FINAL
CONTRACT REPORT

RISK-BASED MANAGEMENT OF GUARDRAILS: SITE SELECTION AND UPGRADE

Center for Risk Management of Engineering Systems
University of Virginia

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16. Abstract

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A user manual accompanying the report describes the three developed software packages (database, screening, and site evaluation) in detail, including a demonstration of the software in a case study of New Kent County, Virginia.

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Center for Risk Management of Engineering Systems
University of Virginia

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Virginia Transportation Research Council

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NOTICE

The project that is the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

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ABSTRACT

This effort addresses the need for a logic-driven process that the Virginia Department of Transportation can used to allocate resources to run-off-road and fixed-object hazards on diverse secondary road systems. In Virginia, there are approximately 60,000 miles of roadway where guardrail upgrade, installation, or related warning signs or protection may be appropriate to address run-off-road and fixed-object hazards. In this project, an information system was developed to aid the planner in guardrail resource allocation by accounting for the potential crash severities, traffic exposures, costs of treatment, and other factors.

A user manual accompanying the report describes the three developed software packages (database, screening, and site evaluation) in detail, including a demonstration of the software in a case study of New Kent County, Virginia.

INTRODUCTION

Transportation agencies across the nation face the fact that there is not enough available funding to implement all warranted safety improvements. The decisions of what projects to fund must be rational and defensible to minimize undue criticism and lawsuits against the agency. In particular, highway agencies receive limited funding for addressing guardrail needs, which include installation of guardrails in new locations and where existing structures are sub-standard or damaged. Agency officials deciding how to allocate the limited guardrail funding need help to prioritize the hazardous sites for guardrail improvements.

Allocation of guardrail funds in VDOT districts is driven by citizen complaints, familiarity of local engineers with the sites, and crash histories. Once a site is determined to meet the requirements for a guardrail, the funding for that site is placed in a queue of projects waiting for funding. Currently, there is no method for recording hazardous locations and their pertinent information such as citizen complaint history and the severity of site. There is no current method for comparing a guardrail improvement with other guardrail improvements. And, there is no current method for coming up with a broad way of describing the impact a guardrail improvement would have compared to non-guardrail improvement projects.

Prior to the current effort, the Richmond District of VDOT started a database of guardrails installed on interstate and primary systems; the database did not include characterization of the protected or unprotected hazards. Thus a need and opportunity for a decision aid to improve the allocation of limited funding to the maintenance and construction of guardrails and similar categories of assets have been identified. The effort was specifically requested by and developed in collaboration with the Richmond District of VDOT.

PURPOSE AND SCOPE

The current effort develops a risk-cost-benefit decision aid for the screening and evaluation of sites needing guardrail improvements. The effort develops a database and decision aids for an allocation decision where there has heretofore been no process: guardrail installation has traditionally been driven by citizen complaints and recent run-off-road crash histories. Engineers have not heretofore had the tools to compare protected hazards (what has been done) with unprotected hazards (what is proposed). While national standards for guardrail specify the equipment that can be placed at a given hazard, the standards and vehicles traveling the roads have evolved over 50 years, leading to many installed guardrails that do not meet current standards of safety. Thus, there can be the dilemma whether to upgrade older equipment or to address previously unprotected hazards with the limited available funds.

The developed approach is in three parts:

1. *Database.* A database of protected and unprotected run-off-road and fixed-object hazards is specified. For each hazard, a variety of statistics are recorded, including,

for example, a run-off-road severity index, the average daily traffic, and the standard of existing guardrail.

2. *Screening*. A corridor-to-corridor comparison is performed across a region based on corridor-wide crash histories, corridor-average daily traffic, extent of guardrail coverage, and other corridor-aggregate factors. Charts for exploratory data analysis help planners select what corridors are most in need of further study.

3. *Evaluation*. Within a corridor of concern, candidate guardrail sites are able to be compared using alternative benefit-cost ratios. The formulation enables the planner to learn by prioritizing locations alternately based on length and severity of the hazards, vehicles per day, vehicle-miles per day, and cost. Applying alternate sets of constraints and criteria suggests those locations where funding would be most consistent with the needs and values of the locality and the transportation agency.

For Fiscal Year 2001-02, there is $875,000 budgeted for maintenance of guardrail in the Richmond District, representing 1.2% of the asset-maintenance budget. For Fiscal Year 2000-01, there is $613,000 in allocation for new construction of guardrail in the Richmond District for the National Highway System (NHS) and interstate, NHS and non-interstate, and primary road systems, representing 0.8% of the total allocation for construction. These percentages are expected to vary from district to district. The percentages should not be viewed as the only opportunity for cost savings presented by an improved resource allocation to guardrails. Rather, improvements to the allocation of guardrail funding as well as the improved management of other categories of assets such as signs, signals, lighting, pavement, and others, are applicable.

The results of this effort can be integrated with other current VDOT initiatives such as ICAS (Inventory Condition Assessment System). ICAS is a project undertaken by VDOT for the purpose of recording all VDOT investments, such as stop signs, road conditions, etc. The current effort can be integrated with the ICAS effort by having resident engineers surveying the roadways indicate potentially hazardous locations and record pertinent information, such as geographic (GPS) coordinates for the hazard site and its severity. Also, the engineers could record suggested remedial measures for the hazard site, which would also be recorded. Once a complete survey of the roadways has been completed, the methodology for prioritizing guardrail projects can be used to highlight those locations where a guardrail improvement would have the most impact.

