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Highway Design, Highway Safety, and Human Factors

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INTRODUCTION

The goals of the highway design engineer include providing roadway facilities which can be safely negotiated by various road users, even under less-than-ideal weather and environmental conditions. To help accomplish this goal, a basic understanding of human characteristics and behaviors as they relate to roadway design features is needed. Road users of interest include not only passenger car drivers, but also drivers of trucks, motorcycles, bicycles, and other vehicles, as well as pedestrians.

The purpose of this paper is to discuss some of the basic safety concepts which are currently known regarding roadway geometric features. Also, gaps in human factors knowledge are identified for which additional research is needed. Roadway features covered include cross-sectional elements (including roadside features), horizontal and vertical alignment, pedestrian and bicycle facilities (including transition curves), intersections, and interchanges. Traffic control devices such as signs, signals, and markings are not covered in this paper.

In discussing each of these topics, it is important not only to concentrate on the "average" driver, but also to point out situations where data exists for certain vehicle types (e.g., heavy trucks) or certain driver populations (e.g., older drivers) which indicate a heightened risk of crash. A major problem here is in defining this heightened risk, due largely to the lack of good exposure data for specific vehicle or driver subgroups. For example, we do not know whether elderly drivers have more problems on horizontal curves than other drivers because of the lack of exposure information on drivers by age in the exposed population. Also, very little exposure data are available on large trucks (by truck size) or pedestrian and bicycle volumes for use in determining the types of roadway features and facilities which affect their safety. Given these problems, the following discussion will explore what is known and what human factors questions remain unanswered.

CROSS-SECTIONAL DESIGN ELEMENTS

Cross-sectional roadway elements are features which are part of a cut-away view of the roadway and include the number of lanes, lane width, shoulder width and type, median width, and roadside design (e.g., roadside slope, placement of roadside obstacles). Elements of a rural two-lane cross-section are shown in Figure 1. From a human factors standpoint, cross-sectional elements can serve several purposes, such as helping drivers to stay in their proper lane (e.g., wide lanes, turn lanes), allowing drivers a place of escape or refuge in an emergency (e.g., wide shoulders and medians), and helping a driver to safely return to his/her lane after leaving it (e.g., mild roadside slopes, paved shoulders).

Not all accident types appear to be affected by cross-sectional elements. From a 1987 study by Zegeer et al. of accident relationships on two-lane roads in seven states, accident types related to lane and shoulder width, shoulder type, and roadside condition include run-off-the-road (fixed object, rollover, and other run-off-the-road), head-on, and opposite and same-direction sideswipe accidents, termed together as "related" accidents. Accident types such as rear-end and angle were not affected by such features. The following is a discussion of several specific cross-sectional elements.

Lanes and Shoulders

The safety literature generally shows that wider lanes and shoulders are associated with reduced accident rates. For example, as illustrated in Figure 2, the number of related accidents (per mile per year) decreases for increases in lane width, or paved shoulder width, based on the seven-state study. A small but significant accident reduction was found from having paved shoulders compared with unpaved shoulders. This study included mostly higher-class two-lane roadways, with traffic volumes generally higher than 1,000 vehicles per day.

While many other studies also support the general trend of reduced accidents for increased lane and shoulder width, one recent study has found evidence that on lower-class, low-volume roads, accident rates may be higher on roadways with 10-foot-lanes (with no shoulder) than on 8- and 9-foot lanes. One possible explanation is that drivers could be slowing down on these very narrow roads (and thus having fewer accidents) and traveling faster on the 10-foot lanes, even though the severe alignment (and hazardous roadside design) on the 10-foot-lane roads is often not adequate to safely handle these higher speeds. Thus, one research issue of interest is:

> What is the nature of driver behavior on various roadway widths, in terms of speeds and lateral placement in their lanes, and how is this behavior affected by roadway alignment?

Concern has also grown in recent years regarding driving behaviors of older drivers. In addition, the accident experience of teenage drivers has long been recognized as a safety problem. One of the issues of concern involves how these two populations of drivers handle their vehicles on roadways with restricted lane and shoulder widths. Therefore, another research issue is:

> Once out of lane, how do different driver groups (e.g., teenagers, elderly) recover? Is there an envelope of recovery angles at different speeds for different driver groups?

Roadside Features

The condition of the roadside is another cross-sectional element which affects crash severity and frequency. This is due to the high percentage of crashes, particularly on two-lane rural roads, which involve a run-off-the-road vehicle. Providing a more forgiving roadside relatively free of steep slopes and rigid objects will allow many of these off-road vehicles to recover without having a serious crash.

In terms of the probability of a crash involving the roadside, studies have shown that greater roadside "clear zones" will greatly reduce crash occurrence. For example, the proportion of related accidents on two-lane roads has been found to be reduced by 13 to 44 percent for increases in roadside recovery distances of 5 to 20 feet, respectively. Flatter roadside slopes were also found to have a substantial effect on single-vehicle accidents. As illustrated in Figure 3, accident rates drop steadily as sideslopes are flattened from 3:1 (i.e. a slope corresponding to a drop of 1 foot for every lateral distance of 3 feet) to 7:1 or flatter. However, very little accident reduction (only 2 percent) is expected from flattening a 2:1 slope to 3:1. The probability of vehicle rollovers is substantially reduced for sideslopes flatter than 4:1.

In addition to crash frequency, the design of roadside features also can affect accident severity. The types of roadside objects which are related to higher crash severities include large trees, wooden utility poles, bridge ends, concrete culverts, rocks and rock walls, and spear-end guardrail terminals, among others. Those objects typically resulting in reduced accident severity when struck by a motor vehicle include sign posts, fences, small trees and brush, and breakaway devices (e.g., crash attenuators, breakaway sign and luminaire poles).

