crashes, similar to the findings of Zegeer et. al. (1981) described above.

Shoulder widths were found to have differing effects on single-vehicle and multiple-vehicle crashes. In the authors' model explaining single-vehicle fixed object crashes, shoulders widths entered negatively at a statistically-significant level, indicating that wider shoulders were associated with a decrease in single-vehicle crashes.

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[17] The model was specified using level-of-service A as a base condition. A negative coefficient for level-of-service C, for example, indicates that there are fewer multiple-vehicle crashes for this operating condition as compared to level-of-service A. Nevertheless, these results were not robust.

Nevertheless, wider shoulders were shown to result in an *increase*, also at a statistically-significant level, in multiple vehicle crashes, thus offsetting reductions in single-vehicle crashes.

In a follow-up study that also examined two-lane rural highways in Connecticut, Ivan, Wang and Bernardo (2000) sought to further investigate single-vehicle crashes as a function of shoulder widths, lighting conditions, time-of-day, and land use effects. The authors find that "the shoulder width coefficient has the wrong[18] sign – we expect crash rate to *decrease* as shoulder width increases" (p. 793). Lighting conditions did not prove significant, although there were generally more crashes at night.

The authors' results on land use influences are highly interesting. To operationalize land use, the authors used the number of driveways for specific land use types along each section of roadway. They found that the number of gas station driveways reduced single-vehicle crashes, while driveways for apartments and other land uses were associated with statistically-significant increases in single-vehicle crashes. Finally, the number of intersections along a roadway was associated with a statistically-significant reduction in single-vehicle crashes. The authors do not elaborate on the implications of these findings other than remarking that "the best single-vehicle crash models tell us that sites with a lot of gas station driveways and street intersections tend to have fewer single-vehicle crashes" (p. 793).

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[18] This does not indicate that the sign is wrong, but instead that there is currently not an adequate theory for interpreting it. This subject will be examined in greater detail in the following chapters.

Milton and Mannering (1998) modeled crash frequencies on principal arterials (Interstates, freeways and other limited-access facilities) in the state of Washington as a function of its traffic volumes and geometric characteristics. Based on the results of a negative binomial model, the authors found that crash frequencies increase with increases in AADT and the number of lanes. Curiously, although the authors had data on actual shoulder widths, they chose to aggregate it into a dummy variable that simply indicated whether or not roadways had shoulders 1.5 m (5 ft) wide.[19] Principal arterials with shoulders greater than 5 feet were found to be safer than those with shoulders less than 5 feet.

A highly interesting finding of this research is that curves, by themselves, were not shown to result in an increase in crash frequency. Indeed, sharp curves (measured by the authors as having a radius of less than 2900 ft) were shown to result in a statistically-significant *decrease* in crashes. Instead, the variable that proved significant in explaining curve-related crashes was the presence of a long, straight tangent on the approach to a curve, indicating that the curve itself is not the hazard, but a curve located after a straight (high-speed) approach. Similarly, Shankar, Mannering and Barfield (1995) examined the crash performance of the Snoqualmie Pass (US 90) in Washington State, finding that fixed-object crashes decrease as the number of curves with a design speed below 60 mph increase.

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[19] The authors provide no justification for this decision. Based on Zegeer and Parker's findings that the safety benefits of shoulders maxes out at roughly 9 feet, it is possible that this measure may have been developed to produce "expected" findings.

In a study of predominantly rural, two-lane roadways in the state of Illinois, Noland and Oh (2004) modeled crashes as a function of a roadway's geometric characteristics using a negative binomial model. The authors found that wider shoulders were associated with a decrease in the number of crashes that occurred, but that they were also associated with an *increase* in fatal crashes, although the authors note that this is not at a statistically-significant level.[20]

Urban Roadside Safety

Most studies addressing geometric design and roadside safety issues focus on two-lane rural highways. Nevertheless, several studies have examined the subject of roadside safety in urban environments. Naderi (2003) examined the safety impacts of aesthetic streetscape treatments placed along the roadside and medians of five arterial roadways in downtown Toronto. Using a quasi-experimental design, the author found that the inclusion of features such as trees and concrete planters along the roadside resulted in statistically-significant *reductions* in the number of mid-block crashes along all five roadways, with the number of crashes decreasing from between 5 and 20 percent as a result of the streetscape improvements. While the cause for these reductions is not clear, the author suggests that the presence of a well-defined roadside edge may be leading drivers to exercise greater caution.

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[20] Stating that it is not "statistically significant" does not address the degree of statistical confidence for the estimate. The t-statistic was 1.4 (n=404), which corresponds to a one-tailed p-value of 0.08. Stating this statistic another way, one can be 92% confident that wider shoulders will increase fatalities.

Ossenbruggen, Pendharkar and Ivan (2001) examined sites with urban, suburban and residential characteristics in New Hampshire, and hypothesized that the urban "village" areas, with greater traffic volumes and more pedestrian activity, would be associated with higher numbers of crashes and injuries. Instead, they found the opposite: the village areas, which had on-street parking and pedestrian-friendly roadside treatments, were two times *less* likely to experience a crash event than the comparison sites. The authors associate these crash reductions with the characteristics of the roadside environment, which included sidewalks, mixed land uses and other "pedestrian-friendly" roadside features. The authors also attributed the safety performance to reduced speeds, noting that "since no speed limit signs are erected at village sites, it suggests [speeds] are self regulating" (p. 496).

Lee and Mannering (1999) examined run-off-roadway crashes for one direction of a 60-mile section of an arterial roadway in Washington State. Using a negative binomial model, and evaluating urban and rural crashes separately, the authors sought to associate crash frequencies with the characteristics of the roadside environment. While their model for rural areas performed as expected, with trees and other features being associated with statistically-significant increases in the number of roadside crashes that occur, their model for urban areas produced radically different results (see Table 4-1). Not only were trees *not* associated with crash increases, but the model coefficients entered *negatively* at statistically-significant levels,[21] indicating that the presence of trees in urban areas was associated with a decrease in the probability that a run-of-roadway crash would occur.

Table 4-1: Lee and Mannering's Results for Urban Run-Off-Roadway Crash Frequencies

Variable	**Estimated Coefficients**	**t-statistic**
Constant	-1.983	
Roadway Characteristics		
Broad lane indicator (1 if lane is greater than 3.69 meters, 0 otherwise)	1.684	3.984
Median width (in meters)	-0.017	-3.781
Roadside Characteristics		
Bridge length	4.610	2.145
Distance from outside shoulder edge to guardrail	0.113	3.655
Fence length	5.781	2.870
Number of isolated trees in a section	-0.093	-1.857
Number of miscellaneous fixed objects in a section)	-0.094	-2.140
Number of sign supports in a section	-0.080	-3.515
Shoulder length	-1.042	-1.461

Other roadside features proved to be statistically related to crash reductions as well. The number of sign supports was associated with crash reductions, as was the presence of miscellaneous fixed-objects, a variable that included the presence of such roadside features as mailboxes. Further, wide lanes and shoulders were associated with

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[21] For n=1,584, the 0.05 confidence level for t is 1.65 for a one-tailed test, and 1.96 for a two-tailed test.

statistically-significant *increases* in crash frequencies. Roadways with lane widths of 12 feet or greater were associated with statistically-significant increases in roadside crashes, as was an increase in the distance between the outside of a roadway's shoulder and an adjacent guardrail.

A Summary of the Empirical Evidence

One examining the empirical evidence on roadside safety is necessarily led to the conclusion that contemporary roadside safety practices have an ambiguous effect on crash performance, at best. Wider shoulders have not been definitively shown to enhance safety, nor has the elimination of sharp curves. The only study to specifically model clear zones in urban environments, rather than shoulders (Lee and Mannering, 1999), found that widening clear zones resulted in *increases* in urban run-off-roadway crashes, rather than reductions. Indeed, the weight of the evidence suggests that seemingly hazardous roadside applications, such as the placement of aesthetic streetscape features adjacent to the vehicle travelway, *enhances* safety, particularly in urban environments.

Clear zones are not the only design area where such safety anomalies appear. Hauer (1999a) re-examined the literature on lane widths, and found that there was little evidence to support the assertion that widening lanes beyond 11 feet enhances safety. Instead, the literature has almost uniformly reported that the safety benefit of widening lanes maxes out at roughly 11 feet, with crash frequencies increasing as lanes approach and exceed the more common 12-foot standard.[22] Indeed, there are a host of safety anomalies in the existing design literature, but the problem is that:

> Studies that find unexpected or unconventional results tend to dismiss these results as aberrations and have not examined them in further detail…. The results of many of these studies lead us to conclude that the impact of various infrastructure and geometric design elements on safety are inconclusive. Most studies using sophisticated statistical techniques either find no association, or an unexpected association from infrastructure changes assumed to be beneficial (Noland & Oh, 2004, p. 527).

Thus, a key question emerges: why does contemporary design guidance recommend practices that the best available evidence suggests may have an ambiguous or even negative impact on safety, and paradoxically, to do so under the auspices that they constitute a safety enhancement? The answer to this question lies in the historical foundations of contemporary safety practice, and is the subject of the next section of this chapter.

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[22] Hauer does comment that "I am not convinced that if research was done on current data, that 12 foot lanes would be found to be less safe than 11 foot lanes. Much has changed since then; trucks grew to be larger and research methods improved. However, at the time the Policy was written, the aforementioned findings by respected researchers should have sounded alarm" (2000, p. 12).

The Passive Safety Paradigm

Transportation engineering, like engineering practice more broadly, is a scientific discipline, and understanding it as such helps clarify the inconsistencies between what is contained in the design guidance, and what exists in the literature. As Kuhn has detailed in his classic work, *The Structure of Scientific Revolutions* (1962), scientific disciplines adopt paradigms to guide research and practice. Paradigms are theoretical worldviews that provide researchers with rules and methods that direct research into a phenomenon of interest. While theoretical, an interesting characteristic of paradigms is that they are rarely stated as an overt set of theoretical propositions. As Kuhn has written, “to the extent that normal research work can be conducted by using the paradigm as a model, rules and assumptions need not be made explicit” (p. 88).

Instead, paradigms are implicitly embedded in the problems, methods, and reference works that are transmitted from one generation of scientists to another, typically through textbooks and, in the case of transportation engineering, transportation design guidance. These works gloss over contradictions and inconsistencies in the prevailing paradigm, presenting the current state of the practice as a unified whole. As a result, “students and professionals come to feel like participants in a long standing historical tradition. Yet the textbook-derived tradition in which scientists come to sense their participation is one that, in fact, never existed” (p. 138).

Paradigms are highly useful for advancing a scientific disciplines because they provide researchers a focus for their work, enabling them to make rapid advancements in an area of interest. Yet the problem that emerges in the course of paradigm-directed research is that a paradigm can lead researchers to disregard contradicting, but potentially important, research findings because they lack a theoretical basis for interpreting their results. Instead, these findings are treated as anomalies, and are either given little attention or disregarded altogether.

A central argument of this dissertation is that contemporary roadside design practice (and indeed, design practice more broadly) is driven by a guiding "paradigm," or theoretical worldview, about the relationship between roadway design and safety. Because of this safety paradigm, key relationships between geometric design and crash performance have been systematically ignored in the existing design guidance, resulting in design practices that produce less-than-optimal safety results.

Lee and Mannering's (1999; 2002) treatment of their research findings is particularly useful as an illustration of the powerful influence that the current paradigm plays on the interpretation and reporting of research results.[23] As detailed previously, the authors' results for rural areas supported the prevailing paradigm on roadside safety practice, with wider lanes, shoulders and clear zones resulting in crash reductions. Conversely, their results for urban areas found that these features resulted in crash *increases*. Such findings, while seemingly anomalous, have substantial life safety implications that should have warranted serious consideration. Yet this did not occur. Instead, when faced with the choice of considering the possibility that trees and other roadside features might enhance safety in urban environments, as evidenced by their

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[23] This work was selected for focused consideration both for its methodological rigor and the appropriateness of its research methods. As such, its conclusions are therefore highly compelling and worthy of detailed consideration.

research findings, or the paradigm-supporting conclusion that these objects should be universally removed, the authors concluded their work by stating, without qualification, that "the results show that run-off roadway accident frequencies and severities can be reduced by widening lanes, bridges and shoulders [and] relocating roadside fixed objects" (p. 103).

This 1999 work was subsequently published in the journal *Accident Analysis and Prevention* (Lee and Mannering, 2002) under the auspices of developing cost-effectiveness measures. While the authors provide a detailed discussion of the overall research effort, including how they developed the specific models used to examine each design environment, they only noted that "there was a significant difference in the factors that determined run-off-roadway accident frequencies… in urban and rural areas" (p. 153). The nature of these differences (i.e., that contemporary roadside design practices were found to negatively affect roadside safety in urban environments) is not reported. Indeed, one reading the article would not know that the authors had arrived at such a finding. Instead, the authors simply state that "to save space, we only present detailed model results from the rural frequency model estimation" (p. 153).[24]

Thus, the anomalous findings for urban environments are entirely removed from consideration, allowing the authors to again conclude that "our results show that run-off-roadway accident frequencies can be reduced by… decreasing the number of isolated trees along a section and increasing the distance from the outside shoulder edge to light

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[24] Interestingly, the reader is then referred to an unpublished dissertation (Lee, 2000) for the urban specifications, rather than the published report that is readily available online from the Washington State Department of Transportation (Lee and Mannering, 1999).

poles" (p. 160). Again, the authors do not qualify these recommendations by noting that, while using the exact same data sources and analysis techniques from which their reported findings are drawn, that they found the exact opposite to be true for urban environments.

That Lee and Mannering would opt to withhold anomalous research findings is not entirely surprising when one considers the nature of paradigm-based research. Kuhn writes that research conducted within a prevailing paradigm "often suppresses fundamental novelties because they are necessarily subversive of its basic commitments" (1962, p. 5). Yet this probably overstates the case. More accurately, the problem is better described as one of interpretation. Most paradigm-driven research begins by assuming not only basic theoretical propositions, but major conclusions as well, taking the form of "puzzle-solving," where major conclusions are already known (i.e., that the provision of clear zones will enhance safety), and where the major research objective is to more clearly specify these intended research results through the development of increasingly sophisticated data collection and modeling techniques. Thus, most paradigmatic research is targeted towards "achieving the expected in a new way" (Kuhn, p. 36).

As an illustration of this puzzle-form, one need only consider the general characteristics of the literature on roadside safety, which is focused on the development of increasingly elaborate models for deriving cost-benefit estimates of providing clear zones, not on evaluating the appropriateness of clear zone practices. The guiding question driving most roadside safety research is not *whether* clear zones enhance safety, but by *how much,* per a given unit of expenditure (Lee and Mannering, 1999; 2002; Mak, Bligh

& Ross, 1995; Milton and Mannering, 1998; Zegeer, Deen and Mayes, 1981). Researchers conducting research under such an assumptions are generally not prepared to comprehend why such features may have a negative effect on safety. It violates their basic theoretical position on the subject.

Which leads to a key question: if a paradigm is indeed driving contemporary roadside safety practice, what does it assume about the nature of roadside crashes, and why have transportation practitioners and researchers found it so compelling that they would allow it to co-opt the findings of a growing body of empirical evidence?

Contemporary Safety Practice: An Historical Examination

The central thesis of Kuhn's (1962) work is that advancements in science emerge out of "scientific revolutions" that rapidly and dramatically alter the theoretical landscape of scientific practice. The revolutionary nature of scientific practice is rarely recognized because these changes occur infrequently, as well as because "the depreciation of historical fact is deeply, and probably functionally, ingrained in the ideology of the scientific profession" (p. 138).[25] There has yet to be a single work that has detailed the basis for the contemporary approach to addressing safety through design, or indeed, even a detailed articulation of the theoretical propositions on which contemporary safety practice is based. Because such information is essential for both understanding how

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[25] Kuhn observes that scientific textbooks usually treat history in a brief note in an introductory chapter. The *Roadside Design Guide* is an excellent illustration of this phenomenon. The entire history of the development of roadside design guidance is contained in the first two paragraphs of the document, and only one relevant historical fact is presented – which is that roadside safety practice first emerged in the 1960s.

safety is currently addressed through design practice, as well as how it might be improved, the remainder of this chapter examines the origins of the contemporary approach to safe transportation design, paying specific attention to the problems it was attempting to solve, as well as the means by which it sought to solve them. It then concludes by detailing the theoretical propositions that shape the current safety paradigm.

A Passive Approach to Transportation System Safety

While the transportation profession has always had at least a nominal concern for road safety, the contemporary approach to addressing safety through design received its theoretical basis as part of the transportation safety movement of the 1960s. This movement dramatically redefined the way safety was perceived and addressed, resulting in the creation of most of the contemporary features of the transportation safety landscape. The Highway Safety Act of 1966, the National Highway Traffic Safety Administration (NHTSA), the inclusion of air bags in new-production motor vehicles, the crash testing of vehicles and roadside hardware, and the existence of safety-related design guidance such as the *Roadside Design Guide* are all products of the transportation safety movement of the 1960s.

If any one person could be said to be the “founding father” of contemporary safety practice, it is William Haddon, who, importantly, was not trained as an engineer, but as a medical doctor and an epidemiologist. William Haddon was the first commissioner of NHTSA, and later the director of the Insurance Institute of Highway Safety. What made Haddon’s contribution to the transportation profession so unique, as well as so lasting, is that he was the first to formally introduce the principles of epidemiology to the area of road safety.

As a profession, epidemiology is based on the work of John Snow, an English physician who sought to address an outbreak of cholera that plagued London in the 1850s. While current medical theory asserted that the spread of cholera was associated with “vapors,” Snow hypothesized that cholera was not airborne, but was instead transmitted through polluted water supplies. Using what was at the time a highly-elaborate, data-driven analysis, Snow mapped out the locations of affected households, and determined that these households were indeed sharing a common water source. In an episode that has since become legendary, Snow sought to resolve this problem in one particularly hard-hit neighborhood by implementing a strategy that was both simple and radical: rather than encouraging residents to adopt behavioral modifications, such as using an alternate water source or boiling infected water before drinking it, Snow simply removed the handle from the pump of the affected well (Rosenberg, 1962).

John Snow’s approach to addressing London’s cholera epidemic resulted in the creation of a new health-related discipline – epidemiology. What distinguishes epidemiology from other health-related disciplines is its focus on the health and well-being of *populations*, rather than individuals. Such a focus naturally leads away from the consideration of the behavior of individuals, and towards a consideration of the broader environmental factors that lead to injury and illness. William Haddon, who received a degree in Public Health from Harvard in 1957, sought to address safety using an epidemiological approach. In so doing, he radically altered the transportation safety landscape.

In the 1950s, transportation safety practice was focused largely on preventing crashes through strategies aimed at educating the driver on safe operating behavior, as well as through the development, adoption, and enforcement of traffic laws. This approach was principally *behavioral* in orientation, with the objective being to reduce crashes, and thus injuries and fatalities, by preventing the behaviors that produced them. The development and codification of the nation's traffic safety laws, as well as the Manual for Uniform Traffic Control Devices (MUTCD), are largely products of this era. Yet Haddon, an epidemiologist by training, believed that it was difficult, if not impossible, to prevent drivers from engaging in these behaviors, because "the driver [is] unreliable, hard to educate, and prone to error" (Gladwell, 2001, p. 53).

Instead, Haddon proposed a *passive* approach: rather than relying on behavioral modifications to prevent crashes, Haddon believed the safety objective should instead be to enable a "crash without an injury" by physically engineering safety features into vehicles and their environments. Through crash testing and the use of safety features such as air bags, Haddon believed that safety engineers could ensure that vehicle occupants were safe during a crash event, even if the crash could not be eliminated. The key piece of reasoning behind Haddon's approach, and the one that subsequent transportation professionals would find so compelling, is the following: drivers will err, make mistakes, and generally engage in behaviors that result in crashes. Such errors and behaviors cannot be entirely prevented. Nevertheless, by designing vehicles and their environments to be safe during a crash event, engineers can render driver behavior irrelevant. Thus, the proper design goal for engineers is not to address driver behavior, which is irrational and unpredictable, but to instead to design vehicles and roadways to ensure that drivers will be safe when a crash event occurs.

Daniel Patrick Moynihan, who first met Haddon while conducting a public meeting on the subject of traffic safety for the state of New York, found Haddon's approach compelling: what if transportation professionals could design vehicles and roadways to eliminate the injuries and fatalities that result from a crash event? The life safety implications were enormous. Haddon's ideas formed the basis of Moynihan's 1959 article, *Epidemic on the Highways*, which provided one of the earliest written accounts of the passive approach. In this work, Moynihan wrote that:

> For clinical medicine, disease is described as it occurs in individuals; for epidemiology, disease is described as it occurs in an aggregation of individuals, with as much attention being paid to the environment in which it occurs – the highway – and the agent through which it is transmitted – the automobile – as to the "host" – the driver – who gets the disease (Moynihan, 1959 in Weingroff, 2003).

The life safety implications of this approach were also not lost on Ralph Nader. While working with Moynihan in the U.S. Department of Labor, Nader was exposed to Haddon's passive safety philosophy, which formed the basis of his 1965 publication *Unsafe at Any Speed: The Designed-in Dangers of the American Automobile*. Nader specifically cites Haddon's influence on his thinking, writing that "both goals – disease prevention and accident prevention – [are] fundamentally ‘engineering’ problems. That is, concentration on the hostile environment… is almost invariably more productive than trying to manipulate the behavior of people” (p. 201).

While Nader’s book is probably best known for the repeal of the Corvair, its more lasting effect was to generate a public outcry about the “designed-in dangers” of the nation’s automobiles and transportation system, leading both the U.S. Senate and AASHO (later AASHTO) to hold special hearings on the subject of transportation safety in 1966. It was during these hearings that transportation safety practice was redefined, leading to the adoption of the Highway Safety Act and the National Traffic and Motor Vehicle Safety Act, as well as forming the intellectual background for the profession’s first design guidance that specifically addressed the subject of transportation safety, 1967’s *Highway Design and Operational Practices Related to Highway Safety* (AASHO).

The 1966 Highway Safety Hearings

Given the litigious nature of contemporary design practice,[26] it is perhaps ironic that the philosophical basis of contemporary design practice is derived from the musings of a lawyer. Yet Nader’s testimony before the AASHO and Senate committees had an enormous effect on the safety practices that were to follow.

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[26] Turner and Blashke (1995) estimate the dollar amount of pending lawsuits against departments of transportation ($14.1 billion in 1990) is the same as the annual Federal expenditure on new transportation investments.

Nader's firmly held belief was that pre-1960s safety practice was misguided in its focus on driver behavior. In testimony that would later provide the basis for the engineering concept of the "design driver,"[27] Nader argued that "even if people have accidents, even if they make mistakes, even if they are looking out the window, or they are drunk, we should have a second line of defense for these people" (Quoted in Weingroff, 2003, p. 154). To provide this second line of defense, Nader proposed two guiding design principles. The first was that "safety measures that do not rely on or require people's voluntary and repeated cooperation are more effective and reliable that those that do;" and second, that "the sequence of events that leads to an accident injury can be broken by engineering measures even before there is a complete understanding of the causal chain" (Quoted in Weingroff, 2003, p. 154).

Given their subsequent influence on design practice, the implications of these principles warrant a brief elaboration. Embedded in these notions is the idea that driver error is unpreventable, and that the best means to address this error is through engineering measures that are not reliant on driver behavior for their success. Also embedded in these principles is the idea that *safety can be addressed without addressing the behavioral causes of crashes,* or even by empirically analyzing actual crash events. Instead, Nader is proposing that designers should address safety through the metaphorical application of the engineering concept of "design failure" by assuming a worst-case-scenario condition, such as a high-speed run-off-roadway event, and then designing

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[27] The "design driver" is a hypothetical worst-case behavioral scenario, such as "a little-old lady driving in the rain at high speeds on an unfamiliar road after having too much to drink." The point of this concept is that safety can best be ensured by designing for worst-case-scenario conditions.

vehicles and roadways to ensure safety during this failure state.[28] In Nader's conceptualization of the problem, there is no consideration of the possibility that such practices might encourage drivers to adopt behaviors that increase their likelihood of being involved in a crash event. By Nader's reasoning, a design that minimizes the consequences of extreme crash events should logically reduce the consequences of all lesser events as well, and thereby enhance a roadway's safety.

While Nader and Haddon were responsible for developing the theoretical basis for contemporary safety practice, Kenneth Stonex [29] was singularly responsible for defining how these principles would ultimately be incorporated into roadway design practice. One of the key safety problems identified by the AASHO Committee was the large number of fatalities associated with single vehicle run-off-roadway events, which amounted to roughly 30-35 percent of the national totals (Stonex, 1960).[30] To address this issue, the committees heard testimony from Stonex, who was a General Motors employee responsible for designing the "Proving Ground," an experimental "crash-proof" highway that had 100-foot clearances on either side of the travelway (McLean, 2002; Weingroff,

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[28] Also important here is where the failure is presumed to rest – which is on the driver. Since roadways are designed for these hypothetical design conditions, the designer assumes that safety has been adequately addressed. Correspondingly, when crashes do occur, the majority (95%) are attributed to "driver failure," rather than design failure, thus suggesting that the designer did all that should have been done to adress the crash (Carsten, 2002; Hauer, 1999b).

