Safety Planning Study of an Urban Freeway-
Proposed Methodology and Review of the Case History

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Abstract

Safety-conscious planning is a relatively new concept. It was developed in response to safety related provisions of the Transportation Equity Act for the 21st Century (TEA-21) of 1998 that required explicit consideration of safety in the transportation planning process.

This paper will revisit the problem of using accident rates in transportation planning and review a case history of applying safety-conscious planning methods by the Colorado Department of Transportation (CDOT). A two-phase process that has been used to evaluate the safety impacts of multiple design alternatives is introduced. The evaluation process is based on the available Safety Performance Functions calibrated specifically for urban freeways in concert with diagnostic investigations, pattern recognition analysis and detailed accident diagramming. The critical importance of accident diagramming is discussed in reference to examining safety history at complex interchange locations.

Introduction

A number of major freeway corridor planning studies are currently under way in the Denver metropolitan area. The primary effort of these corridor studies is focused on providing additional mobility, while considering safety, to meet growing travel demand along the Rocky Mountain Front Range. How to deliver this increased mobility utilizing multimodal transport facilities is a matter of some debate, yet the underlying methodology is reasonably well understood and accepted at present. How to provide safety, however, is not as well understood and is the subject of this paper.

What is the best way to measure safety? How much safety for how much money can we expect? Are roads that are designed to standards as safe as they should be or as safe as they can be? These fundamental questions have not been answered with the kind of accuracy customary in the engineering discipline.

At the same time we seek definitive answers to basic questions on highway safety, the Transportation Equity Act for the 21st Century (TEA-21) currently requires the explicit consideration of safety in the transportation planning process. While this government mandate is well intentioned, little is known about how best to fulfill it. Hauer observed: *Today one can devise a long term transportation plan for a region, one can get approval for a road network in a new subdivision, one can implement a traffic signal coordination and timing plan for a metropolis, one can design a new highway and, in all this, never consider the future crash frequency and severity differences between options and alternatives.(1)*

The National Environmental Policy Act (NEPA) requires that for each transportation alternative under consideration, environmental impacts are identified and mitigation options described clearly within the framework of an Environmental Assessment (EA) or an Environmental Impact Statement (EIS). In contrast to this environmental approach, the safety impacts of design alternatives are not addressed explicitly, but rather by proxy of meeting standards. *Even when design standards are met, however, different alternatives provide different levels of safety.*

We realize that road safety is always a matter of degree, but are efforts to provide an adequate level of safety on a transportation facility less important than those targeting environmental protection? It seems to make sense that the evaluation of multiple design alternatives includes a rigorous assessment of their safety impacts. Such a safety assessment could be a critical factor in selecting the superior design option and, concurrently, satisfy the safety obligations of TEA-21. Safety Assessments specifically evaluating the safety impacts of design alternatives are now a standard practice at the Colorado Department of Transportation (CDOT) when planning transportation improvements. This paper will present a practical methodology used at CDOT for the explicit consideration of safety in planning freeway corridor projects and review a case history.

Problems with Using Accident Rates as a Measure of Safety In Transportation Planning

A recent study by Ravanbakht, Belfield and Nichols *(2)* compiled an extensive regional crash database in Virginia to assist with regional planning. The authors collected accident data for 130 miles of interstate highway and 13,000 intersections. Following crash data collection, the freeway and intersection sites were ranked by descending weighted accident rate. Use of accident rates implies a linear relationship between traffic exposure and the number of accidents, which is not always true. Substantial empirical evidence derived from observing the safety performance of various roads by Kononov and Allery *(3)*, as well as others, suggests that accident rates decline when AADT reaches a certain threshold unique to a particular facility. The study by Ravanbakht, Belfield and Nichols represents a good starting point, however, the use of accident rates for ranking what can be called "sites with promise for safety improvement" would always lead to placing those sites with lower AADT at the top of the list.

The following case history is intended to illustrate problems inherent in using accident rates as a measure of safety. A section of 2-Lane, rural, mountainous highway in Colorado exhibited the following accident history and accident rates during a study period from 1988 through 1995 over a distance of 5.85 miles. The accident rates, measured in accidents per million vehicle-miles traveled (acc/mvmt), were computed as follows using equation 1 and are tabulated in Table 1.

$$Accident\ Rate = \frac{(\#\ Accidents)(1{,}000{,}000)}{(365\ Days)(AADT)(5.85\ Miles)} \qquad (1)$$

Before Gambling				
Year	**Number of Acc.**	**AADT**	**Rate**	**Avg Rate**
1988	13	2,900	2.11	2.28
1989	11	2,900	1.79	
1990	13	3,050	2.01	
1991	23	3,400	3.19	
After Gambling				
Year	**Number of Acc.**	**AADT**	**Rate**	**Avg Rate**
1992	30	10,618	1.33	1.24
1993	30	13,200	1.07	
1994	36	14,300	1.19	
1995	40	13,900	1.36	

Table 1 Accident History and Rates Table

In 1992 the mountain town located at the end of the highway section opened gambling casinos and virtually over night the traffic volume experienced on the highway section quadrupled.

During the 4 year period prior to opening the casinos, the average accident rate was 2.28 acc/mvmt. The following 4 years after legalization of gambling in this mountain town, the accident rate was reduced by almost 50%. The alignment and typical section of the highway did not change with the introduction of gambling, yet by measuring safety with accident rates we could surmise that following the opening of the casinos, safety on the same highway improved by 50%. Further, it is of interest to note that following gambling, the proportion of accidents involving alcohol increased 5 times. This begs the question - *Is drinking and driving in concert with gambling good for safety?* Probably not, but if accident rates are used as a measuring device one would have to conclude that it is. In his work *Physics and Philosophy (4)*, Heisenberg observed: "*Since the measuring device has been constructed by the observer…we have to remember that what we observe is not nature in itself but nature exposed to our method of questioning.*"

The case history presented above clearly shows that accident rates change with AADT and suggests that a measuring device other than accident rate should be used to measure safety.