While past research has clearly found roadside conditions to be of major importance in crash experience, most of the needed research involves how to better quantify the accident severity associated with specific types of roadside hardware (e.g., guardrail sections and ends, bridge rails, breakaway luminaire and utility poles, crash cushions and barriers) for various vehicle types, speeds, and impact angles. Also, there is a need to conduct further research to develop and test improved barrier systems which can then be installed in the field to reduce crash severity for all vehicle classes ranging from small cars, vans, and utility vehicles to large trucks.

We know that accident severity can also be greatly affected by the type of vehicle, use of occupant restraints, vehicle speed, and many other factors. Thus, while the highway safety community can urge drivers to wear safety belts, drive within the speed limit, not to drink and drive, buy "safer" cars, slow down on wet roads, and other such actions, it is probably not fruitful to try to train drivers to dodge certain obstacles once they have left the roadway. This is because most fixed-object and rollover accidents occur after a driver has essentially lost control of his vehicle and probably could not steer his way out of the accident. For example, a driver whose vehicle begins to tumble down a steep slope after missing a sharp horizontal curve may have little control over which tree is struck or even whether the vehicle rolls over. Thus, human factors issues of interest do not involve the actual design of the roadside hardware. On the other hand, there are numerous roadway and geometric improvements which can help to reduce the likelihood that the driver will off the road.

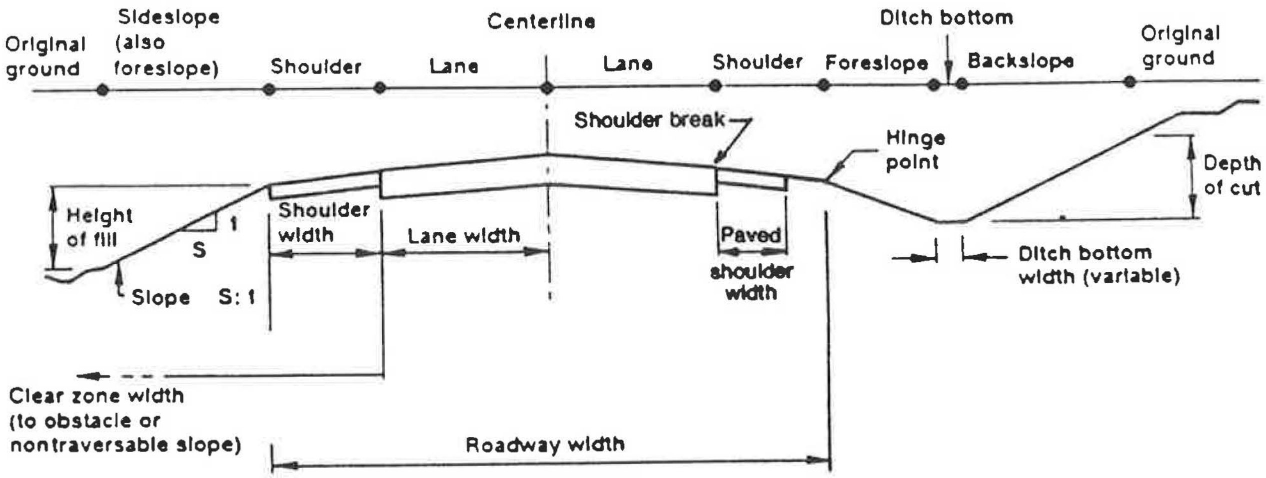


Figure 1. Elements of rural highway cross sections.

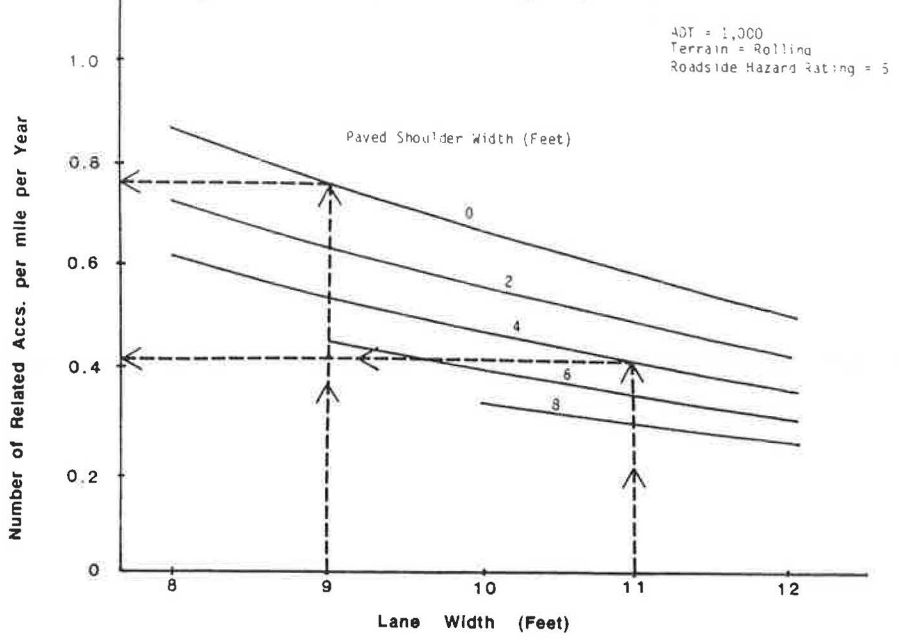


Figure 2. Relationship between accidents and lane and shoulder width.

Therefore, in terms of human factors research needs related to roadside safety, the primary issues of concern include:

1. What causes drivers to leave the roadway in the first place, and what are the probabilities of various roadside encroachment distances for various classes of drivers and vehicles?
2. Further, what types of improvements would be most effective in reducing the probability that a driver will off the road?