[29] In an acknowledgment of Stonex's influence on current design practice, the Transportation Research Board issues a "Kenneth A. Stonex Award" for professionals who have made a substantive contribution to the area of transportation safety.

[30] It is worth observing that in 2002, there were 15,500 fatal single vehicle run-off-roadway crashes, or 40% of the total fatal crashes for that year – a proportional increase of between 5 and 10 percent.

2003).[31] Based on his experiments at the Proving Ground, as well as the general observation that the Interstate system reported fewer fatalities than other roadway types, Stonex was of the opinion that "what we must do is to operate the 90% or more of our surface streets just as we do our freeways… [converting] the surface highway and street network to freeway and Proving Ground road and roadside conditions" (Quoted in Weingroff, 2003, p. 147).

With respect to single-vehicle crashes, Stonex found that roughly 80 percent errant vehicles came to a stop within 33 feet of leaving the travelway (Stonex and Skeels, 1963). Based on this work, the AASHO committee concluded that eliminating fixed-objects within 30 feet[32] of the travelway would eliminate most fixed object crashes. It is important to observe that these findings were based solely on the observation of 56 run-off-roadway events at the Proving Ground, as well as tire markings along the median of a 25-mile (40-km) section of a highway in Illinois.[33] No comparative examination of the relative crash performance of roadways with clear roadsides, and those without, were used in the adoption of this standard, nor was its applicability to other roadway classes or uses considered. Nevertheless, the 30-foot clear zone standard (with adjustments for sideslope) was subsequently incorporated into AASHO's 1967 publication, *Highway Design and Operational Practices Related to Highway Safety*, as well as the revised and

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[31] An approach Nader openly criticized, not for its ineffectiveness, but for its attempt to shift the costs of safe design from motor vehicle manufacturers to the public, since infrastructure improvement costs are borne entirely by the public (Nader, 1965).

[32] Interestingly, Stonex's 33 foot finding was rounded down to 30 feet, rather than up to 35, but this reduced width was nevertheless assumed to reduce 80% of run-off-roadway crashes.

[33] This study by Hutchinson and Kennedy (1967), while examining medians rather than roadsides, nevertheless serves as the basis for the roadside encroachment estimates used in the current ROADSIDE program. McLean (2002) re-analyzed these findings and found that they grossly over-estimate run-off-roadway frequencies.

expanded 1974 edition, and remains in the subsequent editions of the *Roadside Design Guide* (AASHTO, 1974; 2002; McLean, 2001; Weingroff, 2003).

The Passive Safety Revolution

Prior to the 1960s, safety was primarily addressed through attempts to educate drivers and enforce safe driving behavior. There is only limited discussion of the relationship between design and safety in the early design guidance. With respect to the selection of a roadway's design speed, the controlling element in its design, the first edition of the *Green Book* states that the "design speed selected for a highway is determined by consideration of the topography of the area traversed, economic justification based on traffic volume, cost of right-of-way and other factors, traffic characteristics, and other pertinent factors such as aesthetic considerations" (AASHO, 1940, p. 2). Safety is not included among the design criteria. Instead, safety is addressed by first determining the intended operating speed for the roadway, and then designing the roadway to ensure "safe and uniform vehicle operation" (p. 2).

Sorenson (1984) examined the pre-1945 design guidance, and found that the discussion of safety differed markedly from contemporary practice. Indeed, the early perspective on safe roadway design was that safety could best be ensured by designing roadways to *prevent*, rather than forgive, unsafe driving behavior. Consider Harger and Bonney's (1927) recommendation on how to address safety at sharp curves: "it is important that the driver is prepared to handle this difficult maneuver. This can be accomplished by gradually reducing sight distances and increasing curvature on segments of the roadway leading up to the dangerous location" (p. 114). The recommendation here is to design a roadway to increase the driver's preparedness for the oncoming curve through strategies aimed at both reducing approach speeds (shifts in horizontal alignment) as well as the subtle restriction of sight distances – both practices that current designers would regard as detrimental to a roadway's safety performance. Yet in the early literature, there is no embedded assumption that drivers will necessarily leave the travelway, nor an assertion that higher design speeds and "forgiving" environments equate to enhanced safety performance. Indeed, the early edition of the Green Book cautions the designer that the provision of "wider lanes and shoulders may invite higher speeds" (1940, p. 2).

The passive safety revolution fundamentally altered this view on roadway design, resulting in a dramatic change in design practice. The passive approach to transportation safety begins from the perspective that drivers will err, combined with the observation that there are fewer crashes on Interstates than on other roadways. Collectively, this resulted in the theoretical assertion that "highways built with high design standards put the traveler in an environment which is fundamentally safer because it is more likely to compensate for the driving errors he *will* eventually make" [*emphasis added*] (AASHTO, 1974, p. 15).

This perspective is still evident in the most recent edition of AASHTO's Green Book, which remarks that "it is not generally possible for a design or an operational procedure to reduce errors caused by innate driver deficiencies. However, designs should be as forgiving as practical to lessen the consequences of such failures." (2001, p. 54). To ensure that roadways are safe for these deficient drivers, the Green Book states that

> the objective in design of any engineered facility used by the public is to satisfy the public's demand for service in a safe and economical manner. The [highway] facility should, therefore, accommodate nearly all demands with reasonable adequacy and also should not fail under severe or extreme traffic demands… every effort should be made to use as high a design speed as practical to attain a desired degree of safety" (p. 66-67).

Since a roadway's design speed is the controlling element in its design, embedded in the Green Book is the idea that by designing for the "failure state," which is defined as high-speed, "extreme" driving behavior, the designer has ensured that a roadway is appropriately safe. Thus, designs that accommodate high-speed vehicle operations are viewed as being safety enhancements, allowing most transportation departments to list the provision of a "safe and efficient" transportation system as a single agency goal.

Robert Noland (2001) recently sought to understand whether conventional design practices enhance safety once one controls for intervening factors such as increased seat belt use and changes in demographic characteristics of the population. Using a negative binomial model, Noland found that "changes in highway infrastructure that have occurred between 1984 and 1997 have not reduced traffic fatalities and injuries, and have even had the effect of increasing total fatalities and injuries" (Noland, 2001, p, 23). Noland and Oh (2004) repeated this analysis, reporting that "this paper has analyzed HSIS data for the State of Illinois to evaluate the hypothesis that improved road infrastructure geometric design is beneficial to safety. Our results tend to reject this hypothesis in contrast with standard assumptions in the traffic safety literature" (2004, p. 532).

Robert Noland is not the first to question contemporary safety practice. Ezra Hauer, perhaps the leading authority on the subject of highway design and safety, has recently written that:

> Our claim to professionalism in road safety is weak because our substantive professional knowledge in this field is underdeveloped. We have painstakingly developed standards and warrants to guide nominal safety considerations. Our knowledge of substantive safety consequences is lagging behind" (p. 8, 1999b).

The empirical evidence on roadside safety specifically, and contemporary safety practice more generally, leads one to ask several important questions: do "forgiving" design practices necessarily equate to enhanced safety? Further, is it true that forgiving design practices are appropriate in all design contexts? Might there be a better means of enhancing safety that also accounts for the aesthetic and contextual needs of urban environments?

CHAPTER 5

TESTING PASSIVE SAFETY

Scientific honesty consists in specifying, in advance, an experiment such that, if the result contradicts the theory, the theory has to be given up.

- Irme Lakatos, 1974, p. 112

Chapter 4 examined the research on roadside safety, finding little empirical evidence to support the claim that clear zones enhance safety in urban environments. Instead, contemporary safety practice is based on the theoretical assertion that safety can be best ensured through the use of “fail-safe” designs. This approach, termed “passive safety,” begins by assuming that drivers will err in the course of their travel, and that the best means for addressing driver errors is to ensure that roadways and roadside environments are designed to minimize the consequences of high-speed, “extreme” driving behavior.

The use of these extreme behaviors as the base design condition seems inherently logical from an engineering perspective. Structures such as bridges, for example, are designed to bear a specific minimum structural load. Identifying a “fail state” threshold value provides designers with a design value that can be used ensure a given level of safety for a structure. Likewise, to ensure that a roadway’s design is adequately safe, an engineering perspective encourages the identification of the “failure” condition (for the purposes of this study, a high-speed, run-off-roadway event), and to design a roadway to ensure that the roadway is safe in such an event. Thus, just as a bridge that can bear a 60-ton load can also bear a 30-ton load, the passive safety perspective assumes that a roadway designed to be safe for 60 mph operating conditions is also safe for 30 mph operating conditions. Collectively, this sort of engineering reasoning has resulted in a professional tendency to adopt above-minimum design values as a strategy for enhancing a roadway’s safety (Ewing and King, 2002).

While the engineering logic behind this approach has a high degree of face validity, it is not at all clear that human performance has the same characteristics as the performance of a structure. A key assumption embedded in the passive approach is that by designing for high-speed run-off-roadway events an adequate level of safety has been provided. Indeed, the *Roadside Design Guide* states that “regardless of the reason for a vehicle leaving the roadway, a roadside environment free of fixed objects with stable, flattened slopes enhances the opportunity for reducing crash severity” (AASHTO, 2002a, p. 1-2).

Embedded in this approach is another assumption, which is that “forgiving” designs do not encourage behaviors that increase a driver’s probability of being involved in a run-off-roadway event. Driver error is instead treated as a randomly occurring event that is beyond the scope of control of the designer. But it overlooks several important questions: first, how do “average” drivers adapt their behavior to the use of forgiving design values? What about specific at-risk subpopulations? Is it possible that by widening lanes and shoulders and eliminating roadside objects, designers are encouraging "non-design drivers" to engage in behaviors that result in crashes and injuries?

If the passive safety assertion that "the wider the clear zone, the safer it will be" (TRB, 2003, p. V-43) is true, then one would expect that increases in fixed-object offsets will result in fewer roadside crashes and injuries, or, in other words, that there should be a negative relationship between a roadway's paved shoulder width and fixed object offset and its crash performance. Further, such practices should also not be offset in increases in other crash types that may be influenced by the design of the roadside environment. This chapter explicitly tests whether this theoretical assertion is applicable to the safety performance of urban arterial roadways.

Methods and Data Sources

This analysis uses crash data for the Florida Department of Transportation [FDOT] District 5 for the 1999-2003 period, combined with line charts of a roadway's geometric design characteristics and field measurements of shoulder widths and fixed-object offsets. These data sources were used for several key reasons. First, a major problem with national data, such as FARS, is that it only provides information on fatal crashes, thus preventing injurious and non-injurious crashes from being considered in the crash totals. A second and even more critical flaw with FARS data is that it provides only limited information on the geometric and environmental characteristics of the site in which a crash occurred, and does not readily permit field investigations of specific crash locations. FARS data cannot be meaningfully used to evaluate the influence of road and roadside features on crashes frequency and severity. FDOT data, by comparison, provides not only information on all crashes – fatal, injurious and property-damage-only, but also route and milepost numbers that allow the crash locations to be specifically identified.

The ability to geo-locate specific crashes using FDOT data also allows this study to overcome a barrier common to most studies of roadside safety, which is that there is no readily-available secondary data source that provides detailed information on the characteristics of the roadside environment, thus preventing the roadside environment from being specifically modeled in analyses of roadside safety (Council and Stewart, 1996; Hadi et. al., 1995; Lee and Mannering, 1999; Miaou, 1997). This limitation is readily evident in the roadside safety literature; typically, shoulder widths are used in lieu of the actual offset distances between the edge of the travelway and the location of the nearest fixed object. An accurate analysis of the safety effects of clear zone practices requires not just information on shoulder widths, but also on fixed-object offsets. Thus, while FDOT does not provide information on the roadside environment, the ability to geo-locate crashes allows this data to be collected through field observations and measurements.

FDOT District 5 was selected for both theoretical and logistical reasons. From a theoretical perspective, District 5 was valuable because it contained a large number of small metropolitan areas. Small metropolitan areas are desirable for analysis because they provide a high-degree of design variation along relative short roadway lengths, thus helping to control for demographic and weather-related factors that may influence a roadway’s crash performance, since shorter roadways will include a more homogeneous driver population and similar weather events.

Further, since this study is interested in the safety performance of livable street treatments, roadways that included such treatments were specifically targeted for this analysis. Prior to conducting field investigations, it was impossible to determine whether a specific roadway incorporated a livable street treatment. Nevertheless, since pre-automobile developments were necessarily designed around pedestrian, rather than motor vehicle, travel (Muller, 1995), the presence of a historic district along the length of a roadway is a useful indicator of a possible livable street treatment, prior to confirmatory field observations. FDOT District 5 includes a high concentration national-register-designated or national-register eligible historic districts, including DeLand, Kissimmee, Leesburg, Maitland, Mt. Dora, Ocala, Sanford, and St. Cloud, among others.

Beyond the theoretical usefulness of such an area, it also helped resolve a major logistical problem of this research, which was the need to manually collect field data on the road and roadside environment. Because of the high concentration of potentially relevant roadways, an examination of District 5 helped minimize the total travel needed to collect data for multiple sites. Further, because these roadways traveled across small metropolitan areas, I was able to collect field observations for a broad spectrum of urban environments while minimizing the total data collection effort

An additional logistical advantage was that the Florida Department of Transportation, in response to concerns about the safety of one of the roadways in this district (Colonial Drive in Orlando),[34] had already aggregated five years of crash data into a single crash database. A key concern in any study of crash performance is the effect of regression-to-the-mean on study outcomes. Crash performance naturally varies over time, and the safety performance for any single year may fail to accurately capture the actual safety trends of a specific roadway. To address this issue, most safety studies recommend the use of a minimum of 3-years worth of crash data. The Florida DOT data, which provides a 5-year crash history for these roadways, is thus able to overcome potentially-biased results associated with regression-to-the-mean.

Modeling Crash Frequency and Severity

As detailed in the literature in Chapter 4, conventional studies on roadside safety analyze the relationship between geometric design and crash performance using multivariate statistical applications. Nevertheless, much of the existing literature is focused on rural-roadways generally, and two-lane rural highways specifically. Further, where urban areas are considered, they are typically aggregated together with data for rural roadways, preventing a thorough consideration of how, if at all, their safety performance may differ. To date, only Lee and Mannering (1999) have modeled urban roadside safety using an appropriate multivariate statistical technique, and although

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[34] I discuss the safety performance of this roadway in a recently published article (Dumbaugh, 2005).

finding important differences between roadside crash frequency in urban and rural environments, have not examined the nature of these differences. Thus, the first phase of this analysis begins by modeling the crash performance of urban roadways to determine if these authors' findings were anomalous, or if they might perhaps be part of a broader safety pattern.

Design and Methodology

A sizable portion of current safety literature is focused on the development of appropriate crash modeling techniques. To date, much of this literature is focused on the development of an appropriate alternative to linear regression models. Many early safety studies sought to apply linear regression models of crash rates to determine the crash reduction potential of various geometric elements, an approach that has been increasingly criticized as inappropriate. As Jovanis and Chang (1986) show, the variance of crash frequency increases with vehicle kilometers traveled, thus violating the linear regression model's assumption of homoskedasticity.

Researchers have increasingly advocated techniques that are more appropriate for count data. Miaou and Lum (1993) compared Poisson regressions with conventional applications of linear regression models, and found that Poisson regression models were more appropriate for analyzing crash data. Yet a major shortcoming is that Poisson models assume that the mean and the variance are equal. In practice, crash data are overdispersed, with the variance exceeding the mean. To address this problem, a substantial portion of the recent literature has focused on the development of models that address overdispersion, with researchers consistently recommending the use of negative binomial models under these conditions (Karlaftis and Tarko, 1998, Lee and Mannering, 1999; 2002; Milton and Mannering, 1998; Noland, 2001; 2003; Noland and Oh, 2004). The negative binomial is similar to the Poisson, except that it relaxes the assumption that the mean and variance are equal by incorporating a Gamma-based error term into the model (Milton and Mannering, 1998; Shankar et. al., 1995).[35] Correspondingly, this study employs a negative binomial model to analyze crash performance.

Candidate Site Selection

While the presence of a national-register designated or eligible historic district along a roadway's length was useful for determining whether it was worth further investigation, this criteria, by itself, did not lead to a roadway's inclusion in this study (see Table 5-1 for a list of roadways that were investigated). Instead, the criterion for inclusion was whether the roadway incorporated a livable streetscape treatment along its length, with a livable streetscape treatment being defined as one that included both dense roadside development adjacent to the travelway, as well as aesthetic buffer features, such as landscaping or on-street parking, separating the pedestrian realm from adjacent motor vehicle traffic. In most cases, livable street treatments were not included on state roadways, either because the DOT constructed bypass routes around the downtown

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[35] The application of these models to safety analyses is well covered in the literature, both in textbooks, such as Cameron and Trivedi (1998) as well as in the recent safety literature (Milton and Mannering, 1998, Lee and Mannering 2002; Noland, 2003).

business district (see Figure 5-1),[36] or because ownership of the livable street section was ultimately transferred to the local jurisdiction (see Figure 5-2).

Of the seventeen roadways visited for this study, only five met the livable street criteria – State Routes 15 and 44 in Deland, State Route 40 in Ocala, State Route 19 in Eustis, and State Route 526 (Robinson) in Orlando. SR 19 and 526 were ultimately excluded, however, because of their individual characteristics. SR 19 was excluded because, unlike the other roadways considered in this study, it splits into two one-way pairs as it approaches downtown Eustis, only half of which (Bay Street) contains a livable streetscape application. The operational characteristics of one-way streets are markedly different than conventional two-way applications, which can have an effect on a roadway's crash performance. To prevent these differences from undermining the accuracy of the model results, SR 19 was excluded from further consideration in this study.

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[36] While the cynical observer might argue that the decision to bypass these downtown districts is the sole reason for their current existence, the reality is that the Florida DOT is to be commended for not attempting to place a state highway through these excellent examples of Florida's historic past. Indeed, St Cloud (depicted on the left in Figure 5-1) is one of the few physical remnants of Florida's "Cracker Cowboy" past.

Table 5-1: Sites Visited During Field Investgations

City	State Route	Local Name	Livable Urban Section?	Comment
Apopka				
	SR 500	Orange Blossom Trail	No	Suburban arterial
DeLand				
	SR 44	New York Ave	Yes	Candidate site
	SR 15	Woodland Blvd	Yes	Candidate site
Eustis				
	SR 19	Bay Street	Yes	One-way street
	SR 44	Orange Ave	No	Suburban arterial
Kissimmee				
	SR 600	Orange Blossom Trail	Yes	Livable section de-designated to local government – no crash data for the segment
Kissimmee-St. Cloud				
	SR 500	Vine St/Space Coast Pkway/13th St	No	Suburban/rural arterial
Maitland				
	SR 600	N. Mills Rd/N. Orange Av.	No	Suburban arterial
Mt. Dora				
	SR 46/500	US 441	No	Downtown bypass route
Ocala				
	SR 40	Silver Springs Boulevard	Yes	Candidate site
	SR 500	Pine Avenue	No	Suburban arterial
Orlando				
	SR 526	Robinson	Yes	Little design variation
	SR 600	Mills	No	Suburban arterial with some urban characteristics
	SR 500	Orange Blossom Trail	No	Suburban arterial with aesthetic treatment
	SR 50	Colonial Drive	No	Suburban arterial with some urban characteristics
Sanford				
	SR 600	N. Orange Av	No	Suburban arterial
	SR 46	1st Street	Yes	Off state system

Figure 5-1: Downtown St. Cloud and Mt. Dora – Bypassed by the DOT

Figure 5-2: Downtown Sanford and Kissimmee – Off the State System

Figure 5-3: One-Way in Eustis

SR 526 (Robinson Street), on the other hand, is bi-directional, traveling east and west through downtown Orlando to connect two major north-south arterials, Orange Blossom Trail (SR 500) with Mills Ave (SR 600). While this roadway contains design characteristics of value for assessing the safety effect of placing roadside object adjacent to the travelway (see Figure 5-4), it is only 2 miles in length and contains little variation in shoulder width (there is no shoulder) or fixed object setback (5 feet or less).[37] Correspondingly, it was excluded from this analysis.

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[37] Despite the limited offset distance depicted in Figure 5-4, not a single tree-related crash was reported for this roadway during the 5-year analysis period.

Figure 5-4: Robinson Street in Downtown Orlando

Candidate Streets

Ultimately, three streets were included in this phase of the analysis effort, State Routes 15 and 44 in DeLand, and State Route 40 in Ocala. Each of these roadways connects the historic downtown core of a small urban area with suburban and rural environments, and each contains a high degree of design variation along its length, ranging from pedestrian-oriented livable street treatments in the downtown core, to suburban and rural designs as these roadways extend out from the city center (see Figure 5-5). Both DeLand and Ocala contain historic districts listed on the National Register of Historic Places, with all three of these roadways providing arterial access into and through these historic districts.

Figure 5-5: Design Variation in the Urbanized Areas of SR 15 (Woodland Blvd) and SR 40 (Silver Springs Blvd)

Variable Definitions: Dependent Variables and Hypothesized Relationships

There are several dependent variables of interest to this phase of the analysis. The first is a measurement of the frequency and severity of fixed-object crashes occurring along each of the three candidate roadways. Passive safety practice assumes that by widening the distance between the outside of the vehicle travelway and the nearest roadside fixed object will enhance safety by allowing errant vehicles to come to a stop before encountering a fixed object. If so, than roadways with wider clear zones should report fewer total fixed-object crashes and fewer injurious fixed-object crashes than those without.

For clear zones to be truly shown to enhance safety, however, it is not enough that they simply report a reduction in fixed-object crashes and injuries; they must also be shown not to be associated with increases in crash types that may be influenced by the design of the roadside. Thus, total midblock crashes are also analyzed. A midblock crash is defined as any crash that was not located at, or influenced by, an intersection or driveway. The midblock crash variable used in the following analysis consequently includes not only fixed-object related crashes, but also multiple-vehicle and vehicle-pedestrian crashes as well. If it is true that passive safety practices enhance safety, then the reduction in fixed-object crashes should also result in a net decrease in midblock crashes, since fixed-object crashes will be reduced from the midblock totals without increasing the probability of other crash types.

These two crash types (fixed-object and midblock) must further be divided into two categories: total crashes and injurious crashes. Total crashes are simply a measure of total crashes, without regard to a crash's actual severity. Yet a crash that results only in property damage must be regarded as less important than a crash event that leads to death or injury. Thus, in addition to total crashes, injurious crashes, defined as a crash involving at least one injury or fatality, are also considered. Table 5-2, below, details each of the dependent variables, as well as the expected relationship they will have with an increase in paved shoulder widths and fixed-object offsets, assuming passive safety assumptions are true.

Table 5-2: Crash Types and Currently Hypothesized Relationships With Increases in Paved Shoulder and Clear Zone Widths

	Total	**Injurious**
Fixed Object	Decrease	Decrease
Midblock	Decrease	Decrease

Independent and Control Variables

The independent variables of interest to this study are shoulder widths and fixed-object offsets, both of which were obtained through field measurements of the actual roadside environment in these locations. Yet the effects of the roadside environment cannot be considered independently of other cross-sectional effects, such as the number of roadway lanes, as well as lane and median widths. None of the roadways contain any notable curvature, thereby eliminating the need to include this variable in the model. As recommended by Hauer (1997) average daily traffic is included in the model as a control variable to account for the effects of traffic volume on safety performance. Posted speed limits may also have an influence on safety, and are thus included in the models as a control variable as well. Further, as suggested by Ossenbruggen et. al (2001) and Naderi (2003), the overall configuration of these features in urban environments may play a key role in determining their safety effects. Correspondingly, this model also includes a dummy variable to determine whether the roadway segment was designed as a pedestrian-oriented livable street treatment.

Operationalizing the Unit of Analysis

While the unit of analysis for this study is crash frequency and severity, it is necessary to convert roadways into individual units of observation that can be specifically analyzed (Babbie, 2001). Since geometric configurations vary along the length of a roadway, two specific approaches are available. The first is to identify evaluation segments based on the consistency of their geometric characteristics. The problem that emerges in such an approach, however, is that the roadway segments will be of varying lengths; since the length of a roadway segment is itself predictive of the number of crashes that may occur, such a unit of observation is undesirable.

The alternative is to use a fixed-length section as the unit of observation. The major disadvantage of the use of a fixed-length sections is that the geometric design characteristics may vary within a given roadway section. Yet previous research on the subject has found that the advantages of using fixed-length sections outweigh the problems associated with basing segment lengths solely on a roadway’s geometric characteristics (Lee and Mannering, 2002; Shankar et. al, 1995). Thus, fixed-length sections are used for this analysis.

A second question of interest is the determination of the appropriate length of these segments. To date, there is no generally accepted method for determining the appropriate segment length. Shankar et. al. (1995) use 6 km [3.75 mile] sections, while Lee and Mannering opt for 805m (0.5 mile) sections. In the former case, section length was determined by its divisibility into the total roadway length; in the latter, it was chosen because the selected length produced the greatest number of significant variables. As neither approach has any meaningful theoretical basis, 0.25-mile (402 km) segment lengths are used in this analysis both because this unit corresponds well with pedestrian walking distances (and, interestingly enough, the lengths of the livable street sections, which are perfectly divisible into 0.25), as well because it helps minimize the number of roadway segments with internal design variation. Thus, the unit of observation is the number of total and injurious midblock and fixed-object crashes occurring along quarter-mile segments of State Routes 15, 44 and 40 in the urban areas of DeLand and Ocala.