LITERATURE AND PRACTICE REVIEW

The results of a survey of methods of comparing locations for guardrail installation and upgrade are summarized. Techniques for ranking prospective projects and methods of performing cost-effectiveness analyses are described. Elvik (1995) summarizes over 30 studies of the safety effects of median barriers, guardrails along the edge of the road, and crash cushions (impact attenuators). Sources providing warranting methods for identifying locations in need of guardrail installation or upgrade are also identified. Prioritization and cost-effectiveness tools are helpful in comparing locations needing guardrail installations or upgrades, while warranting methods merely indicate when a project is justified. It is unlikely that warranting methods would be used for comparing locations. A summary of a survey of state departments of transportation identifying the methodologies used by some states in evaluating locations needing guardrail installation or upgrade is also provided.

Ranking Techniques

Kentucky requires highway districts to keep an inventory of all substandard guardrails as well as unshielded locations that meet certain criteria (Pigman and Agent 1991). This inventory provides a listing of locations warranting a guardrail project. A procedure for prioritizing the locations to allocate funds most effectively is described by Pigman and Agent (1989). The method first develops critical rates of run-off-the-road accidents. Next, a screened list of locations with a critical rate of accidents is created, and a hazard-index point system is developed with a field study providing the necessary data. Next, the improvement benefits and costs are determined and the cost-effectiveness of the projects are analyzed. The procedure results in a list of projects recommended to receive funding.

The first step of the procedure is the development of critical accident rates. The critical rates serve as indicators of locations with a particularly high number of accidents. The critical accident rate for a type of roadway section is calculated according to equation (1):

$$A_c = A_a + K\sqrt{\frac{A_a}{M}} + \frac{1}{2M} \quad (1)$$

accidents/million vehicle miles - sections

accidents/million vehicles - locations

where

A_c = critical accident rate

A_a = average accident rate, only for accidents where vehicles ran off of the road

K = constant related to level of statistical significance selected (K = 2.576 for a probability of 0.995)

M = exposure (for sections, M is in terms of 100 million vehicle - miles, for spots, M is in terms of millions of vehicles)

The critical rate factor for each location is then determined by dividing the average accident rate for a given section by the critical accident rate for that type of roadway section. Locations with critical rates greater than 1.0 are evaluated further, while locations with a critical factor less than 1.0 are screened out of the process.

Next a hazard-index point system is described. The system is used to rank the screened list of projects. Each factor in the system is weighted based on its level of perceived relevance. The value for each location for each factor, determined by a field study, is multiplied by the factor's weight. The terms are then summed to arrive at the score for a given location. The factors included in the hazard-index system and their associated numerical weights are:

1. Number of run-off-the-road accidents (15)
2. Run-off-the-road accident rate (15)
3. Traffic volume (10)
4. Speed limit or prevailing speed (10)
5. Lane and shoulder width (10)
6. Roadside recovery distance (10)
7. Embankment slope (10)
8. Embankment height (10)
9. Culvert presence (5)
10. Subjective roadside hazard rating (5).

Following this analysis, the improvement costs and benefits are determined. The method uses severity levels and costs in the determination of benefits. Costs associated with each accident severity level, as provided by the Federal Highway Administration, along with the accident reduction factors result in an accident reduction benefit for each improvement alternative. It is unclear, however, how adding guardrails reduces the number of accidents. Nevertheless, a cost-effectiveness analysis is subsequently pursued. The method of cost-effectiveness analysis is not described, although the inputs into the budget optimization are given:

- Number of locations to be analyzed
- Budget levels to be considered
- Costs assigned to each accident severity
- Interest rate
- Traffic growth rate
- Accident history
- Alternatives for reducing accidents
- Expected improvement life
- Improvement cost
- Annual maintenance cost
- Expected reduction in accidents due to improvements.

The methodology presented by Pigman and Agent (1989) is valuable in its identification of factors important in the comparison of locations needing a guardrail project. However, although the hazard-index point system suggested provides a quick method for comparing locations, weighted-sum scores have no real basis in decision theory. For example, there is no discussion of the conflicting units among the different factors. Furthermore, there is no basis for assigning a weight to a factor (Pomerol et al. 2000). Weights, once developed, are likely to be used without introspection by subsequent analysts and managers (Frohwein et al. 1999).

AASHTO (1977) suggests a ranking factor for comparing sites for crash cushion installation (equation (2)). In principle, it would be possible to apply the same theory to guardrail sites.

$$RF = \frac{(1 + NOA) \times ADT \times S}{10{,}000} \tag{2}$$

where

RF = ranking factor ((accidents - veh - miles)/(year - day - hour))

NOA = number of accidents at the site (accidents per year)

ADT = average daily volume of traffic (vehicles per day)

S = operating speed of roadway (miles per hour)

Like the weighted-sum scores presented by Pigman and Agent (1989), the value of the ranking factor is its expediency in comparing locations; however, there is no basis in decision theory. Consider the hypothetical data of Table 1 where although $RF_A = RF_B$, there is no underlying theory to support that a decisionmaker would be indifferent between A and B.

Table 1. Sample Data for Ranking Factor Technique

	NOA	ADT	S	RF
Site A	3	20,000	60	480
Site B	3	40,000	30	480

The ranking factors for these two sites, A and B, are equal, yet it is unlikely that a decision-maker would be indifferent to adding a safety feature to either of the two. Caldwell and Wilson (1999) describe a safety improvement program. Its goal is to identify locations where the largest potential safety benefits can be attained. A section, such as the roadway between two intersections, is given a primary rating factor based on traffic volume and user types such as local, recreational, and tourist. This rating is then adjusted by factors that account for speed, heavy vehicles, and terrain, and the adjusted rating is then used to prioritize the sections. Detailed data collection is not required as each factor is rated subjectively as high, average, or low relative to other road sections in the area.

