# Explicit Consideration of Safety in Transportation Planning and Project Scoping

Jake Kononov and Bryan K. Allery

**The Transportation Equity Act for the 21st Century of 1998 required explicit consideration of safety in the transportation planning process. Although this government mandate is well intentioned, little is known about how to accomplish it. Despite 60 years of modern road building, there is still no consensus among transportation professionals about how to quantify the degree of safety or lack of safety of an existing transportation facility. It is even more difficult to anticipate the level of safety on highways not yet built. A methodology for the explicit consideration of safety in the transportation planning process is presented, followed by a review of two case histories illustrating its application.**

> Those who don't gain knowledge, lose knowledge.
> —*Talmud: Pirkei Avos*

The Transportation Equity Act for the 21st Century (TEA-21) of 1998 required explicit consideration of safety in the transportation planning process. Although this government mandate is well intentioned, little is known about how to accomplish it. Despite 60 years of modern road building, there is still no consensus among transportation professionals about how to quantify the degree of safety or lack of safety of an existing transportation facility. It is even more difficult to anticipate the level of safety on highways not yet built. It is generally believed that compliance with AASHTO design standards, the *Manual on Uniform Traffic Control Devices,* and other guides and manuals will result in an appropriately safe facility. This approach suggests that safety will always be taken care of through adherence to standards, thus relieving the transportation engineering profession of the need to quantify just how much safety can be expected from each design alternative. This would be a sound strategy if those who wrote the standards could anticipate the extent to which important road design decisions affect safety. Hauer observed:

> It may come as a surprise that, typically, writers of standards did not know how what they choose affects safety. To test the verity of my irreverent assertion is simple. One only has to ask the highway designer or the member of the standards committee questions such as: "Approximately how many crashes will be saved by increasing the horizontal radius of this road from 100 m to 200 m; how many by making lanes 12 instead of 11 feet; or by how much will crash severity be reduced by changing this side-slope from 3:1 to 5:1?" If they cannot answer, then the safety built into the current standards cannot be "appropriate" (*1*).

J. Kononov, Colorado Department of Transportation, 2000 South Holly Street, Denver, CO 80222. B. K. Allery, Safety Engineering and Analysis, Colorado Department of Transportation, 4201 East Arkansas Street, Denver, CO 80222.

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Hauer clearly formulated how to measure road safety: "Of two alternative highway designs connecting points A and B and serving the same traffic, that highway design which is likely to have fewer and less severe crashes is the safer one. Thus, the safety of a road is measured by the frequency and severity of crashes expected to occur on it. If so, safety of a road is always a matter of degree. A road can be safer or less safe" (*1*). Hauer's formulation sets out sound principles to follow, but how to incorporate them into transportation planning and project scoping merits further discussion.

## DRAWING A PARALLEL WITH NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 (NEPA) suggested a relevant model from the position of applying principles to practice in the transportation planning process. Spensley wrote, "NEPA has been heralded as the Magna Carta of the country's environmental movement. It was signed into law to address the need for a national environmental policy to guide the growing environmental consciousness and to shape a national response" (*2*). NEPA contains the declaration of national environmental policy and goals as well as "action-forcing" provisions for federal and state agencies to implement those goals. The adoption of NEPA translated into a well-established methodology and institutionalized processes aimed at protecting the environment. In the process of developing environmental impact statements or environmental assessments for transportation projects, complex, multivariate regression models of existing and future air quality are constructed, wetlands delineated, habitats of threatened and endangered species surveyed, noise levels measured, water quality tested, and specific mitigation strategies developed. For each of the transportation alternatives under consideration, environmental impact is described and mitigated explicitly. Consider air quality, for example. The air quality impact associated with each transportation alternative is estimated by computing expected concentration of the pollutants carbon monoxide, volatile organic compounds, nitrogen oxides, and particulate matter.

Concentrations of each pollutant are compared with national ambient air quality standards, and those alternatives not meeting the standards are rejected or modified. In contrast to the environmental review process, the impact each transportation alternative has on safety is not well understoood or well planned for. No standards exist that quantify the amount of safety expected after construction. It is not known how much safety to expect. It is collectively hoped that substantial compliance with standards will automatically produce an appropriately safe facility. When meeting standards becomes too expensive, however, design variance documentation is prepared to justify the decision not to meet them. Is providing an adequate level

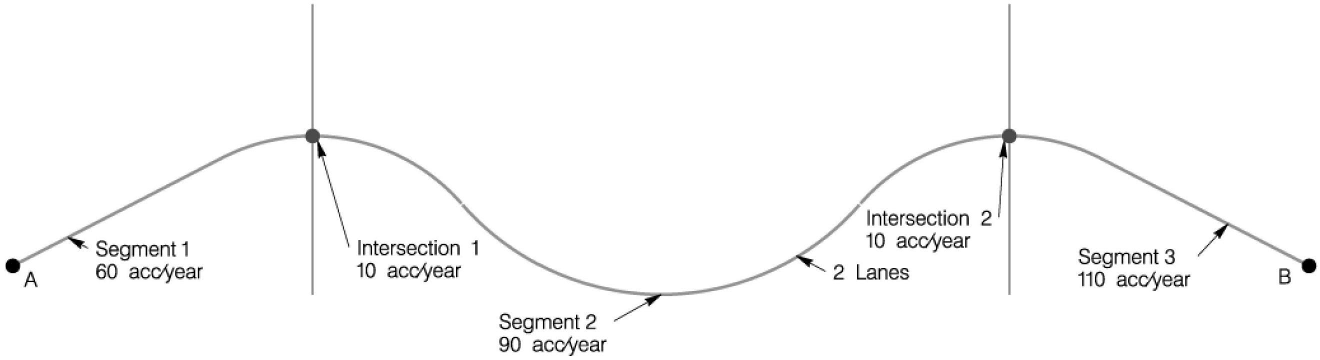


FIGURE 1 Project map schematic and accident history.

of safety on the transportation facility less important than protecting the environment? Both are important societal values that influence the quality of life. In 1942, Sir Alker Tripp, a former commissioner of Scotland Yard and an authority on town planning, reflected, "Any town so planned that its citizens are killed and injured in vast numbers is obviously an ill-planned town" (*3*). Petzold observed: "Because safety-conscious planning is a relatively new concept, specific guidelines are not yet available and opinions about the range of activities that safety-planning initially should address vary. One option is including explicit road safety considerations as a key decision making parameter in evaluating projects and expenditures" (*4*). One must consider the consequences of not exercising this option, specifically, the outcome of continuing with the present methodology that translated into 42,850 fatalities and 2,914,000 injuries in 2002 (*5*).

