Road Accidents Prediction Modeling and Diagnostics of Accident Causality- A Comprehensive Methodology

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SYNOPSIS

Transportation engineers dealt successfully over the years with the question of highway capacity. In contrast to highway capacity, the relationship between traffic volume, physical characteristics of roads and safety is not well understood or known, at least not with the kind of precision customary in other engineering disciplines. Only over the last decade has there been an established consensus among traffic safety researchers that a non-linear, non-Gausian relationship exists between traffic exposure and safety. This relationship is reflected by the Safety Performance Functions (SPF) calibrated for various classes of roads. A Safety Performance Function should provide a realistic estimate of expected accident frequency per unit of traffic exposure over a unit of time for various types of transportation facilities. Development of such estimates is a critical component in the explicit consideration of safety in highway planning and design. Indeed, if expectations are not clearly defined or well understood, then the question becomes; how is it possible to identify a deviation from the norm and then do something about it? In medical terms, for example, how can we expect a physician prescribe a medication effecting blood pressure if the thresholds for diastolic and systolic blood pressure levels has not yet been agreed upon by the medical profession. Fortunately since 1905 there is a consensus among doctors on this subject. This paper introduces the concept of Level of Service of Safety (LOSS) in the framework of Safety Performance Function (SPF) and addresses the issue of problem diagnostics. Level of Service of Safety reflects how the roadway segment is performing in regard to its expected accident frequency at a specific level of AADT. It provides an accident frequency comparison with the expected norm. LOSS qualitatively describes the relative safety or “un-safety” of the roadway segment. The nature of the problem, if it is present, is determined through diagnostic examination using direct diagnostics and pattern recognition techniques also discussed in this paper.

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INTRODUCTION

Transportation engineers dealt successfully over the years with the question of highway capacity. The problem was clearly formulated by the Highway Research Board in 1944 when the Committee on Highway Capacity was first established. The first edition of the Highway Capacity Manual (HCM) was published by the Highway Research Board in 1950 (1), it provided initial fundamentals of capacity for uninterrupted-flow facilities, signalized intersections, weaving sections and ramps. Since that time there have been four new editions of the HCM (TRB, 2000). The relationship between traffic volumes, capacity and level of service for different types of highway facilities is reasonably well understood at present. Our understanding of highway capacity is enhanced with each successive publication of the Highway Capacity Manual by the Transportation Research Board (TRB).

In contrast to highway capacity, the relationship between traffic volume, physical characteristics of roads and safety is not well understood or known, at least not with the kind of precision customary in other engineering disciplines. Until 1999 there has not been a concerted effort by the TRB to produce a Highway Safety Manual. Conceptually such a document should systematically examine the expected accident by-product of roadway segments (freeways, arterials, 2-lane roads etc.) as well as junctions (intersections, interchanges). A special Conference Session was held at the 1999 TRB Annual meeting on the subject of predicting highway safety impacts of design and operations decisions. The session concluded that one reason for a lack of safety emphasis is the absence of a single authoritative document to use for estimating safety impacts. As a follow up to the TRB Conference Session a Highway Safety Manual workshop was held in December of 1999 under the sponsorship of eight TRB committees and the FHWA. A group of 25 researchers and practitioners concluded that there is a compelling need for the development of a Highway Safety Manual and recommended to commence the development work as soon as possible. In January 2000 A Joint Subcommittee for the Development of a Highway Safety Manual was formed by the TRB to direct the efforts to produce an HSM. Later in the year NCHRP Project 17-18(4) was funded to develop HSM Scope, Organization and Outreach strategies. Additionally NCHRP Project 17-26 (Development of Models for Prediction of Expected Safety Performance for Urban and Suburban Arterials) is currently in the final phase of consultant selection. The research contractor for the NCHRP Project 17-26 is directed to work within the framework established for the HSM by the Joint Subcommittee. While some initial and significant progress has been made in the development of HSM much remains to be done in the areas of conceptual development and diagnostics of safety problems.

This paper will introduce the concept of Level of Service of Safety (LOSS) in the framework of Safety Performance Function (SPF) and address the issue of problem diagnostics. Introduction of the LOSS concept will bring about badly needed consensus in the transportation engineering profession on how to quantify the magnitude of safety problems for different classes of roads. It will also enable the following to occur:

- Qualitatively describe the degree of safety or un-safety of a roadway segment
- Effectively communicate the magnitude of the safety problem to other professionals or elected officials
- Bring perception of roadway safety in line with reality of safety performance reflecting a specific facility
- Provide a frame of reference for decision making on non-safety motivated projects (resurfacing or reconstruction for instance)
- Provide a frame of reference from a safety perspective for planning major corridor improvements.

LOSS provides a comparison with the expected frequency and severity norms, it does not, however, provide any information related to the nature of the safety problem itself. If the safety problem is present LOSS will only describe its magnitude. The nature of the problem is determined through diagnostic analysis using direct diagnostics and pattern recognition techniques also discussed in this paper.

SAFETY PERFORMANCE FUNCTIONS AS AN ANALYTICAL FRAMEWORK FOR THE DEVELOPMENT OF LEVEL OF SERVICE OF SAFETY CONCEPT

Highway Safety Manual, among other things, should provide a realistic estimate of expected accident frequency per unit of traffic exposure over a unit of time for various types of transportation facilities. Development of such estimates is a critical component in the explicit consideration of safety in highway planning and design. Indeed, if expectations are not clearly defined or well understood, then the question becomes, how is it possible to identify the deviation from the norm and then do something about it? In medical terms, how can we expect a physician prescribe blood pressure reducing medication if the thresholds for diastolic and systolic blood pressure levels has not yet been agreed upon by the medical profession. Fortunately since 1905 (2) there is a consensus among doctors on this subject. Only over the last decade there is an established consensus among traffic safety researchers that a non-linear, non-Gausian relationship exists between traffic exposure and safety. This relationship is reflected by the Safety Performance Functions (SPF) calibrated for various classes of roads and intersections. SPFs in essence are accident prediction models, which generally relate traffic exposure measured in AADT to safety measured in the number of accidents over a unit of time. In statistical modeling of traffic accidents, we are interested in discovering what we can learn about underlying relationships from empirical data containing a random component. We suppose that some complex phenomenon manifested by accident occurrence (data generating mechanism) has produced the observations and we wish to describe it by some simpler, but still realistic, model that reveals the nature of the underlying relationship. Lindsey (3) observed that in a model we distinguish between systematic and random variability, where the former describes the patterns of the phenomenon in which we are particularly interested. A great deal of substantive and comprehensive work in the area of accident modeling was done by Miaou and Lum (4), Hauer and Persaud (5), Hauer (6) as well as others. The following is a brief description of modeling methodology and data collection used in this study.