Cost-effectiveness Approaches

A body of research uses cost-effectiveness analyses to evaluate safety improvement projects. In general, these methods compare the costs of the improvements to the benefits derived from the improvements. Mak (1993) provides an overview of methods applying cost-effectiveness procedures to the evaluation of roadside safety improvements, i.e., guardrails. A benefit-cost ratio used for comparing design alternatives is presented in equation (3):

$$B / CRatio_{2-1} = (B_2 - B_1)/(C_2 - C_1) \quad (3)$$

where

$B / CRatio_{2-1}$ = Incremental benefit/cost ratio between alternatives 1 and 2;

B_1, B_2 = Benefits associated with alternatives 1 and 2;

C_1, C_2 = Costs associated with alternatives 1 and 2

The study makes a distinction between the use of encroachment probability models and accident data-based models as a basis for the cost-effectiveness analysis in equation (3). In accident data-based models, the prediction of roadside accident frequencies is accomplished using multiple regression models. The study indicates that these models are limited in their usefulness because of inherent problems associated with regression analysis. The best model explains only 60% of the variation in accident frequencies. Furthermore, since over 80% of accidents are caused by driver errors, not roadway elements, using these elements as predictors of accident frequency is not tractable. An alternative to accident data-based models is encroachment probability models. Encroachment probability models include three major mechanisms: (1) a method for predicting the frequency of accidents; (2) a method for predicting the severity of accidents; and (3) a method for estimating accident costs and determining the benefit/cost ratio. These mechanisms are applied in equation (4):

$$E(C) = \sum_{i=1}^{n} P(E) * P(A \mid E) * P(I_i \mid A) * C(I_i) \quad (4)$$

where

$E(C)$ = Expected accident cost;

$P(E)$ = Probability of an encroachment;

$P(A \mid E)$ = Probability of an accident given an encroachment (mechanism (1));

$P(I_i \mid A)$ = Probability of injury severity i, given an accident (mechanism (2)); and

$C(I_i)$ = Cost associated with injury i (mechanism (3))

Accident severities are expressed through severity indices that can be converted to societal or accident costs. Severity indices serve as indicators of the expected injuries consequences of a crash due to some hazard (Hall et al. 1994). The severity index assigned to an object depends on the object's nature, e.g., strength, size.

Mak et al. (1998) provide a similar methodology using four modules: an encroachment module, an accident prediction module, a severity prediction module, and a benefit-cost module. Equation (5) brings together the modules:

$$E(AC)=\sum_{i=1}^{n} V * P(E) * P(A \mid E) * P(I_i \mid A) * C(I_i) \quad (5)$$

where

$E(AC)$ = Expected accident cost

V = traffic volume, ADT

$P(E)$ = Probability of an encroachment (encroachment module)

$P(A \mid E)$ = Probability of an accident given an encroachment (accident prediction module)

$P(I_i \mid A)$ = Probability of injury severity i, given an accident (severity prediction module)

$C(I_i)$ = Cost associated with injury severity n

n = number of injury severity levels

The first three modules are incorporated in the calculation. The benefit-cost module is then:

$$\text{BC ratio} = (\text{AC}_1 - \text{AC}_2)/(\text{DC}_2 - \text{DC}_1) \quad (6)$$

where

AC_1 = Expected accident cost of project 1

AC_2 = Expected accident cost of project 2

DC_1 = Direct cost of implementing project 1

DC_2 = Direct cost of implementing project 2

There are a few minor differences between Mak et al. (1988) and Mak (1993). Mak et al. (1998) incorporate the traffic volume in the calculation of the expected accident cost. Second, the benefit-cost ratio of Mak et al. (1998) is slightly altered from that of Mak (1993). The ratio in Mak et al. (1998) shows that the expected accident cost should be less for the project that has a higher direct cost, forcing the ratio to be non-negative.

Glennon (1974) presents a slightly different cost-effectiveness approach based on a hazard model. The model considers:

1. Vehicular roadside encroachment frequencies
2. The percentile distribution for the lateral displacement of encroaching vehicles
3. The lateral placement of the roadside obstacle
4. The size of the obstacle
5. The accident severity associated with the obstacle.

The model is then:

$$\frac{\text{cost}}{\text{effectiveness}} = \frac{\text{annualized cost of the improvement}}{\text{hazard reduction achieved}} \tag{7}$$

The ratio in equation (7) compares the annualized cost of the improvement under consideration to the hazard reduction achieved by the improvement. This ratio can then be compared to the ratios of other proposed guardrail projects. The hazard score is given by one of two relationships.

The first relationship is:

$$H = V * P(E) * P(C \mid E) * P(I \mid C) \tag{8}$$

where

H = hazard index (expected number of fatal plus nonfatal injury accidents per year)

V = vehicle exposure (number of vehicles per year passing through the section)

$P(E)$ = probabilty that a vehicle will encroach on the roadside within section L; encroachments per vehicle

$P(C \mid E)$ = probability of a collision given that an encroachment has occurred; accidents per encroachment

$P(I \mid C)$ = probability of an injury (fatal or nonfatal) accident given a collision; fatal plus nonfatal injury accidents per year

This model is very similar to equation (4) given by Mak (1993). A second formula is given for calculating the hazard reduction of a given improvement [equation (9)].