## CONCEPTUAL BLUEPRINT FOR PRACTICAL APPROACH

Consider a major reconstruction and safety improvement project on Highway X from Point A to Point B contemplated by the local department of transportation. Within the study area, Highway X is a two-lane undivided rural arterial highway traversing a rolling terrain that carries 14,000 vehicles daily. A schematic of the project map and accident history are presented in Figure 1.

During the public involvement process, a question was raised about a possible realignment to improve safety and expansion to four lanes to improve future mobility. This, of course, represents a significant change in project scope and would require an environmental assessment or even an environmental impact statement. The following discussion illustrates how to consider safety explicitly in the framework of an environmental assessment or an environmental impact statement.

Recent research conducted by Council and Stewart on the safety effects of converting two-lane roads to four lanes finds a 40% to 60% reduction in crashes as a result of conversion to a four-lane divided cross section (*6,* pp. 286–287). Kononov and Allery, in unpublished working papers, obtained similar results by comparing cross-sectional models of two-lane undivided rural highways to four-lane divided highways; they used Colorado accident data for a 14-year period. For the purposes of this study, assume 50% accident reduction can be attributed to widening and realignment combined. In contrast to the safety improvement on roadway segments resulting from widening and realignment, expect the frequency of intersection-related accidents at unsignalized intersections throughout the study area to increase after widening is completed. The literature gives no clear explanation for this rise (*7*); however, it may be related to the increased number of conflict points or increased speed resulting from improved geometrics and capacity. In this example, assume a 20% accident increase at intersections is related to converting the two-lane undivided main line to a four-lane divided section. The expected annual accident frequency resulting from realignment and widening within study limits can now be examined. Figure 2 provides this information.

In the first year following completion of realignment and expansion to a four-lane divided highway, one can expect to prevent the following number of accidents:

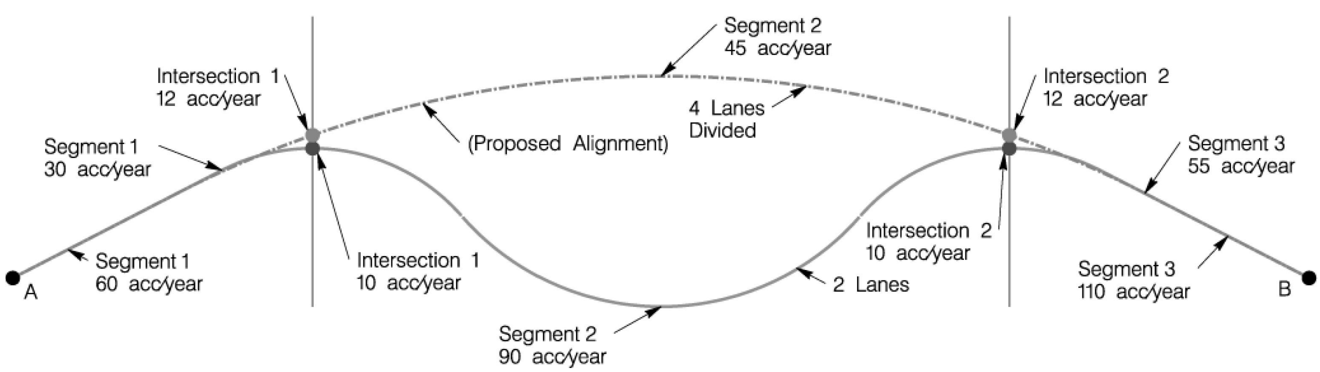


FIGURE 2 Expected accident frequency after realignment and widening.

(60 accidents on Segment 1 + 10 accidents at Intersection 1

+ 90 accidents on Segment 2 + 10 accidents at Intersection 2

+ 110 accidents on Segment 3) − (30 accidents on Segment 1

+ 12 accidents at Intersection 1 + 45 accidents on Segment 2

+ 12 accidents at Intersection 2 + 55 accidents on Segment 3)

= 124 accidents

From 14 years of Colorado data, the average distribution of accidents by severity on rural non-Interstate highways in rolling terrain is as follows:

- Fatal accidents, 3%;
- Injury accidents, 37%; and
- Property-damage-only accidents, 60%.

By considering these proportions, one can now estimate how many accidents can be prevented over the life cycle of the improvement (in this case, 20 years). By assuming a 2% annual growth in the number of accidents caused by increasing traffic over the next 20 years, one can expect to prevent the number of accidents presented in Table 1 if the recommended improvements are constructed. A more accurate estimate of accident frequency related to increase of exposure expressed in annual average daily traffic (AADT) can be obtained by using safety performance functions (SPFs) calibrated specifically for two-lane rural roads. These functions were developed in the framework of the interactive highway safety design model by Harwood et al. (*8*).

By using this straightforward approach, one can estimate how many accidents can be prevented for each alternative under consideration. In the process of evaluating alternatives, safety impact was considered explicitly. When the impact on safety is quantified, it is much easier to generate the support and resources necessary for safety improvements. For instance, if a design engineer can show that as a result of realignment and widening, 1,119 injury accidents, 72 fatal accidents, and 1,822 property-damage-only accidents can be prevented, this would make a compelling case for funding. If the emphasis is on complying with standards, the decision makers would have a more difficult time justifying millions of dollars required for realignment and widening. Although this example illustrates how to consider safety explicitly, the problem was simplified intentionally and a segment of road was examined in isolation. Providing additional capacity may result in some trip redistribution and new trip generation. Consideration of complex interaction between expansion of transportation infrastructure and its net impact on safety is a much more complex problem, which is outside the scope of this paper.