CHOICE OF THE MODEL FORM

Based on substantial empirical evidence derived from observing safety performance of various roads over extended time periods as well as work of other researchers the following understanding of relationship between safety and exposure has emerged. Accident rates decline when AADT reaches certain threshold endemic to a particular facility in a specific environment. This understanding suggests a choice of underlying function which would reflect this phenomenon. Such a function can be represented by a model form that will show some leveling off associated with approaching some threshold exposure value. Two general model forms are usually employed:

$$E\{y\} = X^{\beta_0} e^{\beta_1 x + \beta_2 x^2 \dots} \rightarrow power - family$$

$$E\{y\} = X^{\beta_0}(1 + \beta_1 X + \beta_2 X^2 \dots) \rightarrow polynomial - family$$

In this is E{y} is the annual number of accidents expected to occur on a segment of road, X is the independent variable (here AADT), and β are parameters to be estimated. Hauer in unpublished working papers used Nadaraya-Watson kernel estimator with Gausian kernel to obtain the relationship presented on Figure 1.

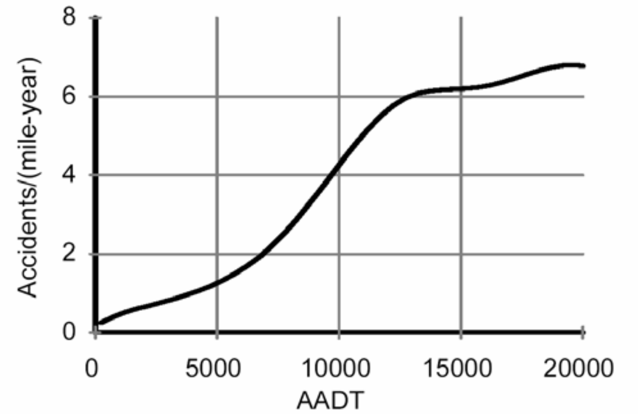

Figure 1 Relationship Between Exposure and Safety from Hauer

Non-parametric kernel regression used by Hauer is a smoothing technique used to obtain clues about the form of the function underlying the data. Similar functional shapes in Figure 2 were developed and described in Kononov (7) using Neural Networks-Radial Basis Function. Neural Networks are not constrained by the underlying distributional assumptions and learn by example inferring a model from training data.

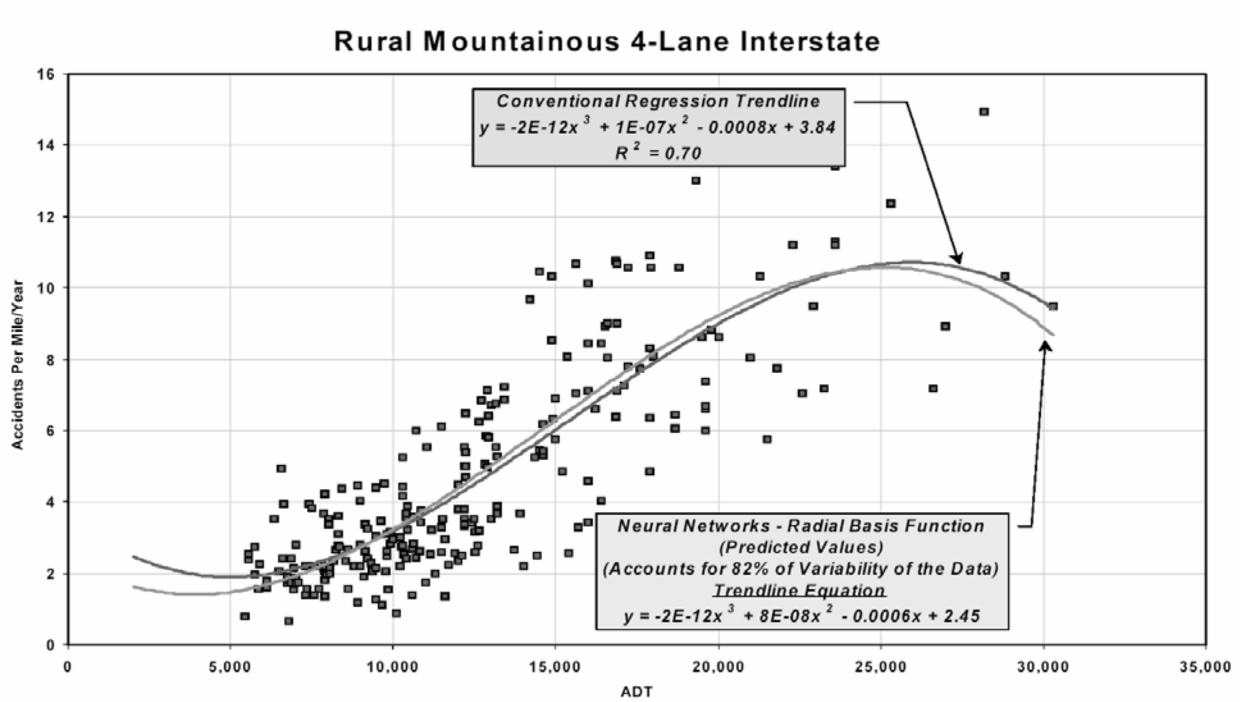

Figure 2 SPF Developed Using Neural Networks

CHOICE OF UNDERLYING DISTRIBUTIONAL ASSUMPTIONS

In statistical modeling of traffic accidents, it is assumed that the random variation follows certain probability laws and can be characterized by a probability function. Miau and Lum (4) observed that "The use of a continuous distribution, such as the normal distribution, is at best an approximation to a truly discrete process. The Poisson distribution, on the other hand, is a natural initial candidate distribution for such random discrete and, typically, sporadic events." At the same time if a Poisson assumption is made about the underlying random variability, it will have a restricting effect of always equating the variance to the mean. In our experience with accident data this assumption is not always true. Similar findings are reported by Dean and Lawles (8). In many cases accident data exhibit extra variation or over-dispersion relative to the Poisson model. In other words, the variance of the data if often greater then the mean. In this study Poisson regression was used for fitting models in the rural areas and Negative Binomial regression was employed for fitting models of urban freeways which generally exhibit over-dispersion.

Data Collection and Dataset Preparation

All of the dataset preparation was performed using the Colorado Department of Transportation (CDOT) accident database. Accident history for each facility was prepared over the period of 14 years. Annual Average Daily Traffic (AADT) for each roadway segment for each of the 14 years was entered into the same dataset. For rural freeways all of the interchange related accidents were isolated from the accident database prior to fitting the model. The reason for isolating interchange-related accidents in the rural area was to remove the influence of accidents resulting from merge/diverge turbulence at an interchange.. On the 2-lane rural roads the data-set was prepared in a similar fashion with the exception that intersection related accidents and 0.1 mile roadway segments containing intersections were removed prior to fitting of the model. Isolating a distance of approximately 250 ft. on both sides of rural intersections is a conservative measure, but it will ensure that intersection related conflicts will not pollute the data-set comprised of non-intersection related accidents and road segments. In the urban environment it is virtually impossible to remove the influence of interchanges on safety and operations. Considering this reality all of the accidents which occurred on ramps and crossroads were removed prior to fitting of the model, which only left accidents occurring on the urban freeway itself. The dataset for urban freeways was prepared emphasizing that each segment should include only one interchange. Figure 3 illustrates how the datasets were prepared for three different facilities.