Assuming an 11-degree encroachment angle and a 6-foot average vehicle length allows Figure 1 to be used to determine the necessary probabilities.

Equation (9) considers the properties of the roadside in determining the necessary probabilities. For example, the probability of a collision given an encroachment is a function of the vehicle's lateral displacement: the distance from the roadside that the vehicle travels, the lateral placement of the obstacle; the distance from the roadside where the obstacle is placed, and the size of the obstacle: its length and width. These factors allow equation (9), a simple formula to use in real practice, to be applied to decisions.

Using Figure 1 with equation (9), the hazard reduction achieved by an improvement is determined. This is found by determining the hazard before the guardrail is added and subtracting the hazard after the guardrail is installed. Equation (7) is now applied to make a comparison of locations needing a guardrail project. The reduced severity of colliding with a guardrail versus the object or slope being shielded will be coupled with an increased probability of colliding with the guardrail because the value of *s*, the lateral placement of obstacle, is now reduced.

$$H = \frac{E_f * S}{10{,}560} * \left\{ l * P[y \geq s] + 31.4 * P[y \geq (s+3)] + \frac{5.14 * w}{n} * \sum_{j=1}^{n} P\left[y \geq \left(s + 6 + \frac{w * (2j-1)}{2n} \right) \right] \right\} \quad (9)$$

where

E_f = encroachment frequency (number of roadside encrouchments per year)

S = severity index (number of fatal and nonfatal injury accidents per total accidents)

l = longitudinal length of the roadside obstacle (feet)

$P[y \geq ...]$ = probability of a vehicle lateral displacement greater than some value, as taken from Figure 1

y = lateral displacement of encroaching vehicle (feet)

s = lateral placement of obstacle (feet)

w = lateral width of the roadside obstacle (feet)

n = number of analysis increments for the hazard associated with the obstacle width. A reasonable subdivision is that, for widths up to 4 feet, each 2.5 feet of width is represented as one increment

j = number of the obstacle- width increment under consideration

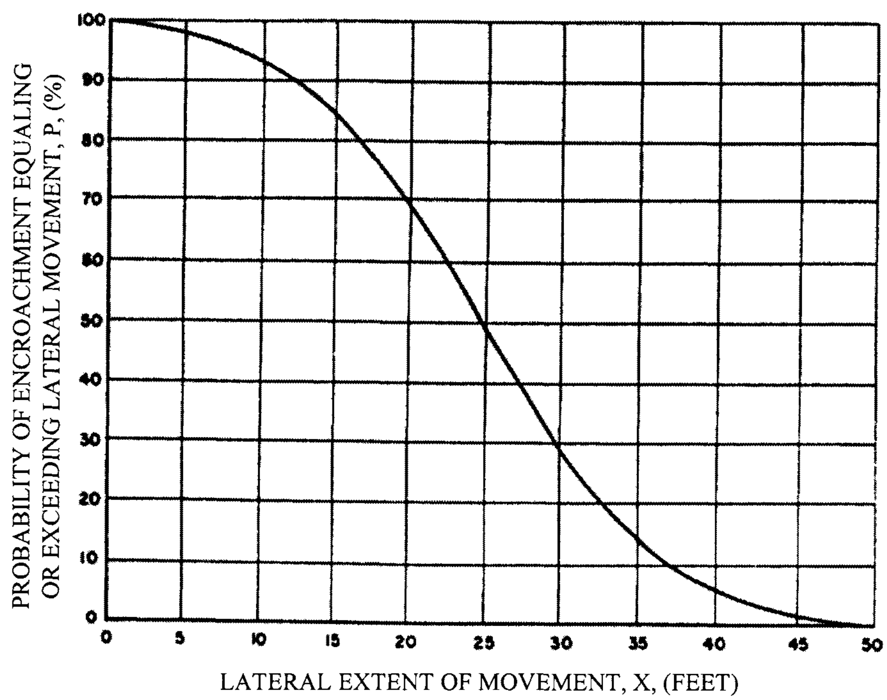

Figure 1. Probability of a vehicle's lateral displacement being greater than X feet

AASHTO (1996) presents a cost-effectiveness procedure. The technique calculates the total present worth of accident costs and highway department costs incurred over the life of the project. Equation (10) is the formula used in calculating the total present worth:

$$TPW = C_a(K_c) + C_I + ARC + C_m(K_t) - C_s(K_j) \tag{10}$$

where

C_a = Accident cost based on initial collision frequency

C_I = Installation cost

C_m = Annual maintenance cost

C_s = Salvage value of feature being studied

K_c = Factor to account for project life, discount rate, and traffic growth rate

K_t = Factor to account for the project life and the discount rate

K_J = Factor to account for the project life

ARC = Present worth of accident repair costs = $\sum K_c * C_d * f$

C_d = Average collision damage repair costs for sides, corners, and face

C = Initial collision frequencies for sides, corners, and face

To use AASHTO (1996) for comparing locations needing guardrail projects, one would compare the total present worth of each of the locations. The accuracy of the methodology can be questioned because of the uncertainties involved in estimating the average collision damage repair costs, initial collision frequencies, and other factors. The selection process should be supplemented by engineering judgment and experience.

The methodology presented in AASHTO (1996) is based on work done in AASHTO (1977). In the procedure, the total present worth cost for each alternative is determined, allowing a comparison to be made. Equation (11) gives the total present worth cost.