A third issue relates to how geometric design features are to be aggregated to the individual segment. Neither of these earlier studies detailed how the authors aggregated their data when there were variations in the geometric design characteristics of the roadway. Two alternatives are available; the first is to average the design variations together across the segment, while the second is to attribute the design characteristics of the majority of the segment to the segment as a whole. This study opted for the latter approach to ensure that the segment was as technically-accurate as possible. In either event, the short lengths of these segments (0.25 miles), produced relatively few instances where there where variations within an individual segment.

A final issue, and one which is not addressed in the literature, is how to code the widths of lanes, shoulders and object offsets when they vary along a roadway segment. Nevertheless this proved not to be an issue with these roadways since most roadways used standard cross-sections, with both sides of the roadway using the same number of lanes, lane and median widths, shoulder widths, and object offsets. In the handful of cases where this proved not to be the case, the more conservative value was used.

Model Results

Before proceeding to the model results, it is important to first clarify the statistics of interest. While most studies using negative binomial models simply report estimated coefficients and z or t[38] statistics for variables that were significant at the 95% confidence level, this approach fails to take full advantage of the information actually contained in the data. Typical null hypothesis tests for statistical significance assume that if a variable cannot be shown to be statistically significant at a 0.05 level that one should then assume that the there is no relationship between the variables. Yet, as Hauer (2004) has shown,

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[38] While t is commonly reported (see, e.g., Lee and Mannering, 2002), z is the correct statistic when using 100% counts of crashes. Thus, z, rather than t, is the statistic reported here. Nevertheless, the t distribution approximates z when n=100.

this practice can lead to the adoption of design strategies that result in increased crashes and injuries because it treats results that are not significant at the 95% confidence level as having no effect on safety.

This problem can be readily illustrated using Noland and Oh's (2004) finding that fatalities increased with an increase in shoulder widths, but then remarking that this finding was "not at a statistically-significant level." While this assertion is technically correct, it leads many readers to thereby infer that since the authors are not 95% confident in the results, that they should assume that there is no relationship between fatalities and shoulder widths. In fact, the t-statistic for this variable was 1.4 (n=404), which corresponds to a one-tailed p-value of 0.08. Stating this statistic another way, one can be 92% confident that wider shoulders will result in an increase in fatalities. Clearly, it is inaccurate to assume that a 92% level of confidence equates to no effect.

Hauer (2004) has found such interpretations to be so endemic to safety analyses that he advocates abandoning null hypothesis testing in favor of crash averages and confidence intervals. While this may be extreme, it is a well-founded point. Consequently, this study reports not only coefficients and significance levels for variables that enter significantly into the models, but for all modeled variables as well.[39] Further, it also reports 95th percentile confidence intervals, since such statistics are much more

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[39] The current convention of only reporting variables that enter significantly at the 95% level is further indicative of the atheoretical nature of much of contemporary safety practice. Appropriately used, statistical models should be used to test an existing theory (the choice of independent variables is necessarily a theory choice) rather than attempting to simply build "statistically-significant" models.

useful for gauging the actual safety impacts of a specific design treatment than are simple z statistics.

Before proceeding to the model results, one further caveat is warranted. It is important to note that these models are theoretically driven. The objective here is not to develop a “best fit” model, but to instead determine whether the passive safety assumptions that drive contemporary safety practice are empirically validated. Thus, this analysis attempts to determine whether, when using appropriate data and analysis methods, current passive safety practices can be shown to enhance safety in urban environments. In other words, if it is true that wider clear zones necessarily enhance safety, then fixed object offsets and shoulders widths should result in a reduction in crash frequency and severity for both fixed-object and midblock crashes.

Geometric Design and Roadside Safety

The following analysis models roadside safety as a function of a roadway’s geometric design. Roadside safety is here defined as a crash involving a roadside feature, including ditches, curbs, culverts, utility poles, and trees. The full geometric characteristics of a roadway are considered, including the number of lanes, their widths, as well as characteristics of the roadside environment, including the width of the paved portion of the shoulder and the distance of a fixed-object from the outside edge of the pavement (measured from either the outside edge of the travel lane or the outside edge of the paved shoulder, where a paved shoulder is provided). Since traffic volumes, the number of lanes, lane and median widths, as well as posted speed limits may all have an effect on a roadway's safety performance, these variables are included here as control variables. Finally, a dummy variable indicating whether the segment incorporates a pedestrian-friendly livable street treatment is also included.

Table 5-3 presents the negative binomial model of total roadside crashes. The only passive safety variable that was related to declines in crash frequency at the 95% confidence level was the median width of a roadway. Moving beyond significance levels, however, and examining the signs of the coefficients and their confidence intervals, ADT entered with the expected sign, suggesting that roadside crashes increase with traffic volumes. The number of lanes was associated with an increase in roadside crashes, while lane widths and fixed-object offsets were both negatively associated with roadside crashes.

Table 5-3: A Negative Binomial Model of Total Roadside Crashes

	Coefficient	**Z Statistic**	**95% Confidence Interval**	
ADT	0.0000267	1.05	-0.000023	0.0000764
Speed Limit	-0.019414	-0.62	-0.0811245	0.0422957
# Lanes	0.0281937	0.13	-0.4062023	0.4625897
Lane Width	-0.099938	-0.62	-0.4157851	0.2159087
Median Width	-0.027056	-1.79	-0.0567412	0.0026294
Paved Shoulder Width	0.0546558	0.85	-0.0716248	0.1809365
Object Offset	-0.038137	-1.51	-0.0874755	0.0112013
Livable	-1.532556	-2.33	-2.823685	-0.2414263

N = 109
Log Likelihood = -144

Of the roadside variables, shoulder widths entered positively at the 80% confidence level, a finding that contradicts conventional roadside design guidance, but which is consistent with earlier research. More interesting, however, were the results for the fixed-object offset and livable street variables. Here, fixed-object offsets entered negatively with a z statistic of -1.51, which corresponds to the 93% confidence level, indicating that safety is generally enhanced by widening the unpaved fixed-object offset along these roadways. While such a finding is supported by conventional design guidance, the livable street variable also entered significantly, and at the 0.009 level of confidence, which indicates that, in addition to being negative, one can be 99% certain that this finding is not the result of random chance. In other words, one can be highly confident that the presence of a livable street treatment will reduce the likelihood of a roadside crash.

From a passive safety perspective, livable street designs, which incorporate roadside objects adjacent to the travelway to buffer the pedestrian from oncoming traffic, should be associated with roadside crash *increases*, not decreases. That this variable should emerge with a *negative* coefficient, and at a statistically-significant level, suggests that there is more at work in the design of safe roadside than simply assuring that errant vehicles can safety recover before encountering a hazardous fixed object.

While this model explains roadside crash frequency, what about roadside crash severity? As shown in Table 5-4, below, the model for roadside crash severity behaves similarly to that of roadside crash frequency, although with two notable exceptions. First, the fact that no injurious roadside injuries occurred on the livable street sections (thus providing no variation that could be modeled) resulted in an over-inflated beta coefficient (-15 roadside injury crashes), and thus a reduced level of significance (z = 0.02). Adjusting for this lack of variation by adding a single injurious crash into one of the livable street cases produces a more meaningful beta coefficient of -2, and a z statistic of -1.75. The significance of fixed-object offsets increases to -1.65, which is statistically-significant at the one-tailed level, but less so than the adjusted livable street variable.

Table 5-4: A Negative Binomial Model of Injurious Roadside Crashes

	Coefficient	**Z Statistic**	**95% Confidence Interval**	
ADT	0.0000473	1.42	-0.0000181	0.0001127
Speed Limit	0.0069163	0.15	-0.0824729	0.0963055
# Lanes	-0.1565274	-0.53	-0.7346002	0.4215455
Lane Width	-0.0976583	-0.41	-0.5621938	0.3668772
Median Width	-0.0268853	-1.32	-0.0668325	0.0130619
Paved Shoulder Width	0.0807912	0.92	-0.0917357	0.253318
Object Offset	-0.0537517	-1.65	-0.1176546	0.0101512
Livable	-2.020123	-1.75	-4.284908	0.2446612

N = 109
Log Likelihood = -107

Considered holistically, there is a seeming paradox indicated here, with roadside safety being enhanced by *both* widening object offsets, as well as by reducing them through the use of livable streetscape treatments. Again, it would appear that factors other than a roadway's fixed-object offset may be involved in explaining injurious roadside crashes.

Considering Net Safety Performance: An Analysis of Midblock Crashes

For passive safety assumptions to be empirically validated, it must be shown that they not only reduce roadside-related crashes, but also that they do lead to an increase in other related crashes. In other words, these practices should result in a net *decrease* in midblock crashes because they both reduce run-off-roadway events, while having little or no effect on the frequency and severity of other related crashes. As currently assumed, the “second line of defense” afforded by the provision of clear zones should reduce the frequency and severity of roadside-related crashes, while having no effect on multi-vehicle or vehicle-pedestrian crashes. Thus, one would expect these practices to result in a net decrease in midblock crashes, defined here as all crashes not located in, or associated with, a driveway or intersection. Excluding the performance of intersections, which can be affected by such features as traffic control devices and traffic volumes on intersecting streets, wider clear zones should equate to enhanced midblock safety performance.

As shown in Table 5-5, the passive safety assumptions do not hold. While wider lanes are associated with increased midblock safety performance, neither shoulder widths nor fixed-object offsets were shown to reduce crashes. Both variables entered with *positive* coefficients, suggesting that, on average, these features actually *increase* the likelihood of a midblock crash. Conversely, the livable streets variable again entered with a negative coefficient, and with a z statistic of -1.66. Of the control variables, ADT entered at a statistically-significant level, as did lane and median widths, with both of these variables associated with statistically-significant reductions in midblock crash frequencies.

Table 5-5: A Negative Binomial Total Model of Midblock Crashes

	Coefficient	Z Statistic	95% Confidence Interval	
ADT	0.0000603	4.46	0.0000338	0.0000868
Speed Limit	0.0052272	0.29	-0.0305573	0.0410116
# Lanes	0.1758359	1.33	-0.0827752	0.434447
Lane Width	-0.4355661	-3.39	-0.687361	-0.1837712
Median Width	-0.0226616	-2.68	-0.039212	-0.0061113
Paved Shoulder Width	0.0034967	0.09	-0.0695613	0.0765546
Object Offset	0.0033041	0.24	-0.0239571	0.0305653
Livable	-0.649918	-1.66	-1.416271	0.1164354

N = 109
Log Likelihood = -240

The net effect of conventional roadside safety practices on reducing injurious midblock crashes is likewise ambiguous. While wider lanes were associated with substantial reduction in midblock injury crashes, the same cannot be said for widening shoulders and fixed-object offsets. Based on the model results, one can be 92% confident that providing or widening paved shoulders in urban areas will actually *increase* midblock crash injuries. Further, while fixed-object offsets entered with a negative coefficient, it entered at such a low level of statistical significance as to be insubstantial. The 95th percentile confidence interval shows that the average safety benefit of increasing the offset to roadside fixed objects is approximately zero (see Table 5-6). In other words, unpaved fixed-object offsets had no effect, either positive or negative, on the number of injurious midblock crashes that occurred on these roadways.

Table 5-6: A Negative Binomial Model of Injurious Midblock Crashes

	Coefficient	Z Statistic	95% Confidence Interval	
ADT	0.0000539	3.9	0.0000268	0.000081
Speed Limit	-0.0009352	-0.05	-0.0388115	0.0369412
# Lanes	0.1742244	1.27	-0.0936884	0.4421372
Lane Width	-0.4142634	-2.93	-0.6916505	-0.1368763
Median Width	-0.0237771	-2.65	-0.0413807	-0.0061735
Paved Shoulder Width	0.0545745	1.39	-0.022513	0.1316621
Object Offset	-0.0007401	-0.05	-0.0293898	0.0279096
Livable	-0.5258942	-1.28	-1.329347	0.2775581

N = 109
Log Likelihood = -204

While shoulder and offset widths entered positively into the model, the livable street dummy variable again entered negatively, with a z-statistic of -1.28. Although not significant at the 0.05 level, it does indicate that we can be 90% confident that such treatments will reduce total injurious midblock crashes. Further, it is worth noting that the presence of a livable street treatment, unlike either paved shoulders or fixed-object offsets, was consistently shown to lead to *reductions* in both crash frequency and severity and that, considered on the whole, one would expect such treatments to enhance a roadway's midblock and roadside crash performance.

The same cannot be said of widening shoulders and fixed-object offsets. As shown in Table 5-7, below, widening shoulders had no effect on total midblock crashes, while paved shoulders were found to *increase* injurious roadside and midblock crashes.

Thus, this study, like many previous studies on this subject, finds that the empirical evidence does not support passive safety assumptions.

Table 5-7: Estimated Effect of Various Roadside Design Strategies on Total and Injurious Crash Frequency, and Corresponding Test Statistics.

Measure	**Paved Shoulders**	**Object Offsets**	**Livable Street Treatments**
Total Roadside Crashes	Increase (0.93)	Decrease (-1.45)	Decrease (-2.33)
Injurious Roadside Crashes	Increase (0.94)	Decrease (-1.65)	Decrease (-1.75)
Total Midblock Crashes	No effect (0.09)	Increase (0.24)	Decrease (-1.66)
Injurious Midblock Crashes	Increase (1.39)	No Effect (-0.05)	Decrease (-1.28)

But if the provision of paved shoulders and clear zones is not a guaranteed means of enhancing safety, why might this be the case? While other researchers have arrived at similarly anomalous conclusions, the reasons for such findings have remained largely unexplored. To better develop the theory and practice of roadside design, the next chapter of this dissertation moves beyond aggregate statistical applications to more thoroughly examine the characteristics of roadside crashes in urban environments.

CHAPTER 6

EXPLORING URBAN ROADSIDE SAFETY: A FIELD INVESTIGATION

While Chapter 5 sought to test the theory that governs contemporary roadside safety practice, this chapter seeks to better understand the nature of urban roadside crashes and injuries. Of particular interest is the relative safety performance of livable streetscape applications. These treatments utilize designs that are deliberately “unforgiving” by design. That they should be the only roadside design strategy to consistently report crash reductions suggests that other factors are involved in the design of safe roadsides than simply ensuring that they are forgiving to errant motorists. Thus this chapter moves beyond conventional safety expectations to better understand the nature of roadside crashes in urban environments.

A Mixed-Methods Approach

Despite the volume of literature and guidance on the subject of roadside safety, there have been very few studies that have actually examined the locations where run-off-roadway crashes have occurred. Most contemporary studies on the subject employ secondary data sources to develop models of roadside safety performance, rather than conducting detailed field investigations of crash sites. Thus, in addition to collecting field measurements of a roadway’s geometric design and fixed object offsets, this study also included detailed site visits to locations where fixed-object crashes occurred.

Contemporary passive safety practices assume that roadside fixed-object crashes are random events that can be attributed to the driver error; indeed, up to 95% of all crash events are attributed to driver error, rather than to the roadway's design (Carsten, 2002; Hauer, 1999b). Yet detailed site investigations suggest there is nothing random about the majority of these crashes. Before proceeding to the results of this analysis, however, it is essential to begin by briefly discussing the overall field analysis effort, which employs a combination of quantitative field measurements as well as qualitative observations. The sections below detail the methodological approach that guided the field analysis effort, followed by a detailed discussion of the results and findings.

Field Measurement Methodology

Multivariate statistical models are useful for identifying broad trends in large datasets, but they do not provide detailed qualitative information on the phenomenon being observed. In addition to obtaining field measurements, this study also identified the locations of tree and utility pole crashes along these three roadways. Trees and utility poles were selected for specific analysis because they could be readily identified. Signs and ditches, the two other prevalent crash types along these roadways, were much harder to identify, ditches because it is impossible to determine where, exactly, such a crash occurred (ditches are typically used for roadside drainage, and extend linearly along the length of the travelway), and signs because, in most cases, they occurred near intersections where multiple signs were present, making it difficult to isolate the specific sign involved in the crash. Trees and utility pole crashes, on the other hand, were much easier to identify. In most cases, only one tree or utility pole was located in the vicinity of the milepost number listed in the crash data, making the object involved in the crash readily identifiable.

Crashes for this analysis were further restricted to roadside crashes only. Crashes involving a medians were beyond the scope of this study. Thus, the totals for tree-related crashes were reduced from 25 to 20. As no poles were located in medians for these roadways, pole-related crash totals were not affected. In short, 51 candidate pole and tree crash locations were selected for specific field investigation.

Of these 51 objects, the locations of 40 (78%) were precisely located, although for the remaining eleven, the specific tree or pole involved in the crash could not be precisely identified. The inability to locate a specific crash appears to be the result of one or more of two possible reasons. First, in some locations, individual trees could not be identified due to the density of the tree cover adjacent to the roadside (see Figure 6-1). In other others, the object could not be identified because no tree or pole could be found at the location listed for the milepost. Whether the inconsistency between the data and the site location was a product of data coding errors, or else a subsequent elimination of the object involved in the crash is unknown.

Figure 6-1: A Tree Crash Location that Could Not Be Exactly Identified

Qualitative Observational Data

During the course of examining and measuring these roadways, I was also an active participant on them, driving and walking along many high-crash locations for roughly 10 hours a day for a 14-day period. As such, I both observed and (unwittingly) participated in many driving events that cast an important light on the nature of run-off-roadway crashes. Thus, in addition to simply reporting the results of my field measurements, I also include qualitative field observations and ad-hoc follow-up investigations that help illuminate the nature of run-off-roadway crash events. While these observations and analyses are qualitative in nature, the inadequacy of the current theory on safe roadside design makes them an important data source for this research effort. This approach, termed participant observation, is uncommon in the field of engineering, but is well established in the social sciences, where it is regarded as a superior data source for investigating complex phenomenon. Indeed, as Becker and a Geer (1970) write:

> The most complete form of sociological datum, after all, is the form in which the participant observer gathers it: an observation of some social event, the events which precede and follow it, and explanations of its meaning… before during and after its occurrence. Such a datum gives us more information about the event under study than data gathered by any other sociological method (p. 133).

As detailed by Patton (2002) participant-observation has many advantages over conventional quantitative analyses. First, unlike many quantitative analyses that rely heavily on variables included in pre-existing data sources, field observations place the researcher in direct contact with the environment or social setting where the phenomenon of interest occurs, thereby providing a richer source of data than is contained within a given quantitative data set. Further, because it frees a researcher from prior conceptualizations (as determined by the operationalization of specific data variables), it allows him or her to be discovery-oriented, identifying and examining phenomenon that often escape more rigidly-quantified studies. Indeed, as will be discussed in the sections that follow, my experience provided key insights into the nature of these crashes that have been overlooked in conventional studies relying exclusively on quantitative datasets. Finally, because of the qualitative nature of participant observation, it allows the researcher to use personal insights and reflections to develop a more complex understanding of a phenomenon of interest.

Despite these advantages, a major concern is the role of the researcher in the selection, analysis and interpretation of the qualitative data. To address concerns about researcher bias in the use of personal observation, I have deliberately sought to triangulate my findings, combining quantitative data with qualitative observations and insights that elaborates their meaning. Thus, my personal observations are limited exclusively to those findings suggested by the data, and are conveyed as illustrative cases intended to elaborate on the meanings and implications of the quantitative findings.

Examining Object Offsets

Previous studies on roadside safety that have included field measurements have largely used these findings to estimate threshold values for fixed-object offsets. Turner and Mansfield (1990), for example, found that roughly 80% of all tree-related crashes in the City of Hunstville, Alabama occurred within 20 feet of the right of way, data that were similar to Ziegler’s (1987) findings of tree-related crashes in rural Michigan. A similar analysis was conducted on the data used in this analysis, which likewise found that 80% of roadside crashes involving roadside trees occurred within 20 feet of the travelway (see Figure 6-2). Further, such statistics are even more pronounced when one examines crashes involving utility and light poles – fully 90% occurred within 20 feet of the travelway (see Figure 6-3).

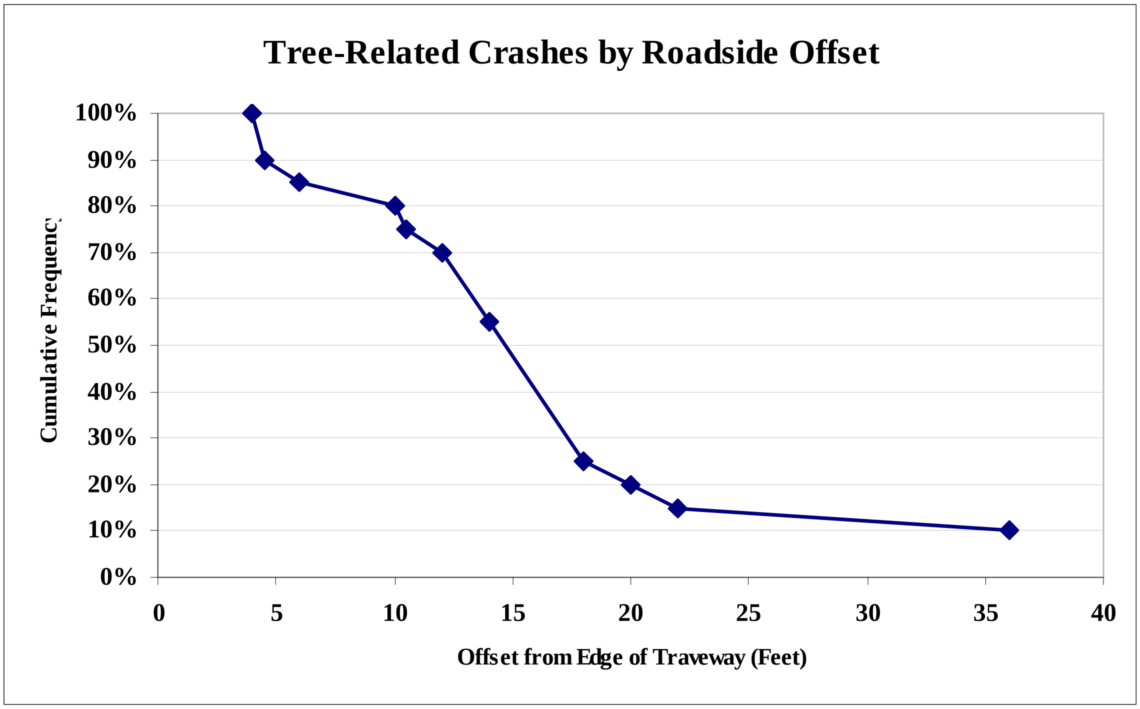

Figure 6-2: Tree-Related Crashes by Roadside Offset

In previous studies, such statistics are used to suggest that roadways with wider fixed-object offsets are less likely to experience a crash event; since only 20% of the crashes occur when offsets are greater than 20 feet, the assumption is that 80% of roadside crashes can be eliminated through the provision of a 20-foot wide clear zone. Yet one should be cautious about such interpretations of these statistics. The fact that a small percentage of crashes occur on roadway segments with offsets greater than 20 feet may simply be a result of the fact that there are few roadway segments that have offsets more than 20 feet. None of these earlier studies has compared their statistics against the distribution of roadways with a given fixed-object offset.

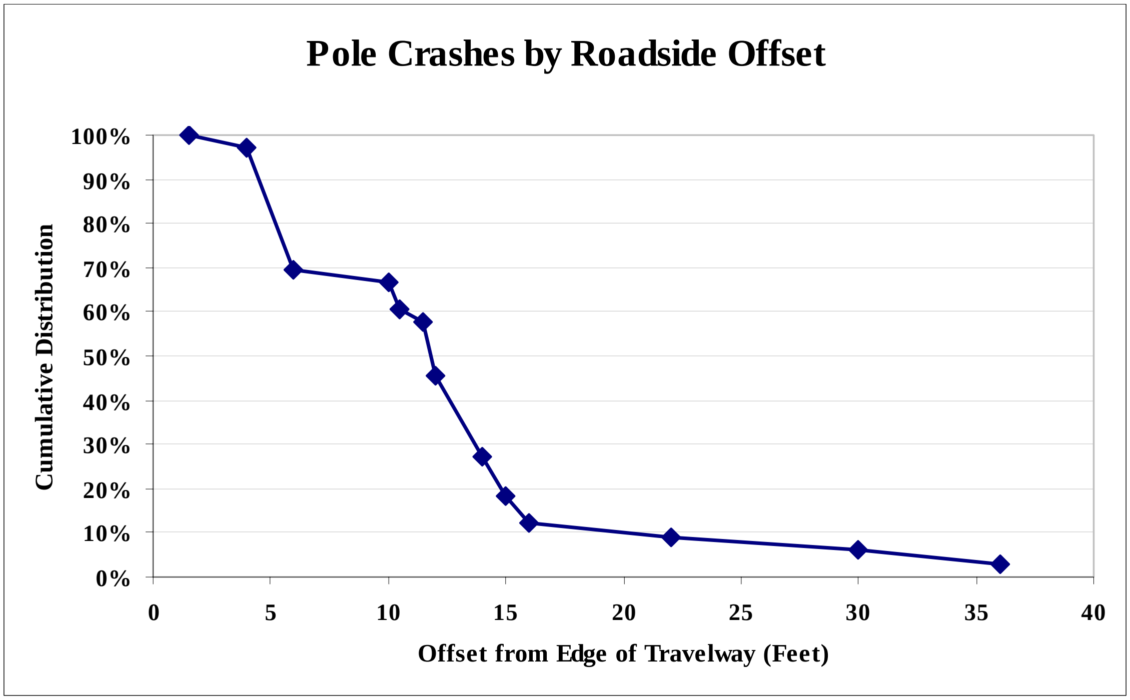

Figure 6-3 Pole Crashes by Roadside Offset

When one compares the cumulative frequency distributions of total roadside crashes to the cumulative frequency distribution for roadside offsets, the slopes are very similar (see Figure 6-4). Roadside crashes along segments with widths up to 15 feet almost perfectly matches the slope of the number of segments with these offset widths, which suggests that the probability of a fixed-object crash is roughly constant for all roadways with offsets up to 15 feet. As clear zones widen from 15 to 30 feet, there appears to be a slight (5-10%) reduction in fixed-object crash frequency.