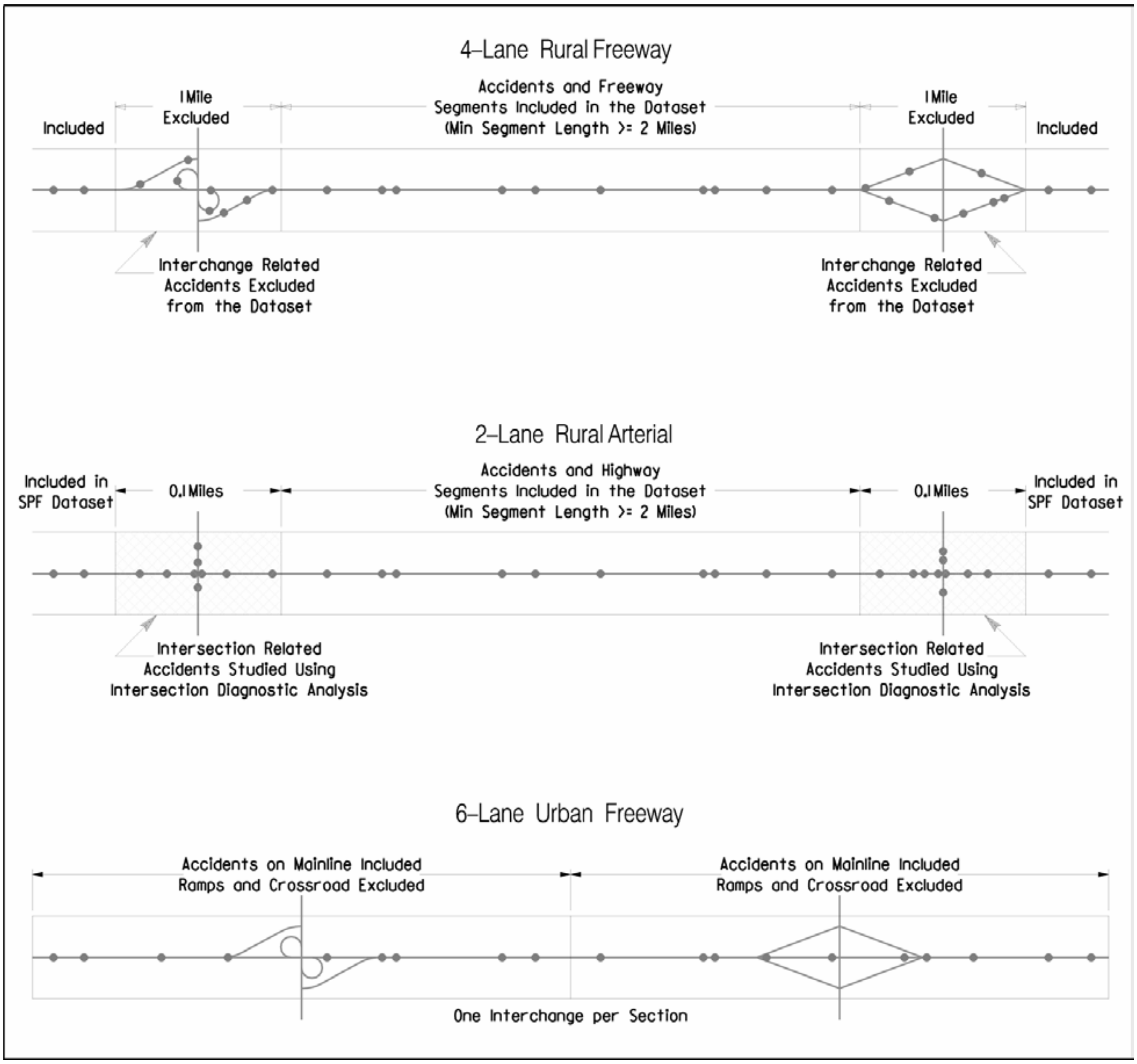

Figure 3 Details of Dataset Preparation

MODEL FITTING

The model parameters were estimated by the maximum-likelihood method using GLM spreadsheet of STATISTICA (9). For rural freeways and arterials which typically do not exhibit over-dispersion the regression parameters are estimated by maximizing Poisson log-likelihood function. Maximizing log-likelihood function has computational advantages over maximizing ordinary likelihood function L, which represent the product of the individual Poisson probability density functions.

Where,

μ - Estimated number of accidents on a roadway segment over a period of a year
y_i - Observed number of accidents on roadway segment over a period of a year
$L(\mu_p)$- Poisson likelihood function
β - Estimated regression parameters

$$\mu\{acc.\} = ADT^{\beta_0}(1 + ADT^{\beta_1} + ADT^{\beta_2} + \dots ADT^{\beta_n})$$

$$\mu \in Poisson \therefore Var(y) = \mu \therefore \sigma = \sqrt{\mu}$$

$$P(x = y_i) = \frac{\mu_i^{y_i}}{y_i!} e^{-\mu_i} \therefore L(\mu_p) = \prod_{i=1}^{n} \left(\frac{\mu_i^{y_i} e^{-\mu_i}}{y_i!}\right)$$

$$Ln(L) = \sum_{i=1}^{n} (y_i \ln \mu_i - \mu_i - \ln y_i!)$$

$$\mu\{acc.\} = ADT^{\beta_0}(1 + ADT^{\beta_1} + ADT^{\beta_2} + \dots ADT^{\beta_n})$$

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$$Ln(L) = \sum_{i=1}^{n} (y_i \ln \mu_i - \mu_i - \ln y_i!)$$

Urban freeways datasets generally exhibit over-dispersion. Although geometric characteristics of the freeways themselves are fairly uniform because they are designed to the interstate standards the over-dispersion was consistently present. This can possibly be explained by the influence of ramp flows and spacing on safety performance. The influence of ramps was not introduced as an independent variable but was reflected by the number of accidents on the main line. In order to minimize the influence each urban freeway segment in the dataset contained only one interchange. The β parameters for the urban freeways were estimated by maximizing log-likelihood function of the Negative Binomial distribution.