As is the case with the procedure presented in AASHTO (1996), the uncertainties involved in estimating these factors raise doubts with regard to the usefulness of the methodology. Indeed, this is the case with all cost-effectiveness procedures that use estimates of encroachment frequencies, collision frequencies, and/or accident severities.

Warranting Methods

Another body of research identifies when guardrail projects are warranted. Instead of comparing locations, these methods tell an analyst if a given location is justified in receiving a guardrail upgrade or an installation. Therefore, it is difficult to use a warranting method to compare locations needing guardrail installation or upgrade. One may envision that comparisons could be made by considering which locations more strongly warrant guardrails.

$$C_T = (C_I) + (C_d * f * T) + (C_{OVD} * f * K_t) + (C_m * K_t) - (C_s * K_j) \quad (11)$$

where

C_I = Installation cost

C_d = Average collision damage repair costs (present dollars)

C_m = Annual maintenance cost (present dollars)

C_{OVD} = Average occupant injury and vehicle damage cost per accident (present dollars). A severity index assigned to the obstacle helps determine the accident costs

C_s = Salvage value of feature being studied

f = collision frequency (accidents per year)

T = useful life of the obstacle (years)

K_t = Factor toaccount for the project life and the discount rate

K_J = Factor to account for the project life

Warranting methods can be divided into three main categories: charts, flow-charts, and guidance tables and figures. The Georgia Department of Transportation gives a number of charts for determining locations that warrant guardrails, such as Figure 2 and Figure 3.

According to Figure 2, locations with slopes less drastic than 3:1 never warrant guardrails. Slopes more drastic than 3:1 may warrant guardrails if the roadside height is sufficiently severe. Georgia (1991) provides different figures for different traffic volumes, attempting to provide guardrails in the busiest locations in order to save the most lives and avoid the most injuries.

While Figure 2 is used for roads with more than 3000 vehicles per day, Figure 3 evaluates roads with slightly less daily traffic. As a result, the shape of the warranting curve is slightly altered. The combination of slope and height must be more drastic on the lower traffic volume road in order for guardrail to be warranted. For example, in Figure 2, at a height of 10 feet and a slope of 2.5:1, a guardrail is warranted. In Figure 3, these conditions would not warrant guardrail. The changing warranting curves attempt to incorporate a cost-effectiveness analysis by allowing higher trafficked roads to more easily warrant guardrails. The California Department of Transportation uses a similar graphic shown in Figure 4.

Figure 4 is similar to the charts used in Georgia (1991). However, there is only one chart provided; thus, the traffic volume aspect addressed by Georgia (1991) is omitted.

Wolford and Sicking (1997) develop simplified charts for determining when guardrails are warranted. The charts are derived from a benefit-cost analysis evaluating the severity of embankment heights of varying magnitude and varying lateral offsets of culverts. Three charts are given. Figure 5 provides warranting guidelines for cable guardrail; Figure 6 gives warranting guidelines for W-beam guardrails; and Figure 7 provides warranting guidelines when culverts are present.

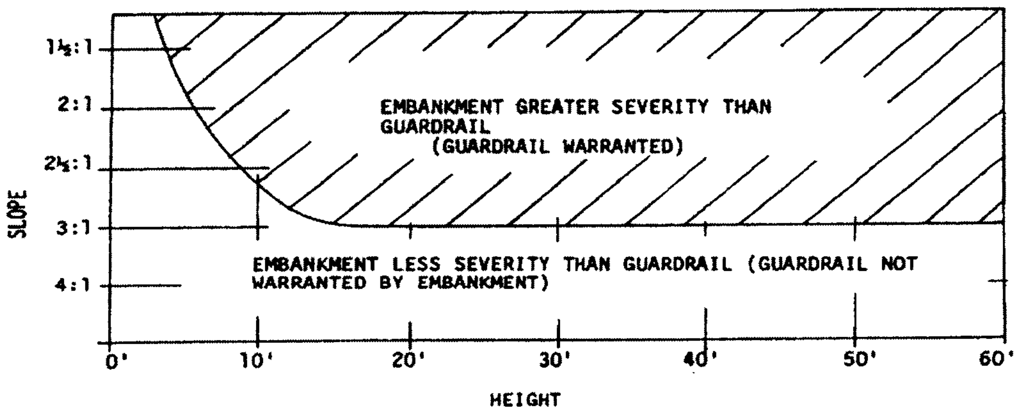

Figure 2. Chart giving guardrail warrants (Georgia DOT 1991)

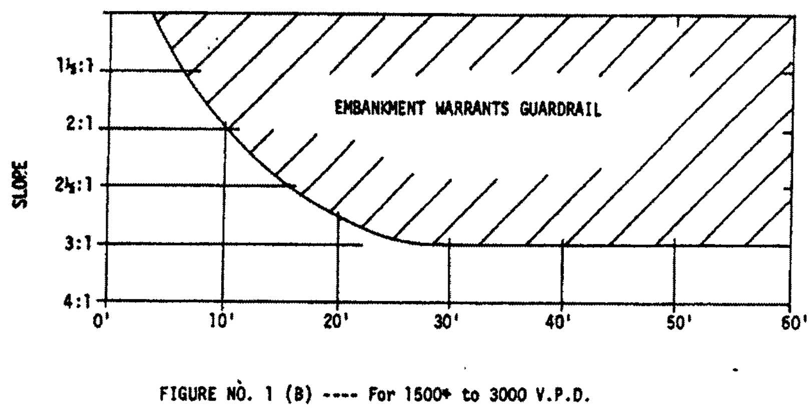

Figure 3. Warranting chart for 1,500 to 3,000 vehicles per day (Georgia DOT 1991)

Like the figures provided in Georgia (1991), these warranting charts attempt to bring a cost-effectiveness factor into the decision. Adjusting the warranting conditions according to daily traffic aims to put limited funds toward areas where the most citizens will benefit.