Highway Bridges

Highway bridges are sometimes associated with accident problems, particularly rural highway bridges with narrow width, poor sight distance (e.g., a bridge just past a sharp horizontal curve), and/or with inadequate signing and delineation. Numerous studies have analyzed the effects of various traffic control devices (e.g., signs and markings) on crashes and on vehicle operations (e.g., speed change and vehicle placement on the bridge). However, research is scarce on the effects of bridge geometrics on crash experience. The features which are most important in terms of affecting bridge accident rate are bridge width and the width of the bridge in relation to the approach width. The best-known accident relationship with bridge width was developed in a 1984 study by Turner, where an accident model was developed as a function of "relative bridge width" (RW), which is defined as the bridge width (C) minus the width of the traveled way (B) (see Figure 4).

According to Turner's model, and as shown in Figure 5, the number of accidents per million vehicles decreases as the relative bridge width increases. This relationship indicates that it is desirable to have bridge widths at least 6 feet wider than the traveled way. In other words, shoulders of 3 feet or more should be provided on each side of the bridge. Thus, the key human factors questions regarding bridges include:

1. How do drivers react (if at all) to various narrow bridge situations in terms of when they perceive a potential danger?
2. At what point do drivers adjust their speed when approaching a narrow bridge, and what type of traffic control or delineation increases their awareness of the bridge at night?

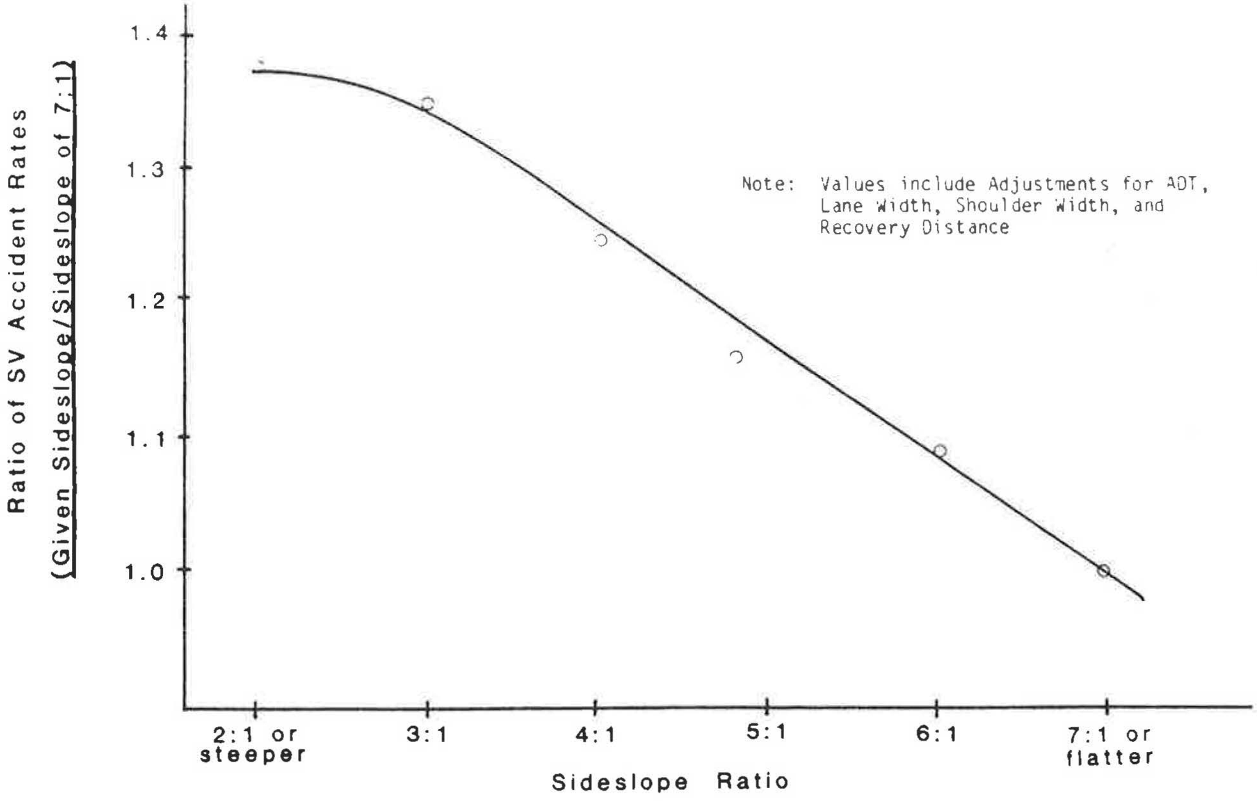
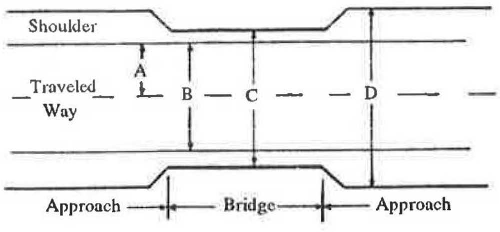


Figure 3. Relationship between accidents and sideslope.



Where:
A = Lane Width
B = Traveled Way Width
C = Bridge Width
D = Approach Roadway Width

RW = Relative Bridge Width
= Bridge Width · Traveled Way Width
= (C-B)

Figure 4. Key elements of a bridge site.

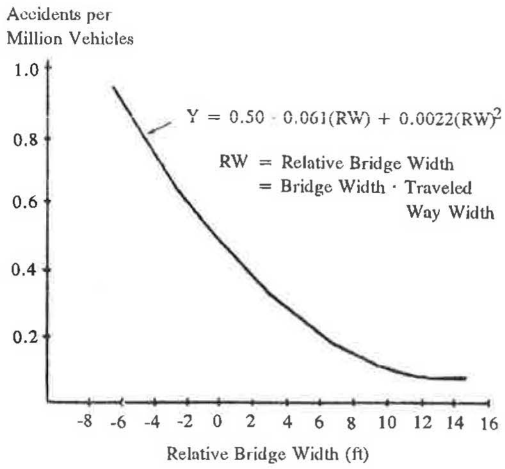


Figure 5. Accident rate by relative bridge width.