Where, α - Over-dispersion parameter also estimated by maximizing Negative Binomial log-likelihood function.

$$\mu \in Negative - Binomial \therefore Var. > \mu$$

$$Var.(y) = \mu(1+\alpha\mu) = \mu + \alpha\mu^2 \therefore \sigma = \sqrt{\mu + \alpha\mu^2}$$

$$L(\alpha,\mu) = \prod_{i=1}^{n} \frac{\Gamma(\alpha^{-1}+y_i)}{\Gamma(\alpha^{-1})y_i!}\left(\frac{\alpha\mu_i}{1+\mu_i}\right)^{y_i}\left(\frac{1}{1+\alpha\mu_i}\right)^{\alpha^{-1}}$$

$$Ln(L(\alpha,\mu)) = \sum_{i=1}^{n}\left[\ln\left(\frac{\Gamma(\alpha^{-1}+y_i)}{\Gamma(\alpha^{-1})y_i!}\right) + y_i \ln\left(\frac{\alpha\mu_i}{1+\alpha\mu_i}\right) + \alpha^{-1}\ln\left(\frac{1}{1+\alpha\mu_i}\right)\right]$$

The quality of fit was examined with the Cumulative Residuals (CURE) method described in Hauer and Bamfo (10). This method consists of plotting the cumulative residuals for each independent variable. The goal is to graphically observe how well the function fits the data-set. To generate a CURE plot, sites are sorted by their average AADT. Then, for each site, the residual (= predicted accidents-observed accidents) is computed. The residuals are then added up and a cumulative residual value is plotted for each value of the independent variable. Because of the random nature of accident counts, the cumulative residual line represents a so called 'random walk'. For a model that fits well in all ranges of AADT, the cumulative residual plot should oscillate around zero. If cumulative residual value steadily increases within an ADT range, this means that within that AADT range the model predicts more accidents than have been observed. Conversely, a decreasing cumulative residual line in an AADT range indicates that in that range more accidents have been observed than are predicted by the model. A frequent departure of the cumulative residual line beyond two standard deviations of a random walk indicates a presence of outliers or signifies an ill fitting model. All of the models in the study produced a very satisfactory fit, where random walk stays well within 2 standard deviations while oscillating around zero. Figure 4 illustrates Cumulative Residual Plot reflecting the model fit for the SPF calibrated for 2-Lane Rural Mountainous Highways.

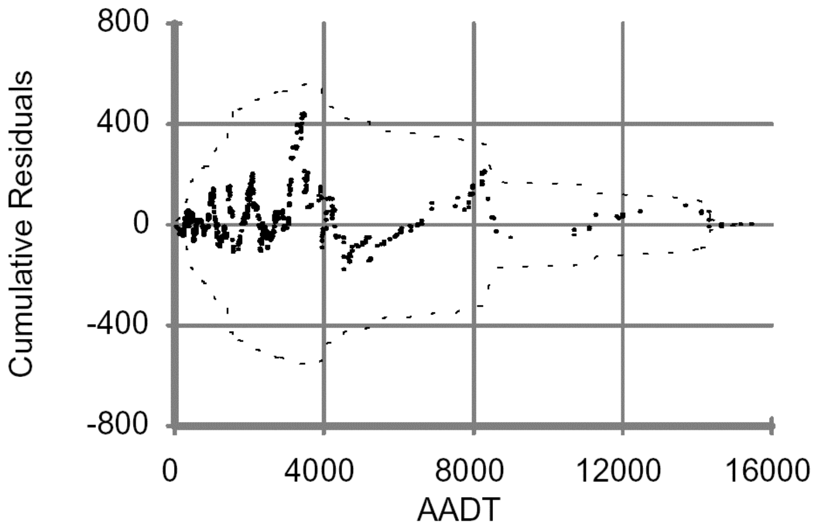


Figure 4 – Cumulative Residual Plot, 2-Lane Mountainous Highways

LEVEL OF SERVICE OF SAFETY (LOSS)

Development of the SPF lends itself well to the conceptual formulation of the Level of Service of Safety. The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance. If the level of safety predicted by the SPF will represent normal or expected number of accidents at a specific level of AADT, then the degree of deviation from the norm can be stratified to represent specific levels of safety. Road safety should be described from the frequency and severity standpoint. Toward this goal we have calibrated two kinds of SPF, one for the total number of accidents and the other for injury and fatal accidents only. So when the magnitude of the safety problem is assessed it is described from the frequency and severity standpoint. Figures 5 and 6 illustrate the concept using SPF calibrated for the total and injury and fatal only accidents expected on the 6 lane urban freeways. The delineated boundary line is located 1.5 standard deviations from the mean. Four Levels of Service of Safety (LOSS) can be proposed:

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

For instance a segment can have LOSS-II on the total accidents SPF and LOSS-III on the injuries+fatals SPF. So from the safety perspective the same segment can be described as having LOSS-II frequency and LOSS-III severity. In our experience, however, most segments generally exhibit the same LOSS from the frequency and severity perspective. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in accidents/mile as AADT increases. This increase is consistent with Poisson error structure for the rural freeways and arterials. For the urban freeways Negative Binomial error structure reflects over-dispersion typical of this environment. Possible explanation for the over-dispersion in the urban freeway dataset may be the influence of different ramp volumes on the freeway safety performance.