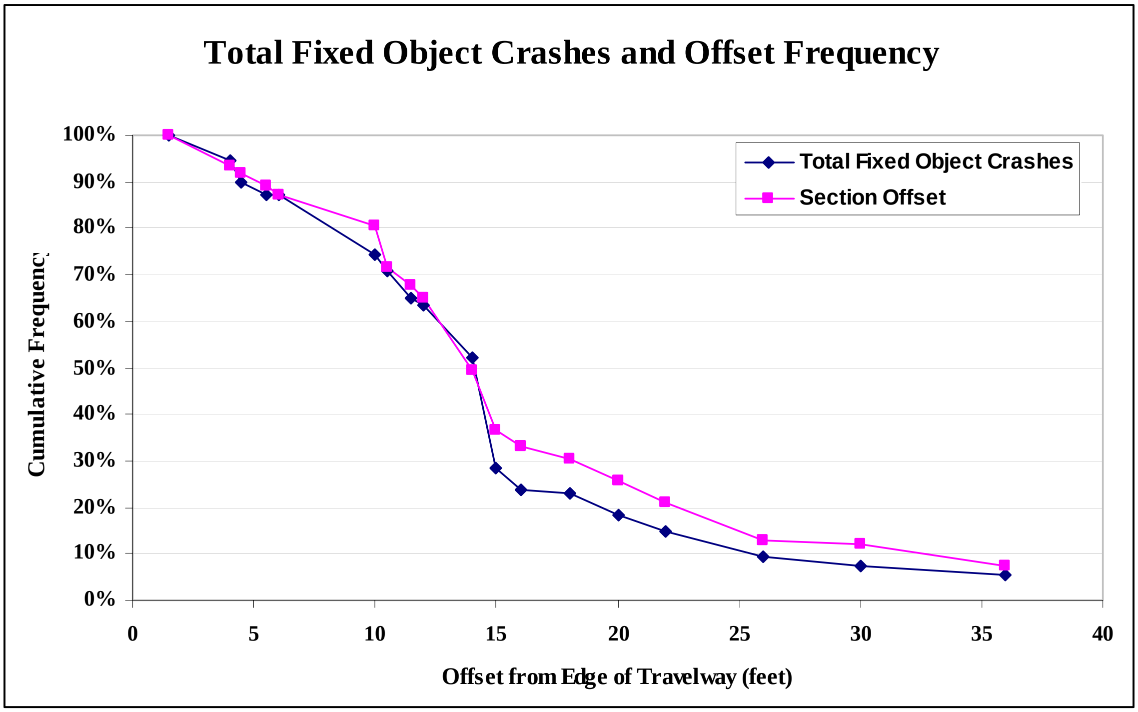

Figure 6-4: Total Fixed Object Crashes and Offset Frequency

Further, when one limits this analysis to only injurious roadside crashes, the slopes become almost identical. As shown in Figure 6-5, below, the slopes of injurious roadside crashes almost exactly matches the distribution of segments with specific fixed-object offset widths. Stating these statistics another way, widening clear zones beyond 15 feet appears to have a slight effect on reducing crash frequency, but almost no effect on the probability of an injurious or fatal crash. Note that these findings are very similar to the findings that were reported in the negative binomial models, detailed above.

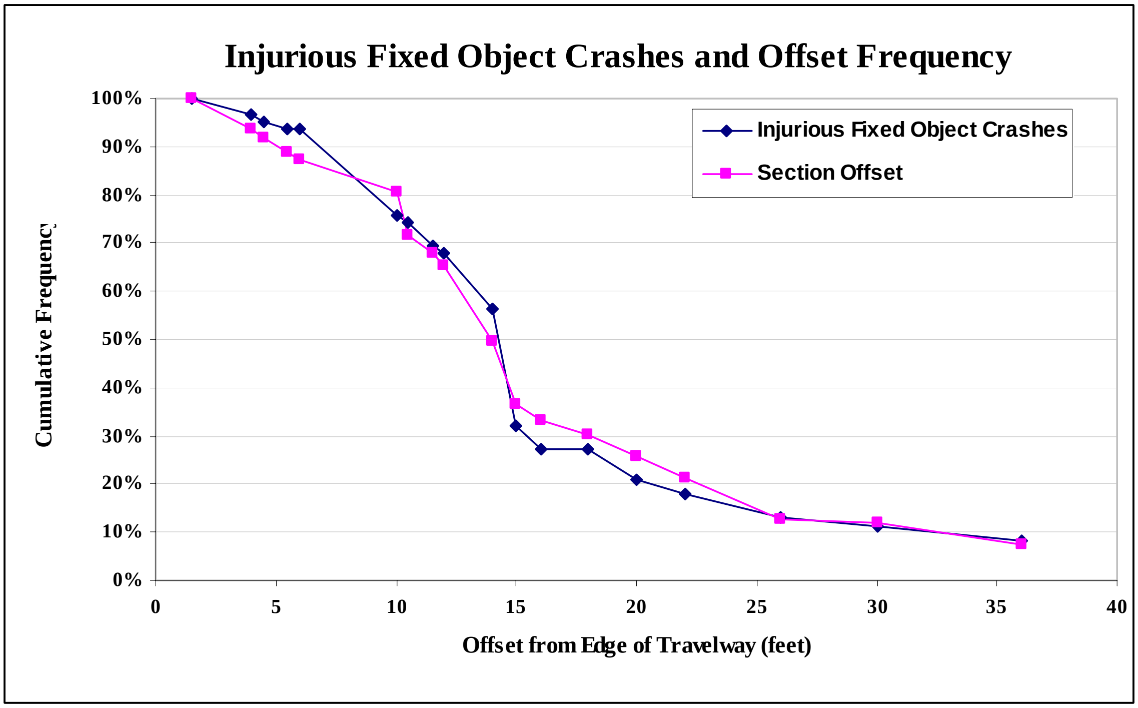

Figure 6-5: Injurious Fixed Object Crashes and Offset Frequency

Considering the Causes of Roadside Crashes

If forgiving roadside design does little to explain the safety performance of urban roadways, how is the designer to design safe roadsides in these environments? A major problem with the conventional literature on roadside safety is that it is oriented towards understanding the degree to which such practices enhance safety, paying little attention to the factors that actually lead to a run-off-roadway event. Indeed, there is nothing in the literature to suggest that these crashes are attributable to anything other than random error on the part of the driver. But is it reasonable to assume that run-off-roadway crashes are purely the result of random and unpreventable errors on the part of the driver, or might there perhaps systematic patterns to these crashes that would allow them to be addressed through enhanced design practices?

One of the most interesting findings of the field analysis effort was that there was indeed a systematic regularity to the locations involving tree and pole crashes. As shown in Table 6-1, 83% of identified trees and utility poles – and 65% of the *total* – were located at driveways or intersections. This is a substantially high proportion, particularly when one considers the fact that intersections and driveways comprise a small percentage of the length of any given roadway.

Table 6-1: Location of Pole and Trees Involved in Fixed-Object Crashes

Location	**Pole**	**Tree**	**Total**	**Pct. (Identified)**	**Pct. (Total)**
Intersection	22	5	27	67.5%	52.9%
Driveway	4	2	6	15.0%	11.8%
Midblock/Not at Intersection	3	4	7	17.5%	13.7%
Not Located	4	7	11		21.6%
Total	33	18	51		100.00%

Figure 6-6, below, shows a highly representative example of an urban run-off-roadway crash. At this location, and indeed at majority of crash locations that I visited, the offending fixed object is located behind a side street or driveway, suggesting that the crash is not so much a product of a random run-off-roadway event, but instead the result of a vehicle attempting to negotiate a turn at high speeds. As is obvious from this figure, a vehicle making a right-turn from the main arterial is headed directly into the utility pole located behind the side street; the only thing preventing a head-on crash with this utility pole is the ability of the driver to successfully negotiate the turn.

Figure 6-6: A Representative Urban Fixed-Object Crash Location

But if such a high proportion of these crashes are associated with driveways and intersections, a key question is this: why have researchers not identified this trend earlier? My suspicion was that part of the reason might be attributable to the nature of police accident reports, which are used to develop the datasets used in conventional crash analyses. To evaluate the accuracy of the data for these roadways, I compared my own field observations with the information included in the FDOT dataset. As shown in Table 6-2, our findings agreed for only half of the total cases. While I could not locate 11 of these fixed objects (22%), part of these were attributable to the density of tree cover along the roadside. More important, however, is the discrepancy between the actual location of an object, and its reported location in the police-reported crash statistics. While I located 33 crashes at a driveway or intersection, the police-reported data included only 25. Of these, my field observations and the police-reported data agree for only 19 of the cases, although 3 were coded as having occurred at a driveway or intersection where I was unable to locate the specific object.

Table 6-2: Location of Pole and Tree Crashes – Field Observations vs. Police Reports.

	Police Reported Location			
Field Identification	**Intersection**	**Driveway**	**Not at Intersection**	**Total**
Intersection	**19**	1	7	27
Driveway	2	**0**	4	6
Not At Intersection	0	0	**7**	7
Not Located	2	1	8	11
Total	23	2	26	**51**

Assuming that crashes involving trees or poles that I could not specifically locate occurred at the reported location, this places 36 roadside crashes behind a driveway or intersection – ***71% of the total***. Based on these observations, it is possible to derive a rule-of-thumb correction factor for estimating the number of crashes that occurred at a driveway or intersection. In this case, intersection crashes were under-reported by 44%. To convert reported intersection-related crashes to the observed totals, one can multiply the reported total by 1.44 to arrive at actual totals. To equalize the totals, the difference between the reported and actual intersection crashes can be subtracted from the number of crashes reported as having occurred midblock/not at an intersection.

I further sought to determine whether the same role of intersections and driveways held constant for all roadside crashes occurring on each of these three roadways (see Table 6-3). As reported in the police statistics, roughly half of all roadside crashes occurred at an intersection or driveway – the same percentage as reported in the crash data for tree and pole crashes. Thus, assuming the same 1.44 correction factor, the total number of intersection and driveway-related crashes would appear to be roughly 70%. Regardless of whether the actual number is 50% or 70%, these figures nevertheless raise an important concern – specifically, that a startlingly high proportion of roadside crashes involve intersections and driveways.

Table 6-3: Location of All Roadside Crashes, Reported and Adjusted

	Police-Reported		**Intersection-Adjusted**	
Location	**Count**	**Pct.**	**Count**	**Pct.**
Not at Intersection	57	52%	34	31%
Intersection/Driveway	52	48%	75	69%
Total	109	100%	109	100%

Turning Movements and Run-off-Roadway Events

The high percentage of run-off-roadway crashes occurring at driveways and intersections suggests that turning maneuvers are responsible for many roadside crashes. Typically, most basic examinations of crash data look only at the vehicle maneuver information encoded into crash databases, an analysis approach that is misleading. For example, knowing that a vehicle is traveling straight ahead is useful, but it is also necessary to know the *direction* in which the vehicle was traveling. As I discovered from my analysis of the FDOT data, while the majority of these vehicles were listed as traveling “straight ahead” (73%), a substantial proportion was listed as traveling straight ahead *in the direction of the side street*. In other words, the crash occurred after the vehicle had completed (or attempted to complete) a turning maneuver and was consequently traveling straight ahead in the direction of the side street, not the main arterial. Thus, in attempting to understand the possible influence of turn-related driving maneuvers on fixed-object crash events, I have combined turns and “wrong direction” crashes into a single category, with a “wrong direction” crash identified as a crash that was both located at an intersection and which was also traveling in the direction of the side street, rather than the main arterial.

To illustrate this phenomenon, Figure 6-7 shows the location of a crash involving a tree (pictured in foreground). In this case, the crash is recorded as having occurred been a “straight-ahead” crash, but the direction of the crash was east – the direction in which the side street departs from the main arterial (SR 15, in this case). This information, combined with the physical fact that this crash could only have been the result of a left-turning maneuver,[40] is indicative of the need to look at not only the police-reported vehicle movement, but also the direction that the vehicle was heading at the time of impact.

Figure 6-7: A Left-Turn Crash Involving a Tree, Reported as “Straight Ahead”

Table 6-4, below, shows the results of this analysis for all crashes occurring on these roadways. In this case, 54% were identified as either engaging in a turning maneuver, or else just having completed a turning maneuver and thus traveling in the

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[40] This is a T-Intersection, so all eastbound traffic necessarily originates from SR 15.

"wrong" direction." These percentages are similar (54% vs. 48%) to the raw number of crashes identified as having occurred at a driveway or intersection. This suggests that the same correction factor may apply, raising the number of roadside crashes associated with a turning maneuver to 78%. Regardless of whether a correction factor is appropriate, it can be definitively stated that *at least half of these crashes involved a turning movement*, although the results of the field analysis suggests this percentage may be as high as 75%.

Table 6-4: Vehicle Maneuver/Direction Prior to a Fixed-Object Crash

Direction	**Count**	**Percent**
Straight Ahead	40	36.7%
Wrong Direction/Turn	59	54.1%
Other/Unknown	10	9.2%
Total	109	100.0%

The Anatomy of a Roadside Crash: A Qualitative Discussion

Quantitative data are limited in their ability to explain the factors that result in a fixed-object crash event. In the course of collecting field data, I visited many locations where these crashes occurred, and in doing so, came close to being involved in one myself, an experience that provided insights into the precipitating causes of run-off-roadway crashes. This experience, while purely qualitative, proved to be much more informative than simple statistics in my understanding the nature of roadside crashes.

My near run-off-roadway event occurred at the intersection of Heavensgate Road[41] and SR 15 in DeLand. This roadway is located just outside the urban area boundary that delimits the study area used for this analysis. At this location, SR 15 is a 4-lane, median-separated arterial with a posted speed limit of 55 mph. Figure 6-8, below, faces south towards downtown DeLand, the direction in which I was traveling at the time of the event. In this case, I was traveling slightly less than the posted speed limit (roughly 45-50 mph) and attempting to locate Heavensgate Road.

Figure 6-8: SR 15 and Heavensgate Road

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[41] This roadway is aptly named.

After reading the sign,[42] I reduced my operating speed to turn from SR 15 onto Heavensgate Road, and soon discovered that although I was traveling well below the posted speed limit, I was still traveling much too fast to safely negotiate the turn, with my vehicle trajectory aimed *directly towards the ditch located behind the arterial*. While I was able to avoid crashing into the ditch through a combination of hard braking and sharp turning, I must re-iterate that I attempted this maneuver at less than the posted speed limit, during the day, and on dry pavement. Under less ideal conditions, this maneuver may very well have had a dramatically different outcome.

The nature of this crash is radically different than that assumed in the hypothetical design scenarios used in crash testing and simulations. Because passive safety practice assumes that run-off-roadway events are the product of random error on the part of the driver, these crashes are generally assumed to occur at midblock locations. Thus, the procedure for simulating a crash event proposed under NCHRP 350 encourages the use of a 25-degree angle for crash testing (TRB, 1993), and more recent research, also using hypothetical scenarios, rather than real-world observations, has further recommended *reducing* the crash angle to 20 degrees (Mak and Bligh, 2002). Yet the angle of impact for this crash would not have been 20- or 25-degrees, but ***head-on***.

Despite the attention paid to the provision of clear zones and forgiving roadsides, *current roadside safety practices would have had exactly no effect on reducing the roadside hazard of this location* – the hazard here was not the "random" driver error

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[42] My vision is 20-20.

assumed by passive safety principles, but instead a roadside hazard that was systematically designed into the roadway under the auspices of enhancing its safety. Two factors are involved – the first is the posted (and thus operating) speed of the primary arterial, and the second is the placement of the roadside hazard.

Design Speed

The first factor was the posted speed of SR 15 (55 mph), which is altogether too high to allow a driver to successfully to negotiate a turn onto this side street. While the engineer responsible for the design of the arterial may assert that the design of side streets is the responsibility of the local jurisdiction, the reality is that the prevailing design speed for the arterial strongly influences the speed at which the driver will attempt to negotiate a turn. Asserting that the designer of the driveway or intersection is solely responsible for this crash events results in design practices that systematically incorporate driver error into the roadway's design.

There is a double-hazard involved here. On one hand, a driver attempting to safely negotiate this turn must decelerate well below the posted speed limit to successfully negotiate the turn. Yet the problem that emerges is that drivers approaching from the rear expect lead vehicles to be traveling at or near the roadway's prevailing operating speed (which often differs dramatically from a roadway's posted speed). My casual observation of mid-day operating speeds for this section of SR 15 was that the typical vehicle was traveling at roughly 70 mph. Requiring a driver to decelerate to 20 mph to safely negotiate a turn thus results in a 50-mph speed differential between the turning vehicle and a vehicle approaching from the rear. As is patently obvious, such dramatic differentials between lead and following vehicles creates a latent opportunity for a rear-end collision. Further exacerbating the problem is the expectation of following vehicles that the lead vehicle will travel at or above the posted speed limit. Following vehicles appear to be largely unprepared to quickly react to decelerations on the part of a lead vehicle.

Additionally, the drivers of lead vehicles preparing to negotiate a turn are likewise aware of the potential for a rear-end collision, an awareness that results in a willingness to undertake higher-than-desirable turning maneuvers to avoid being rear-ended by an approaching vehicle. Thus, in an attempt to avoid an immediate hazard – a rear-end collision – drivers may engage in behaviors that can lead to a run-off-roadway event.

These hazards are also socially-reinforced. One thing I noticed during the course of traveling along this roadway was drivers following a lead vehicle were highly impatient when the lead vehicle attempted to decelerate in front of them, responding by hitting their horn (indicating an inter-personal offense), as well as taking aggressive reactionary maneuvers, such as rapidly shifting to the inside lane to pass the decelerating vehicle. This latter maneuver thus creates the possibility of a sideswipe crash, as a reacting driver that shifts into the inside lane may thus crash into a third vehicle already traveling in this location. Thus, the *use of high design speeds in areas where driveways and intersections are present seem to result in the increased possibility of not only run-off-roadway events, but rear-end and sideswipe collisions as well.*

Object Offset

By itself, attempting to undertake the turn at a high speed would not be particularly hazardous, provided the area behind the side street were free of fixed-objects or other roadside hazards. In this case, a driver would simply leave the travelway behind the side street or intersection. Yet the second problem that arises is that *current roadside design practices can result in the placement of roadside objects in the location where they are most likely to be struck*. Currently, the professional assumption is that the farther back an object is placed from the primary arterial, the safer the roadway will be. There is no consideration of the roadside safety hazard posed by drivers attempting to accomplish turning maneuvers from arterials to side streets in the literature.

For Heavensgate Road, the object that posed the greatest potential hazard was neither the mailbox nor the sign post, both located within the "clear zone," but the ditch, which was located *36 feet* from the edge of the travelway, exceeding even the recommended clear offset distance by 6 feet. A safety audit of this location, were one conducted, would not have identified the ditch as being a potentially hazardous roadside feature, but would instead have concluded by recommending the elimination of the mailbox and sign post – eliminations which would have had exactly no effect on the actual crash performance of this location. Indeed, between 1999 and 2003, neither the pole nor the signpost were involved in a crash event, while two injuries were associated with a vehicle crashing into the seemingly "safe" ditch located directly behind Heavensgate Road.

This is far from the only location where such hazards emerge. Figures 6-6 and 6-7 both depict variations on the same theme – a turning maneuver that places a fixed-object directly in the vehicle's trajectory. In Figure 6-7, like the Heavensgate Road example above, the object involved in a roadside crash in not the one located nearest to the travelway, but instead the tree set back 20 feet from the main thoroughfare. Again, a safety audit of this location would identify the utility poles and shrubbery as being hazardous, but would leave the real hazard – the tree on the side street –fully intact.

Considering the Overall Design Implications

The results of these findings have two important implications on roadside safety, both of which have been suggested above. The high percentages of intersections and turning maneuvers associated with these crash events (between 65-83%), suggests that run-off-roadway events are not simply the result of random driver error, but may in fact be *hazards that have been systematically designed into the roadway under the auspices of enhancing its safety*. From a safety perspective, there is a clear need to more thoroughly examine the role that intersections and turning maneuvers have on roadside safety, paying particular attention to how the combination of an arterial's design and operating speeds influence both the speed at which a driver attempts to negotiate a turn, as well as how to design intersections and driveways prevent these events. Assuming that the combination of a high design speed and a wider roadside object offset enhances safety is not sufficient for ensuring that a roadside is safe. As detailed in the examples above, a safety audit based on passive safety assumptions would have done little to address the actual roadside hazards at these locations.

A further implication of these findings is that the assumptions on which most conventional roadside crash tests are based may be inadequate for addressing real-world crashes. NCHRP 350 currently recommends the use of a 25-degree crash angle when modeling the performance of roadside features such as guardrails (TRB, 1993), and recent work on the subject has recommended further *reducing* the measured angle of impact to 20 degrees (Mak and Bligh, 2002). These angles are based on the assumption that run-off-roadway events involve random midblock encroachments onto the roadside. Yet this study finds that these events are typically not random, and are more likely than not to involve a vehicle striking an object on the side street, rather than an object located midblock on the major roadway. In these cases, the angle of impact is not 25 degrees, as currently assumed, but *head on*. As such, there may be a need to update NCHRP 350 standards.

Reconsidering Livable Streets

Unlike clear zones and paved shoulders, livable street treatments were found to be consistently associated with reductions in *both* roadside and midblock crashes. In other words, these treatments reduced not only the probability of a roadside crash, but also the likelihood that reductions in roadside crashes were offset by increases in other crash types influenced by the design of the roadside environment. Stated simply, such treatments were consistently found to dramatically improve a roadway's safety performance.

In this study, four individual livable streetscape applications were identified, two on SR 15 (Woodland Blvd) in Deland, and one each on SR 44 (New York Ave) and SR 40 in Ocala. All four livable sections roughly correspond to the boundaries of four unique national-register designated historic districts, and incorporate streetscape treatments aimed at enhancing the pedestrian character of the street. Table 6-5, below, provides a summary of these streets.

It is important to recognize that these roadways incorporate streetscape treatments that are seemingly undesirable from a conventional roadside safety perspective. In these cases, roadside objects are deliberately located adjacent to the travelway to buffer the pedestrian environment from oncoming traffic, and are intentionally “unforgiving” by design. Further, the widest offset on any of the four roadways is 4 feet, much less than the preferred 30 ft clear zone recommended in the design guidance.

Table 6-5: Livable Street Sections

Livable Street Section	Illustrations
SR 15, Downtown DeLand • Length: 0.5 Miles • 2 x 12 ft Lanes • 4 ft Object Offset • Center Turn Lane at Intersections • Intermittent On-Street Parking	 
SR 15 Stetson Campus • Length: 0.5 Miles • 2 x 12 ft Lanes • 4 ft Object Offset • 10’ Paved Median • Tree-Lined Along Length	 
SR 44, Downtown DeLand • Length: 0.75 Miles • 2 x 11 ft Lanes • 2 ft Object Offset • Intermittent On-Street Parking	 
SR 40, Downtown Ocala • Length: 0.25 Miles • 4 ft Object Offset • 4 x 12 ft Lanes • 13 ft Raised Median • Boulevard-type Access Lane on South Side of Street	 

A key question for this study is whether these design applications are more or less safe than one would expect when compared against the typical crash performance of the urban sections of the roadways on which they are located. To evaluate this, I normalized crashes for both the livable sections individually, as well as the three urban roadways as a whole, by the number of crashes per 100 million vehicle miles traveled[43] on these roadways during the 5-year period, thereby developing a measure of exposure that could be used to directly compare safety performance. Nevertheless, it is important to recognize that VMT does not have a linear relationship with crash performance (Ivan et. al., 1999), which may be attributable to the fact that high levels of congestion during peak periods can have the dual effect of both increasing the denominator of the measure (vehicle miles traveled) while simultaneously reducing operating speeds, the combination of which may underestimate a roadway's actual hazard during low-volume, free-flow travel periods (such as late night travel). As a secondary means for comparing their relative safety performance, I also evaluated them based on the number of crashes per mile, a metric which makes no assumptions about the relationship between traffic volumes and safety performance.

Table 6-6, below, reports the results of this analysis. As is readily evident, the livable sections are markedly safer than the urbanized portions of these roadways as a whole. Collectively, livable street sections reported 67% fewer total roadside crashes per vehicle mile traveled, and 100% fewer injurious roadside crashes. Comparing crashes per mile, the livable sections had 50% fewer total crashes, and 100% fewer injurious crashes.

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[43] Vehicle miles traveled is computed as the average daily traffic for the roadway or roadway section * the number of roadway miles * 365 days * 5 years.