Hauer and Persaud *(5)* introduced a more objective measure of safety using Safety Performance Functions (SPF). SPFs, in essence, are accident prediction models, which relate traffic exposure, measured in AADT, to safety, measured in the number of accidents over a unit of time. Details concerning dataset preparation and model fitting for the development of Safety Performance Functions (SPF) are described by Hauer *(6)*, Lord, Washington and Ivan *(7)* and Kononov and Allery *(3)*. The model parameters in the current study were estimated by the maximum-likelihood method in the Generalized Linear Modeling (GLM) framework using a dataset containing 10 years of accident history. In all cases, accident data in the urban area exhibited extra-variation or over-dispersion relative to the Poisson model.

Development of the SPF lends itself well to the conceptual formulation of the Level of Service of Safety (LOSS). The concept of level of service uses quantitative measures to characterize the observed safety of a roadway segment in reference to the safety performance expected for similar types of roadways. If the level of safety predicted by the SPF represents the normal or expected number of accidents at any specified level of AADT, then the degree of deviation from this norm can be stratified to represent specific levels of safety. The delineated level of service of safety boundary line is located 1.5 standard deviations from the expected line or SPF. In selecting 1.5 standard deviations in a Poisson or negative binomial structure we were seeking to identify both those segments of highways with some potential for accident reduction and those segments performing well. Alternatively, stratifying the dataset by 2 or more standard deviations would distinguish only extreme or unusual cases. Four Levels of Service of Safety (LOSS) were proposed by Kononov and Allery in *(3)*:

- *LOSS-I - Indicates low potential for accident reduction*
- *LOSS-II - Indicates better than expected safety performance*
- *LOSS-III - Indicates less than expected safety performance*
- *LOSS-IV - Indicates high potential for accident reduction*

While LOSS defines the magnitude of the safety problem, it is important to understand that accident patterns may exist without over-representation in total frequency or be readily detectable by SPF methods. The LOSS concept is widely used by the Colorado Department of Transportation (CDOT) in system-level planning as well as project scoping and is described in Kononov and Allery *(8)*.

Level of Service of Safety (LOSS) reflects how a roadway segment is performing in reference to its expected accident frequency and severity at a specific level of AADT. It only provides a comparison with the expected norm. It does not provide any information related to the nature of the safety problem itself. If a safety problem is present, LOSS will only describe its magnitude. The nature of the problem is determined through diagnostic analysis using direct diagnostics, pattern recognition techniques and accident diagramming in concert with site visits and plan reviews. In the course of the in-depth, project-level safety study of hundreds of locations, a comprehensive methodology was developed to conduct diagnostic analysis of safety problems for different classes of roads in various environments. Direct diagnostic methods and a pattern recognition algorithm are described in Kononov *(9)*, and Kononov and Janson *(10)*.

Case History Review and Benefits of Accident Diagramming

Several NEPA studies examining existing urban freeway corridors are currently under way in the Denver metropolitan area. As part of these studies, the traffic safety impacts associated with the work are considered. The safety provisions of one study will be reviewed, as a case history, from the standpoint of addressing safety in an Environmental Impact Statement (EIS) context.

The study involves two heavily congested, older, 6-lane, urban freeways: Interstate 25 and 6th Ave. freeway or State Highway 6 (SH 6). When planning safety improvements for an existing corridor, it is necessary to identify the nature and magnitude of the present safety problem.

The magnitude of the problem is determined using the Level of Service of Safety (LOSS) concept. Its use makes it possible to accomplish the following:

- Quantitatively and qualitatively describe the degree of safety or lack of safety on a roadway segment.
- Effectively communicate the magnitude of the safety problem to other professionals or elected officials.
- Bring the perception of roadway safety in line with the reality of safety performance reflecting a specific facility.
- Provide a frame of reference for decision making on non-safety motivated projects.

The nature of the safety problem, again, was described through diagnostic analysis using direct diagnostics, pattern recognition techniques and accident diagramming in conjunction with site visits and plan reviews.

To conduct direct diagnostic and pattern recognition analysis in complex areas typical of urban environments we must resort to accident diagramming. It will become obvious from the case history presented later in this paper that without detailed accident diagramming it is virtually impossible to identify and define problems related to interchange ramps and ramp connected intersections.

The safety chapter of the EIS encompasses two phases. Phase I will prepare a framework for the evaluation of alternatives from a safety standpoint and accomplish the following:

- Assess the magnitude and nature of the safety problem within the project limits.
- Relate accident causality to roadway geometrics, roadside features, traffic control devices, traffic operations, driver behavior and vehicle type.
- Suggest cost effective counter measures to address identified problems.
- Provide guidance on how to identify the preferred alternative from a safety standpoint.

In Phase II we will assess how well each alternative addresses safety problems identified in Phase I. The extent to which these problems are addressed is quantified by the estimated accident reduction for each design alternative. The estimated accident reduction for each design alternative is based on the nature and magnitude of the existing safety problem and its susceptibility to correction. These estimates are inherently associated with some degree of uncertainty, yet we believe this approach will allow us to identify design alternatives that are more safe than others. The estimated accident reduction for each design alternative is based on the nature and magnitude of the existing safety problem and its susceptibility to correction. Considering format and size requirements of this paper, only selected elements of Phase I and Phase II of the EIS safety chapter will be examined.

Development of accident prediction models has always attracted the interest of traffic safety researchers. It offers opportunities to obtain research grants, it provides data collection for writing doctoral dissertations, and is on the forefront of national efforts in road safety research. It is also a subject of numerous papers published by the Transportation Research Board (TRB).