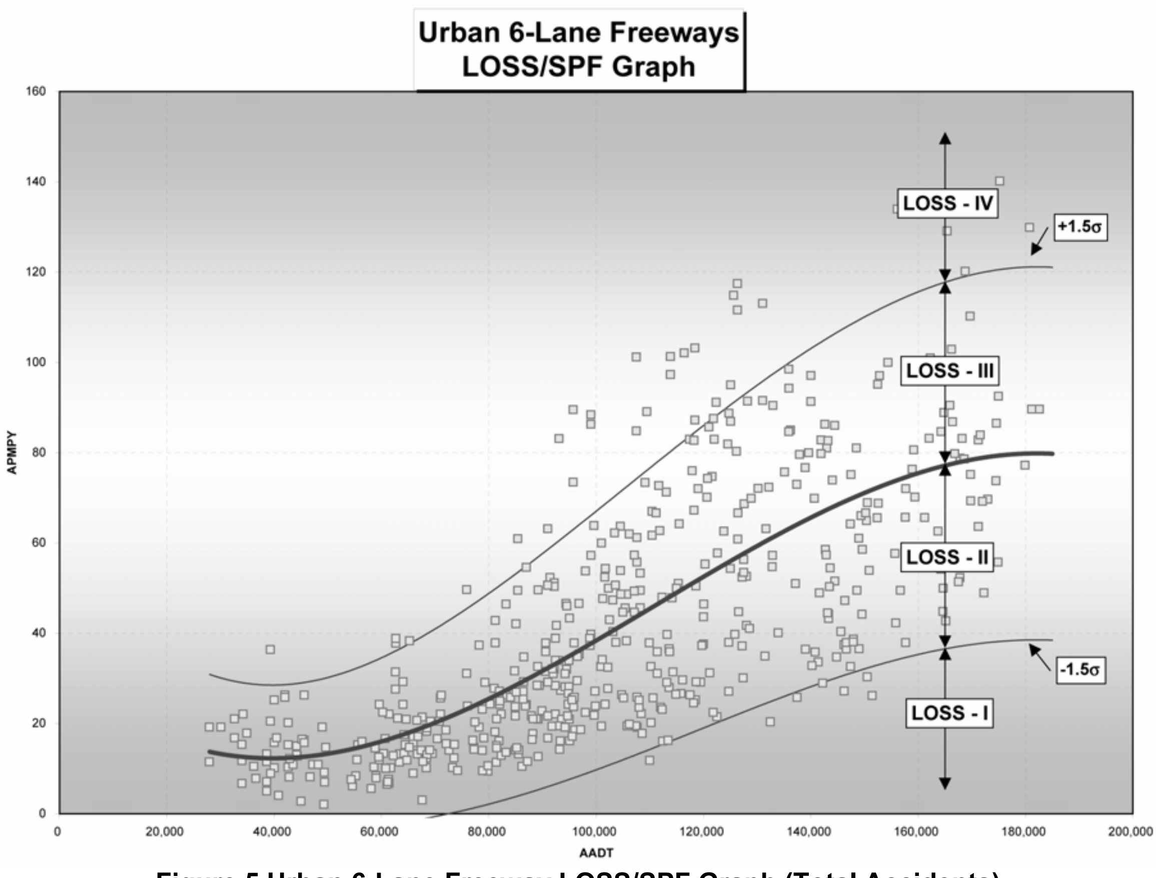


Figure 5 Urban 6-Lane Freeway LOSS/SPF Graph (Total Accidents)

Level of Service of Safety (LOSS) reflects how the roadway segment is performing in regard to its expected accident frequency and severity at a specific level of AADT. It only provides an accident frequency and severity comparison with the expected norm, it does not, however, provide any information related to the nature of the safety problem itself. If the safety problem is present, LOSS will only describes its magnitude. The nature of the problem is determined through diagnostic analysis using direct diagnostics and pattern recognition techniques.

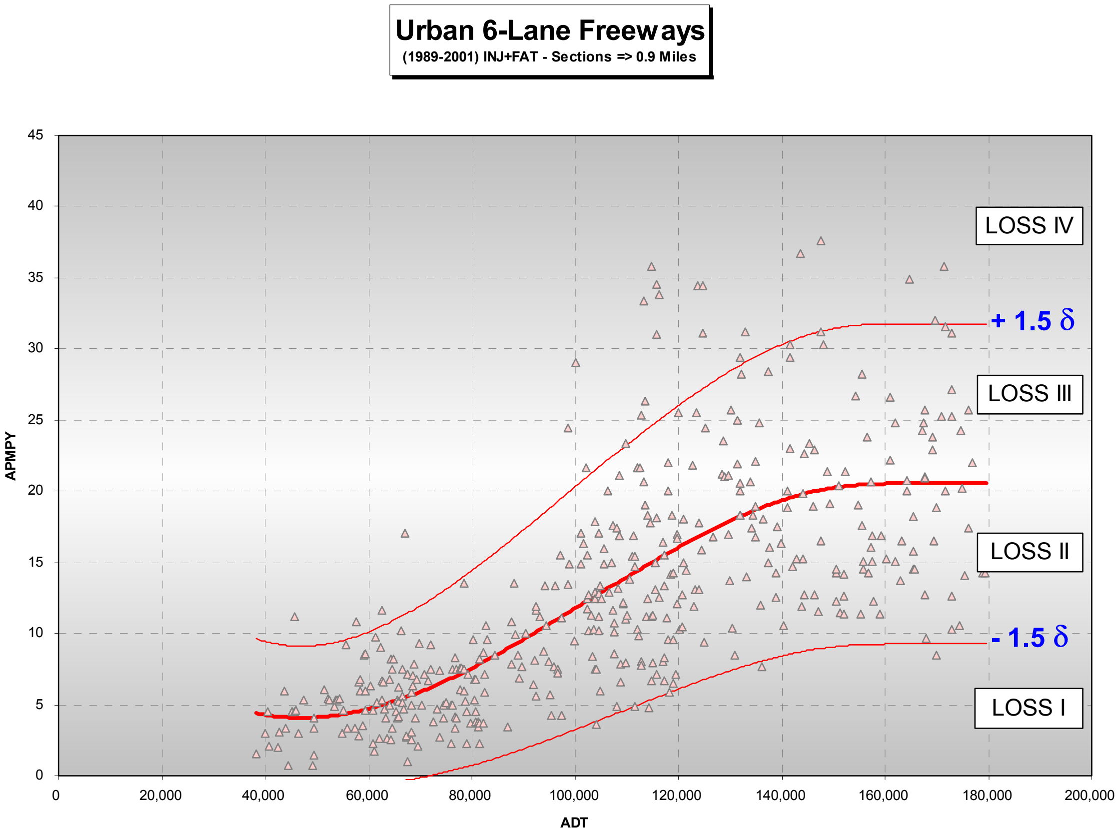
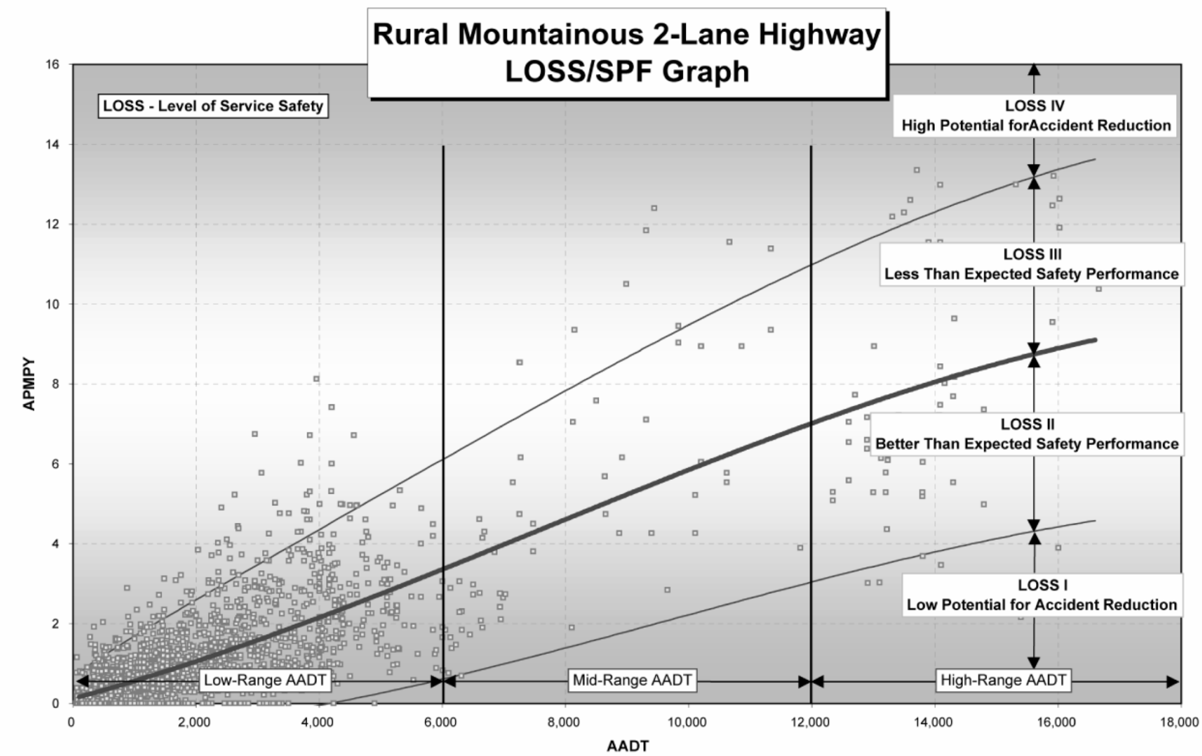