In short, there can be no doubt that livable street treatments are safer than one would expect from baseline roadway averages, particularly for injurious crashes. Indeed, that not a single injurious roadside crash occurred on these roadways during the 5-year evaluation period is a profoundly important finding.

Table 6-6: Roadside Crash Performance of Urban Roadways vs. Livable Sections

		Crashes Per 100 MVMT			Crashes Per Mile		
		Urban (All)	Livable Only	Difference (%)	Urban (All)	Livable Only	Difference (%)
SR 15	Total Roadside	7.1	3.2	-55.0%	3.5	1	-71.7%
	Injurious Roadside	4	0	-100.0%	2	0	-100.0%
SR 44	Total Roadside	11.4	6.1	-46.3%	5.5	1.3	-75.7%
	Injurious Roadside	5.8	0	-100.0%	2.8	0	-100.0%
SR 40	Total Roadside	15	15.7	4.0%	3.5	8	128.6%
	Injurious Roadside	9.2	0	-100.0%	2.1	0	-100.0%
Averages	Total Roadside	10.1	3.3	-67.3%	4	2	-50.0%
	Injurious Roadside	5.7	0	-100.0%	2.3	0	-100.0%

Individually, one finding bears noting. Specifically, SR 40 in Ocala reports a much higher total percentage (128%) of roadside crashes per mile than the comparison roadway. But this may be a misleading estimate. In this case, two crashes occurred on a 0.25 mile roadway section, thus producing a crash rate of 8 crashes per mile. Nevertheless, both of these crashes involved a single median tree, rather than a tree located in the “pedestrian buffer zone.” Further, neither of these crashes involved an injury or a fatality, which is perhaps the true measure of a roadway’s safety performance.

While most objections raised in the use of livable street applications relate to their safety effects, the fact that these roadways to produce substantially fewer roadside crashes than their more "safe" counterparts, as well as a complete elimination of roadside-related injuries and fatalities, leads to another important question: how do these design applications affect midblock crash performance? As shown in Table 6-7, the livable sections reported fewer total and injurious crashes than one would expect from the baseline roadway averages. Considered in aggregate, one would expect livable street applications to produce between 40-55% fewer total midblock crashes, and between 30-45% fewer injurious midblock crashes. Further, of the midblock injury crashes that occurred on the livable roadways, none – whether involving a motorist of a pedestrian – involved a fatality. Considered holistically, the safety benefits of these roadways are substantial, suggesting that such treatments might not only be a useful strategy for enhancing a roadway's livability, but its safety as well.

Table 6-7: Midblock Crash Performance of Urban Roadways vs. Livable Sections

		Crashes Per 100 MVMT			**Crashes Per Mile**		
		Urban (All)	Livable Only	Difference (%)	Urban (All)	Livable Only	Difference (%)
SR 15	Total Midblock	31.9	28.6	-10.5%	16.0	9.0	-43.8%
	Injurious Midblock	22.7	22.2	-2.2%	11.4	7.0	-38.5%
SR 44	Total Midblock	37.1	18.3	-50.7%	8.7	4.0	-54.2%
	Injurious Midblock	27.7	18.3	-33.9%	6.5	4.0	-38.6%
SR 40	Total Midblock	42.0	15.7	-62.8%	18.0	8.0	-55.6%
	Injurious Midblock	25.7	7.8	-69.5%	11.0	4.0	-63.6%
Averages	Total Midblock	38.3	23.1	-39.7%	15.2	7.0	-54.0%
	Injurious Midblock	25.1	18.1	-27.7%	10.0	5.5	-44.9%

Livable Streets vs. Conventional Urban Arterials

The data on both midblock and roadside safety point to a consistent trend – specifically, that livable street treatments are not only less hazardous than one would expect based on the prevailing design guidance, but that such applications, properly designed, might even constitute a substantial safety enhancement. As with run-off-roadway events more generally, it would appear that the feature that is responsible for the improved safety performance of the livable roadways is their operating speed. Regardless of the time of day (I had the opportunity to drive these roadways both during the day and at night during my field visits), the constrained design environment of the livable roadway sections seems to encourage lower overall operating speeds and thus an increased ability to quickly respond to potential hazards.

For the downtown sections of SR 15, SR 44 and SR 40, these low speeds can be partially attributed to the frequent spacing of signalized intersections. Yet it does not account for the low operating speeds I observed for the livable section of State Road 15 that travels through the Stetson University campus. There are 6 intersections along this stretch of roadway, but only one, at the northernmost edge of the section, contains any form of stop control (in this case, a signalized intersection). As a result, the only factor influencing a driver's operating speed is his or her own personal speed preference.[44] Indeed, the roadway's cross section – two 12 ft lanes and a painted median – is often used for arterials with posted speeds of 45 mph and greater.

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[44] At no point during my field investigations did I observe traffic enforcement along any segment of SR 15.

Yet one does not observe high operating speeds along this roadway. After walking this section to measure its geometric characteristics, I was surprised by how slow vehicles seemed to be traveling (see Figure 6-9). To derive an estimate of the roadway's mean operating speed, I conducted an ad-hoc floating car study, getting behind a lead vehicle as it entered the roadway section, and following it through to the other end. I performed 5 runs along this roadway section between roughly 11:00 am and 12 noon on February 15, 2005. While my measurements were not exact (I was monitoring my speedometer rather than using an appropriately-instrumented vehicle), the speed of the lead vehicle was in all cases between 25-and 30 mph. These speeds were at or even slightly below the posted speed limit of 30 mph.

Figure 6-9: 30 MPH on SR 15

This is a highly interesting finding for a variety of reasons. First, as has been evidenced in a variety of works, a key feature of urban travel is that between 50-75% of all drivers exceed (and often greatly exceed) posted speed limits (Fitzpatrick et. al., 2003; Fitzpatrick et. al., 1996; Tarris et. al, 2000). While 5 runs on a single day is not a truly representative sample, it is interesting to note that in no case was a vehicle observed to exceed the posted speed limit. These low operating speeds help explain a second interesting finding, which is that despite the presence of mature roadside trees located directly adjacent to the travelway along this roadway segment's length, *not a single roadside crash was reported for this road segment during the 1999-2003 time period*, let alone an injurious one. Collectively, this suggests that the presence of dense roadside trees seems to indicate to the driver that greater caution is warranted, resulting in both reduced operating speeds, as well as reduced roadside crash frequencies.

Further, while livable street advocates regularly argue for lane narrowing as a means of reducing vehicle operating speeds (with a preferred preference for 10 feet),[45] it should be observed that the lower speeds associated with this roadway cannot be attributed to lane widths, which were 12 feet throughout the section. While crossing this roadway as a pedestrian was somewhat unpleasant due to the absence of signalized intersections, it would nevertheless appear that speed reductions can be achieved without narrowing travel lanes. Indeed, as shown in the negative binomial results reported in

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[45] From the perspective of pedestrian exposure – a second justification used by livable street advocates to encourage lane width reductions – the safety benefit associated with narrowing 12 foot lanes to 10 foot lanes appears to be minimal. Given that average pedestrian walking speeds are roughly 3.5 feet per second, narrowing two 12 foot lanes to two 10 foot lanes reduces the pedestrian's exposure during the a roadway crossing from 6.9 seconds to 5.7 – only a 1.2 second difference.

chapter 5, wider lanes appear to be, on the whole, beneficial to a roadway's safety performance. The implication of this finding is that, if speed reduction were indeed a design objective, the inclusion of a dense lining of mature roadside trees would appear to be a potential means for doing so.

A Summary of the Empirical Evidence Presented in Chapters 4-6

This section, comprised of Chapters 4-6, has examined the empirical and philosophical basis of contemporary roadside safety practice. Interestingly, it found that many of the assumptions that drive contemporary roadside design practice are not supported by empirical observations of a roadway's crash performance. Instead, urban roadside crashes instead appear to be strongly associated with vehicle turning movements – a factor not currently considered in roadside design practice.

Livable street applications – which are discouraged because of concerns about their safety effects – were found to not only result in decreased roadside crash frequency, but also to ***eliminate*** the injuries and fatalities associated with run-off-roadway events. Not a single injurious or fatal roadside crash occurred on any of the livable roadway sections during the 5-year evaluation period. Further, unlike widening shoulders and clear zones, livable street treatments were also found to dramatically reduce midblock, multiple-vehicle and pedestrian crashes and injuries as well.

Alternatively, neither a roadway's fixed object offset, nor the provision of a paved shoulder, was found to meaningfully enhance a roadway's safety performance. While widening fixed-object offsets was found to reduce fixed-object crashes, it had no effect on a roadway's midblock crash performance, suggesting that reductions in fixed-object crashes are being offset by increases in multiple-vehicle and vehicle-pedestrian crashes. Paved shoulders were found to lead to increases in both roadside and midblock crashes.

Collectively, these findings suggest that the current passive safety assumptions that guide roadside and roadway design practice may fail to adequately address a roadway's actual safety performance, at least when one measures safety in terms of empirical observations of crashes and injuries, rather than hypothetical design scenarios.

So a final question: if passive safety principles cannot account for a roadway's safety performance, and indeed, may even be detrimental to safety in certain contexts, what are the appropriate principles on which to base safe design practice? Because of the clear need for a more empirically-justified approach to urban roadway design, the remainder of this dissertation outlines a new theory for the design of safe roadways that is better supported by both the existing empirical evidence on roadside and roadway safety, as well as by recent developments in the emerging area of traffic psychology.

CHAPTER 7

A POSITIVE APPROACH TO ROAD SAFETY

…competent drivers can be given appropriate information about hazards and inefficiencies to avoid errors.

- Federal Highway Administration, 1990, p. 1-1

This chapter begins the third and final section of this dissertation. Chapters 1-3 outlined the issues surrounding the design of urban roadsides, and detailed how they are currently addressed through design practice. Chapters 4-6 examined the theoretical and empirical basis for these practices. This chapter proposes an alternative approach to transportation safety and roadway design that may not only better address safety, but may further enhance a roadway's livability as well.

Rethinking Driver Error

As discussed in previous chapters, passive safety begins by assuming a hypothetical "worst-case-scenario" design condition, and then attempts to design roadways to be as "forgiving" as possible for such an event. The rationale behind this approach is that drivers are prone to error and will necessarily engage in behaviors that result in crashes. Thus, by designing *all* roadways to be “forgiving” for worst-case scenario events and behaviors, a designer can assume that he or she has made a roadway adequately safe.

This design approach is successful to the extent that driver errors can be attributed to **random error**, or error that is the result of unpreventable mistakes on the part of the driver. While passive safety admits that driver errors may be precipitated by a host of factors – driving under the influence of drugs or alcohol, driver distraction, or simple recklessness – the presumption is that a roadway’s design has little actual influence on the probability of a driver committing an error that leads to a crash. Indeed, 95% of all crashes are attributed to errors on the part of the driver, rather than errors that are a product of the roadway’s design (Carsten, 2002; Hauer, 1999b).

The early empirical evidence on the subject of road safety seemed to confirm these assumptions. In the 1960s, when the first design guidance on the subject of safety was developed, researchers observed that the Interstate highway system, which used high design values to accommodate high-speed travel, had fewer crashes per mile traveled than other roadway classes. These researchers attributed the Interstate system’s safety performance to the use of high design values, assuming that they were “forgiving” to unpreventable driver errors. Thus, the concept of “forgiving” design practice emerged as a *post-hoc* explanation for understanding of the safety performance of the Interstate system.

While this logic remains compelling, at least from an engineering perspective, the problem is that it overlooks some of the other characteristics of Interstate highways, characteristics that better explain its safety performance than does its use of high design values. First, these roadways are designed for a single user type – motorists. Pedestrians and bicyclists are legally excluded from the Interstate system. Given that the high vehicle speeds that occur on the Interstate system are unaccommodating to pedestrians and bicyclists,[46] eliminating these users from the system makes sense. Yet it must be recognized that eliminating such users dramatically changes a roadway's operational and safety performance.

Second, and more important from a roadside safety perspective, *Interstate highways do not provide direct land use access*. Access to the Interstate highway system is strictly controlled through the design and construction of highway ramps, which are designed for vehicle acceleration/deceleration and gradual turning movements. Since between 65-85% of all urban run-off-roadway events appear to be associated with turning movements at driveways and side streets, roadways where access is controlled through on and off-ramps thus eliminate the turning movements that result in run-off-roadway crashes. Asserting that the roadside safety performance of these roadways is attributable to their use of "forgiving" design values is misleading; Interstates seem to report lower rates of roadside crashes simply because they eliminate the vehicle turning movements that produce a large percentage of these crashes.

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[46] Pedestrian survival rate in a crash is strongly influenced by vehicle speed; when a pedestrian crash involves a vehicle traveling a 20 mph, pedestrians have roughly a 95% chance of survival; double the vehicle speed to 40 mph and a pedestrian has only a 10% chance of survival (Durkin and Pheby, 1992; Retting, 1999). To the extent that ensuring pedestrian survival in a pedestrian-vehicle crash event is a design objective, it is clear that operating speeds should be kept low in areas with pedestrian activity.

Systematic Error

If the passive safety assumption of random, unpreventable error were true, then forgiving design practices should *universally* result in reductions in roadside crash rates on all roadway classes, once one accounts for traffic volumes. In other words, if driver errors are purely a random product of unpreventable behavior on the part of the driver, then errors that lead to run-off-roadway events should be expected to occur at relatively constant rates along a roadway, and the probability of an error should be simply a function of the number of drivers using a roadway. Thus, the relative rate of error can be viewed as a design constant, and designs that “forgive” errors should therefore in general reduce crashes and injuries, while designs that are less forgiving should be associated with higher numbers of crashes and injuries.

Yet this study did not find that that forgiving roadside designs adequately explained a roadway’s safety performance. Instead, a substantial portion of roadside crashes appears to be attributable to **systematic error**. Unlike random error, systematic error is the result of mismatch in human-and-machine or human-and-environment interactions (Carsten, 2002). From a design perspective, systematic errors occur when the design of a roadway produces misleading expectations on the part of the driver, such as the expectation that a roadway can safely accommodate high-speed travel. Thus, systematic error occurs when there is a mismatch between what the driver *perceives* as safe operating behavior, and the behavior that is actually required to minimize his or her likelihood of being involved in a crash.

As discussed previously, between 65% and 83% of fixed-object crashes can be attributed to a single *systematic* cause – drivers attempting to undertake higher-speed turning maneuvers at driveways and intersections. In these cases, high-speed designs for urban arterials, combined with limited turning room on intersecting driveways and side streets, result in a *latent opportunity* for a run-off-roadway event; all that is needed to transform this design condition into a run-off-roadway event is a driver willing to attempt a turning maneuver at the "safe" operating speed suggested by the design of the arterial.

Systematic Error and Livable Streets

The role of systematic error in roadside crashes is further highlighted by the fact that the livable street treatments considered in this study, which employ "unforgiving" designs, reported statistically-significant reductions in *both* roadside and midblock crashes when compared to other urban arterial treatments. These roadways are located in historic business district locations that have high numbers of cross-streets and turning movements. Yet, unlike the higher-speed roadway sections examined in this study, the turning movements that occur in these environments do not result in fixed-object crashes because livable design treatments also encourage lower operating speeds, thereby eliminating the high-speed behavior that contributes to run-off-roadway events.

Further, the percentage of injurious urban roadside crashes that may be attributable to systematic error is undoubtedly higher than 83%. One of the more important findings of this research is that *not a single injurious crash involving a roadside object occurred on any of the livable street treatments during the 5-year period* *considered for this study*, despite the fact that these objects were located no more than four feet from the edge of the travelway. Such a finding underscores the obvious fact that impact speed and crash severity are related, but it also raises a second important point: specifically, that it may be possible to dramatically reduce or even eliminate injurious and fatal roadside crashes.

Further, such treatments seem to meaningfully address random error as well. Assuming that random error cannot be eliminated form the system, then the design objective should be to ensure that any crashes and injuries associated with such events are not injurious. Given the zero-incidence of injurious roadside crashes and the extremely low rates of midblock injuries (18 per 100 MVMT),[47] it would appear that these designs are effective at reducing the injuries associated with "unpreventable" random error as well.

The success of livable street treatments, like that of the Interstate system, is that their design eliminates the precipitating factors that result in roadside crashes. In the case of Interstates and freeways, crash frequencies are reduced because the design of these roadways eliminates the driveways and intersections that result in turning maneuvers. Yet it is patently unreasonable to assume that all roadways, or even all arterial roadways, should be designed to prohibit land use access. At the most basic level, the sole purpose of a transportation system is to allow travelers to access destinations; most travel does not

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[47] It is worth observing that this is substantially lower than the crash performance of the Interstate system. When one considers only fatal fixed object crashes (thus ignoring all other midblock crashes as well as all injurious crashes) there are 23 fatal fixed-object crashes per 100 MVMT on the Interstate system. See Table 2-5).

occur for its own sake. For roadways where land use access and turning maneuvers are to be expected, the design objective cannot be to prohibit such maneuvers, as is done on the Interstate system, but to instead prevent these maneuvers from occurring at unsafe speeds. The lower-speed, “unforgiving” designs embodied by livable street treatments appear to be an effective means for reducing turning speeds, thus resulting in improved safety performance, despite the fact that they violate the core assumptions of contemporary design practice.

Risk, Behavior, and Crash Prevention

While the empirical evidence on roadside safety seems to contradict conventional design practice, it confirms a trend that many researchers and practicing engineers have observed for some time, but which to date has received little substantive elaboration: specifically, that clear zones and other forgiving design practices have an ambiguous relationship to safety in urban environments, and may, in certain design contexts, have a negative effect on safety. The passive safety approach presumes that run-off-roadway events are random and unpreventable, yet these crashes are much less likely to occur on livable street treatments. Why might this be the case?

The best possible explanation for the safety performance of the livable street treatments considered in this study is that drivers are “reading” the potential hazards of the road environment, and adjusting their behavior in response. While the idea that unforgiving designs can result in behavioral adjustments, and thus enhanced safety performance, contradicts the prevailing theory of safe roadway design, it is supported by research and literature in areas of driver psychology and behavior, which has focused on the subject of traffic safety as a means for understanding how individuals adapt their behavior to perceived risks and hazards.

Risk Homeostasis Theory

Risk homeostasis theory, as developed by Wilde (1982; 1988; 1994), asserts that individuals make decisions on whether to engage in specific behaviors or activities by weighing the relative utility of an action against its perceived risk. While all actions involve some risk, risk homeostasis theory asserts that individuals will adjust their behavior to maintain a static level of exposure to perceived hazard or harm. With respect to driving behavior, risk homeostasis theory posits that drivers intuitively balance the relative benefits of traveling at higher speeds or engaging in other higher-risk driving behavior against their individual perceptions of how hazardous engaging in such behavior might be. Where hazards are present and visible, such as in the case of livable streetscape treatments, risk homeostasis theory would expect drivers to compensate for these hazards by modifying their behavior to reduce their risk to an acceptable level. Indeed, the fact that livable street treatments did not demonstrate higher rates of midblock and roadside crashes and injuries than other roadway sections is readily understandable when one considers the common-sense fact that few drivers intend to be killed or injured as part of their driving activity.[48] Since the roadside features used in livable street treatments are not only clearly visible to the driver, but also expected, drivers behave as reasonable people would be expected to: they simply adjust their behavior to avoid crashing into them.

What is less understandable is that livable street treatments should consistently report *fewer* crashes and injuries than their comparison roadways. Risk homeostasis theory would assert that, *ceteris paribus,* the relative crash performance of a roadway should remain constant along its length, regardless of specific design variations, since any change in perceived hazard will be offset by corresponding adjustments in behavior. Thus, according to risk homeostasis theory, the livable street sections should be no more or less safe than their comparison roadways overall.

Yet as Hauer (1999b) describes, there is an important distinction between **safety**, which is (or should be) an empirical measure of crash performance, and **security**, which is an individual's subjective perception of safety (or conversely, perceived exposure to harm). The presence of features such as paved shoulders and clear zones would appear to reduce the perception of risk, giving drivers an increased but false sense of security, and thereby encouraging them to engage in behaviors that may increase their likelihood of becoming involved in a crash.[49]

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[48] According to the Web-based Injury Statistics Query and Reporting System (WISQARS), produced by the National Center for Injury and Prevention Control, only 91 suicides were transportation-related. Of the roughly 40,000 fatal crashes in 2001, this equates to 0.2% of the totals for that year.

[49] This was also the perspective of the earliest edition of the AASHTO Green Book (1940), which cautioned designers about the speed-inducing effects of such design practices.

If a roadway's design can indeed influence drivers' perceptions of safety, and thus their driving behavior, then this would explain why the livable streetscape treatments examined in this study resulted in not only fewer fixed-object crashes, but fewer multiple vehicle and pedestrian crashes as well. Such treatments appear to help balance a driver's sense of security with the real levels of risk in their environment, providing them with more accurate information on the appropriate level of caution, and resulting in behavioral adaptations that better prepare them for not only roadside crashes, but the potentially hazardous vehicle and pedestrian conflicts that one encounters in urban environments as well.

Risk homeostasis theory would further assert that the use of high design values is not "forgiving," but is instead "permissive." The use of wide shoulders and clear zones can be viewed as a safety enhancement only if driver behavior and driver errors can be held constant both before and after a roadside "improvement." But because behavior is directed by a driver's target risk level, "forgiving" designs may have the effect of reducing the *perceived* risk of traveling at high speeds or being involved in a run-off-roadway event, thereby encouraging drivers to increase operating speeds and reduce their levels of caution. Thus, a risk-centered perspective of safety would expect that the provision of paved shoulders and clear zones should have little or no effect on a roadway's safety performance. Indeed, this finding is confirmed by the negative binomial results for midblock crashes reported in Chapter 5, which found that the net safety benefit of widening clear zones was approximately zero, and that widening shoulders actually resulted in *increases* in midblock crashes.

Other researchers finding similar safety anomalies in their work have likewise suggested that the relationship between risk and behavior accounts for their unexpected findings. Ossenbruggen et. al. (2001), speculated that the better safety performance of urban villages may be attributable to the fact that the roadside environment "warn[s] drivers that they must maintain a low speed and use caution" (p. 496). Noland (2001), in explaining why new roadway improvements were shown to result in an increase in crashes and injuries suggested that "higher design standards [allow] drivers to increase their speeds on roads and reduce their levels of caution" (p. 24).

Given the consistency of these findings throughout the empirical literature, a key design objective, from the perspective of enhancing a roadway's safety, would be to encourage designs that link drivers' perceptions of hazard to the actual risks they face in a particular design environment. Thus, designs that incorporate clearly visible hazards, such as the section of Woodland Avenue that travels through the Stetson University campus (see Figure 6-9), would be expected to result in behavioral adaptations that reduce systematic errors, and thus a driver's likelihood of being involved in a crash event. Again, the findings of this research confirm these expectations.

Drivers Read the Road

The passive approach to road safety begins by designing a roadway to safely accommodate high-speed, "extreme" driving events, and then attempts to discourage higher-speed travel through the use of posted speed limits. The problem that emerges with this approach, however, is that signs and roadways are communicating substantially different information, with the net result being that a majority of drivers learn to disregard posted speed limits, since they quickly learn that road signs have little meaningful relationship to their likelihood of being involved in a crash or an injury. Further, drivers seem to learn to disregard road signs altogether, even when they display information that is essential to their safety. Thus, in the absence of aggressive law enforcement,[50] drivers will increase their operating speeds to the "safe" speed they infer from a roadway's design (Chowdhury et. al., 1998; Fitzpatrick et. al., 2003; 1996; Kubilins, 2000; Tarris et. al, 2000).

A risk-centered approach to transportation design explains why drivers do not comply with posted speed-limit practices, as well as a host of other safety anomalies the passive approach simply cannot account for, such as Naderi's (2003) findings on aesthetic streetscape treatments, the livable street examples included in this study, or indeed, the wide array of safety anomalies present in the roadway safety literature. It further explains why midblock narrowings and chicanes, two traffic calming applications that modify the roadside in a manner that passive safety would suggest should increase crashes and injuries, have been shown to result in substantial (74%-82%) crash reductions (Zein et. al., 1997). Indeed, all traffic calming measures appear to reduce crashes by reducing speeds and/or increasing driver caution (Ewing, 1999).[51] In all of these cases, driving behavior can be attributed to a driver's perception of risk, which is a

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[50] While Australian practice clearly indicates the success of speed enforcement in ensuring compliance and thus reducing crashes (FHWA, 2004), it is by no means clear that the best use of law-enforcement personnel is to employ them in the enforcement of roadways that are inappropriately designed.

[51] The safety benefits of traffic-calming applications are widely acknowledged by European designers, who view them not as "livability" features, but instead as ***safety countermeasures*** (Skene, 1999). I discuss European design practice in greater detail later in this chapter.

function of what they perceive from the road and roadway environment, resulting in behavioral adaptations that seek to maximize the benefits of driving without exceeding the level of acceptable risk that a driver is willing to accept for the task. Stated simply, drivers “read the road.”

The Road as Text

If drivers “read the road,” then the road and roadway environment can be viewed as a “text” that communicates information on safe operating behavior to the driver. To date there has been very little meaningful consideration of the effects that a roadway’s design may have on the performance expectations of the driver, and indeed, little substantive examination into the relationship between design and driver behavior (Kanellaidis, 1996; Noland, 2001; Noland and Oh, 2004). What is needed is a design approach that meaningfully links the information used by the driver to determine his or her operating behavior with the actual behavior necessary to avoid a crash event.