Median Design

Elements of median design which may influence accident frequency or severity include median width, median slope, median type (raised or depressed), and presence or absence of a median barrier. Wide medians are considered desirable in that they reduce the likelihood of head-on crashes between vehicles in opposite directions and may reduce other "same direction" crashes by providing an emergency "escape" area. Median slope and design can affect rollover accidents and also other single-vehicle crashes. The installation of median barriers typically increases overall accident frequency due to the increased number of impacts to the barrier, but reduces crash severity by redirecting or eliminating head-on impacts with opposing traffic. A controlling factor in median width is often the limited amount of highway right-of-way which is available.

The two major studies conducted to date on safety effects of median design include those by Foody and Culp (1974) and Garner and Dean (1973). Taken together, the two studies indicate that where a wide median width can be provided (e.g., 84 feet or greater), a mildly depressed median (depressed by 4 feet with 8:1 downslopes) and mound median (3:1 upslope) provide about the same crash experience. However, in cases with narrower medians (e.g., 20 to 40 feet), slopes of 6:1 or flatter are particularly important. Deeply depressed medians with slopes of 4:1 or steeper are clearly associated with a greater occurrence of overturn crashes. While accident relationships are unclear for median widths of less than 20 feet, wider medians in general are better, and median widths in the range of 60 to 80 feet or more with flat slopes appear to be desirable, where feasible.

With these points in mind, some of the key human factors questions of interest related to median design are:

1. How is a driver's perception of the true hazard affected by median width, type, and design?
2. Do medians of certain widths result in underjudgment of true risk?
3. How does the presence of concrete median barriers affect the speed and placement of vehicles in the adjacent lanes?

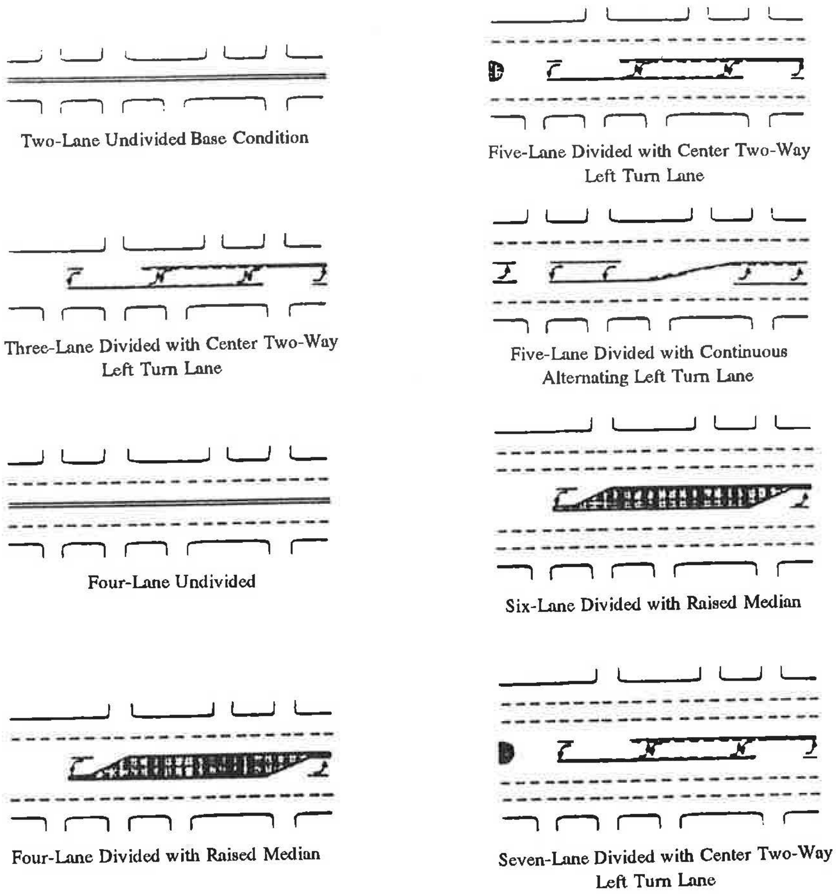
Multilane Design Alternatives

Although most two-lane roads carry relatively low traffic volumes, considerable safety and operational problems exist on some higher-volume roads, particularly in suburban and commercial areas. Various types of geometric treatments have been used to reduce such problems, such as passing lanes, short four-lane sections, turnout lanes, and two-way left-turn lanes (TWLTLs). A 1985 study by Harwood found that TWLTLs can reduce accidents by approximately 35 percent in suburban areas and as much as 75 to 85 percent in some rural areas. Accident reductions of 25 to 40 percent were reported for passing lanes, short four-lane sections, and turnout lanes.

A 1986 NCHRP study by Harwood investigated multilane designs for suburban areas. These designs generally involve adding one or more lanes to a two-lane road design and are generally more extensive than the two-lane undivided road alternatives discussed above. These include designs with between 3 and 7 lanes, where some are divided and some are not, as shown in Figure 6. Based on an accident analysis, the 3-lane design with TWLTL had a safety advantage over the 2-lane undivided design and requires only a minor amount of increase in road width. Four-lane undivided highways had generally higher accident rates than other multilane designs, partly because of the lack of special provisions for left-turn vehicles. Installation of a five-lane highway with a TWLTL was associated with reduced accident rates compared with other four-lane design options.

Several human factors issues should be addressed to help gain a better understanding of multilane design alternatives:

1. How do drivers react to turn lanes?
2. Why do some drivers make their turns from a through lane rather than use a TWLTL or other turn lane?