If a good accident prediction model (SPF) is developed, what are its uses? We can use it in transportation planning for new and existing highways. We can use it as a tool to identify problem areas or "sites with promise" or we can compare its predicted values with observed accident frequency within project limits. Its use however does nothing to help us with understanding the nature of the problem itself.

Diagnostic investigation into accident causality is necessarily informed by accident diagramming. Accident diagramming is an underappreciated task, yet a critical one. Traditionally, the task of accident diagramming has been assigned to the junior level technicians and is institutionally undervalued. Its importance, however, can't be overemphasized. Its benefits are no less significant than the benefits of developing good accident prediction models. When it comes to ramps and ramp related intersections, accident diagramming should be done by carefully reading accident reports and then plotting accidents and related information on the interchange layout.

Phase-I Safety Assessment

Figure 1 shows the EIS study region for the I-25/SH 6 freeway area.

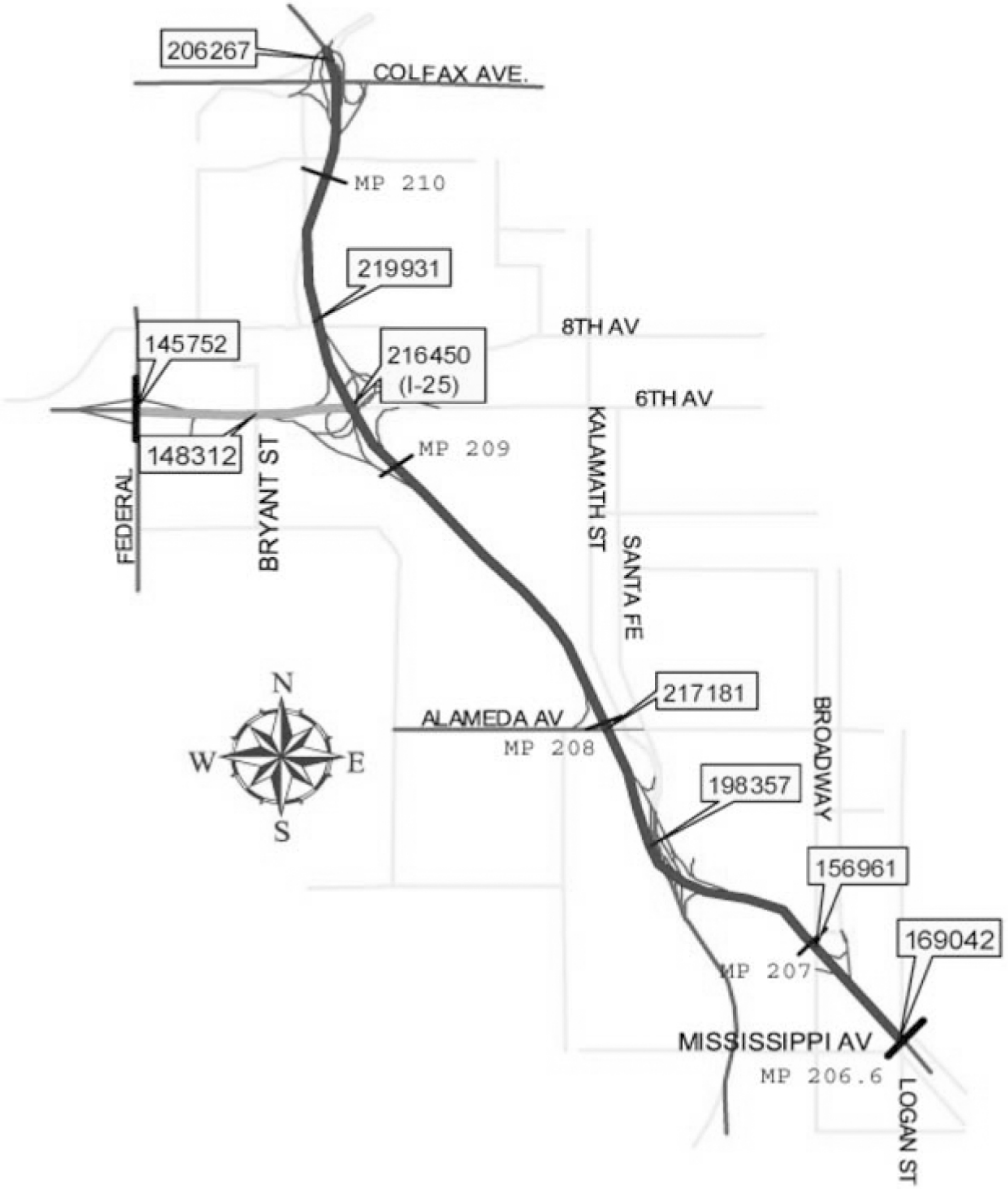

Figure 1 EIS Study Region with AADT

The overall study area was partitioned into shorter segments and collision data (covering a 3-year period) for each segment was plotted on appropriate SPF graphs for evaluation. The ordinate value of the plotted points corresponds to the number of accidents occurring within each segment divided by the segment length, in miles and the study period, in years. SPF analysis is made for both total accidents and for injury + fatal collisions.

Figures 2 and 3 display the SPF (total accidents and severe accidents, respectively) calibrated specifically for 6-lane, urban freeways together with plotted points representing the observed average three year crash history. Segment lengths range between 1 and 1.4 miles.

From figure 2, it can be observed that all three I-25 sections are LOSS IV (*high potential for accident reduction*). Since we have so few segments of urban 6-lane freeway with continuous auxiliary lanes and carrying in excess of 200,000 cars per day in Colorado, it is difficult to predict the expected safety performance with confidence. Even when this uncertainty is taken into consideration, accident frequency in excess of 180 accidents per mile per year suggests a high potential for accident reduction in our opinion. The SH 6 section is performing at the upper bounds of LOSS III and is approaching LOSS IV.