The next question to consider is how much safety can be provided for how much money. When decisions are made about road safety it is critical to understand that "expenditure of limited available funds on improvements in places where it prevents few injuries and saves few lives can mean that injuries will occur and lives will be lost by not spending them in places where more accidents could have been prevented." (*9*) Benefit–cost analysis produces ratios of the expected accident reduction benefits to the costs of construction and maintenance over the useful life of an improvement. These ratios bring all alternatives to the same common denominator and can be used as a guide in the decision-making process for selecting design alternatives.

## ANALYTICAL FRAMEWORK AND CASE HISTORY

The previous example represents a greatly simplified rendering of the complex reality typical of transportation planning and project scoping, yet it formulates a conceptual blueprint that can be applied to more complex situations. Several related concepts are needed to carry out safety-conscious planning: SPFs, level of service of safety (LOSS), and diagnostic analysis.

### SPFs

SPFs are accident prediction models that relate traffic exposure measured in AADT to safety measured in the number of accidents over a unit of time. Much substantive and comprehensive work in the area of accident modeling was undertaken by Miaou et al. (*10*), Miaou and Lum (*11*), Hauer and Persaud (*12*), and Hauer (*13*). Details concerning data set preparation and model fitting for the development of the SPF were described by Kononov and Allery (*14*). The model parameters are estimated by the maximum likelihood method in the generalized linear modeling framework by using a data set containing 14 years of accident data. In many cases, accident data exhibit extravariation or overdispersion relative to the Poisson model.

**TABLE 1 Estimated Number of Accidents Prevented in 20 Years**

| Year | FAT | INJ | PDO | Total |
|---|---|---|---|---|
| 1 | 3 | 46 | 75 | 124 |
| 2 | 3 | 47 | 77 | 127 |
| 3 | 3 | 48 | 78 | 129 |
| 4 | 3 | 49 | 80 | 132 |
| 5 | 3 | 50 | 81 | 134 |
| 6 | 3 | 51 | 83 | 137 |
| 7 | 3 | 52 | 84 | 139 |
| 8 | 3 | 53 | 86 | 142 |
| 9 | 4 | 54 | 88 | 146 |
| 10 | 4 | 55 | 90 | 149 |

| Year | FAT | INJ | PDO | Total |
|---|---|---|---|---|
| 11 | 4 | 56 | 91 | 151 |
| 12 | 4 | 57 | 93 | 154 |
| 13 | 4 | 58 | 95 | 157 |
| 14 | 4 | 60 | 97 | 161 |
| 15 | 4 | 61 | 99 | 164 |
| 16 | 4 | 62 | 101 | 167 |
| 17 | 4 | 63 | 103 | 170 |
| 18 | 4 | 64 | 105 | 173 |
| 19 | 4 | 66 | 107 | 177 |
| 20 | 4 | 67 | 109 | 180 |

| Year | FAT | INJ | PDO | Total |
|---|---|---|---|---|
| **Total** | **72** | **1,119** | **1,822** | **3,013** |

NOTE: FAT = fatal accidents; INJ = injury accidents; PDO = property-damage-only accidents.

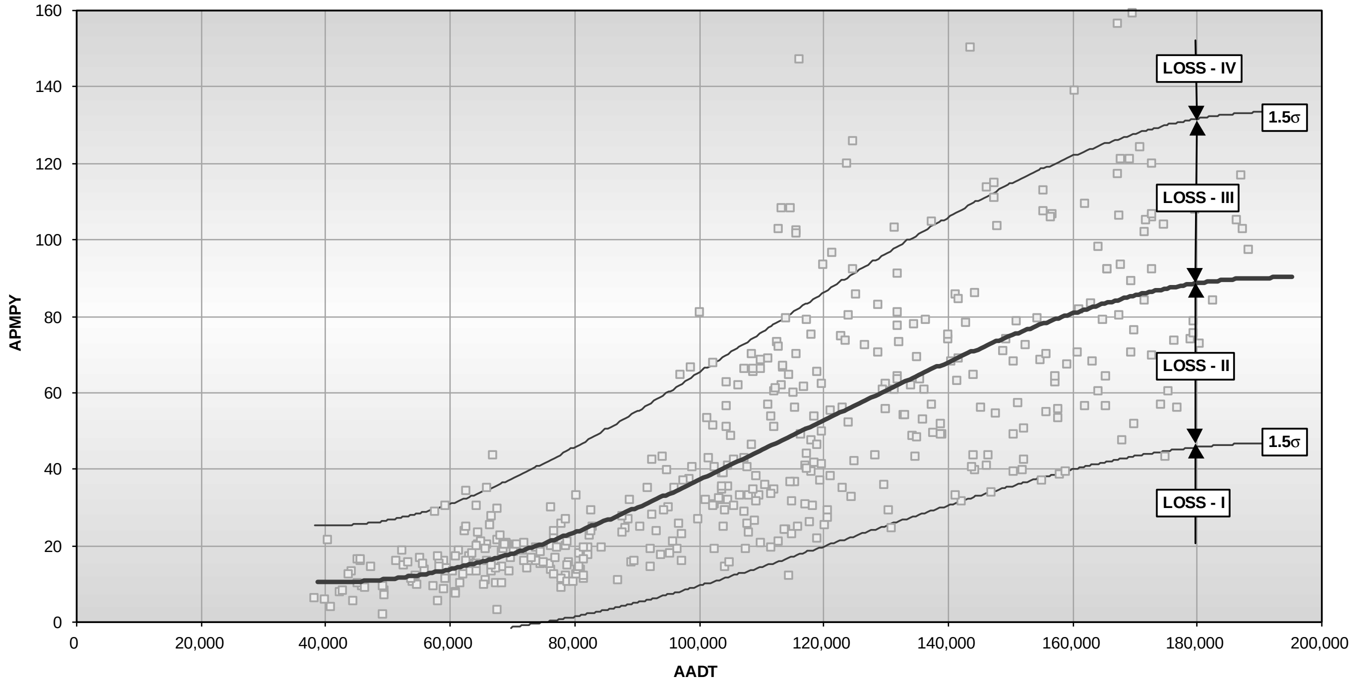


FIGURE 3 SPF total accidents on six-lane urban freeway (APMPY = accidents per mile per year).