Two-Lane Undivided Base Condition

Three-Lane Divided with Center Two-Way Left Turn Lane

Four-Lane Undivided

Four-Lane Divided with Raised Median

Five-Lane Divided with Center Two-Way Left Turn Lane

Five-Lane Divided with Continuous Alternating Left Turn Lane

Six-Lane Divided with Raised Median

Seven-Lane Divided with Center Two-Way Left Turn Lane

Figure 6. Multilane design alternatives.

HORIZONTAL ALIGNMENT

Accident studies indicate that horizontal curves experience a higher accident rate than tangents, with rates ranging from one and a half to four times greater than those for tangent sections. Past research studies have identified a number of traffic, roadway, and geometric features which are related to safety of horizontal curves. Those factors related to higher accident frequency on horizontal curves include higher traffic volumes, sharper curvature, greater central angle, lack of a transition curve, narrower roadway, more hazardous roadside conditions, less stopping sight distance, steep grade on curve, long distance since last curve (which can create a driver expectancy problem), lower pavement friction, and lack of proper signs and delineation.

A 1991 study by Zegeer et al. for FHWA found that the types of accidents generally found to exhibit higher percentages on horizontal curves compared with tangents included more severe (fatal and A-type injury) crashes, head-on and opposite -direction-sideswipe crashes, fixed-object and rollover crashes, crashes at night, and crashes involving drinking drivers.

A 1983 study by Glennon et al. investigated many safety and operational effects of horizontal curve features. They found that greater speed reductions for approaching vehicles were found to be associated with sharper horizontal curves. The authors also found that there was a measurable benefit of spiral transition curves, since they drastically reduce the friction demands for vehicles. The study also found that such elements as curve length and sharpness, shoulder width, roadside condition, and pavement skid resistance were important in the probability that a curve will be a high-accident site.

The accident effects of numerous curve features were quantified in the 1991 FHWA study by Zegeer et al., which involved a sample of 10,900 curve sites. Curve flattening can lead to reduced run-off-the-road crashes. For example, from Table 1, flattening a 20-degree curve to 5 degrees on a 40-degree central angle would result in an expected 64 percent reduction in curve crashes. Roadway widening on curves can reduce accidents by up to 21 percent for 4 feet of lane widening (e.g., widening from 8- to 12-foot lanes) and as much as 33 percent for shoulder widening (e.g., adding 10-foot paved shoulders). The presence of spiral transition curves can reduce accidents by approximately 5 percent, while correcting deficient superelevation was associated with a 10 to 12 percent accident reduction.

Based on these and other research findings, some of the primary human factors issues related to horizontal curves include:

1. At what point do drivers perceive a curve, and what are their cues?
2. How do drivers judge the sharpness of a curve before entering? Under what conditions are they underestimating or overestimating curve sharpness?
3. Once on a curve, how do drivers "track" in terms of visual cues? How do distractions (e.g., other vehicles) affect tracking?
4. Do different driver groups track differently (e.g., inexperienced, elderly)?
5. What advanced signing do drivers actually notice? How do drivers perceive and react to roadway delineation, chevron signs, etc., particularly at night?
6. Do drivers track better on spiralled horizontal curve entries and exits compared with curves with no spiral curves? Why or why not?

VERTICAL ALIGNMENT

The vertical alignment of a highway consists of the vertical curves (i.e., sags and crests) and the grades (upgrades and downgrades). While formal safety research on vertical alignment is limited, evidence shows that accident experience is higher on roadways with steeper grades and more severe vertical curves (particularly crests, where sight distance is restricted). Studies have also found large trucks to have particular accident problems on steep upgrades (particularly at night because of higher-speed passenger cars striking the rear end of slow-moving trucks) and long downgrades (where truck brakes fail, causing the trucks to run off the road or run into passenger cars). Certain combinations of vertical and horizontal alignment are believed by some designers and researchers to present particular problems to motorists, although the specifics of this problem have not been properly quantified.

Some of the research questions of concern relative to vertical alignment include:

1. How do truck drivers perceive downgrades? Does a downgrade affect a driver's perception of a horizontal curve?
2. How do drivers (and truck drivers in particular) react to various combinations of horizontal and vertical alignment?

Table 1. Percent accident reductions for curve flattening project.

Degree of Curve		Central Angle in Degrees									
		10		20		30		40		50	
Original (Do)	New (Dn)	Non-Isolated	Isolated*	Non-Isolated	Isolated	Non-Isolated	Isolated	Non-Isolated	Isolated	Non-Isolated	Isolated
30	25	16	17*	16	17	16	17	15	16	15	16
30	20	33	33	32	33	31	33	31	33	30	33
30	15	49	50	48	50	47	50	46	50	46	50
30	12	59	60	57	60	56	60	55	60	55	60
30	10	65	67	64	66	63	66	62	66	61	66
30	8	72	73	70	73	69	73	68	73	68	73
30	5	82	83	80	83	79	83	78	83	78	83
25	20	19	20	19	20	18	20	18	20	17	20
25	15	39	40	38	40	36	40	36	40	35	40
25	12	50	52	49	52	48	52	46	52	46	51
25	10	58	60	56	60	55	60	54	59	53	59
25	8	66	68	64	68	62	68	61	67	60	67
25	5	77	80	75	80	74	79	72	79	72	79
20	15	24	25	23	25	22	25	21	25	20	24
20	12	38	40	36	40	35	40	34	39	33	39
20	10	48	50	45	50	44	49	42	49	41	49
20	8	57	60	54	60	52	59	51	59	50	59
20	5	71	75	68	74	66	74	64	74	64	74
15	10	30	33	28	33	26	33	25	32	24	32
15	8	43	46	40	46	37	46	35	45	34	45
15	5	61	66	56	66	53	65	51	65	50	65
15	3	73	79	68	79	64	78	63	78	63	78
10	5	41	49	36	48	32	48	29	47	28	47
10	3	58	69	50	68	45	67	43	66	42	66
5	3	22	37	15	35	13	33	11	32	11	31

*Isolated curves include curves with tangents of 650 ft (.124 mi) or greater on each end.