The SH 6 safety problem largely manifests itself in the eastbound direction exhibiting an accident frequency three times greater than that in the westbound lanes as shown in figure 4. This unbalanced distribution of accidents suggests significant problems susceptible to correction. It seems that safety performance is heavily influenced by interchange spacing, even though ramp accidents are deleted from the model. The spacing of interchanges, and therefore, ramps on the I-25 and SH 6 study sections is less than at other urban locations. This is a partial explanation for the elevated accident frequencies in the study area.

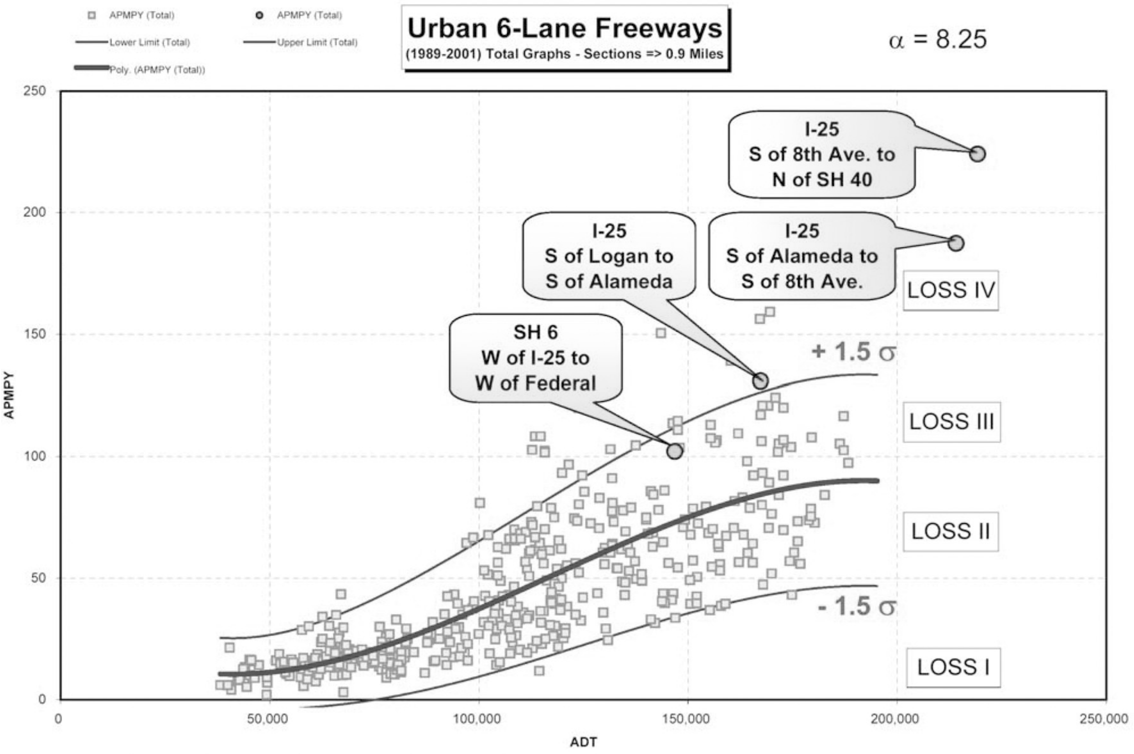

Figure 2 Urban 6-Lane Freeway SPF (Total Accidents) (APMPY = Accidents Per Mile Per Year)

Figure 3 depicts the SPF graph calibrated for injury and fatal accidents only. The result of this analysis closely approximates that of the total accident analysis shown in figure 2.