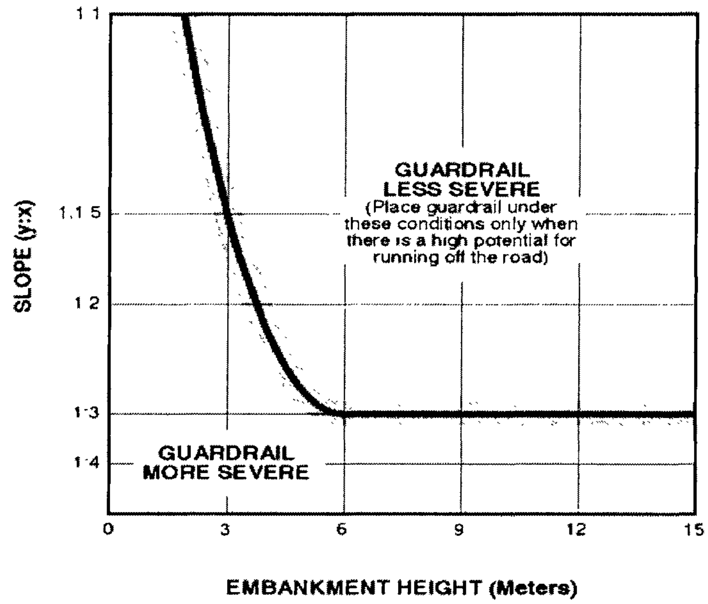

Figure 4. Warranting chart (California DOT 1999)

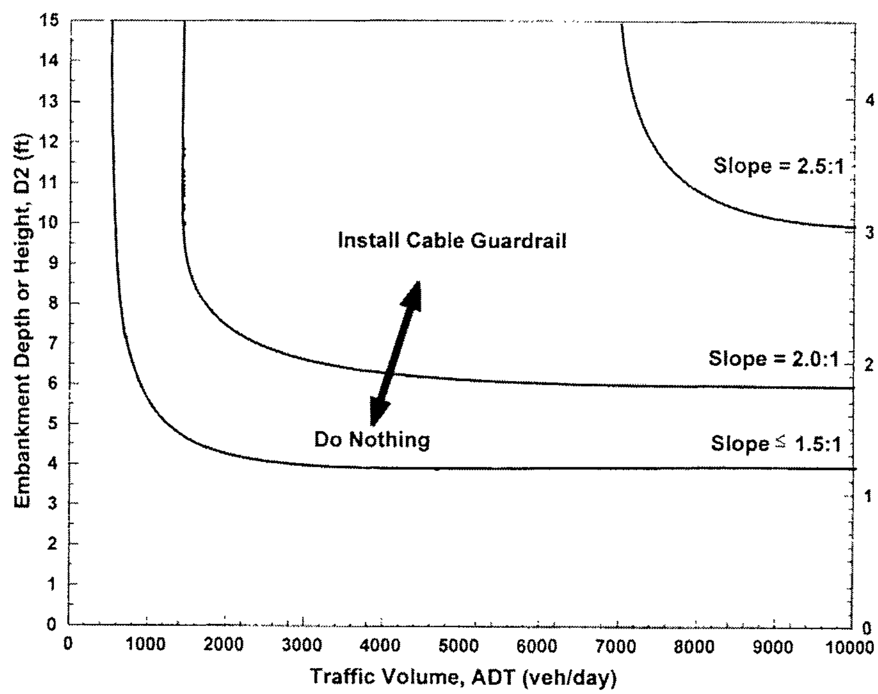

Figure 5. Cable guardrail need for embankments (Wolford and Sicking 1997)