## LOSS

Development of the SPF lends itself well to the conceptual formulation of the LOSS. The concept of level of service (LOS) 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. Two kinds of SPF were calibrated toward this goal, one for the total number of accidents and one for injury and fatal accidents only. Thus when the magnitude of the safety problem is assessed, it is described from the perspective of frequency and severity. Figures 3 and 4, from Kononov and Allery (*14*), illustrate the concept of using SPF calibrated for the total and injury and fatal only accidents

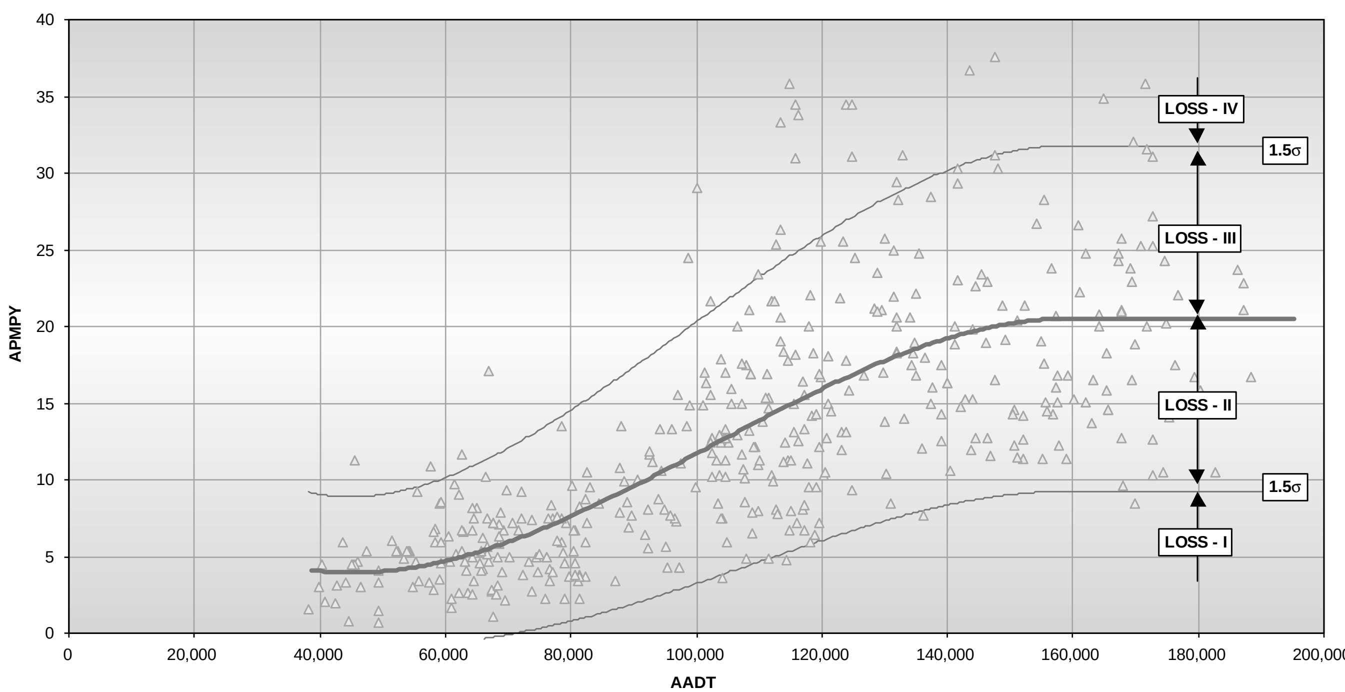


FIGURE 4 SPF injury + fatal accidents on six-lane urban freeway.

expected on six-lane urban freeways. The delineated boundary line is located 1.5 standard deviations from the mean. Selection of 1.5 standard deviations in the Poisson or negative binomial framework is made to identify segments of highways with some potential for accident reduction or to recognize a particularly good performance. Use of 2 or more standard deviations would leave in only extreme or unusual cases. Four LOSSs were proposed by Kononov and Allery (*14*):

- LOSS I indicates low potential for accident reduction,
- LOSS II indicates better-than-expected safety performance,
- LOSS III indicates less-than-expected safety performance, and
- LOSS IV indicates high potential for accident reduction.

Although 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 overrepresentation in total frequency detected by the SPF. The LOSS concept is widely used by the Colorado Department of Transportation in system-level planning as well as project scoping. This approach brings about badly needed consensus in the transportation engineering profession on the subject of the magnitude of safety problems for different classes of roads. It will also make possible the following critical steps for effective and responsible resource allocation directed at improving road safety:

- Qualitatively describe the degree of safety or unsafety of 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 reality of safety performance reflecting a specific facility,
- Provide a frame of reference for decision making on nonsafety motivated projects (resurfacing or reconstruction, for instance), and
- Provide a frame of reference from a safety perspective for planning major corridor improvements.

### Diagnostic Analysis

LOSS reflects how the roadway segment is performing relative to its expected accident frequency and severity at a specific level of AADT. It provides only an accident frequency and severity 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 describe only its magnitude. The nature of the problem is determined through diagnostic analysis by using direct diagnostics and pattern-recognition techniques. 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 the pattern-recognition algorithm were described by Kononov (*15*) and Kononov and Janson (*16*). A framework of 84 normative parameters was developed to provide a 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, and location; road condition; direction of travel; lighting condition; vehicle type; human factors; driver condition; weather condition; and time of day.

## SAFETY-CONSCIOUS PLANNING IN URBAN FREEWAY CORRIDOR: CASE HISTORY

A segment of a major six-lane urban freeway in the Denver metro area is used to illustrate the application of the concept. A project area map is presented in Figure 5. First, LOSS analysis is conducted to reflect average safety performance of the last 3 years followed by the diagnostic investigation of accident causality. Use of the average of the last 3 years will smooth peaks related to annual fluctuation in accident frequency. The results of the LOSS total frequency analysis of the urban six-lane freeway in the study area are presented in Figure 6. The results of the LOSS injury and fatal only analysis are presented in Figure 7.