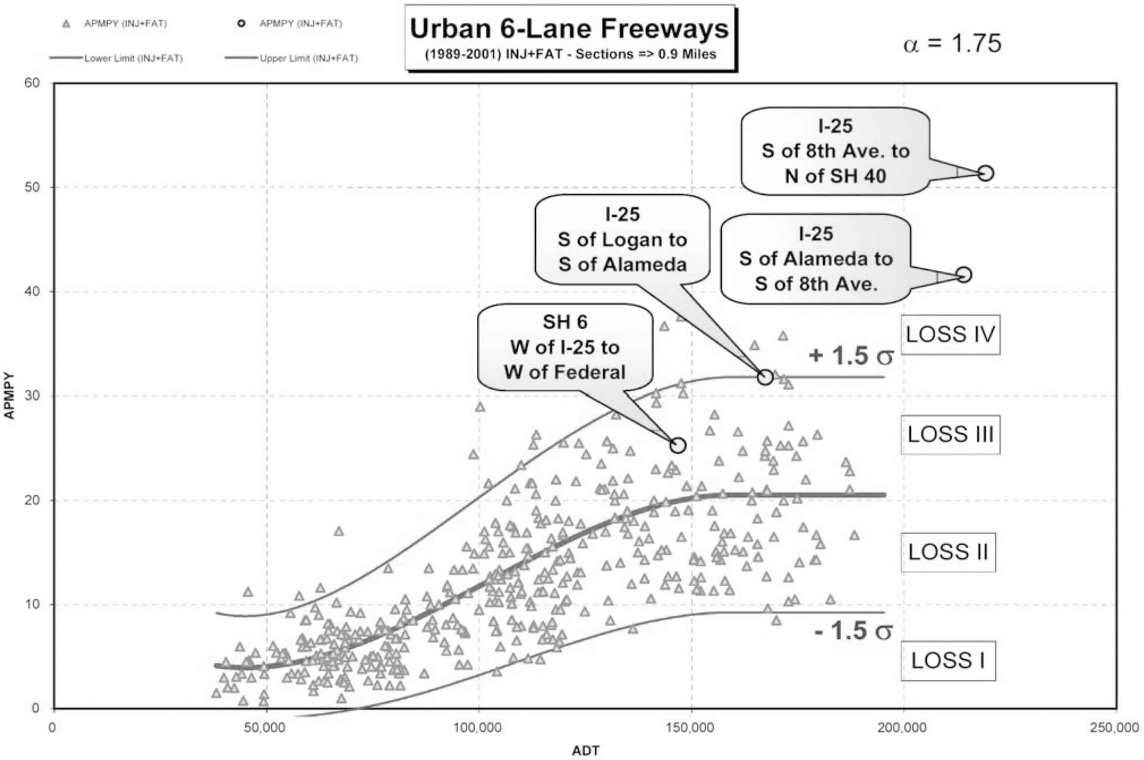

Figure 3 Urban 6-Lane Freeway SPF (Injuries plus Fatalities Only) (APMPY = Accidents Per Mile Per Year)

We have further examined the roadway segments for accident concentrations and patterns. The freeways within the EIS study limits were tested for the presence of accident patterns related to type, severity, direction of travel, road condition and time of day. Results of the pattern recognition analysis are presented in Figure 4. Pattern recognition analysis was conducted using methodology described by Kononov *(9)*, and Kononov and Janson *(10)*. Diagnostic norms are developed using the same data points as those used in generating the SPF. The norms for this type of freeway are presented in Table 2.

Urban 6-Lane Freeways

Description	Percent	Description	Percent	Description	Percent
PDO	71.14%	Daylight	68.75%	Wild Animal	0.44%
INJ	28.49%	Dawn or Dusk	3.79%	Light or Utility Pole	1.40%
FAT	0.36%	Dark - Lighted	19.58%	Traffic Signal Pole	0.04%
Single Vehicle Accidents	21.23%	Dark - Unlighted	5.91%	Sign	0.87%
Two Vehicle Accidents	59.61%	Unknown Lighting	1.97%	Bridge Rail	0.36%
Three or more Vehicle Accident	19.00%	No Adverse Weather	81.12%	Guard Rail	3.85%
Unknown Number of Vehicles	0.16%	Rain	6.61%	Median Barrier	8.61%
On Road	77.55%	Snow or Sleet or Hail	9.72%	Bridge Abutment	0.11%
Off Road	21.63%	Fog	0.21%	Column or Pier	0.06%
Off Road Left	11.02%	Dust	0.01%	Culvert or Headwall	0.07%
Off Road Right	10.45%	Wind	0.32%	Embankment	0.36%
Off Road at Tee	0.04%	Unknown Weather	2.00%	Curb	0.47%
Off Road in Median	0.12%	Overturning	2.74%	Delineator Post	0.47%
Unknown Road Location	0.82%	Other Non Collision	1.48%	Fence	0.83%
Dry Road	75.53%	School Age Pedestrians	0.05%	Tree	0.21%
Wet Road	10.24%	All Other Pedestrians	0.17%	Large Boulder	0.03%
Muddy Road	0.07%	Broadside	1.29%	Rocks in Roadway	0.05%
Snowy Road	2.83%	Head On	0.23%	Barricade	0.17%
Icy Road	6.37%	Rear End	50.27%	Wall or Building	0.19%
Slushy Road	1.82%	Sideswipe (Same Direction)	18.78%	Crash Cushion	0.30%
Foreign Material Road	0.13%	Sideswipe (Opposite Direction)	0.20%	Mailbox	0.01%
With Road Treatment	0.20%	Approach Turn	1.10%	Other Fixed Object	0.26%
Dry with Icy Road Treatment	0.04%	Overtaking Turn	0.35%	Involving Other Object	1.79%
Wet with Icy Road Treatment	0.05%	Parked Motor Vehicle	1.47%	Road Maintenance Equipment	0.10%
Snowy with Icy Road Treatment	0.05%	Railway Vehicle	0.00%	Unknown Accident Type	0.75%
Icy with Icy Road Treatment	0.09%	Bicycle	0.03%	Total Fixed Objects	18.68%
Slushy with Icy Road Treatment	0.02%	Motorized Bicycle	0.00%	Total Other Objects	1.93%
Unknown Road Condition	2.55%	Domestic Animal	0.03%	**Total Accidents**	**23,849**