A useful starting point for the development of such a behavior-centric approach to design is the field of semiotics. Literally, the field of semiotics pertains to study of signs and their interpretation, yet the field of semiotics is more broadly concerned with how meaning is conveyed and interpreted. A sign, from a semiotic perspective, is not simply a physical object (such as a road sign), but instead a relationship between an object (signifier) and its meaning (signified), as understood by an interpreter (Chandler, 2002;

Peirce, 1955; Saussure, 1983).[52] As such, its fundamental concern is with communication – or the means by which information is expressed and received. Information is not only communicated through formal symbolic mechanisms, such as language or writing, but through features in the environment[53] (Eco, 1976; 1982; Jakobson, 1971; Jameson, 1972). Thus, a semiotic approach to roadway design begins from the perspective that roadways have a "meaning" that is communicated to, and interpreted by, a driver.

The Physiological Characteristics of Driving and Scene Viewing

How drivers read the roadway is comprised of both a physiological component, as well as a cognitive one. Both are intrinsically related, but to adequately understand what a driver reads, it is first essential to detail the physical process through which the driver reads it.

Psychologists use measurements of eye movements (saccades) and visual fixations to understand how an individual analyzes and processes visual information. As Henderson and Hollingsworth (1998) have found, the physiological characteristics of reading and scene processing are very similar in terms of fixations and saccades, each of which are discussed briefly below.

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[52] The terms "signified" and "signifier" refer to a Saussurean model of semiotics, which focuses on the relation between the signifier (sign) and the signified (meaning) (Saussure, 1983). An alternative approach was developed earlier (1897) by Peirce (1955), and differs in that it presents semiotics as a triangulation between a representamen (the form that a sign takes), an interpretant, (the meaning of the sign, as interpreted by an individual), and an object (which is the intended meaning of the sign). While the Saussurean model is the conventional basis for contemporary semiotics, most semioticians also recognize the role of the interpreter as the medium through which semiosis occurs (Chandler, 2002).

[53] Semioticians term a self-referential sign an "index."

Saccades

Like reading, saccade movements in scene viewing are directed by an internal logic governed by the medium being examined. In reading, saccades are targeted towards the next word in the series, where the structure of a written text places the next word in a series adjacent to the previous one.[54] Such a structural framework is very efficient for minimizing the distances between individual saccades. Like reading, there is an embedded logic in the selection of saccade targets in scene viewing. While saccades in reading are directed towards the next word in a series, saccades in scene viewing are oriented towards the "salient" features of a scene.

To effectively process the complex information presented by a scene, individuals cognitively dissect it into specific regions (referred to by psychologists as a salience map), each of which is instinctively assigned a salience weight based on whether the region is likely to contain sought-after information (i.e., the expectation that a stop sign will be based on the right-hand side of an intersection will lead drivers to visually direct their eyes towards this location), as well as a region's degree of visual interest, which is determined by variations in color, texture, and contrast. From a biological perspective, such a framework of scene processing allows individuals to efficiently process and interpret complex scenes (Groeger, 2000; Henderson and Hollingsworth, 1998; Koch and Ullman, 1985; Mahoney and Ullman, 1988).

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[54] In Germanic and Romantic languages (as well as this text), the next word in a series is located to the right of the previous word. In Hebrew, words are oriented from right to left, while Asiatic texts are often oriented vertically, from top to bottom. In all cases, the physical structure of the text is designed to minimize saccade distance by placing the next object of fixation adjacent to the previous one in a pre-defined structural order.

There is a clear structural pattern to the locations of eye fixations used in vehicle navigation, locations which thus serve as saccade targets. In vehicle navigation, drivers focus on four specific areas - a point of distant fixation for orientation, and short-term navigational fixations on the area directly in front of the vehicle, as well as on either side. Designs that heighten the salience of the roadside regions naturally increase the driver's attentiveness to these areas (see Figure 7-1), resulting in more "correct" navigation and, as a result, fewer "errors"[55] (Cavallo, Mestre and Berthelon, 1997; Groeger, 2000; Liu, 1998). Further, a highly interesting finding is that studies on the relationship between visual activity, driving, and a roadway's design environment find that drivers are much more visually active in urban environments when compared to rural ones, a finding that suggests both a heightened awareness to potential hazards, as well as an enhanced preparedness to react to them when they occur (Chapman and Underwood, 1998; Roge et. al., 2002).

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[55] Error is reduced in part because the presence of roadside objects aids in a driver's estimate of time-to-collision. Individuals estimate the time at which they will collide with an object based not on speed, but instead on an object's perceived rate of expansion. As an object approaches, the edges and texture of the object expand from the point of view of the observer, the rate of which is used to derive an estimate of their time to impact. Psychologists refer to this phenomenon as "local tau" (Tresilian, 1991), and it has been observed on not only humans, but in other animals as well (Wagner, 1982; Wang and Frost, 1992). Studies of human time-to-collision estimates have found that individuals generally underestimate actual time-to-collision by about 20-30%, or, in other words, that they have a "built-in" safety margin that causes them to err on the side of safety (Cavallo, Mestre and Berthelon, 1997; Schiff and Oldak, 1990). Yet an interesting phenomenon is that these estimates will change based on the presence of peripheral objects; where the periphery of a visual scene is enriched, drivers will further underestimate time-to-collision, perhaps because of the presence of nearby features on which local tau can be readily determined (Cavallo et. al., 1997; Larish and Flach, 1990). From a practical perspective, what this means is that the presence of roadside objects increases the driver's preparedness to react to potential collisions by estimating that a crash will occur substantially earlier in time than it in fact will.

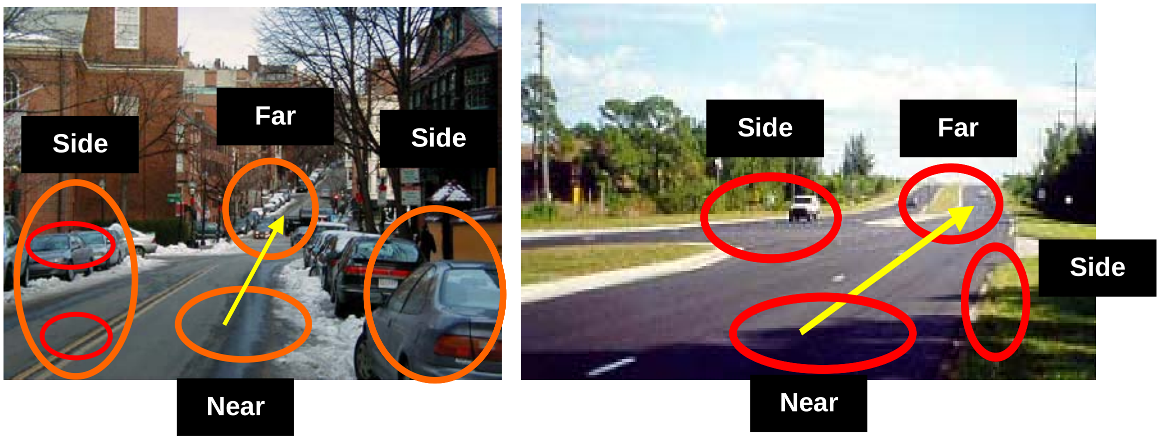

Figure 7-1: Navigation Points and Salience in Two Design Environments

Fixations

Saccades move the eye towards locations upon which it fixates, with the presumption being that a visual fixation corresponds with some level of comprehension or awareness of what is observed. For both reading and scene viewing, modal fixation durations last roughly 300 ms, or 3/10th of one second, although there is greater variability in the fixation durations of scene viewing as compared to reading. That this is so is perhaps unsurprising; while words have prescribed meanings that may be quickly referenced, scenes are often more complex, and may require greater amounts of time to comprehend their meaning (Henderson and Hollingsworth, 1998). What is surprising, from a cognitive perspective, is not that fixations may have greater variability in reading than in scene viewing, but that meaning from a visual region can be inferred, in general, within 300 ms. This is remarkably short period of time to cognitively grasp the broad array of factors that may have an effect on safe vehicle operation. How can the human mind process such a broad array of visual information so quickly?

Categorization and Comprehension: A Driver's View of the Road

At the most basic level, individuals process external information by relating it into specific cognitive categories. Categorization allows individuals to quickly and efficiently process copious amounts of sensory information, and apply it to the situation at hand (Rosch, 1978; Van Elslande and Faucher-Alberton, 1997).[56] With respect to a roadway, what this means is that drivers infer an overall sense of a roadway based on their existing knowledge of, and experience with, similar "types"[57] of roadways, with a roadway's "type" being inferred by the presence of key visual indicators, such as the presence of dense roadside development. In the language of semiotics, such indicators are referred to as "indexical signs." This categorization then produces embedded expectations regarding the nature of the roadway, which relate to **scripts**, or expected patterns of appropriate behavior, as well as **schemata**, or expectations regarding the location, characteristics, and behavior of roadway objects or other roadway users (Theeuwes, 1997). Thus, a roadway's "meaning" is inferred through a cognitive process of sign identification, categorization, and association, which when combined produce expectations regarding the potential hazards of a roadway environment, as well as the behavior necessary to minimize one's potential exposure to *expected* hazards, or hazards for which a driver is cognitively prepared based on their prior experience with similar roadways.

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[56] A hiker hearing a rattling sound coming from a nearby bush, for example, would readily equate the sound (an indexical sign) with a type of thing that produces such a sound – a rattlesnake. This in turn would be immediately related to the class of "hazardous things," and produce a corresponding reaction – moving away from the sound. This is an almost immediate interpretive process that enables an individual to quickly react to a potential hazard – a reaction only made possible through the innate tendency of humans to quickly synthesize and categorize external information.

[57] Eco (1999) makes the distinction between "types" and "tokens," where a token is a specific manifestation that is observed, while a type is a broader class of things to which the token refers. Thus, an observed roadway is a token that relates to a driver's cognitive understanding of its type.

Taking this information collectively, the cognitive process used by drivers is relatively straightforward: drivers gleam an overall sense of a roadway by relating it to similar types of roadways they have encountered previously, which produces expectations on the potential hazards they can reasonably expect to encounter along such a roadway (schemata), as well as the behavior (scripts) that they expect twill minimize their exposure to these hazards. These expectations thus allow the driver to obtain visual information from the road environment relatively quickly (generally around 300 ms) because they are actively searching only for information that is presumed to be necessary to avoid unwanted risk.[58]

There is thus a *communicative process that occurs between the road environment and the roadway user* that directs the user's operating expectations for a particular roadway and the subsequent behavior he or she perceives as being safe and appropriate. Since a roadway is a human-designed product that provides information to a user, then this suggests that the design of a roadway results in a communicative event between a roadway designer and a roadway user. In other words, the roadway is a text that, when successfully designed, provides the roadway user with clear information on safe and appropriate behavior. If the communication between the designer and the user is successful, the result will be the reduction in the mismatch between driver expectancy and actual safety, or *a reduction in systematic error*.

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[58] An example of this is the "looked but did not see" crash, a crash type that typically involves pedestrians and bicyclists. In these cases, pedestrians and bicyclists are not included in a driver's schemata, resulting in the driver failing to observe them during their visual scans of the road environment. As a result, drivers engage in driving maneuvers that result in a collision with an "unobserved" pedestrian or bicyclist.

The Functional Classification System and the Language of Design

If transportation safety is a product of a driver's behavior, and if driver behavior is the result of a driver being able to correctly infer information from the roadway environment, then the key to enhancing safety is to ensure that a roadway is designed to effectively communicate information to the driver on safe operating behavior. Effective communication, by definition, is the transmittal of information from a sender to a receiver, where the information transmitted by the sender is *correctly* interpreted by the receiver. Thus, designs that are successful at addressing transportation safety are those where a roadway user can examine the roadway to obtain clear information on safe operating behavior.

For successful communication between a roadway designer and a roadway user to occur, it is necessary that the way a designer conceives a roadway, and thus designs it, is reasonably well correlated with how this roadway is perceived and interpreted by the driver. In simple terms, there should be a *common language of design*, where there is a meaningful correspondence between the how a roadway is designed, and how the roadway user understands it. Thus, a designer's intention regarding the design and use of a roadway should match the way it is read and interpreted by the road user to ensure that he or she is receiving correct information on safe operating behavior.

But what is the design language used by design engineers? Currently, the design of roadways in the United States are directed by the AASHTO functional classification system (see Figure 7-2), which categorizes roadways based on their location in an urban or rural environment,[59] as well as on the type of vehicle movement they are intended to accommodate. Under this framework, a designer conceives of a roadway as principally serving either *vehicle* access or mobility functions, with little attention paid to the physical or environmental context in which a roadway is placed, or on the types of users or behaviors that may be expected within individual design environments. Each functional class is then associated with a range of design speeds (see Figure 7-3),[60] with passive safety practices resulting in the assumption that higher is better.

How a user perceives and interprets a roadway is not covered under this framework; nor is the relationship between a roadway's design and the types of uses or users that can be expected to be found along it. Instead, the principal objective of this framework is to characterize a roadway in terms of the types of vehicle operations that each roadway class is intended to serve. To date, their has been little consideration of when, and under what conditions, specific design ranges are appropriate, and almost no consideration of how such classifications relate to driver expectations or behavior. There is little information on how such categorizations, and the designs they produce, affect a roadway's actual safety performance.

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[59] The AASHTO classification system uses the urban and rural classifications specified in the United States Code, Section 101, Title 23, where "urban" is defined as a Census-designated place with more than 5,000 residents, and a rural area is any non-urban area.
[60] A roadway's design speed is the controlling element in its design. Lane widths, roadway curvature, and other geometric features are all designed in accordance with a roadway's design speed (AASHTO, 2001).

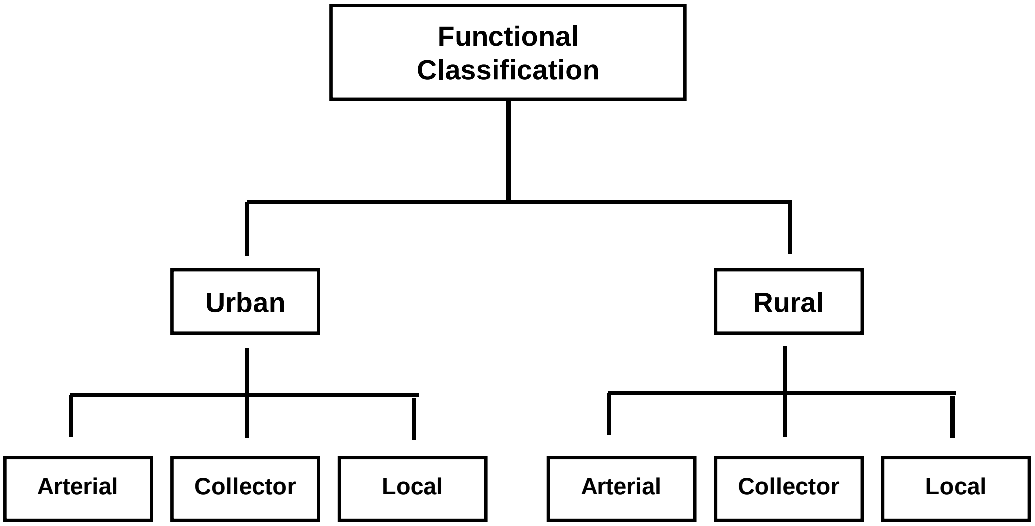

Figure 7-2: The US Functional Classification System

Context, Road Use, and Safety Performance

An emerging critique of US practice is that the functional classification system, which determines the organization and design (i.e., “composition”) of a roadway, is incompatible with the needs and uses of many urban areas. As a result, many cities[61] and design professionals have abandoned this framework in favor of others that is more meaningfully related to the operating characteristics of urban environments (de Cerreno and Pierson, 2004; Duany Plater-Zyberk and Co., 2002; Forbes, 2000; Kubilins, 2000). Indeed, even the *Highway Capacity Manual* (TRB, 2000), which is used by design engineers to evaluate the operational performance of “functionally-designed” roadways, finds it necessary to categorize roads based not only on the functional classification system, but also on the density of roadside development, the expected presence of

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[61] Charlotte, NC and Portland, OR are two cities that have adopted alternative roadway classifications.

pedestrians and bicyclists, and the level of land use access provided by the roadway (measured in the HCM through driveway density). In all of these cases, the design objective is to better connect the "meaning" of a roadway with its appropriate design and use.

Classification	***Example***	***Description***	***Design Speed***
Arterial		Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.	**30-60 mph**
Collector		Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.	**30 mph or higher**
Local		Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through-movement.	**20-30 mph**

Figure 7-3: Urban Roadway Defintiions Under the Functional Classification System (Adapted from AASHTO, 2001)

An Illustration: Two Contexts, One Roadway Classification

The disconnect between a roadway's functional classification and its actual context and use can be readily shown through an illustration. Figure 7-4 shows two roadways currently classified as minor arterials, with the roadway on the left being located in an historic, pre-automobile community, while the latter was constructed on an undeveloped suburban site during the last five years. The roadway illustrated on the right meets all the design criteria currently specified in the design guidance – high design speeds, paved shoulders and deceleration lanes to allow turning vehicles to reduce their speed before turning into an adjacent development. This roadway has a posted speed of 45 mph, but can safely accommodate much higher operating speeds. Development along this roadway is set back from the travelway, and accessible only through driveways spaced at intervals of 0.5 miles or more. Turning movements are further controlled through the use of a paved median. In short, this roadway is a textbook example of the type of roadway specified under conventional design guidance – a quasi-freeway design that uses high design speeds, limits land use access, and emphasizes vehicle through-movement.

Yet the same design classification and specifications that direct the design of the contemporary roadway is also used to direct the design of the pre-automobile roadway, a roadway that is patently different in terms of its function, characteristics, and use. Here, intersections are closely-spaced, roadside development is located adjacent to the travelway, and much of the travel it supports occurs through non-motorized modes. Under these design conditions, low operating speeds are warranted, and land use access is (or should be) a major design consideration. Yet the designation of this roadway as an "arterial" results in a design preference for design speeds that are a *minimum* of 30 mph, and preferably greater. Classifying this roadway as an arterial[62] further suggests that the roadway should be designed to limit land use access – an impossibility based on the character of the development located adjacent to the roadway. Attempts to superimpose higher-speed, more "forgiving" designs on such a roadway are unlikely to enhance its safety performance; indeed, such designs will, if anything, have little or no effect on its safety performance, and are most likely to result in an *increase* in roadside and midblock crashes.

Figure 7-4: Historic (Left) and Contemporary (Right) Roadways Classified as "Arterials"

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[62] Prior to the advent of the personal motor vehicle, commercial districts naturally located along major thoroughfares, which were originally intended for horse and pedestrian traffic. In pre-automobile conditions, concentrating commercial activities in high traffic volume locations allowed local merchants to capture pass-by traffic, which necessarily occurred at low speeds (Calthorpe, 1993; Jackson, 1985; Jacobs, J., 1961; Muller, 1995; Mumford, 1961; Oldenburg, 1989; Warner, 1962). Since these roadways were located along major thoroughfares, they were later classified as urban arterials, thereby producing the current design problem – a low-speed roadway with a high-speed definition.

Functional Classification and Systematic Error: A Case Analysis of Orange Blossom Trail

The designs presented in Figure 7-4 were each relatively well-suited to their respective design contexts, and thus represent “pure” illustrations of a livable urban street and a conventional urban arterial. While the differences between these roadways are obvious, contemporary safety practice attempts to superimpose the limited-access design solution represented by the contemporary roadway on all other roadways designated as arterials, an approach that can result in unnecessary crashes and injuries.

The safety problem created by the use of the functional classification system can be readily observed by examining the safety performance of a 4-mile long “context-sensitive” design treatment along Orange Blossom Trail, an arterial roadway located in Orlando, Florida. This section of Orange Blossom Trail connects many of the tourist attractions to the south of Orlando with its downtown business district, and is lined with relatively dense concentrations of hotels, restaurants, retail establishments, and other non-residential activities. In short, it is representative of many arterial roadways in suburban environments. From a passive safety perspective, it should not be particularly unsafe – the cross section consists of 11.5-ft travel lanes, a 12-ft painted median, and 7-ft offsets to roadside objects (see Figure 7-5).

Note that this roadway, like the livable streets examined earlier, must accommodate a high degree of land use access due to the character of roadside development. Unlike the livable street treatments considered in this study, however, it attempts to do so by using conventional design principles, including high design speeds and forgiving roadside applications. Thus, it presents a reasonably representative illustration of a “functionally-defined” arterial common to suburban environments.

Figure 7-5: Orange Blossom Trail in Orlando

As shown in Table 7-1, this roadway is markedly less safe than the livable streets examined in this study. In terms of crashes per million vehicle miles traveled, Orange Blossom Trail is 4 times more likely to experience a roadside or midblock crash than the livable streets considered in this study. On a per mile basis, the ratio increases to being 6 times more likely to experience a roadside crash, and 15 times more likely to experience one midblock.

Table 7-1: Safety Performance - Livable Streets vs. Orange Blossom Trail

	Crashes per 100 MVMT			**Crashes Per Mile**		
	Livable Streets (Avg)	OBT	Ratio OBT/Livable	Livable Streets (Avg)	OBT	Ratio OBT/Livable
Total Roadside	3.3	12.1	3.7	2	12	6
Injurious Roadside	0	5.3	NA	0	5.3	NA
Total Midblock	23.1	102.2	4.4	7	101.1	14.5
Injurious Midblock	18.1	64.6	3.6	5.5	64	11.6

The problem with Orange Blossom Trail, from a safety perspective, is the inherent problem with the functional classification system and passive safety practices – the roadway's design has no meaningful relationship with its developmental context, which in turn determines the types of users that can be found along the roadway, as well as how they can be expected to use it. In other words, the design is ***contextually*** **in*appropriate***. What is particularly egregious about this design is that its designers clearly understood that this roadway was a major commercial thoroughfare intended to provide access to adjacent land uses, as well as to accommodate multi-modal travel. The decision to use "aesthetic" light posts, intersection treatments, and sidewalk coloring represents an attempt to accommodate a diverse set of road users on a "functionally-defined" roadway.

While passive safety advocates might assert that access management principles (i.e., adding a raised median) will resolve the safety problem along this roadway, the types of crashes that occur on Orange Blossom Trail are not likely to be affected by the presence of a raised median. Collectively, head-on and turn-related crashes, the types of crashes that are directly affected by a raised median – account for less than 3% of the total (see Table 7-2). Instead, the key safety problem of this roadway is the result of a design that produces substantial speed differentials between vehicles. Roughly half of the crashes on this roadway are rear-end crashes, which are associated with the presence of driveways on higher-speed roads. Likewise, sideswipe crashes occur when a driver attempts to swerve around a slow lead vehicle and crashes into a vehicle located in the adjacent lane. Collectively, these two crash types account for 60% of the total. Add roadside and pedestrian crashes[63] to the list and the total number of crashes that may have been prevented through a lower-speed, more contextually-appropriate design climbs to 75%.

The safety problem on Orange Blossom Trail stems directly from the fact that the roadway's design is inappropriate for its use, which is a function of its environmental context. There is nothing in the existing design guidance that would suggest that there is a problem with such designs. If anything, current design guidance encourages such designs, thus exacerbating existing safety problems.

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[63] 20 of the 24 pedestrian and bicyclist crashes occurred in the travel lanes, rather than in the center turn lane. Thus, the ability of a raised median to act as a pedestrian refuge island would have had little effect on the pedestrian and bicyclist crash totals.

Table 7-2: Midblock Crash Types on Orange Blossom Trail

Crash Type	**Count**	**Percent**
Rear-End	188	46.4%
Head-On	6	1.5%
Angle	52	12.8%
Left-Turn	5	1.2%
Right-Turn	1	0.2%
Sideswipe	63	15.6%
Pedestrian/Bicyclist	24	5.9%
Roadside	23	5.7%
Other/System Missing	43	10.6%
Total	**405**	**100.0%**

Designing Contextually-Appropriate Roadways

A factor that is unrecognized in the current functional classification system is the role that a roadway's developmental context will have on the types of users that can be found on a given roadway, and well as how these road users will behave. Pedestrians and bicyclists, for example, can be expected in areas where there are reasonably high concentrations of roadside development; the close proximity of compatible land uses encourages pedestrian activity. Further, roadways in areas of dense roadside development can likewise be expected to accommodate substantial vehicle access functions. Where dense roadside development is located adjacent to the roadway, drivers will attempt to negotiate turns to arrive at their intended travel destinations. One cannot assume away these maneuvers simply by classifying a roadway as an arterial; whether classified as a local road or a principal arterial, a trip attraction located adjacent to a roadway will attract turning maneuvers. Where these driveways are located on higher-speed roadways, such maneuvers may result in the systematic errors that produce roadside crashes.

In order to better advance both safety and livability, what is needed is a design approach that meaningfully links specific design applications to the environmental contexts in which they may be most appropriately used. A ***context-appropriate*** roadway, as defined here, is a roadway that is explicitly designed to ensure that it is safe within its given design physical and operating context. Unlike context-sensitive solutions, this approach attempts to enhance safety by first understanding a roadway's physical and operational context, and then designing a roadway to encourage drivers to operate appropriately. While a context-appropriate roadway will often produce designs that are sought by many project stakeholders, and thus result in a context-sensitive outcome, the distinction between these two terms is important. Context-sensitive solutions are concerned with designing a roadway to meet the concerns raised by project stakeholders in the design process, while context-appropriate design is concerned, first and foremost, with transportation safety.