3. How do drivers react to various crest vertical curves in terms of their speed profile for mild vs. severe curvature?
4. How much of the vehicle ahead do drivers need to perceive and DO THEY NEED TO judge its speed profile for mild vs. severe vertical alignment?

PEDESTRIAN AND BICYCLE FACILITIES

Collisions between pedestrians and motor vehicles continue to represent a serious safety problem in the United States. In 1989, for example, 6,552 pedestrians were killed, and an estimated 112,000 pedestrians were injured during that same year. In addition, approximately 900 bicyclists are killed and thousands injured in collisions with motor vehicles. While dozens of different types of traffic control measures have been used in an effort to reduce accident risks for pedestrians and bicyclists, little quantitative information is available on the accident effects of specific geometric improvements.

Perhaps the most beneficial facilities for pedestrians are well-designed sidewalks and pedestrian pathways. Research by Knoblauch et al. (1987) has shown a clear safety benefit from such facilities, based on pedestrian accident and exposure data. Based on research in Japan, grade-separated crossings (i.e., overpasses and underpasses) have also been found to reduce accidents involving pedestrians who need to cross major streets. However, the installation of such facilities is quite expensive, and their effectiveness depends largely on their use by pedestrians. Many pedestrians are unwilling to use overpasses or underpasses, because of their inconvenience, the walking distances involved, and the time to cross compared with crossing at street level.

Other geometric facilities which are believed to be beneficial to pedestrians under certain conditions include refuge islands (on wide streets), pedestrian malls, widened lanes and shoulders (particularly in rural areas), and various neighborhood traffic control measures (e.g., traffic circles, cul-de-sacs). Many other types of nongeometric measures (e.g., barriers, overhead lighting, signs, crosswalks, pedestrian signals) have also been used with varying degrees of success.

While various types of signs, signals, and other roadway improvements are sometimes used in an attempt to improve bicycle safety, bicycle lanes and bicycle paths are the roadway measures probably most beneficial in reducing collisions between bicycles and motor vehicles. This is because these two measures allow for separation of bicycles from motor vehicle travel.

Human factors issues may be discussed in terms of the pedestrians and bicyclists themselves, or in terms of how motor vehicle drivers are influenced by these types of highway users. Issues related to pedestrians (which may vary widely by region of the country, ethnic group, sex, etc.) include:

1. What are the walking speeds of various groups of pedestrians (e.g., age group, handicapped pedestrians, joggers)?
2. How well do pedestrians understand the meaning of proper use of pedestrian signals, pushbutton signals, signs, crosswalks, refuge islands, and other measures?
3. How do pedestrians behave when attempting to cross streets at intersections (by type of signal control), or at midblock locations (for narrow and wide streets, with and without medians, by age group, etc.)? For example, how observant are pedestrians of motor vehicle traffic? Do pedestrians practice proper search behavior? Do they cross during the appropriate interval? What is their gap acceptance when crossing roads and streets with no signal control?
4. How do pedestrians behave when walking along roadways at night and during the day in terms of where they walk (placement in the lane, on the shoulder, etc.), the types of routes that they select, the side of the street where they walk, etc.?

Examples of human factors issues for bicyclists (which can also be determined by bicyclist age, sex, region of the country, etc.) include:

1. How do bicyclists behave with respect to their speeds and where they ride their bikes (e.g., on the sidewalk, on the shoulder, placement in the travel lane, etc.)?
2. How do bicyclists behave with respect to compliance with stop signs, yield signs, traffic signals, and direction of travel on two-way and one-way streets and when making right and left turns?
3. What is the understanding by bicyclists of rules of the road and traffic control measures? Does understanding translate into practice? Are there ways to ensure both better understanding and practice?

With respect to motor vehicle drivers and how they are affected by pedestrians and bicyclists, issues include:

1. How do drivers position their vehicles and adjust their speeds when passing a pedestrian or bicyclist on a road with no shoulder (as a function of road width)?
2. How does driver behavior change for various widths of paved shoulder or in the presence of bike lanes?
3. How do drivers react to pedestrians who cross streets in front of them, in terms of their speed profile, recognition of the pedestrians, attitude about pedestrians? Also, what is the general driver understanding of laws and regulations concerning yielding to pedestrians in crosswalks and yielding to them when making right or left turns? Again, does understanding affect practice?
4. How soon do drivers detect pedestrians and bicyclists during daytime and nighttime conditions under various traffic and roadway conditions and for various levels of reflectivity on the pedestrian and bicyclist, headlight illumination, etc.?

INTERSECTION GEOMETRICS

While at-grade intersections cover only a relatively small part of the total roadway network, they represent a large part of the accident problem. Over one-half of the motor vehicle accidents in the nation occur at intersections. As the nation becomes more urbanized, intersection accidents will continue to be a growing part of the total accident problem. Based on research to date, it appears that the severity of crashes at intersections is decreasing slightly over time, perhaps because of the urbanization of society. Crashes at urban intersections are more likely to be at lower speeds than similar crashes at rural intersections, and thus driver injury would be expected to be less.

Based on unpublished data from two states within the Federal Highway Administration's "Highway Safety Information System," it appears that approximately 10 to 15 percent of urban intersection accidents are head-on, turning collisions, approximately 30 percent are right-angle collisions, and approximately 10 percent are rear-end impacts. The same patterns hold true for rural intersections, with the percentage being slightly lower in each of three major categories. Preliminary information has also indicated that when one looks at accidents involving different driver groups at signalized intersections, elderly drivers appear to have more problems than do middle-aged drivers with both left-turning accidents (in which the vehicle turns left in front of an oncoming vehicle) and right-angle collisions. At stop-controlled intersections, elderly drivers are more likely than middle aged drivers to be involved in accidents which involve starting from a stop and turning.