Table 2 Diagnostic Norms for Urban 6-Lane Freeways

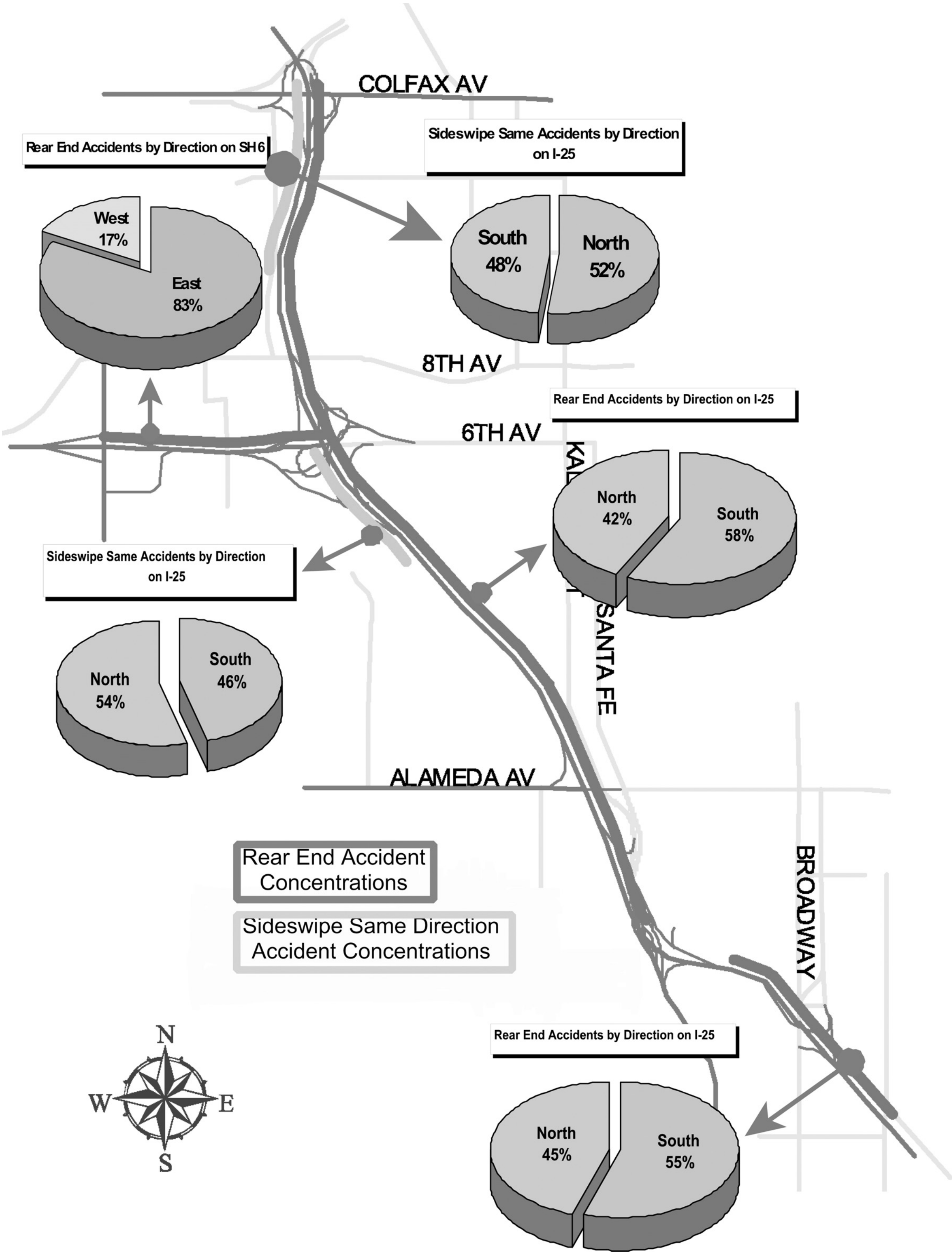

Figure 4 Results of Pattern Recognition Analysis

In addition to the SPF/LOSS analysis and collision pattern evaluation for the study's freeway segments, an investigation of the involved interchanges was undertaken. Detailed accident diagrams were prepared for the interchange-related intersections. These diagrams substantiate the crash location and provide descriptive information on the accident type, concentration, and travel direction. Subsequent to accident diagramming, a direct diagnostic analysis was conducted at individual intersections of interest to identify statistically over-represented crash types. An illustration of the product of this type of focused investigation is presented in Figure 5, below. In this case, for the I-25 and Broadway/Lincoln interchange. Included on the accident diagram are figures showing the accident type distribution for each intersection.

A significant broadside collision problem is evident at the signalized intersection of the southbound (SB) I-25 off ramp and Broadway. Thirty-two accidents occurred at this location during the 3 year study period, 22 of which were broadsides in the SB direction. This suggests a signal head visibility problem. During the reconstruction of this intersection, signal heads must be specified and positioned for maximum visibility of traffic.

Approach turn collisions are a significant problem at the Broadway and Kentucky/SB on-ramp. They constitute 63% of the total number of accidents. Same direction sideswipe accidents also appear to be occurring at a somewhat higher than expected frequency. An effective method of preventing approach turn accidents is to use protected-only phasing for left turn movements. Same direction sideswipe accidents can be reduced by providing standard lane width, longer auxiliary lanes and improved signing, striping and delineation.

A low frequency sideswipe pattern is present at the NB I-25 on and off-ramps and Lincoln St. intersection. A total of 8 accidents occurred here in the 3 year period. Again, the incidence of sideswipe same accidents can be reduced by providing standard lane width, longer auxiliary lanes and improved signing, striping and delineation.

A low frequency pattern of single vehicle accidents developed on the NB I-25 off ramp. While only 5 single vehicle accidents occurred in this area, the severity of these fixed object collision and overturning accidents was high, with 4 of the 5 accidents resulting in injuries. Providing appropriate warning signs and distinct pavement markings can help motorists judge the ramp curvature and geometry. Future interchange design alternatives will need to consider the high severity of accidents on this ramp.