The models presented in Figures 6 and 7 reflect 14 years of data. Model parameters were estimated by using the maximum likelihood method with the negative binomial error structure. The outcomes of the LOSS frequency and severity analysis are similar. Segments 1, 3, 4, and 5 perform more or less as expected for an aging urban freeway. Observed frequency and severity are in the

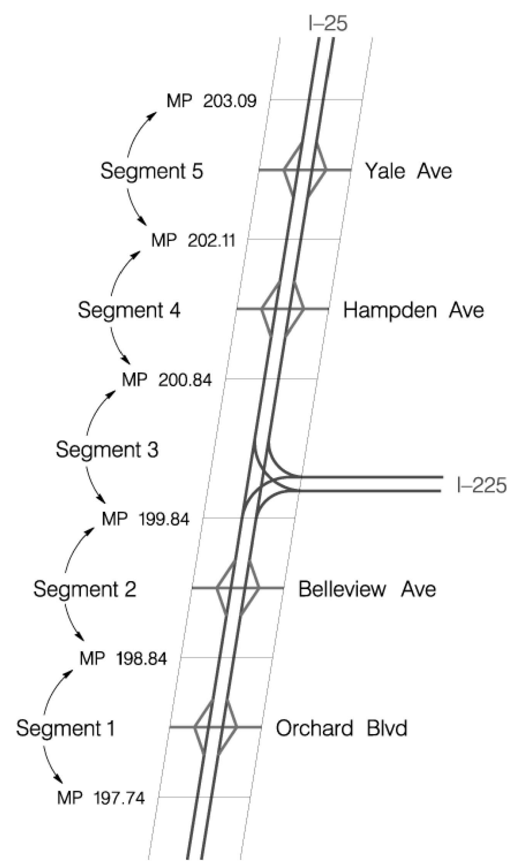


FIGURE 5 Project area map.

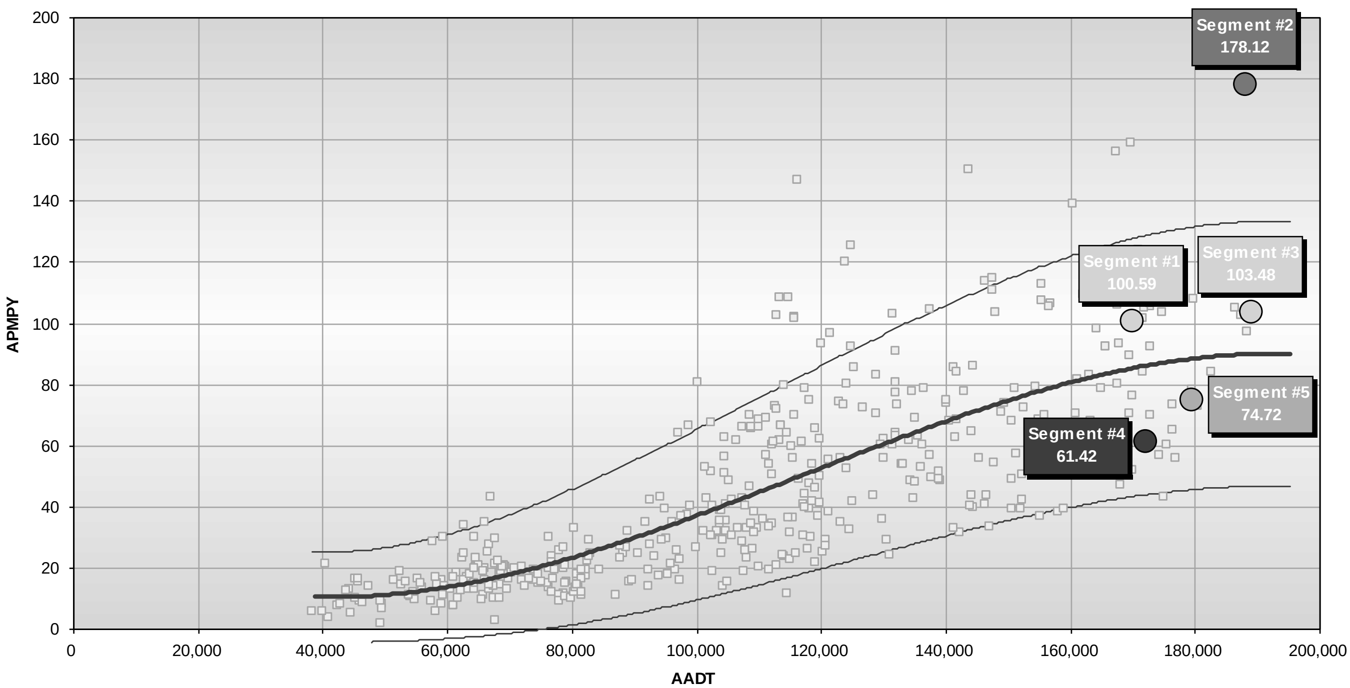


FIGURE 6 LOSS total accident frequency in study area.

LOSS II and LOSS III range. Segment 2, however, exhibits highly undesirable safety performance in the high range of LOSS IV for both frequency and severity, which suggests a high potential for accident reduction. At this point of the diagnostic investigation, all that is known is that the site has experienced significantly more accidents than expected, yet the cause is not known. Examine the accident type distribution profile observed on the study segment over the last 3 years. As can be seen from Figure 8, the most frequent accident type is a rear-end collision, followed by sideswipes in the same direction.

Rear-end collisions represent 73% of the total. This is higher than the expected 44.5% typical for six-lane urban freeways. Sideswipes (same direction) at 18% are also higher than the expected 12.6%. Conduct direct diagnostics tests that consider the following