Figure 6 Urban 6-Lane Freeway LOSS/SPF Graph (Injuries + Fatals Only)

DIAGNOSTICS OF SAFETY PROBLEMS

In the course of in-depth project level safety studies 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 diagnostics methods and pattern recognition algorithm are described in Kononov (*11*) and Kononov and Janson (*12*). A framework of 84 normative parameters was developed to provide diagnostic knowledge base for different classes of roads in rural and urban environments. Considering that traffic accidents can be viewed as random Bernoulli trials it is possible to detect deviation from the random statistical process by computing observed cumulative probability for each of the 84 normative parameters. The 84 parameters can be grouped into 11 more general categories: accident type, severity, accident location, road condition, direction of travel, lighting condition, vehicle type, human factors, driver condition, weather condition and time of day. It is important to note that some, but not all normative parameters change with AADT within the same SPF. For instance, in general, severity is gradually decreasing with AADT and distribution by accident type changes. With this in mind 84 normative parameters were stratified for 3 ranges of AADT; low, medium and high. In the process of assessing the nature and magnitude of safety problems at specific locations SPF analysis should be used in conjunction with appropriate diagnostic investigation using pattern recognition algorithm. The stratification of the diagnostic parameters by AADT improves our ability to identify accident patterns more accurately. For instance for the low range of AADT on 2 lane mountainous roads the average percent (%) of head-on collisions is 2%, while it is 8% for the high range of AADT. Not accounting for this change would lead to misdiagnosis of the problem. Figure 7 represents LOSS/SPF graph with normative diagnostic categories for 3 ranges of AADT. While LOSS provides assessment of the magnitude of the safety problem, it is important to understand that accident patterns susceptible to correction may exist with or without over-representation in total frequency detected by the SPF.



Low-Range AADT

Normative % for Diagnostics

- Accident Type %
- Severity %
- Accident Location %
- Road Condition %
- Direction of Travel %
- Lighting Condition %
- Vehicle Type %
- Human Factors %
- Driver Condition %
- Weather Condition %
- Time of Day %

Mid-Range AADT

Normative % for Diagnostics

- Accident Type %
- Severity %
- Accident Location %
- Road Condition %
- Direction of Travel %
- Lighting Condition %
- Vehicle Type %
- Human Factors %
- Driver Condition %
- Weather Condition %
- Time of Day %

High Range AADT

Normative % for Diagnostics

- Accident Type %
- Severity %
- Accident Location %
- Road Condition %
- Direction of Travel %
- Lighting Condition %
- Vehicle Type %
- Human Factors %
- Driver Condition %
- Weather Condition %
- Time of Day %

Figure 7 LOSS/SPF with Stratified Diagnostic Norms

APPLICATION OF LOSS ANALYSIS AND DIAGNOSTIC INVESTIGATION

To illustrate the application of the concept let's select a roadway segment in the rural mountainous area and conduct LOSS analysis followed by the diagnostic examination of accident causality. The selected site is located on a 2-lane mountainous road in south-western Colorado. The selected site is approximately 3 miles long, it is located between mile posts 196.00 and 199.00 on Highway 50. This roadway segment carries approximately 2,200 cars per day and experienced approximately 5.5 accidents per mile/per year over the last 3 years. Accident frequency and severity observed at the site exhibit LOSS-IV (only frequency graph is shown on Figure 8 due to the format limitation), which suggests a high potential for accident reduction.