The process through which a context-appropriate road should be designed is relatively straightforward. First, the designer should determine a roadway's developmental context. Next, he or she can then determine the uses and users that are associated with the roadway's enviornment. Finally, the roadway should then be designed to ensure that the design of the roadway clearly communicates information on appropriate behavior to the roadway user. Where higher-speed designs are warranted, conventional passive safety practices can be meaningfully used. Yet there are many conditions, such as in highly-urbanized areas, where such design applications are undesirable. In these cases, the designer should strive to prevent the types of behaviors that result in crashes and injuries through the use of behaviorally-restrictive, rather than forgiving, designs.

A context-appropriate design approach represents a significant departure from contemporary US design practice, and will in some cases encourage designs that are antithetical to what is currently recommended. Yet this approach to addressing safety is better supported by the empirical evidence on road safety, and indeed, is better supported by the knowledge of driver behavior and psychology.

Before discussing the application of this approach, it is important to first begin by stating what this approach implies, and what it does not. First this approach does not assert that roadways cannot or should not be designed for higher-speed mobility functions. For contemporary freeways and Interstates, passive safety strategies are often contextually-appropriate because these roadways are intended for higher-speed operation in environments where roadside access is restricted. The key point of departure for a contextually-appropriate approach to roadway design is that this approach recognizes that there are design conditions where higher-speed, “forgiving” designs will result in a *decline* in a roadway’s safety performance. Thus, a contextually-appropriate approach to roadway design represents a conscious attempt to link the design vocabulary used by the designer with that read and interpreted by the roadway user, with the design objective being to reduce crashes and injuries, rather than emphasize vehicle operations. While this approach is largely unprecedented in the United States, it is very similar to the design approach employed by European designers, who design markedly safer roadways than their US counterparts.

The European Approach to Roadway Design

Before specifically discussing the European design approach, it is worth presenting some basic safety statistics. In 1966, the year that passive safety principles first became entrenched in US design practice, the United States had fewer transportation-related fatalities per capita (26 per 100,000 population) than all other countries except Great Britain (15 per 100,000). By 2000, the fatality rate in the United States had dropped to 15 fatalities per 100,000, but fell even further behind Great Britain (6 per 100,000), and had additionally fallen behind the entirety of the European Union (11 per 100,000), Australia (10 per 100,000), Japan and Germany (8 per 100,000), and indeed, the rest of the developed world (FARS; Statistisches Bundesamt; World Health Organization, 2004). In short, US safety performance in terms of fatalities per capita[64] has fallen dramatically behind its international counterparts, a finding that has led many in the transportation community to begin fundamentally rethinking the current approach to addressing transportation system safety (FHWA, 2001; 2003a; 2003b).

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[64] Contemporary designers might argue that US drivers nevertheless drive more miles per year than their European counterparts. While this may be true, it overlooks the gruesome fact that more people per year are getting killed as a consequence of their travel activity. Asserting that US drivers travel more miles assumes that there is some benefit associated with their doing so. Yet few drivers drive for pleasure; instead, longer-distance travel is necessitated by the physical design of cities and regions in the United States. This travel cannot be regarded as an optional luxury that a driver could elect to forego, but as an activity that is mandated through design. Stating that US drivers travel more miles is little more than a reflection of the fact that U.S. cities and regions have less accessibility and fewer modal options than their international counterparts, thereby forcing US citizens to travel more using a transportation mode that increases their likelihood of being killed or injured.

Unlike designers in the United States, European designers have not embraced the passive safety philosophy (Gladwell, 2001). Instead, European designers use an "environmental reference speed" when designing a roadway, beginning the design process by tightly specifying the appropriate operating speed of a roadway, and then using this intended operating speed as the roadway's design speed, providing posted speed limits that match (Lamm, Psarianos and Mailender, 1999; FHWA, 2001). Roadways are thus designed to be self-explaining and self-enforcing, conveying a single and consistent message to the driver on safe operating behavior.

Further, European designers view high-speed driving as being incompatible with the safe operation of many urban roadways. For all streets with any concentration of roadside development or anticipated pedestrian activity, design speeds are severely restricted, rarely exceeding 50 km/h (30 mph).[65] As a 2001 FHWA scan of European design practice concluded:

> [European] countries have very high safety goals (ranging from zero fatalities to reduction of more than 40 percent for all crashes) that guide the design approach and philosophy. To achieve these goals, planners are willing to provide roadways that self-enforce speed reductions, potentially increase levels of congestion and promote alternative forms of transportation. This approach contrasts with the U.S. design philosophy, in which wider roads are deemed safer, there is a heavier reliance on signs to

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[65] Note that the *highest* design speed regarded as appropriate for the equivalent of an arterial roadway in a European city (30 mph) is also the *minimum* design speed recommended for an arterial roadway under the US functional classification system.

> communicate the intended message, and there is a lower tolerance for congestion and speed reduction (p. viii).

The European approach is achievable because designers explicitly recognize that a roadway's environmental context plays a key role in determining its safe design and operation. German designers, for example, use a 30-celled functional classification system that accounts for not only mobility and access, but also variations in a roadway's design environment and the needs of a diverse set of user groups (See Figure 7-6). Thus, practicing designers are provided with clear guidance on the safe and appropriate design of roadways in a range of physical and environmental contexts.

Under the German classification system, the design solution used for Orange Blossom Trail would have either have been prevented through the use of a lower design speed (Class C IV – 20-25 mph), or else explicitly flagged as being ***problematic*** (Class C II). Further, German designers have placed no prohibitions against the use of livable street treatments on "arterials" in central business districts because they recognize that these designs encourage safe operating behavior. Indeed, the characteristics of the built environment in locations where urban advocates encourage the use of livable street treatments would lead German designers to naturally classify these roadways as belonging to category C III, which has a design speed of 20-30 mph – or roughly the design speed currently used for US livable street treatments. Stated another way, the German system openly recognizes that livable street treatments are highly desirable on roadways located in central business districts and community main streets, an assertion that is supported by the existing evidence on their safety performance.

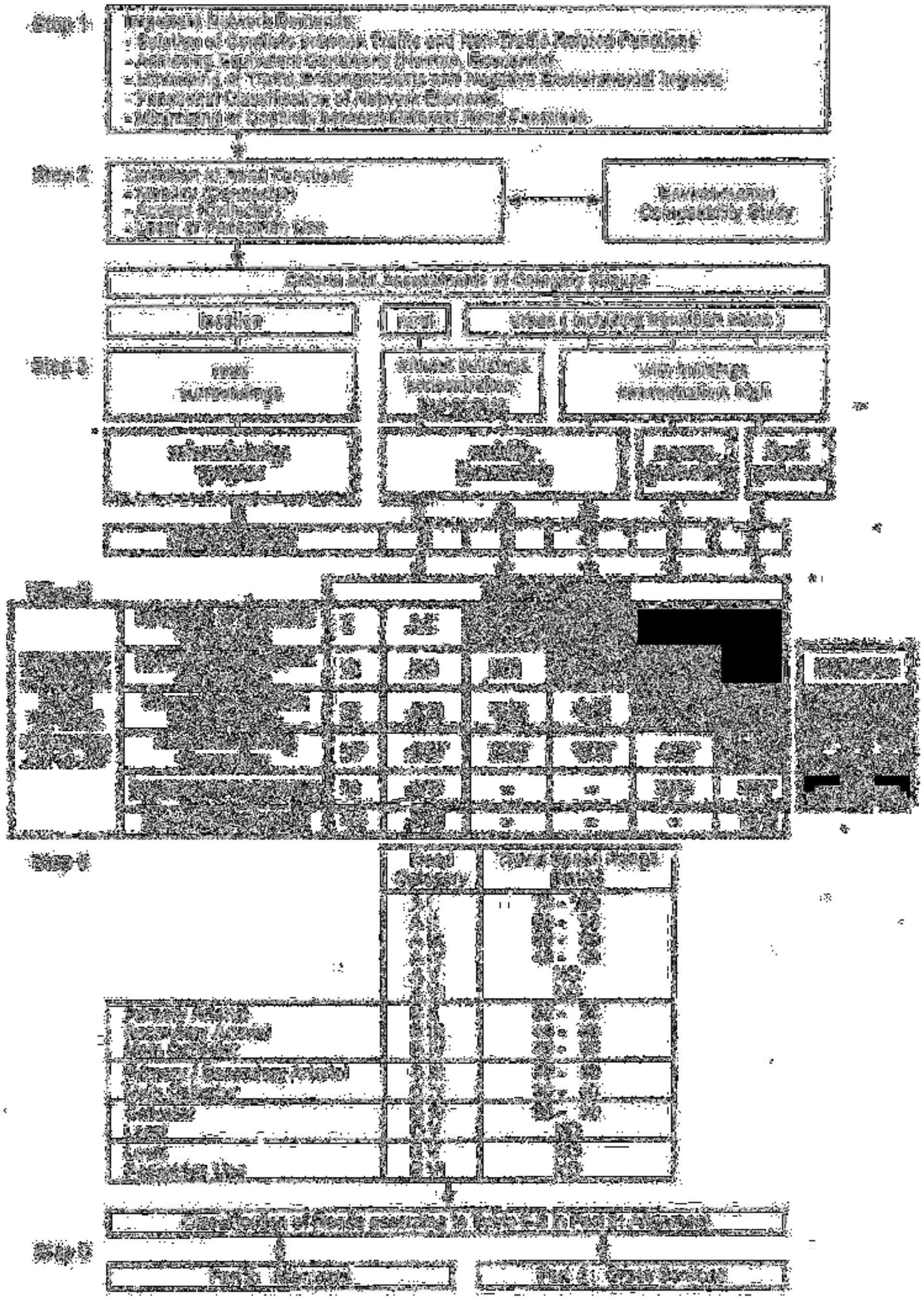

Figure 7-6: German Functional Classification System (Source: Lamm et. al., 1999)

Unlike the coarse, two-context framework provided under the US functional classification system, the German framework provides designers with meaningful design specifications that relate specific design values to specific design contexts. By so doing, German designers are able to design roadways that are not only more appropriate for their respective design contexts, but also markedly safer. Indeed, a citizen on the United States is almost twice as likely to be killed in a transportation-related crash than a resident of Germany, with the United States having roughly 15 fatalities per 100,000 population in 2002, compared to 8 per 100,000 in Germany (Source: FARS; Statistisches Bundesamt). In short, the German system encourages designs that are both safe *and* livable because it recognizes that *safety and livability are often compatible design objectives*.

A Positive Approach to Roadway Design

The idea that safety can be addressed by focusing on a driver's perception of risk, rather than relying on passive engineering principles, is not without precedent in the US engineering community. Two important by-products of the passive safety approach are the related concepts of positive guidance and driver expectancy, which first emerged in the Appendix to the second edition of AASHTO's *Highway Design and Operational Practices Related to Highway Safety* (1974) as a means to address crashes associated with narrow bridges. While emphasizing that the consistent[66] application of freeway

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[66] Design consistency, a term often used by designers to discuss how they address safety through design, also emerged in the 1974 guide, which states: "consistency in design standards is desirable on any section of road, because problem locations are generally at the point where minimum design treatment is used (p.

standards is the preferred solution for addressing safety at narrow bridges, the guide remarks that “it would take years and billions of dollars to effect such a program” (p. 83).

In an attempt to satisfice a lower-cost, more implementable solution, the guidance proposes that “[h]ighway safety can be considerably improved by restructuring the driver’s expectancies so that he is prepared for the narrow bridge situation [and] the narrowing of the shoulder and/or roadside…” (p. 83). The guidance then proceeds to detail how to adequately sign and mark the approach to the “restricted” roadside condition of a narrow bridge.

What distinguishes this approach from contemporary passive safety practices is that, rather than attempting to address safety through “fail-safe” design, it is instead focused on a driver’s risk perception. Under the design scenarios where positive guidance is warranted (e.g., locations with a restricted roadside environment), the objective is to increase the driver’s awareness of the forthcoming hazard to encourage them to adopt behaviors that will reduce their likelihood of being involved in a crash. To date, positive guidance has focused largely on the use of pavement markings and signs to convey safety information, and there has been relatively little advancement in this area since 1990, when the most recent edition of FHWA’s *A Users Guide to Positive Guidance* was published.[67] Nevertheless, it may be time to resurrect this concept, particularly as it may relate to the physical design of highways and streets.

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15). Restated another way, design consistency, as it was originally conceived, encourages the consistent adoption of high design values.

[67] In the 1994 and 2001 editions of the AASHTO’s Green Book, the sections dealing with these subjects contain no data, nor has a word been changed.

The empirical evidence on urban roadway design suggests that the principles of positive guidance may be highly-applicable to the geometric design of roadways – not just signs and pavement markings. Thus, a positive approach to design, like positive guidance, focuses on the needs and abilities of roadway users to enhance a roadway's safety. In the case of positive design, this indicates that the safe and appropriate design of a roadway should be linked to a roadway's environmental context, which in turn determines the types of uses and users that a roadway must serve. A design is successful to the extent that the roadway's design communicates information on appropriate behavior to the roadway user, thereby providing them with the information they need to avoid being involved in a crash.

Towards a Comprehensive Model of Road Safety

Moving beyond design engineering specifically, and considering the subject of transportation safety more broadly, a positive approach to road safety provides a means for comprehensively evaluating a full-suite of transportation safety solutions. Currently there is a professional divide between those strategies that seek to enhance safety by addressing driver behavior, and those that attempt to enhance safety through roadway design (Dumbaugh, Meyer, and Washington, 2004). What is needed is a comprehensive approach to transportation safety that can fully account for the broad array of behavioral and design strategies that can enhance a roadway's safety performance. Figure 7-7, below, presents such a model.

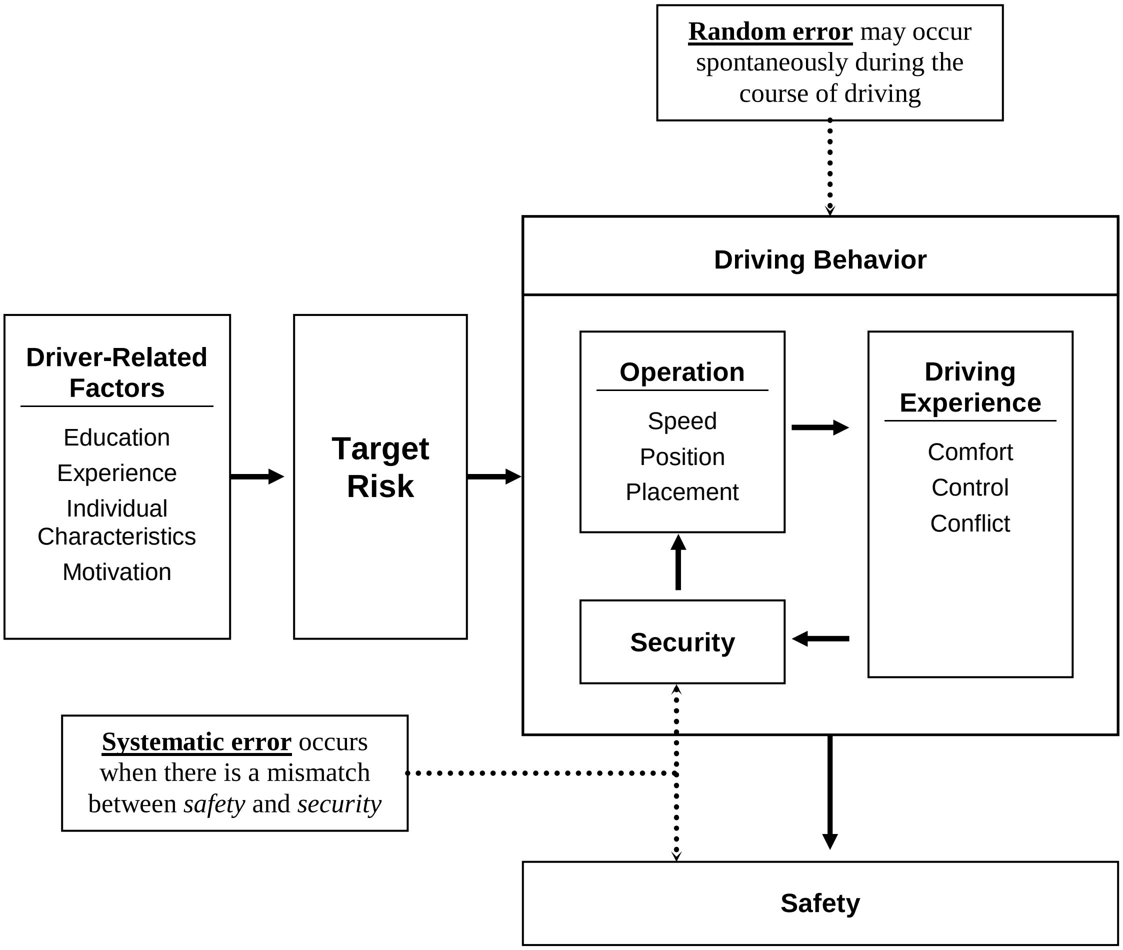

Figure 7-7: A Positive Model of Road Safety

Target Risk

The positive model of road safety depicted in Figure 7-1 is centered on a driver's **target risk**, or the level of risk that a driver uses as a threshold value during the course of their driving activity. As discussed in Wilde (1994), all activities involve some non-zero level of risk that an individual is willing to accept as a consequence of engaging in an activity.[68] Once an individual elects to undertake an activity, such as driving, their target risk level thus directs their subsequent behavior, with the objective of the being not simply to minimize risk, but to maximize the benefits derived from an activity without exceeding their target risk threshold.

Driver-Related Factors

Four major **driver-related factors** function as inputs into a driver's level of target risk. First, education on driving hazards can shape drivers' target risk levels by increasing their awareness of their potential exposure to a crash or injury. Driver education programs often take the form of specific courses intended to provide instruction on safe driving behavior, such as those often offered in high schools or state-funded "traffic schools." In these cases, the educational objective is to increase a driver's knowledge and awareness of the potential hazards of driving, as well as to provide instruction on the types of driving behavior that will help minimize his or her exposure to harm. A second common educational approach is embodied by national advertising campaigns, such as those on the risk associated with driving under the influence of drugs or alcohol. In this case, the educational objective is targeted towards increasing a driver's perception of the risk associated with this activity in the hopes of encouraging them to forego the activity.

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[68] Where an activity is perceived as exceeding an individual's target risk level, the individual will forego the activity altogether if it is possible to do so. This is readily evidenced by the way elderly drivers change their driving activities as their vision and motor abilities decline. For example, many elderly drivers avoid higher-speed routes such as Interstates due to the perception that they can no longer safely drive under these conditions.

Previous driving experience likewise shapes target risk. With greater driving experience, individuals develop subjective assessments of the risks associated with driving, which in turn directs their behavior. Generally speaking, one expects that risk tolerance declines as individuals age, which is evidenced in the fact that the number of people involved in crashes declines logarithmically with age (see Figure 2-1). Nevertheless, there may be exceptions to this rule, such when individuals repeatedly drive while under the influence of alcohol without consequence. Based on such experience, one may begin to believe that the risk associated with this behavior is overstated, and modify his or her behavior accordingly (Van Elslande and Faucher-Alberton, 1997).

Target risk levels may also vary as a result of individual characteristics. Individual characteristics can include demographic factors, such as the higher-risk behavior exhibited by young males,[69] but may also be influenced by psychological characteristics and personality types as well. For example, "Type A" personalities may be more aggressive about accomplishing their travel objectives than other personality types. Likewise, many individuals may be psychologically-predisposed towards higher risk behavior due to decreased concern about harm or injury, or an overestimation of their driving abilities.

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[69] The reasons for higher-risk behavior among young males appears to be biological. Research in the area of developmental psychology, for example, suggests that the portions of the brain the relate to executive-level control (the frontal lobe), and thus risk-assessment and behavior, do not fully develop until an individual has passed through their teenage years (National Institute of Mental Health [NIMH], 2003).

Finally, motivation is also an important factor that shapes an individual's level of acceptable risk. When an individual has an important travel objective to accomplish, such as being on-time for work, he or she may be willing to accept higher levels of short-term risk than under normal, less time-constrained occasions. Alternatively, the presence of a child or loved one in the vehicle may possibly reduce a driver's target risk level out of concern for the safety of the passenger.

Driving Behavior

Collectively, these driver-related factors shape a driver's level of target risk, which in turn directs his or her **driving behavior**. Under the framework presented in Figure 7-1, driving behavior is treated as a dynamic process that involves vehicle operation, driving experience, and subjective sense of security. With an individual's target risk functioning as a static threshold against which driving behavior is based, an individual determines an acceptable operating speed, lane placement, and position in relation to other vehicles or roadway features. The adequacy of vehicle operation is determined through the individual's driving experience, which is a combination of a driver's comfort with his or her current vehicle operation, the degree of control he or she has over the vehicle, as well as the presence of any possible conflicts with other vehicles and/or roadway hazards. This driving experience thus provides the driver with a sense of **security**, or a *perceived* likelihood of being involved in a hazard or injury. Security thus serves as a feedback loop which is used to adjust vehicle operation. Under a positive framework, driving behavior is a dynamic process that may change based on variations in the roadway environment, traffic conditions, or a driver’s perception of their exposure to harm.

Safety and the “3 E’s”

Finally, a positive model of road safety treats safety as an *outcome* of driver-related factors, target risk, and driving behavior, and can be affected by changes in any of the intervening variables. This is a complete model of safety that fully accounts for the “3 E’s” of traffic safety – education, enforcement and engineering. As discussed previously, driver **education** programs can influence drivers’ levels of target risk, and thus serves as an important input that directs their driving behavior. Many of the activities currently carried out under the section 402 program strive to address safety through education and indeed, prior to the 1960s, driver education was viewed as *the* central strategy for enhancing road safety (Gladwell, 2001)

Traffic law **enforcement**, on the other hand, may relate to both driver-related factors, as well as security. From a driver-related perspective, traffic law enforcement may impact a driver’s motivation. Traffic enforcement programs that levy points against a driver’s license can reduce a driver’s acceptable risk level; increased points against a license can result in the negative effects of increased insurance penalties, as well as the possible loss of one’s license. Thus, as points accrue, the driver is provided with increased motivation to minimize their likelihood of receiving an additional motor-vehicle citation.[70]

Traffic enforcement may likewise impact a driver's level of security. The possibility of receiving a traffic citation is treated as a hazard associated with a roadway; where traffic enforcement is known or suspected, drivers will adjust their behavior to minimize their likelihood of being ticketed. A common example of this is the rapid braking movements one observes when vehicles spot a police vehicle parked on the side of a freeway.[71]

Finally, such a model allows strategies that attempt to address safety through design **engineering** to be meaningfully considered as part of a broad suite of transportation safety solutions. As discussed in this study, the design of a roadway has a profound influence on a driver's perception of risk (i.e., security), and their subsequent driving behavior. By designing a roadway to provide drivers with clear instruction on the appropriate operating behavior within a specific design context, it is possible to substantially reduce and even eliminate systematic error, which is a product of a driver's operating behavior.

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[70] The issue of traffic enforcement and motivation also shapes a number of practices common in the trucking and freight industry. For example, overlimit freight vehicles regularly bypass known highway checkpoints to avoid weight violation citations. Further, with mandatory laws restricting the number of hours that a trucker may drive during a single shift and week, many truckers keep two logs of their driving activity – one reporting their actual mileage (truckers are often paid by the mile), and a second, "doctored" travel log that under-reports their actual driving activity, which is used solely in the event that a trucker is stopped by a police officer and forced to account for this or her travel (O'Neill, 2004).

[71] Note that the rapid braking movements associated with a driver's awareness of a police vehicle results in dramatic speed differentials between vehicles. Thus, the presence of a police vehicle may actually increase the possibility of a rear-end collision as the lead vehicles in a speeding platoon will rapidly decelerate to a roadway's posted speed. Vehicles that are following must then likewise rapidly decelerate to account for the reduction in the offset to the lead vehicle.

Implications for US Design Practice

While a positive approach to design represents a fundamental shift in the core assumptions of modern design practice, it is not a wholesale repudiation of passive safety principles. There are clearly conditions where high speed, forgiving design practices are warranted: the safety performance of the Interstate system[72] provides an immediate example of this. But because a certain set of design solutions are appropriate to the design of freeways and Interstates does not mean that they are also appropriate for all other roadways as well. Yet this is the assumption that is currently made by contemporary design practice.

And thus the problem with passive safety. Passive safety is a design paradigm derived from limited observations of Interstates and high-speed rural arterials, and has been subjected to very little empirical testing for its appropriateness in other design contexts. Yet, as currently embodied in design guidance, it is presumed to be a complete theory of roadway design, in spite of a growing body of contradicting empirical evidence. Common sense suggests that it is unreasonable to assume that design practices appropriate for high-speed roadways that exclude non-motorists and do not to provide land access are also appropriate for all other roadway types. Nevertheless, contemporary roadside design practice is based on *exactly* this assumption.

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[72] It is worth observing that the basis for the US Interstate system is the German Autobahn (Ambrose, 1990), which does not use posted speed limits. Since the Autobahn is designed for high-speed travel, it allows high-speed travel. The only criterion applied to travel on the Autobahn is behavioral – vehicles may only pass on the left. As such, it creates an environment where travel is predictable and safe.