With respect to specific geometrics at intersections, it appears that both stop-controlled and signalized T-intersections (intersections in which one road dead-ends at a second road) have lower accident rates than four-way intersections (intersections in which two roads cross each other) in rural areas. Also, stop-controlled T-intersections have lower rates in urban areas where the intersection handles more than 20,000 vehicles per day. Clearly, part of the reason for this finding is that T-intersections eliminate certain maneuvers (e.g., opposing through and left-turning vehicles on the dead-end road). This reduces the probability of certain crash types such as accidents resulting from vehicles running the traffic signal or failing to yield during a left turn. In short, overall exposure to risk is decreased.

With respect to sight distance (the distance provided a driver approaching the intersection to see a vehicle in the same roadway or coming from a crossing road), poor sight distance was found to increase total accident rate by 15 to 20 percent in one study. It is noted in another study that "specific reductions in accident rate expected from specific increases in sight distance remains open to question." Thus, this issue is still being studied.

A second major design characteristic at intersections is the degree of "channelization" -- the degree to which traffic islands and raised markers or curbs are used to channel traffic into certain patterns. Channelization is often used to provide left-turn lanes by using part of the existing median. There is some indication in the research literature that multivehicle accident involvements do indeed decrease with channelization. In other studies, it appears that for rural intersections, "passing" accidents (i.e., accidents in which a vehicle overtakes and passes a vehicle travelling in the same direction) decrease with left-turn lanes. Passing accidents at intersections would normally involve vehicles attempting to make left turns.

In summary, there are various geometric characteristics that can be modified in the design of at-grade intersections. Unfortunately, we do not know much about the actual effects of left or right turn lanes, channelization, offset T-intersections to replace four-way intersections, minimum intersection spacing in urban areas, or other design changes. In addition, from the human factors perspective, we know little about why drivers are involved in certain types of angle and turning accidents, particularly given that many of these occur at intersections where sight distance is adequate and/or where signalization is present. Thus, from the human factors perspective, the following issues are of interest.

1. In general, intersections are roadway elements where accidents tend to cluster because of conflicting or merging vehicle maneuvers. How do different groups of driver (i.e., by age or experience) perceive possible risks at intersections -- what do they "see" under different levels of distraction (traffic)? More important (from a roadway design perspective), what risks do they not see?
2. Elderly drivers appear to have problems when making left turns (and right turns) at signalized and stop-controlled intersections and when starting from a stop at stop-controlled intersections. Is this due to decreases in gap judgment skills, decreases in perceived visual field, distraction level, or other causes?
3. Most intersections are unsignalized (particularly in rural areas). Current design criteria for intersection sight distance have been questioned in recent years. What are the characteristics of driver gap acceptance (for elderly as well as other drivers) by various traffic and geometric conditions that can be used to reexamine current sight distance criteria?

INTERCHANGES

In contrast to an at-grade intersection in which two roads cross at the same level, an interchange is a system of interconnecting roadways that provides for movement of vehicles from highways which cross each other at different elevations -- one crossing above the other. Many interchange configurations are defined in the American Association of State Highway and Transportation Officials Policy on Geometric Design of Highways and Streets. As shown in Figure 7, the designs include cloverleafs, variations of each of these major types, resulting in twelve or more interchange types that are recognized as "standard" for engineering design. Safety research is focused primarily on the most common types -- diamonds and cloverleafs.

As shown in Figure 8, the components of a cloverleaf interchange include the two main roadways, which are referred to as the "main line" and the crossing route, and a series of ramps which allow turning vehicles to get from one of the roadways to the other. The outer connector ramps allow vehicles to turn right from one roadway and enter on the right side of the other, while the inner loop ramps allow vehicles to exit right in order to make what would be a left-turn maneuver at an at-grade intersection. The area between the ends or terminals of the inner loop ramps is known as the weave section, since vehicles which are entering one inner loop must "weave" in and out with vehicles exiting from the other nearby inner loop. Additional components of interchanges include the acceleration and deceleration sections that are found at the ends of each of the outer connection ramps.

With respect to overall geometric design, some research indicates that urban interchanges have a higher accident rate per million vehicles than do rural interchanges in general, particularly at entrance ramps (i.e., the end of a ramp where a vehicle is entering the main line or crossing route). This higher rate is probably due both to increased conflicts resulting from the increased traffic flow and also to the inadequate length of the acceleration and deceleration lanes that are usually found in urban areas where space for interchange design is limited.

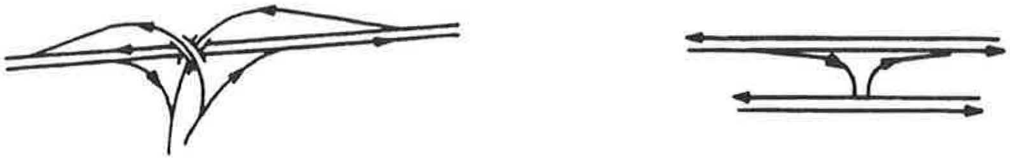
It is fair to say that most of the accident problem with interchanges is related to the design of the inner and outer ramps. With respect to the inner loop ramps, research indicates that the sharper the ramp and the more traffic that is on it, the higher the accident rate. For the outer connector ramps, exit ramps (where vehicles are leaving a roadway) appear to have a higher accident rate than do entrance ramps. This is probably due to the large numbers of vehicles that exit the main line and enter off-ramps at high speeds and must then decrease their speed rapidly to safely traverse the ramps. It also appears that upgrade off-ramps have lower accident rates than do downgrade off-ramps. Thus, because most of the traffic entering ramps usually comes from the freeway rather than from the crossing route, it is desirable for the freeway to always pass underneath the crossing route such that all exit ramps from the freeway are going upgrade rather than descending.