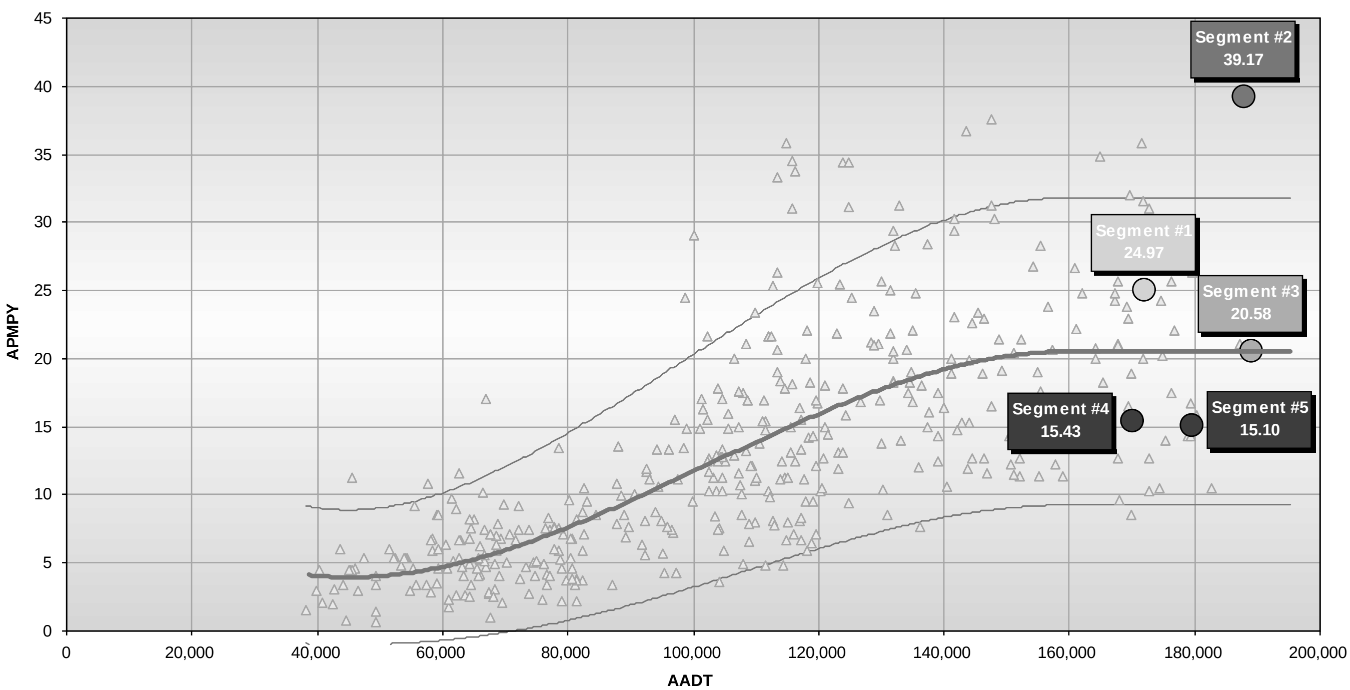


FIGURE 7 LOSS injury + fatal accident frequency in study area.

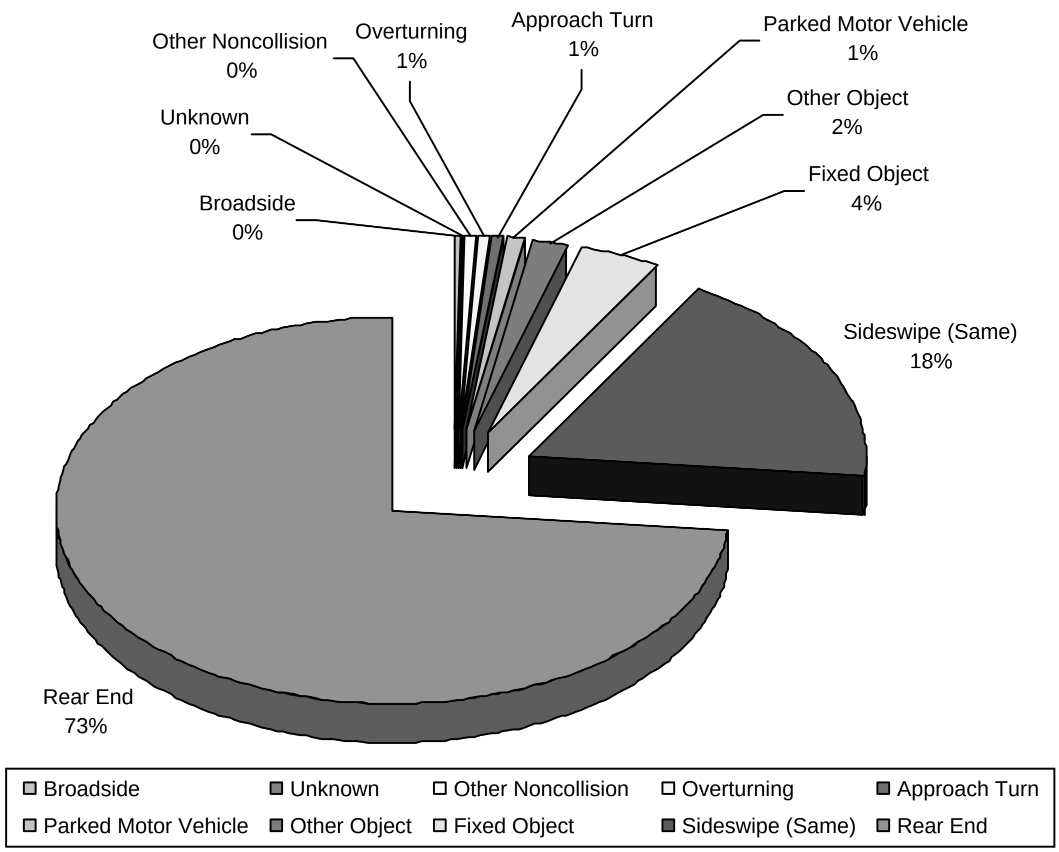


**FIGURE 8 Breakdown by accident type in study area.**

observed accident history over a period of 3 years: 523 total accidents, 389 rear-end collisions, and 92 sideswipe collisions:

$$P(X \geq 389) = 1 - P(X \leq 388)$$

$$P(X \geq 389) = 1 - \sum_{i=0}^{388} \frac{523!}{(523-i)!i!}(.445)^i(1-.445)^{523-i} = 0$$

$$P(X \geq 92) = 1 - P(X \leq 91)$$

$$P(X \geq 92) = 1 - \sum_{i=0}^{91} \frac{523!}{(523-i)!i!}(.126)^i(1-.126)^{523-i} = 0$$

where $P$ represents cumulative probability of observing 389 rear-end collisions or more and 92 sideswipe collisions or more of 523 total accidents. As noted, 0.445 is the Bernoulli probability of rear-end collisions and 0.126 is the Bernoulli probability of sideswipe collisions in the six-lane urban freeway environment.