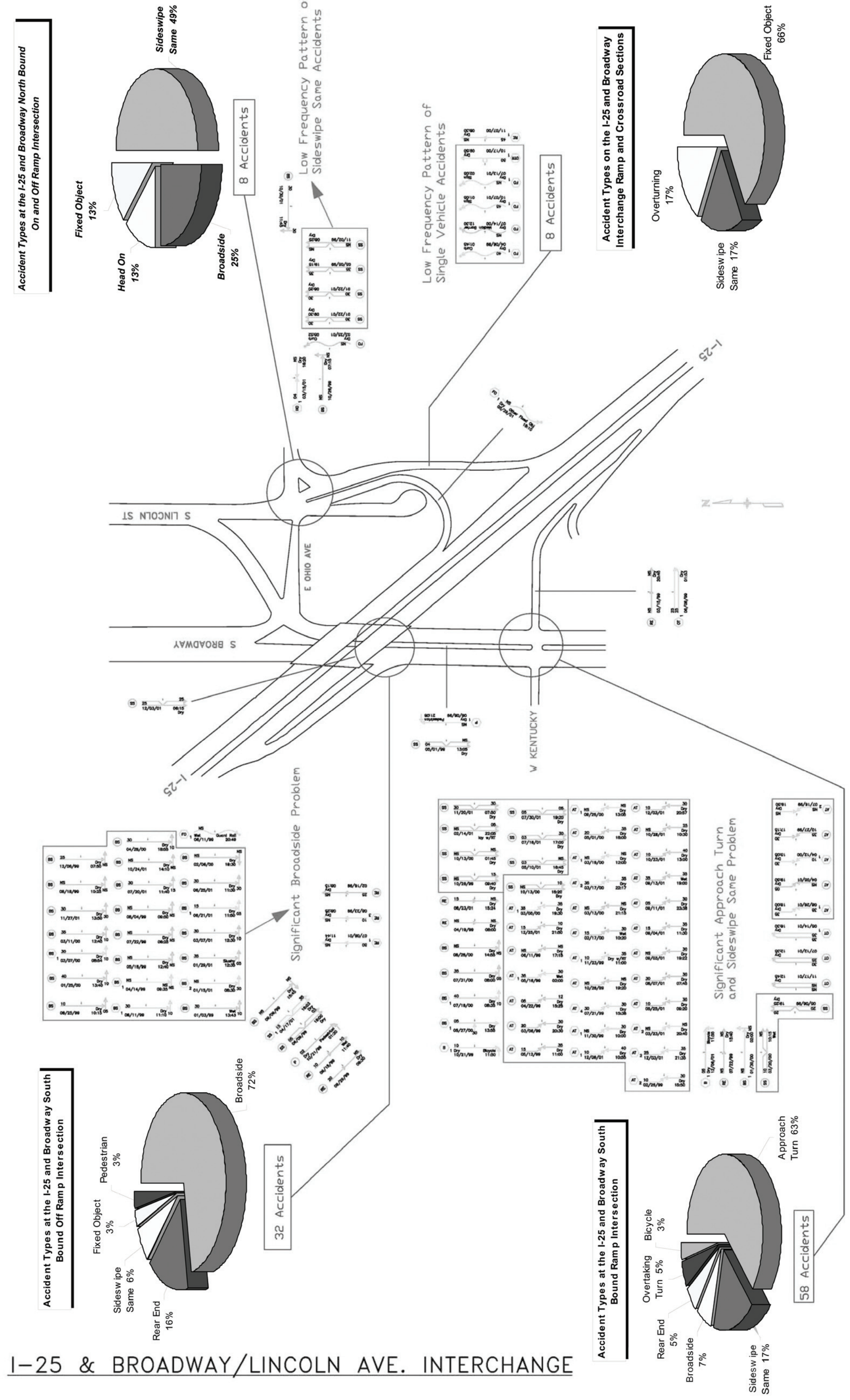

Figure 5 Accident Diagrams at Interchange Related Intersections

Summarizing the Phase I investigation, Level of Service of Safety (LOSS) analysis indicates that the entire section of I-25 in the study area is performing at LOSS IV from the frequency as well severity perspective. SH 6 is performing at LOSS III for both frequency and severity. This suggests a high potential for accident reduction in the study area. Safety problems on I-25 and SH-6 can be related to congestion, recurrent and frequent queuing, close interchange spacing and the geometric characteristics of the existing I-25 alignment. New alternatives will need to provide better geometrics and improved traffic operations including improved lane balance, ramp metering, full shoulders and adjusted ramp spacing. Most of the safety problems on interchange ramps can be attributed to congestion and backups on mainline I-25 and SH 6 that result in rear ends and sideswipe same direction accidents. Accident problems at interchange-related ramp intersections can be addressed by improving traffic signal visibility, sight distances and implementing protected only left turn phases where approach turn problems exist.

Phase II

Main Line I-25

The preferred design alternative will provide the following improvements that are expected to enhance mainline safety:

- Lane balance.
- Ramp metering.
- Full shoulders throughout the study area and standard acceleration and deceleration at every ramp.

By providing lane balance in concert with full shoulders, standard auxiliary lanes and ramp metering, we estimate a composite accident reduction of 20% can be achieved on the mainline. This conservative estimate was developed based on observational before and after studies in Colorado.

An estimate of the long term accident savings potentially available following implementation of the mainline improvements can be determined. Assuming a 2% annual growth in the number of accidents associated with increasing traffic volume over the next 20 years, we can expect to prevent the number of accidents presented in table 3:

Year	Accidents	Year	Accidents	Year	Accidents	Year	Accidents
1	413	6	456	11	503	16	556
2	421	7	465	12	514	17	567
3	430	8	474	13	524	18	578
4	438	9	484	14	534	19	590
5	447	10	494	15	545	20	602

Table 3 Expected Reduction in Accidents Mainline I-25

We estimate the 20-year expected accident reduction to be in the range of 9,840-10,240 total accidents. Of those, 2230-2420 would be prevented injuries.

I-25 at Broadway/Lincoln Interchange

In Phase I we identified the following problems: Broadside accidents are over-represented at the SB off-ramp intersection. Additionally, approach turn accidents are over-represented at the Kentucky/SB on-ramp intersection. In order to achieve a maximum safety benefit from reconstruction of this interchange, these problems should be addressed and corrected by the preferred alternative.

I-25 & Broadway/Lincoln preferred alternative 3 geometry is shown figure 6. The safety benefits gained from this alternative will, primarily, be through the implementation of revised signal phasing, increased visibility of signal heads and improved lane geometry. The potential safety improvements are summarized below:

- With intersection improvements, the frequency of broadside accidents will be reduced by 50% at the SB off-ramp intersection.
- With intersection improvements, the frequency of approach turn accidents will be reduced by 70% at the Kentucky/SB on-ramp intersection.
- With intersection and geometric enhancements, the frequency of same direction sideswipe accidents will be reduced by 80% at the Kentucky/SB on-ramp intersection.