There are also interchanges in which traffic must exit from a roadway on a left-side ramp. Research has shown that such left-side ramps have higher accident rates than do right-side ramps. This is probably because they violate driver expectations of the side on which ramps should be diverging and merging.

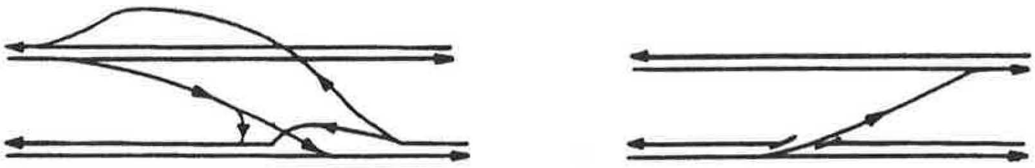
One of the key issues related to freeway interchange design involves heavy truck accidents at interchanges. It appears that truck accident rates are higher on both loop and outer ramps than are the rates of other vehicle types, and that these increased rate are due both to truck skidding and to truck rollover crashes.

Diamond **Trumpet**

Cloverleaf **Cloverleaf with collector-distributor**



Direct Connection **Buttonhook**



Scissor **Left Side**

Figure 7. Typical interchange designs.

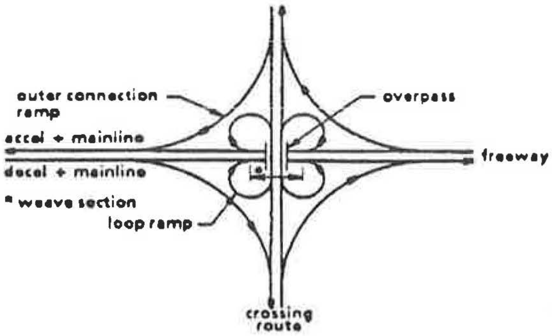


Figure 8. Cloverleaf interchange elements.

Finally, in urban areas where interchanges must carry very high volumes of turning traffic, it appears that the use of collector/distributor roadways enhances safety. These roadways require all turning vehicles to exit the main line prior to the interchange proper and allow these vehicles much longer diverge and merge areas at lower speeds than is the case with the standard cloverleaf. While such interchanges may violate, to some extent, driver expectation of what a standard (cloverleaf) interchange looks like, it appears that the benefit from the separation of the inner-loop merging and diverging vehicles from the main flow on the freeway outweighs any problems resulting from unmet driver expectations.

Thus, with respect to interchanges, the human factors issues of interest are as follows:

1. It has been hypothesized that elderly and inexperienced drivers have problems merging at interchange on-ramps. Is this true, why?
2. Many drivers have problems in the merge area on cloverleafs when attempting to merge right to exit. What are the major human factors causes of these particular problems?
3. Heavy trucks appear to experience increased risk of crashes on interchange ramps. Are there perception, judgment, or other problems which lead to these safety problems?
4. Many drivers have problems in the merge area on cloverleafs when attempting to merge right to exit. What are the major human factors causes of those problems?

CONCLUSION

Highway safety is influenced heavily by highway design features and the interaction of various human factors on these features. Roadway design features include cross-sectional design (lane and shoulder width and type, roadside features, highway bridges, median design, multilane design alternatives), horizontal and vertical alignment, pedestrian and bicycle facilities (sidewalks, bike lanes, and paths), intersection design, and interchanges. Safety relationships have been developed with many, but not all, of these roadway design elements. However, much human factors research is needed to help us better understand road users so we can design and upgrade roadways for enhanced safety and mobility.

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RECENT ACCIDENT TYPOLOGY RESEARCH

Recent Research in Developing Accident Typologies

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INTRODUCTION

The identification of Intelligent Vehicle/Highway Systems (IVHS) as a national priority has rekindled interest in collision avoidance. Collision avoidance, however, is much broader than IVHS. Similarly, the topic of this symposium, Human Factors in Highway Safety, is also much broader than IVHS. A positive aspect of this new IVHS interest may be that the seemingly unlimited potential of advanced technology will stimulate us to take a new approach to these issues. Recently, we at UMTRI have been looking at existing accident data to see if new approaches could be developed that would provide information to support the development of advanced technologies for collision avoidance. Such an approach necessarily focuses on the precollision events, which is also the area dominated by human factors. Thus, the Federal Highway Administration felt that even though the original work was intended to address vehicle-based collision avoidance technology, the findings may also be relevant to this conference. The conference break-out groups are organized around four collision types, taken more or less, from a collision typology presented in a recent paper (Campbell, 1991). My presentation here is intended to summarize the development of the typology and provide available accident data on the four collision types that have been selected as the focus for this workshop.

The objective of collision avoidance research is to identify countermeasures that will prevent the collision. Thus, the focus is on the precollision sequence of events to identify opportunities for intervention. There is a problem with using existing accident data for this research because the focus of the accident data elements is primarily on the most harmful event. While this focus is appropriate for the analysis of vehicle crashworthiness, the most harmful event is often *not* the initiating event. Collision-type coding based on the most harmful event can be misleading if one tries to infer the precollision events. The approach that will be described here tries to work around the limitations of existing accident data. The objective is to group collisions with common precollision characteristics.

METHOD

The approach seeks to develop a list of collision situations ranked according to the potential benefits of collision avoidance and a characteristic sequence of events for each. This information will support the identification of opportunities where intervention has the potential to prevent or mitigate the collision and the nature of the required intervention. The steps in the proposed method are summarized below.

1. Define relevant collision situations (types).
2. Rank the collision types by the potential benefits of collision avoidance.
3. Identify contributing factors associated with each collision type.