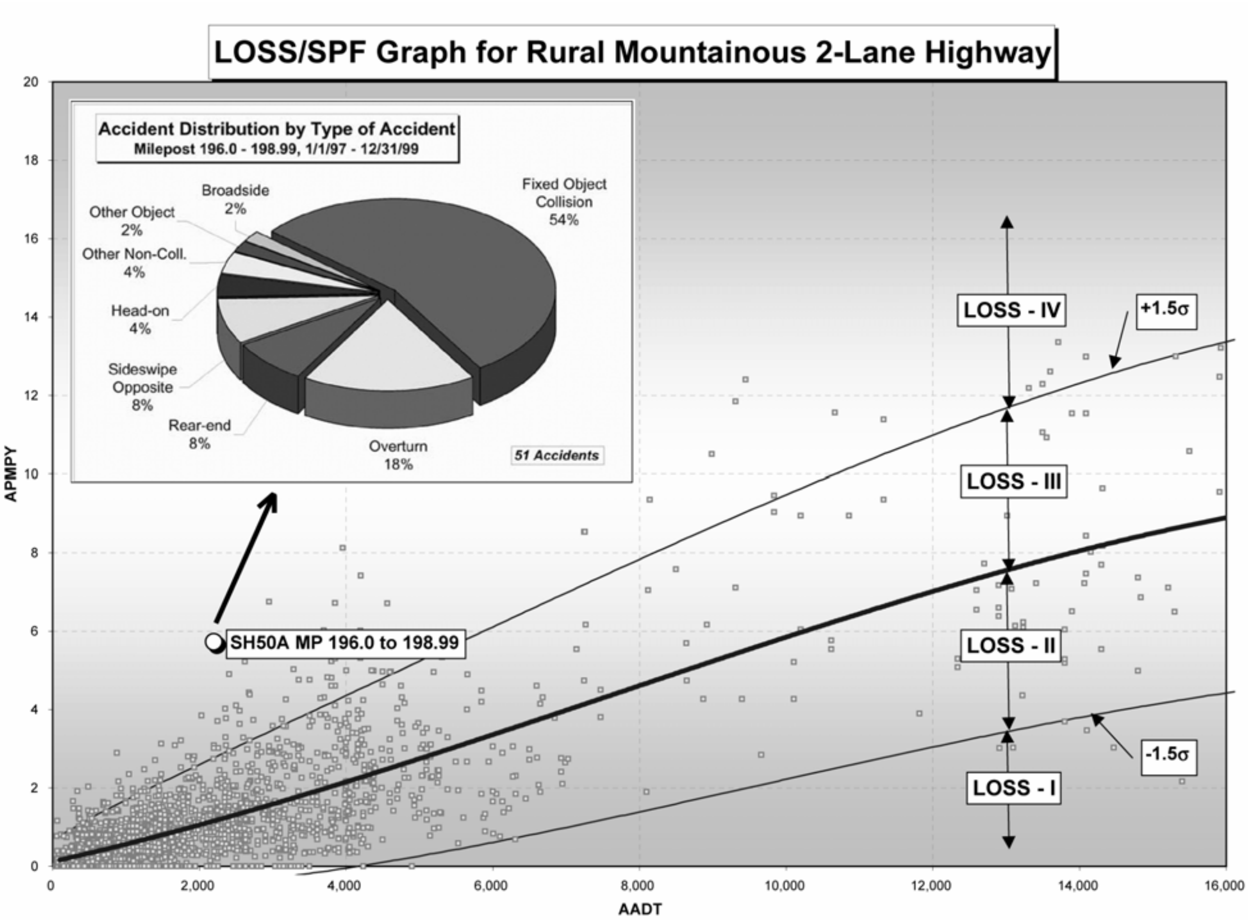


Figure 8 LOSS Analysis with Initial Diagnostics

At this point of the diagnostic investigation all we know is that the site has experienced significantly more accidents than expected, but nothing is yet known as to why. Let's examine the accident type distribution profile observed on the study segment over the last three (3) years. As can be seen from Figure 8, the most frequent accident type is a fixed object collision. Fixed object collisions represent 54% of the total. This appears somewhat higher than expected 39% typical of a low AADT range for the 2-lane mountainous road in the rural environment. Let's apply direct diagnostics test considering the following observed accident history: 51 total accidents, 28 fixed object collisions.

$$P(X \geq 28) = 1 - P(X \leq 27)$$

$$P(X \geq 28) = 1 - \sum_{i=0}^{27} \frac{51!}{(51-i)!\,i!} 0.39^{i} (1-0.39)^{51-i} =$$

$$= 0.015$$

Where P represents cumulative probability of observing 28 fixed object collisions or more out of 51 total accidents and 0.39 is the Bernoulli probability of fixed object collisions in the low AADT range on the 2-lane mountainous roads.

The result of the direct diagnostics test for fixed object collisions suggests that there is something in the roadway environment, which triggers deviation from the random process of accident occurrence in the direction of reduced safety. More specifically, it triggers fixed object collisions. As of yet we don’t know what it is.

Let’s now return to the study segment and examine it for the concentrations of fixed object accidents. Figure 9 contains a cumulative graph of fixed object collisions throughout the study area. The cumulative graph of fixed object collisions reveals two apparent accident clusters, one between mile posts 196-196.5 and the other between mile posts 197.5-197.8. Application of the pattern recognition algorithm described by Kononov (*11*), confirmed that observed accident clusters represent patterns of the fixed object collisions. It is of interest to note that despite the fact that this site is located within the mountain pass zone (5 miles from the summit) the percentage of weather and road conditions related accidents is well within expected range. We can now conclude that significantly higher than expected accident frequency (LOSS-IV) reflected in the SPF analysis can be attributed to the presence of two sizable accident clusters of fixed object collisions. These clusters are located between MP 196.00-196.50 and MP 197.50-198.00. Let’s take a closer look at the accidents within clusters and try to identify additional common characteristics among them. Filtering of accidents by direction revealed that all fixed object collisions in both clusters occurred while traveling in the westbound direction. Both accident clusters are contained within horizontal curves situated on the downgrade in the westbound direction.