What this study adds to the subject of roadway design and safety is a framework for understanding the already-existing empirical evidence. Currently, the wide array of safety “anomalies” have been ignored by US design practice, as has any meaningful consideration of driver behavior (Kannelaidis, 1996). Yet when one examines the subject of road safety as a function of driver behavior, the empirical evidence ceases to be anomalous, and instead reorganizes itself into a meaningful whole.

So what are the negative implications of incorporating a positive approach to design in the US design context? From a practical perspective, the answer is “none.” Such a framework absorbs the coarse functional classification system used by US designers, and provides it with greater detail that better relates the design of specific roadways to their appropriate contexts and uses. It is important to reiterate that this framework does not prohibit the design of high-speed roadways. Orienting design around human behavior, rather than motor vehicle operations, simply provides clear criteria for determining when, and under what contexts, such design applications may be most appropriate.

The only significant implication of this approach is that it will require designers to disinvest themselves of the blanket use of passive safety principles, as well as the erroneous assertion that “safety” and “efficiency” are necessarily compatible design objectives. In exchange, a behavior-based approach provides a means for not only enhancing safety, but a means for enhancing the livability as well. In short, it provides a basis for designing roadways that are safer, more livable, and more readily acceptable to the project stakeholders that represent the core constituency for design professionals.

CHAPTER 8

SAFE STREETS, LIVABLE STREETS: SUMMARY AND CONCLUSION

This dissertation began as an attempt to understand the safety effects of livable streetscape treatments in urban environments. Specifically, it was interested in the degree to which the placement of aesthetic roadside features adjacent to the vehicle travelway would decrease a roadway's safety performance. Yet an interesting finding that emerged in the existing literature on urban roadside safety, and confirmed through an independent analysis conducted as part of this research effort, was that recommended practices regarding the design of "safe" roadsides were not meaningfully related to a roadway's actual safety performance, particularly in urban areas. Further, livable street treatments, which are conventionally regarded as being detrimental to safety because they are "unforgiving" to errors, were found to substantially enhance safety. Indeed, during the 5-year period for which they were examined, *not a single injurious roadside crash occurred on any of the livable streets* considered in this study.

The Passive Safety Paradigm

Because of the radical inconsistency between what is asserted in contemporary design guidance (and perpetuated through transportation design courses), and that which one can reasonably conclude from observations of crash performance, this dissertation further sought to understand *why* design guidance proved to be so incongruent with the existing empirical evidence on roadside safety. Thus, this study also included an historical analysis that sought to better understand the basis for the current assumptions on the relationship between design and safety.

The current approach to addressing safety through design, termed **passive safety** by this study, emerged out of the broader transportation safety movement that occurred in the mid-1960s. This approach assumes that drivers are prone to error, and that driver errors cannot be prevented through a roadway's design. Nevertheless, through the use of high, "forgiving" design values, this approach assumes that it is possible to ensure that drivers are not injured when they commit an error. Thus, by designing a roadway to be safe for a worst-case-scenario driving event, such as a vehicle leaving the travelway at a high speed, this approach assumes that an adequate level of safety can be designed into the roadway.

The low rates of crashes observed on the Interstate system compared to other roadway classes seemed to confirm this theory. Since Interstates used high design values, and also reported low rates of crashes, it seemed logical to infer that use of high design values were responsible for the low rates of crashes. Thus, it was assumed that the application of "forgiving," high-speed design practices would likewise enhance the safety of other roadway types as well. Such a finding further led to an appealing conclusion, one currently embodied in the goal statements of many transportation agencies, which is that a high-speed, "efficient" roadway is also a "safe" one. Thus, the provision of a "safe and efficient transportation system" is often listed as a single, all-inclusive design goal.

Driving Behavior and Systematic Error

The inference that higher, more “forgiving” design values are responsible for the Interstate system’s safety performance overlooks some of the other characteristics of the Interstate system, characteristics that better explain its safety performance than does its use of high design values. First, the Interstate system legally prohibits use by non-motorized travelers, thus limiting its use to a single user class – motorists. Further, and perhaps more importantly, access to the system is severely restricted. Interstate highways do not provide direct land use access, and severely restrict system access through the use of on- and off-ramps designed to account for vehicle acceleration and deceleration. Thus, *the operating characteristics of the Interstate system are radically unlike the operating characteristics of most non-Interstate urban roadways*.

Passive safety practices do not account for a roadway’s design and environmental contexts, contexts that have a profound influence on roadway’s operating characteristics. Instead, the assumption is that since the use of high design values is appropriate for Interstate highways, they must therefore also be appropriate for all other roadways as well. Such an assertion is possible only by assuming that a crash is the product of random, purely unpreventable error on the part of the driver. In other words, passive safety assumes that the driver is singularly responsible for the behavior that resulted in a crash, and that the design of the roadway has little influence on the operating behavior that led to the crash.

Yet one examining roadside crashes in urban environments cannot conclude that these crashes are simply the result of purely random and unpreventable errors on the part of the driver. Instead, there was a clearly discernible pattern to these crashes, a pattern that appears to be strongly influenced by a roadway's design. Between 65-83% of all fixed-objects involved in a roadside crash are located behind a driveway or intersection, rather than at random locations located along the roadway. The behavioral pattern that seems to produce these crashes is that drivers are attempting to negotiate turns into driveways and intersections at the high-speeds designed into the main arterial, a maneuver that causes them to leave the travelway at the back-end of the driveway or intersection. When an object is present at this location, a fixed-object crash occurs.

Were such events purely random, one would expect them to occur randomly along the length of a roadway, with the majority occurring at midblock locations since the majority of a roadway's length does not include driveways or intersections. The fact that the majority of these crashes are located at a very specific location along a roadway suggests that there is a *systematic pattern to roadside crashes*. Systematic error, as defined in this study, occurs when there is a mismatch between what a roadway user perceives as safe operating behavior, and the behavior actually required to safely use the roadway. In the case of urban roadside crashes, systematic error appears to be the direct result of the use of "forgiving" design values along arterial roadways, which encourages drivers to negotiate turns at higher-than-appropriate speeds.

Passive safety does not account for systematic error. Instead, this approach simply assumes that the further back a roadside object is set from the travelway, the lower the probability of a fixed-object crash. Yet the roadside object most likely to be involved in a roadside crash is often not that which is closest to the travelway, but that which is located behind a driveway or intersection. In many cases, *designs aimed at enhancing safety by increasing the offset between an arterial thoroughfare and the nearest roadside fixed object can result in the placement of a roadside hazard in the location where it is most likely to be struck*. As discussed in Chapter 7, roadside safety audits based on passive safety assumptions will often do little to address the actual hazards of urban roadways.

The use of “forgiving” designs along arterial roadways where there are a large number of intersecting streets, or where land access is a major use of the roadway, can further result in drivers traveling at speeds that limit their ability to respond to the vehicle and pedestrian hazards that naturally occur in these environments. As illustrated by the Orange Blossom Trail example, the use of conventional arterial design applications in urbanized environments are not only undesirable from a livability perspective, but also from a safety perspective. Such designs increase the speed differentials between vehicles, resulting in unnecessarily high numbers of rear-end and sideswipe collisions.

Alternatively, the livable street designs, which provide comparable or even better land use access than Orange Blossom Trail using a much-less forgiving design, report dramatically fewer roadside and midblock crashes – 4 times fewer injurious midblock crashes per vehicle mile traveled, on average, and exactly no injurious roadside crashes. To the extent to which safety is measured not by hypothetical passive safety principles, but by crash frequency and severity, there can be little doubt that livable street designs are markedly safer in this design context.

The ability of livable streets to perform similar functions while reporting markedly fewer crashes and injuries is a result of the fact that these designs eliminate the systematic error that produces crashes and injuries – namely, the high operating speeds, that produce speed differentials between vehicles and dangerous turning maneuvers. In short, *under design conditions where land access is a major function of a roadway, or where there are frequent driveways and intersections, lower-speed, less-"forgiving" designs can substantially enhance a roadway's safety*.

A Positive Approach to Roadway Design

To better address the current approach to addressing transportation system safety, this dissertation proposes a new approach to roadway design that better accounts for the existing empirical evidence. The positive model of road safety presented in Chapter 7 is derived from both the available empirical evidence on crash performance, as well as more recent developments in the areas of driver psychology and behavior. Unlike passive safety, however, this model is centered on the way drivers read and interpret a roadway, and adapt their behavior as a result.

Rather than beginning from the erroneous assertion that there is a single "fail-safe" design that can be applied in all design contexts, a positive model of roadway safety is instead centered on a system user's "target risk." Target risk is a psychological concept that asserts that all individuals have a certain level of risk that they are willing to accept in exchange for the ability to engage in a particular activity. An individual's target risk level is thus a static threshold, psychologically-determined, that influences how an individual will behave. The concept of target risk, derived from risk homeostasis theory, asserts that an individual will seek to maximize the benefit derived from a particular behavior or activity up to the point where doing so exceeds the level of risk that they are willing to accept in exchange for the ability to engage in the activity. With respect to driving, risk homeostasis theory asserts that drivers will increase their operating speeds (thereby reducing travel times) until the relative hazard of traveling at higher speeds exceeds the risk they are willing to accept for doing so. A driver’s target risk level thus informs their subsequent driving behavior, which under the positive model of roadway safety is a combination of vehicle operation, driving experience, and *security*, or a driver’s *perception* of harm or hazard. Thus, driving behavior is a dynamic process that can be influenced by a driver’s relative target risk level, his or her level of comfort with operating a vehicle under various design conditions, and his or her awareness or perception of a potential roadway hazard.

Because it is derived from an understanding of the relationship between driver behavior and crash performance, it is better able to explain the existing empirical evidence on safety than is the passive approach. The safety performance of Interstate highways, for example, can be understood in that these roadways both present the appearance that higher-speed driving is safe, and because the overall context and operating conditions of these roadways are appropriate for higher-speed travel. In other words, the driver’s perception of the relative hazard associated with higher-speed travel is meaningfully linked to the actual risk associated with such travel under the design and environmental conditions of the Interstate system. Likewise, livable streets address safety in highly-urbanized environments since they inform drivers that higher-speed travel is hazardous, resulting in drivers adopting lower, more contextually-appropriate operating speeds. Again, the perception of hazard is well-matched to the actual hazards present in the roadway's environment.

Conversely, the design of a roadway like Orange Blossom Trail, which is representative of many suburban roadways in the United States, is not well-matched to its environmental context. The design of Orange Blossom Trail gives drivers *a <u>false illusion</u> of being able to safely travel at high speeds*, resulting in increased rates of crashes and injuries. In this case, the roadway is designed to be "forgiving" to high-speed travel, resulting in increased operating speeds. Yet the problem that emerges is that under the roadway's design condition, high-speed travel will increase a driver's probability of being involved in a crash, or, in other words, that it *increases the likelihood of systematic error*.

The positive model of road safety addresses systematic error by relating a roadway's design to its appropriate use, with the design objective being to provide drivers and other roadway users with clear and consistent information on safe operating behavior. As discussed in Chapter 7, a roadway's safety performance can be understood as a communicative event between a roadway designer and a roadway user. Where designs are successful at providing roadway users with correct information on safe operating behavior, a roadway's safety will be enhanced. When inaccurate or false expectations are communicated by a roadway, systematic errors occur.

There are multiple advantages of the positive model over the contemporary passive safety approach. First, and most importantly, it meaningfully accounts for the actual crash performance one observes on real-world roadways. The positive model is an empirically-driven approach to addressing safety that adequately explains the variations in crash performance that one observes for a wide variety of individual roadways. Further, because it understands safety as a function of driver behavior, it is a complete approach to safety that fully accounts for the 3 “Es” of traffic safety – education, enforcement and engineering. As such, it provides a comprehensive framework for addressing safety that allows practitioners from a host of safety-related disciplines to consider the comparative benefits of a wide array of safety strategies. By defining safety as a function of behavior, it is thus possible to more meaningfully understand the nature of specific safety problems, as well as to link these problems with the types of solutions that are best able to address them.

Future Research

This study has examined the history and literature on roadside safety as it relates to the design of urban roadways, identified current deficiencies regarding the design of roadways in urban environments, and has outlined a viable alternative that may be better able to balance the twin goals of safety and livability. Yet much remains to be done. There is a critical need to enhance professional knowledge on the safe design of non-freeway streets. Researchers must move beyond simply transferring the findings from one environment (rural) or one roadway class (principal arterial) to all others, and to begin systematically developing a **comprehensive language of design** that can be used to relate specific design applications to their appropriate design contexts. The development of such an approach will require researchers to move beyond the use of hypothetical design scenarios, and begin to meaningfully examine how a roadway’s design relates to its environmental and developmental context, as well as how the combination of design and environment encourage or prevent the behaviors that result in crashes.

While Chapter 7 has synthesized the current knowledge in the areas of road safety, psychology, and behavior to provide a theoretical framework for such an approach, and has presented the German functional classification system as a basis for better linking a roadway’s design to its developmental context and safety performance, this should be viewed as a point-of-departure, rather than an end point. To date, there have been relatively few studies that have explicitly examined how the combination of a roadway’s geometric design and environmental context influences a driver’s expectations on safe operating behavior, or the role that such relationships may have on a roadway’s safety performance.

Further, this dissertation has focused principally on one crash type – roadside fixed-object crashes – and has provided only a limited examination into multiple-vehicle and vehicle-pedestrian crashes. Additional research is needed into each crash type to better understand their unique behavioral characteristics, which are currently assumed, rather than known. As this study has demonstrated, broad quantitative analyses must be combined with detailed site investigations of actual crash locations; the over-reliance on aggregate data sets is undoubtedly a major reason why there has been little meaningful advancement in the professional approach to addressing safety during the last 40 years.

More thoroughly examining crashes in a variety of design environments will provide much-needed information on safety in the short-term. Yet over the longer-term, there is a clear need to more fully understand the unique behavioral patterns that result in crashes and injuries. To develop such an understanding, new research approaches are needed. The sections below detail several research strategies that will be able to supply such information.

Examining Behavioral Schemata and Scripts

As discussed previously, systematic error occurs when there is a disconnect between a driver's expectations on safe operating behavior, and the actual behavior necessary to minimize their exposure to injury or harm. Yet little is currently known about how a roadway's design can induce specific expectations, whether correct or incorrect, or indeed, even what these expectations may be. To better advance design practice, research into the schemata and scripts used by drivers to determine their operating behavior is needed.

Examining Schemata

A straightforward study that would advance professional understanding of the schemata drivers associate with particular design environments would be to present individuals with images depicting specific geometric designs in a range of design environments, and then have them report the types of hazards they expect to be associated with each. To corroborate the respondent's expectations with actual hazards, as well as to evaluate their relationship to a roadway's actual crash performance, the images should depict real-world roadways where crash performance and environmental factors are known. For each image, the survey respondent can be provided with a fixed amount of time (as a hypothetical starting point, 3 seconds, which would permit three 300 ms revolutions of the four fixation points used in navigation), after which the respondent is asked about his or her expectancies regarding certain hazards. Table 8-1, below, lists several features that may be included in such a study.

Table 8-1: Elements Included in Schemata-Recognition Study

Do You Expect…	**Yes**	**No**
Trees adjacent to the travelway		
Light posts adjacent to the travelway		
Utility poles adjacent to the travelway		
Bicyclists along the roadway		
Pedestrians along the roadway		
Vehicles turning into a driveway		
Vehicles existing a driveway		
Vehicles present in an adjacent lane		
Vehicles present in the opposing direction		
The presence of a traffic signal		
The presence of a stop sign		

As shown in Table 8-2, each response will fall into one of four categories, which can then be used to determine the ability of a roadway to effectively communicate information on potential hazards, as well as the efficiency with which it does so. Where respondents are able to accurately anticipate features that are present along a road, then the roadway can be regarded as being **effective** at communicating necessary information.

Yet it is important to recognize that there are limits to the amount of external information that an individual can cognitively process. As discussed in Dewar, Olsen, and Alexander (2002), roadway safety can often be enhanced by limiting a driver's need to process unnecessary external information. Thus, a roadway can be said to be **efficient** at communicating information if drivers are not expecting hazards that are not present. Stated another way, a roadway that is communicatively efficient is one that allows drivers to focus exclusively on the actual hazards of a roadway.

Table 8-2: Road Hazards, Road Schemata and Driver Expectancy

	Present	**Not Present**
Expected	Effective	Type B Error
Unexpected	Type A Error	Efficient

Errors occur when a driver's expectancies do not match the actual hazards of a roadway. Here, error is categorized into two types. Type A error is *communicative error*, where a roadway fails to induce expectations on the part of the driver for hazards that are, in fact, present. Type A error would seem to be the type of error that most directly relates to a driver's probability of being involved in a crash. Because a driver does not anticipate a particular type of hazard in the observed environment, he or she is not prepared to engage in preventative behaviors to avoid the hazard.

Type B error is *processing error,* where a roadway encourages the driver to actively search for hazards that are not present. Processing error can result in crashes since it distracts a driver’s attention away from other features of the roadway, thereby limiting the amount of attention that can be directed towards the identification of more relevant roadway features.

Responses can then be aggregated to determine the percentage of respondents correctly identifying the hazards associated with each roadway, which can then be used as independent variables to explain the degree to which correct expectations are associated with a roadway’s actual crash performance. Where there is a great degree of consistency in the expectations across the sampled population, and where such expectancies are meaningfully related to an roadway’s safety performance, the individual roadway can be regarded as a “type” that may be useful as a specific roadway class for future design efforts.

Where a representative cross-section of the population is used in such an analysis, it further permits researchers to determine if expectancies vary for specific subpopulations. For example, while most roadway users may be able to derive correct expectations from a particular roadway, it is possible that certain subpopulations, such as young males, may have incorrect expectations, thus being more likely to be involved in a crash. The expectations of the specific subpopulation can then be examined against its proportional representation in crashes to determine the degree to which such expectations place them at increased risk of hazard or harm. If incorrect expectancies do, in fact, increase their exposure, then safety strategies can be specifically targeted to address this subpopulation’s need.

It is important to note that “safety strategies” do not necessarily equate to “design changes.” Where a roadway is relatively safe for most drivers, strategies aimed at better educating members of the at-risk subpopulation about the hazards associated with specific environments may be more effective, particularly in the short-term, than a substantive redesign. Information on the driver and safety performance of specific populations can provide safety professionals with the information needed to target specific safety countermeasures to specific safety needs.

Identifying Scripts

Scripts relate to the behavioral patterns adopted by drivers based on their expectations regarding safe and appropriate operating behavior. This dissertation has found that many urban run-off-roadway events appear to be precipitated by behavioral scripts that encourage high-speed turning maneuvers, while such events are prevented when a roadway’s design encourages scripts that promote lower-speed operating behavior. While such behavioral descriptions explain observations of crash performance, they do not provide meaningful information on the specific characteristics of driver behavior. What, specifically, are the objects or features that encourage appropriate behavioral scripts? Do certain features, more than others, result in the adoption of appropriate scripts, and do the presence or absence of others result in inappropriate behavioral scripts? The answers to these questions are currently unknown.

Traditionally, it has been difficult to examine the behavior of drivers under varying real-world design environments, both because there are ethical concerns about placing real drivers in potentially hazardous environments, as well as because of the absence of a meaningful framework on which to measure driving performance. Nevertheless, recent technological advancements increasingly provide the means to do so. Advanced driving simulators, such as the National Advanced Driving Simulator (NADS) at the University of Iowa, enable researchers to examine driving behavior under increasingly realistic operating conditions. The NADS system, for example, places drivers in a highly realistic virtual environment, providing not only realistic simulations of a roadway environment, but also providing users with the physical sensation of acceleration, braking, and turning as well. The emergence of advanced driving simulators, combined with human performance monitoring technologies that track and record eye movements and heart rates, make it possible to examine a driver's behavioral and physiological responses to changes in their operating environment. Such technologies thus promise to dramatically increase the professional understanding of the human aspects that affect a roadway's safety performance.

To date, driving simulators have been largely used for driver training and education, or else for conducting studies on the influence of alcohol and age on operating performance. Yet such applications, more broadly used, can also provide important new insights into the relationship between a roadway's design and driver behavior as well. Specifically, it allows researchers to place a broad cross section of drivers into a host of design environments to evaluate how they adapt their operating behavior in response to varying design conditions. Important behavioral questions that can be answered through the use of driving simulators are the following:

- What are the elements of the road and roadway environment that most influence a driver’s choice of operating speed or other behaviors? Variables that can be examined through the use of simulators include:
    - Cross sectional elements
    - Presence of other roadway users (motorized and non-motorized)
    - Presence/absence of specific roadside features (both expected and unexpected)
    - Salience
- What are the objects or features on which a driver is focusing most heavily when navigational errors occur?
- How do drivers adapt their behavior to the presence of *expected* objects or features, and what are their response times?
- How do drivers adapt their behavior (if at all) to the presence of *unexpected* objects or features, and how do response times differ from a driver’s response to expected hazards?

Collectively, the objective of such analyses should be to identify those areas where there is a high degree of behavioral consistency across broad segments of the population. Where there is a high degree of behavioral homogeneity, such patterns of behavior can be regarded as behavioral scripts. Yet simply identifying behavioral scripts is not enough; scripts, by themselves may enhance safety, may have no effect on safety, or may even lead to a declines in safety when the script produces behaviors that increase errors, and thus crashes. Thus, such research should be undertaken with an eye towards their relationship to real-world safety performance.

Linking Scripts, Schemata and Safety

A straightforward means for developing a linkage between scripts, schemata, and safety is to simulate, as accurately as possible, actual roadways for which crash performance is known. For example, the state routes considered in this study could be reasonably simulated to examine how a driver adapts his or her behavior to changes in the design conditions along a roadway’s length. These behavioral adaptations can then be compared against the specific crash performance of individual road segments to determine how, if at all, specific behavioral scripts may influence a roadway’s crash performance.

Further, another important application would be to develop simulations of both high-crash and low-crash locations in various design environments, and examine the differences in operating behavior for each. Such a study would permit researchers to begin to understand the specific types of behavioral scripts that result in crashes and injuries, and will undoubtedly suggest important countermeasures that can be used to enhance safety.

While such research is exciting, there is an important caveat, and one that has not been examined, to my knowledge. Specifically, that while driving simulators can provide increasingly realistic representations of the real world, are not the real world. The lack of meaningful consequences may have a strong influence on a driver's operating behavior. Further, simulations are conducted in conditions where a driver knows he or she is being monitored; a respondent's awareness of being monitored may also influence his or her operating behavior. Nevertheless, the development of a simulated roadway based upon the design of a real roadway will permit researchers to examine the degree to which simulated driver behavior corresponds to actual driving behavior. The observable, external characteristics of the actual roadway, such as its operating speed and headways between vehicles, can be compared with that of the simulated environment to determine the extent to which the two correspond. Where there is a high degree of consistency between the real roadway and its simulation, the simulated roadway can be viewed as a reasonable proxy for the actual roadway. Such an analysis is useful for not only better understanding driver behavior, but may also be used to enhance the quality and realism of driving simulators as well.

Conclusion

At the most basic level, the major tension in the design of urban roadways does not appear to be a matter of balancing safety and livability. As this research has shown, there are many circumstances where safety and livability are mutually-supportive design objectives. There is currently little evidence to support the claim that livable street treatments are less safe than their more conventional counterparts, and a growing body of evidence to suggest that, appropriately used, such designs will actually enhance a roadway's safety performance. Instead, the more basic problem is that safety and livability objectives are often both in direct conflict with the overall objective of mobility and its proxy – speed.

The passive approach to transportation safety began with the observation that the Interstate Highway System produced fewer crashes and injuries than other roadway classes, and attributed this safety performance to the use of higher speed, more "forgiving" design values. Yet it must be recognized that the safety performance of the Interstate system is probably better explained by the fact that these roadways physically restrict access, channelize vehicle movements, and limit their use to a single user type – motorists – than because they permit higher operating speeds.

Conventional safety practice attempts to superimpose these high-speed, limited-access design characteristics on other roadway types, but it is not at all clear that these designs are either safe or appropriate in an urban context. At the most basic level, the primary function of cities, and thus the streets that serve them, is to concentrate compatible developments and activities together and to encourage a high-degree of access between them, traditionally through non-motorized modes. High speed, limited-access roadways are inherently antithetical to these purposes.

Finally, it is important that future researchers do not lose sight of the fact that crashes and injuries are the dependent variables of interest in any study that attempts to address the subject of road safety. Regardless of the internal logic of a given theory of safety – be it the passive theory currently embraced by many practicing designers, or the positive theory detailed in this study – such theories are valid only insofar as they are meaningfully related to observations of a roadway's safety performance. Where empirical observations of crash performance contradict a given design theory, the empirical findings should prevail.

This study has argued that many of the safety concerns that emerge on urban streets result from design practices that that fail to link a roadway's design to its environmental context, thereby providing motorists in urban environments with a false sense of security and increasing their potential exposure to crashes and injuries. It has further provided a theoretical framework that better accounts for existing empirical evidence on roadway safety, and suggested the means through which such a theory can be used to enhance roadway design practice. This study thus concludes with the hope that by better accounting for the relationship between design, driver behavior and safety, we can begin to design roadways that are not only safe, but also livable.

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