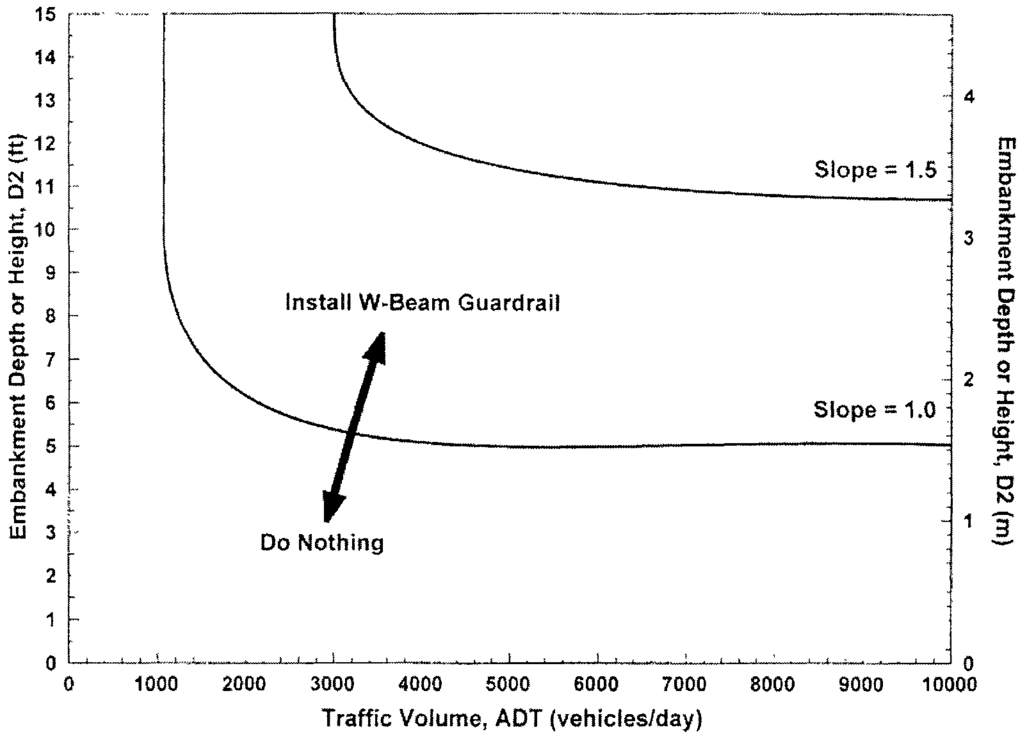

Figure 6. W-beam guardrail need for embankments (Wolford and Sicking 1997)

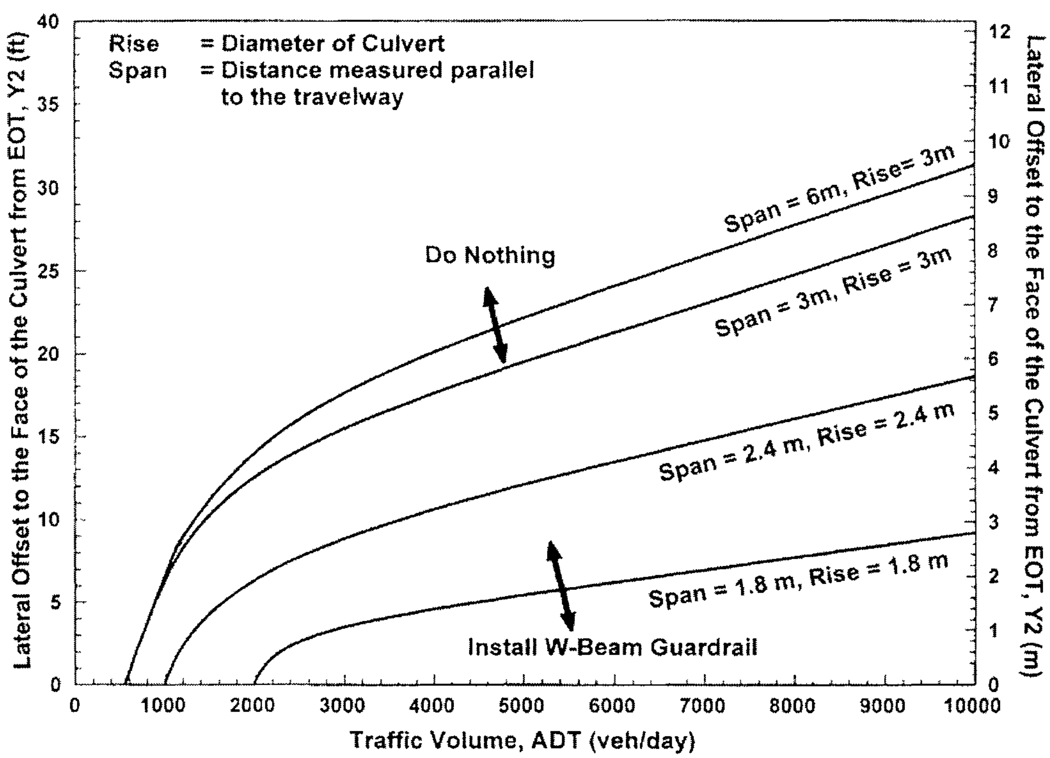

Figure 7. W-beam guardrail need for culverts (Wolford and Sicking 1997)

AASHTO (1977) presents flow charts shown in Figure 8.