The result of the direct diagnostics test for fixed-object collisions suggests that something in the roadway environment triggers a deviation from the random process of accident occurrence in the direction of reduced safety. Something triggers rear-end and sideswipe collisions, although at this point in the analysis one cannot know the cause. It was noticed, however, that there were significantly more accidents in the southbound direction than in the northbound.

Plan reviews in concert with a site visit revealed the existence of a highly constrained Weave Type C within Segment 2 in the southbound direction (Figures 9 and 10). Specifically, vehicles entering the freeway on the left side were attempting to exit on the right side while crossing three highly congested through lanes of traffic and one auxiliary lane over a very short distance. Operational LOS analysis that used procedures outlined in the *Highway Capacity Manual* (*17*) showed a LOS F in the weaving section in the southbound direction. In this case, a traffic operational problem related to the highly constrained Weave Type C translated into a significant safety problem manifested by the high frequency and severity of rear-end and sideswipe collisions. The high number of rear-end and sideswipe accidents is the reason behind the highly elevated accident frequency and severity on this segment. To solve the problem, the Type C weave would have to be removed by reconfiguring the interchange and constructing a flyover ramp or a tunnel to facilitate movement.

The question now becomes, What would be the expected safety performance of the segment following the reconfiguration of the interchange? With the removal of Weave Type C, it is reasonable to assume that Segment 2 will perform at least as well as an average six-lane freeway segment in an urban environment. To determine an expected accident frequency and severity, consult the SPF graphs and observe that at the present AADT level of 188,000, approximately 90 accidents per mile can be expected, of which 20.5 collisions will result in injuries or fatalities. This would lead to a reduction of approximately 88 accidents, including 19.5 injuries, during the first year following construction. It is relevant to observe that within Segment 2, every injury crash results in injuries to 1.3 people. This suggests that if the Type C weave is removed, injuries to 25 people could be prevented in the first year following construction. Figures 9

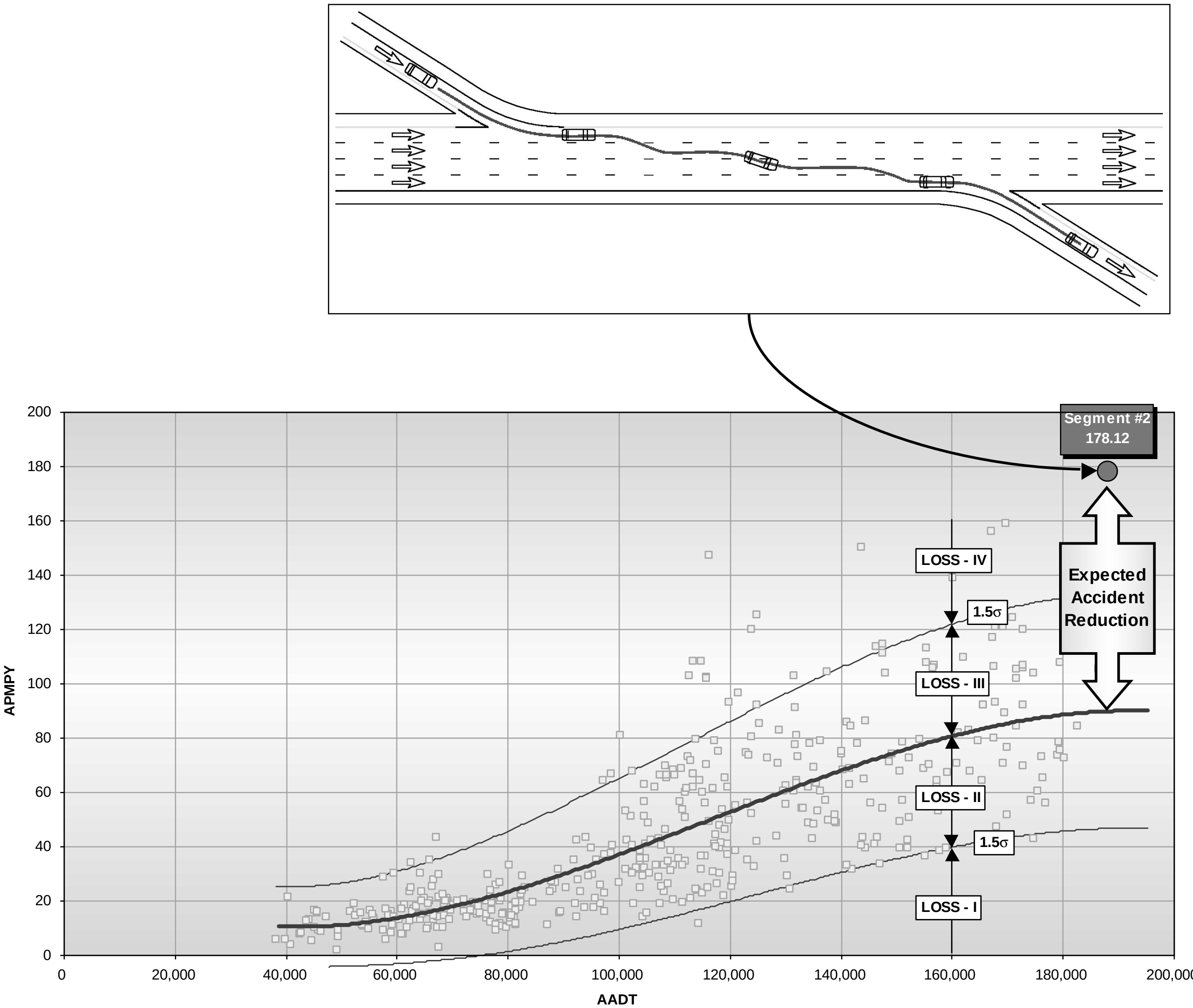


**FIGURE 9 Weave Type C LOSS analysis for total accidents, urban six-lane freeways.**

and 10 graphically illustrate the accident reduction resulting from the elimination of the constrained weave in the southbound direction.