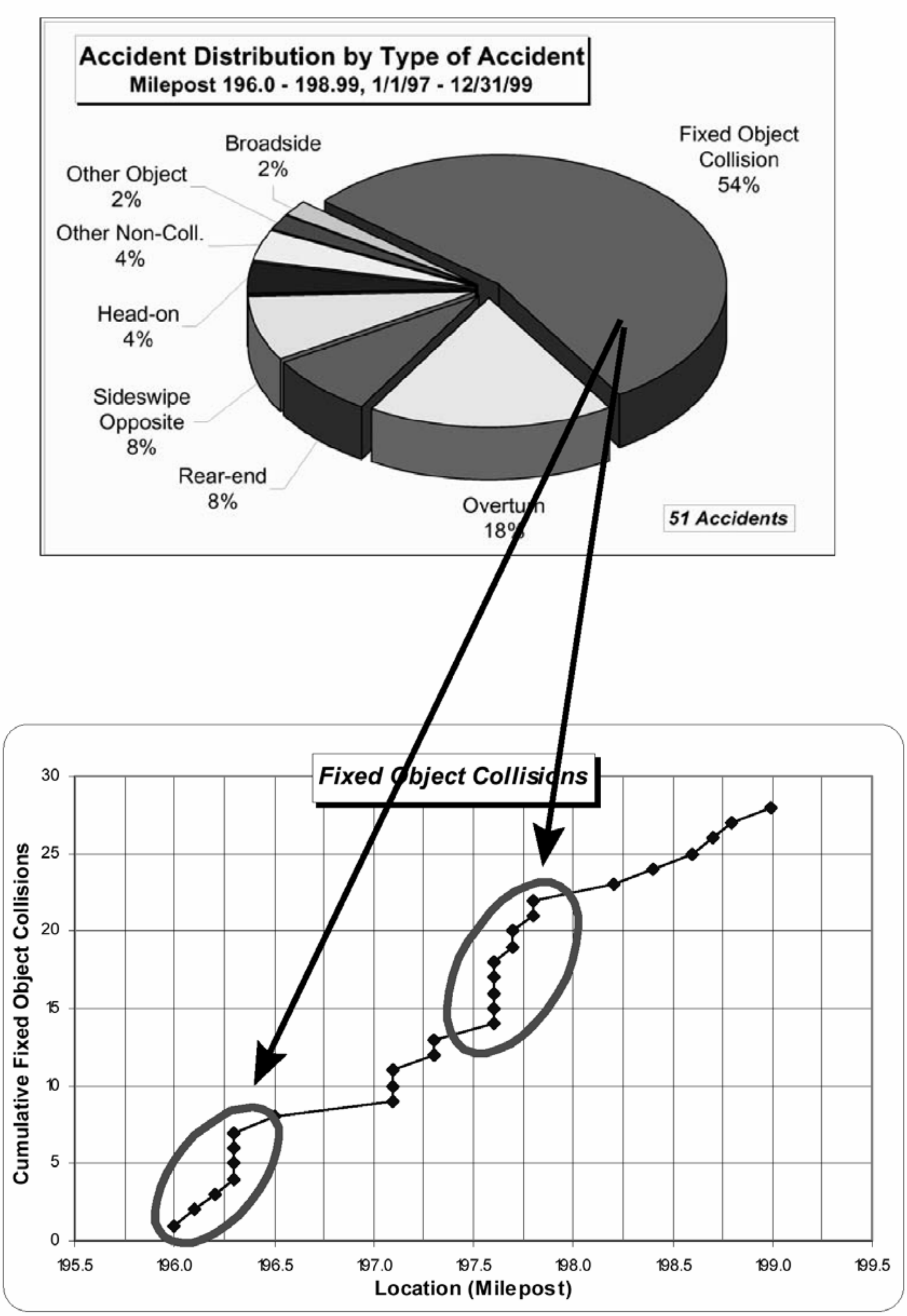


Figure 9 Fixed Object Collisions Cumulative Concentration Graph

Review of the existing plans indicated that design speed of horizontal curves containing accident clusters is only 30 mile per hour. Both curves are preceded by long segments of tangent or mild horizontal curvature situated on the steep vertical grade. All of this information is presented on Figure 10. A combination of steep grades, sharp horizontal curvature and long tangents or segments of mild curvature preceding the curves are known to be associated with loss of control on the curves, which result in accidents. Possible counter-measures may include guard-rail around the curves and additional signing in combination with automated speed detection system connected to the VMS boards.

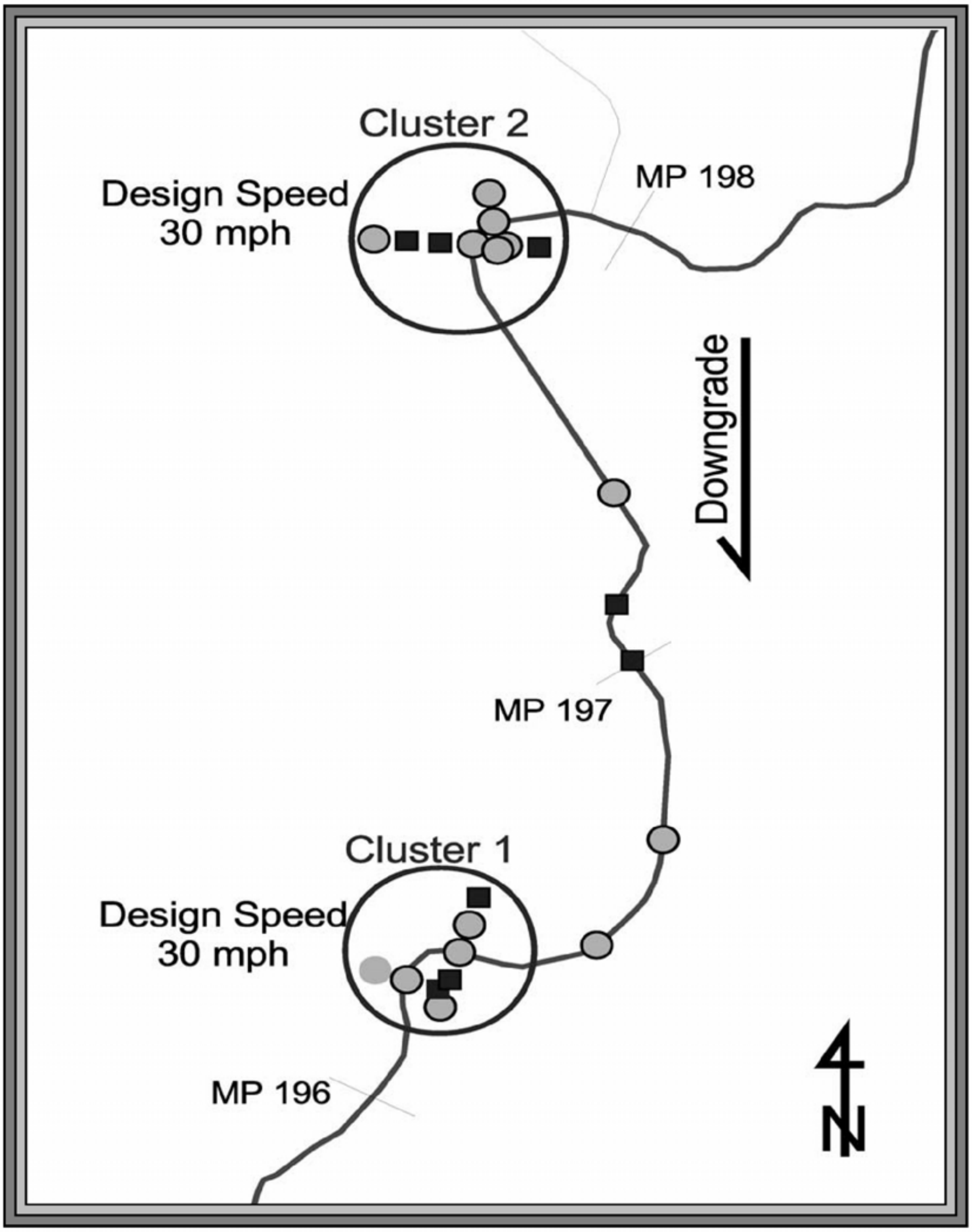


Figure 10 Accident Concentration GIS Map

CONCLUSIONS

Development of the SPF lends itself well to the conceptual formulation of the Level of Service of Safety. The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance. Four Levels of Service of Safety (LOSS) are proposed:

- ***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***

Road safety should be described from the frequency and severity perspective using Safety Performance Functions calibrated for the total and injury and fatal only accidents. Although most segments generally exhibit the same LOSS from the frequency and severity perspective it is not always the case.

Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in accidents/mile as AADT increases. This increase is consistent with Poisson error structure for the rural freeways and arterials. For the urban freeways Negative Binomial error structure reflects over-dispersion typical of this environment. Level of Service of Safety (LOSS) reflects how the roadway segment is performing in regard to its expected accident frequency at a specific level of AADT. It only provides an accident frequency and severity comparison with the expected norm, it does not, however, provide any information related to the nature of the safety problem itself. If the safety problem is present, LOSS will only describe its magnitude. The nature of the problem is determined through diagnostic analysis using direct diagnostics and pattern recognition techniques.

Safety Performance Functions and diagnostic norms were developed using Colorado Department of Transportation accident databases. While the methodology presented in this paper can be applied to other States and Countries, such an application would require local calibration to reflect prevalent characteristics of accident reporting, climate, driver behavior, design practices and other local factors.

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