In a manner similar to the mainline forecast, we can estimate the potential crash savings linked to the preferred interchange improvements. By assuming a 2% annual growth in the number of accidents accompanying increasing traffic volume over the next 20 years, we can expect to prevent the number of accidents shown in table 4:

Year	Accidents	Year	Accidents	Year	Accidents	Year	Accidents
1	15	6	17	11	18	16	20
2	15	7	17	12	19	17	21
3	16	8	17	13	19	18	21
4	16	9	18	14	19	19	21
5	16	10	18	15	20	20	22

Table 4 Expected Reduction in Accidents I-25 Broadway/Lincoln Interchange

We estimate the 20-year expected accident reduction to be in the range of 330-400 total accidents. Of those, 70 -100 would be prevented injuries.

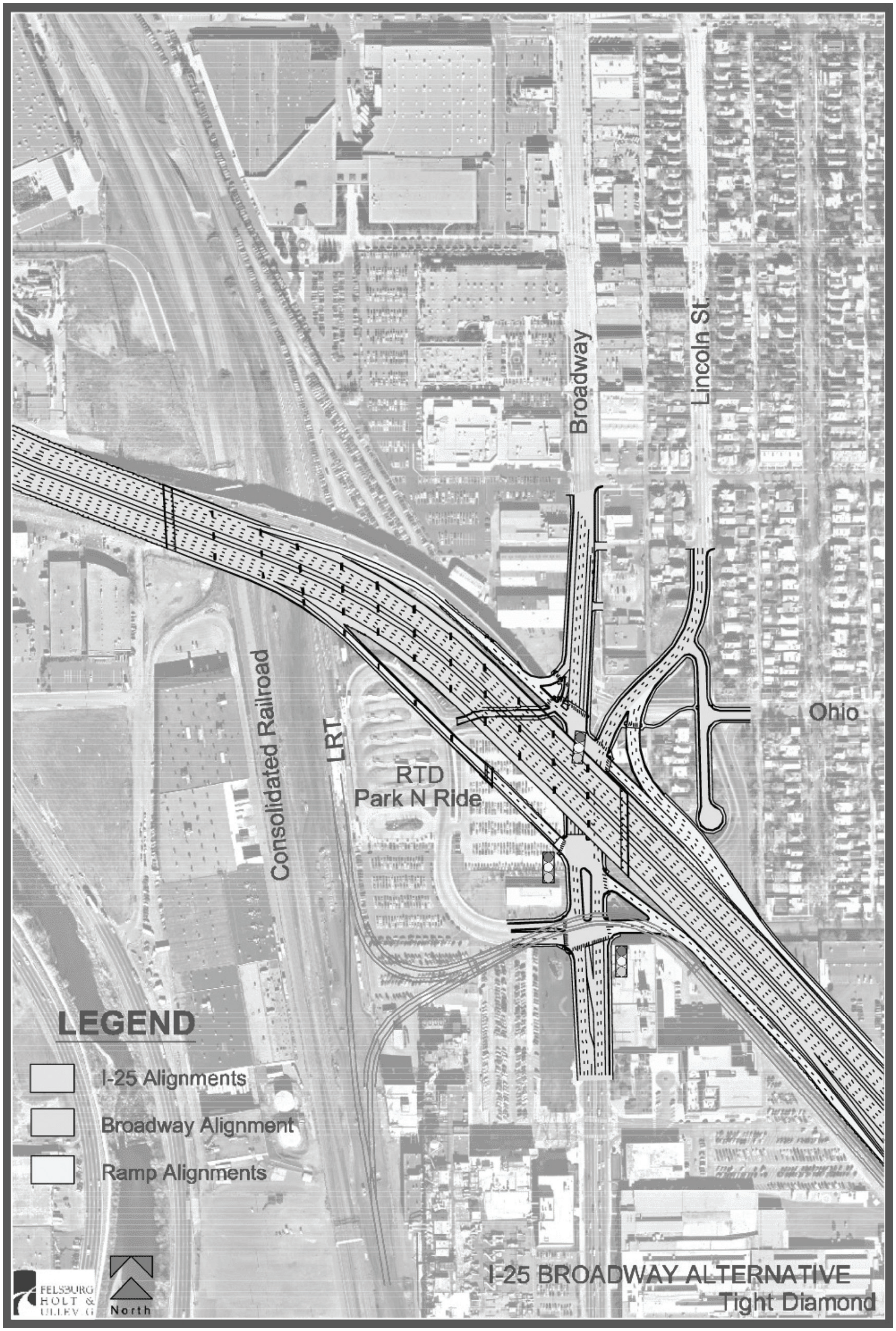

Figure 6 I-25 & Broadway/Lincoln Preferred Alternative 3 Geometry

Conclusions

A two phase process to explicitly evaluate the safety impacts of multiple design alternatives within the scope of a transportation planning study has been developed. Phase I will accomplish the following:

- Assessment of the magnitude and nature of safety problems within study limits.
- Relate crash causality to roadway geometrics, roadside features, traffic control devices, traffic operations, driver behavior and vehicle type.
- Suggest cost effective countermeasures to address identified problems.
- Provide guidance on identifying the preferred alternative from a safety standpoint.

Throughout Phase I, safety performance functions (SPFs), diagnostic menus, pattern recognition analysis and accident diagramming are used in concert with site visits and plan reviews. We have found that the use of accident diagramming to aid in diagnostic analysis is essential for effective countermeasure development, particularly in complex urban environments.

Phase-II quantifies how well each design alternative addresses safety problems identified in Phase-I. The extent to which an alternative resolves these problems is quantified by its estimated accident reduction which, in turn, is based on the nature and magnitude of existing safety problems and their susceptibility to correction. These accident reduction estimates are inherently associated with some degree of uncertainty, yet we believe this approach will allow us to identify design alternatives that are "more safe" than others.

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