In addition to safety improvements, a corridor expansion from six to eight lanes was planned. On the basis of the SPF comparison calibrated for four- and six-lane freeways by Kononov and Allery, expansion to six lanes provides a 15% to 20% accident reduction. Although data establishing the safety benefits of highway expansion from six to eight lanes are not available in Colorado, a 10% reduction in accidents may be a reasonable assumption to make until the real data are obtained from California. One can now determine a combined annual accident reduction within project limits subsequent to removing the Weave Type C and widening to eight lanes. Three years of recently observed accident history show that an average of 340 collisions per year occur within study limits as currently configured. Injury accidents account for 115 of the 340 total accidents. Thus the accident reduction attributed to widening would translate into 34 accidents prevented, 11.5 of which are injuries. Combining the 88 accidents averted by eliminating the constrained weave results in the prevention of 122 accidents, including 31 injuries in just the first year following construction. This real case history illustrates how to address safety explicitly while planning long-range major transportation improvements in urban corridors.

## SUMMARY

Explicit consideration of environmental impact mandated by NEPA resulted in much improved air and water quality, reduced noise pollution, and preserved wetlands. When transportation design alternatives are evaluated, the air quality and water quality as well as other parameters are measured and adverse effects are mitigated to ensure compliance with national standards. No standards that quantify the amount of safety to be expected following construction exist; how much safety to expect is unknown. Safety-

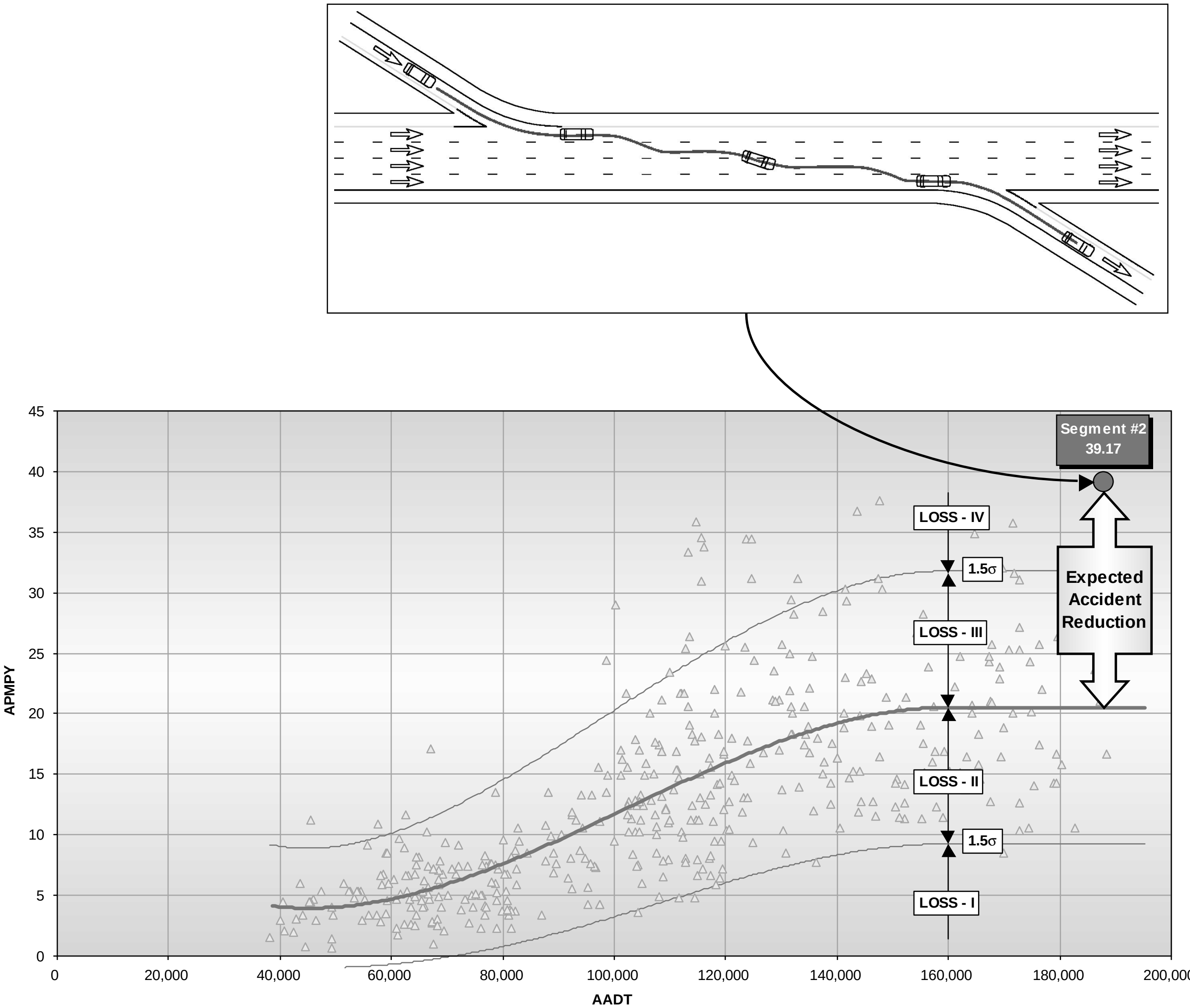


**FIGURE 10 Weave Type C LOSS analysis for injury + fatal accidents, urban six-lane freeways.**

based performance standards should be considered in transportation planning, where LOSS I and LOSS II are design norms for the construction of new facilities and LOSS III or safer is the design norm for the retrofitting of older highways. Mandatory postconstruction accident analysis should be institutionalized to determine if the facility is performing as expected. If the observed LOSS is found to be outside the acceptable range, a diagnostic investigation should be required. The findings of these investigations should be used to contribute to the professional knowledge base and supply potential sites for safety improvement programs. NEPA suggests a relevant model for the transportation planning process from the standpoint of applying sound principles to practice. Use of SPF will provide realistic estimates of the safety performance of existing and future facilities. The LOSS concept will quantify the degree of safety or unsafety existing on transportation facilities and provide a frame of reference for transportation planning from a safety perspective. Diagnostic analysis will identify the nature of the existing problems by using direct diagnostic and pattern recognition techniques. Use of these concepts in concert with practical experience will allow a transition from mere compliance with design standards to an informed and defensible safety planning position that is based on knowledge and fact. It will also allow assessment of how much safety can be obtained and at what cost.

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