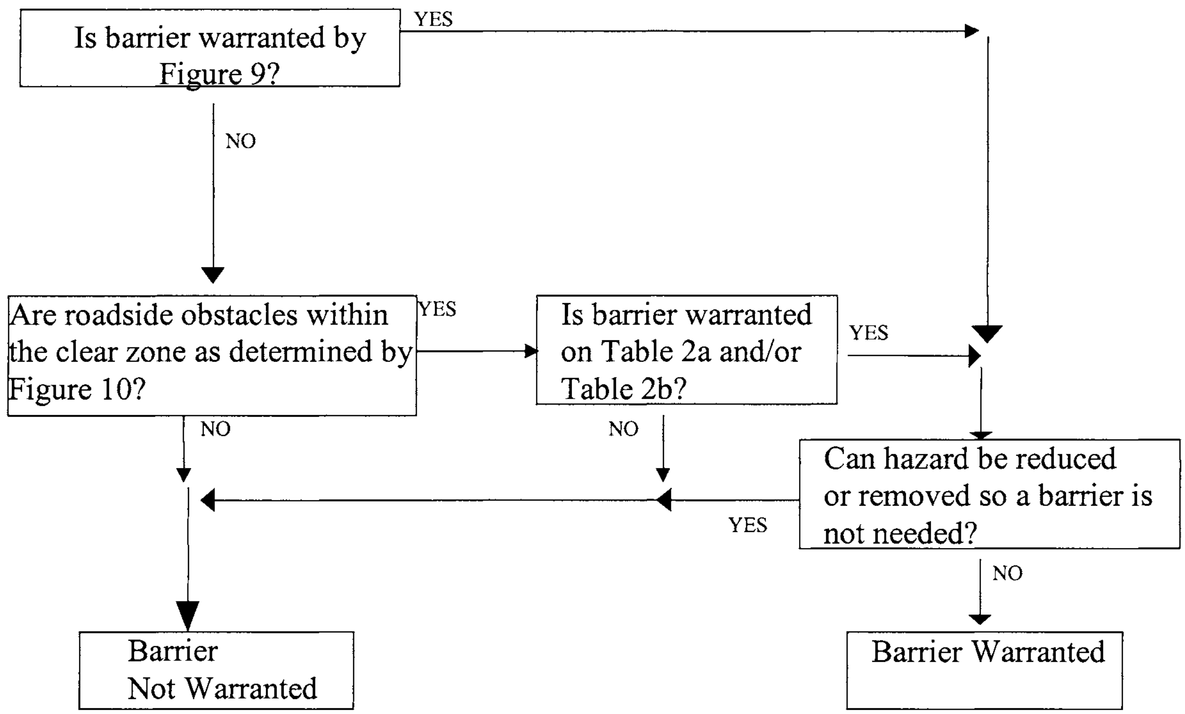

Figure 8. Flow chart used for warranting guardrail (AASHTO 1977)

Figure 9 is a chart similar to those already discussed.

Tables 2a and 2b are also used with the flowchart shown in Figure 8. These tables provide another means of determining if a guardrail is warranted.

Table 2a. Guidance Table

Non-traversable Hazard Within Clear Zone as Determined by Figure 10	Traffic Barrier Required?	
	Yes	No
Rough rock cuts	X	
Large boulders	X	
Streams or permanent bodies of water less than 2 feet in depth		X
Streams or permanent bodies of water more than 2 feet in depth	X	
Shoulder drop-off with slope steeper than 1:1		
a. Height greater than 2 ft.	X	
b. Height less than 2 ft.		X

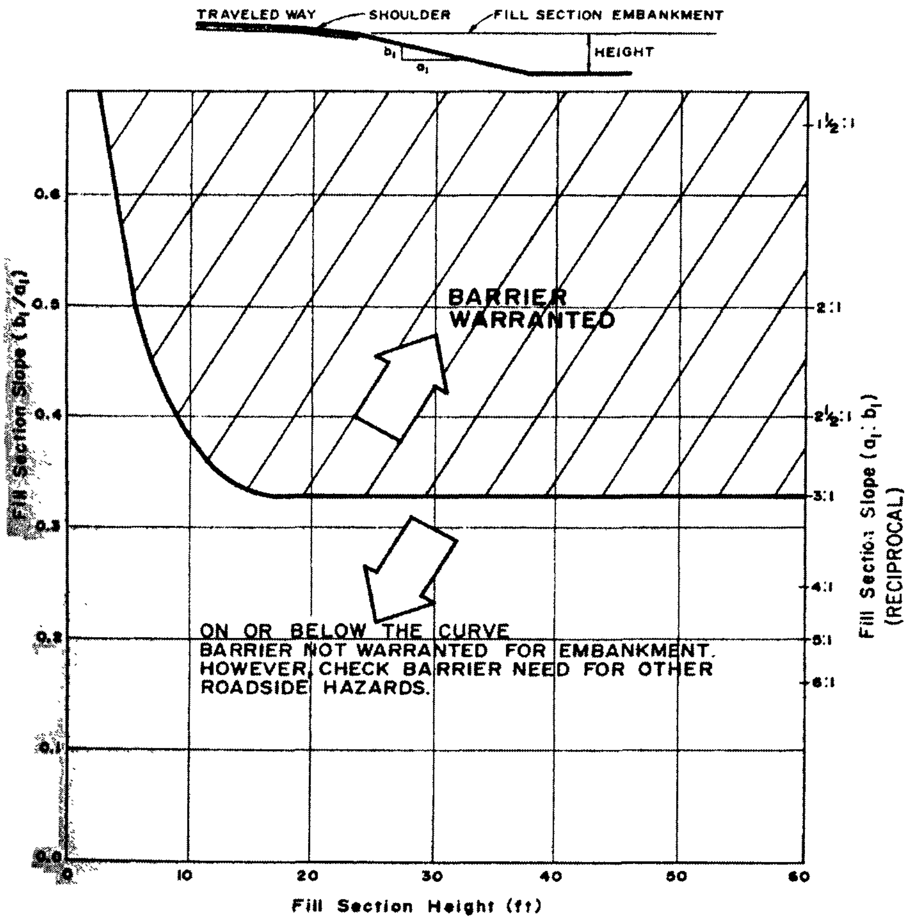

Figure 9. Warranting guideline (AASHTO 1977)

Table 2b. Guidance Table

Fixed Objects Within Clear Zone as Determined By Figure 10	Traffic Barrier Required?	
	Yes	No
Sign, traffic signal, and luminaire supports		
a. Breakaway or yielding design with linear impulse:		
1. less than 1,100 lb-sec		X
2. Greater than 1,100 lb-sec	X	
b. Concrete base extending 6 in. or more above ground	X	
Fixed sign bridge supports	X	
Bridge piers and abutments at underpasses	X	
Retaining walls and culverts	X	
Trees with diameter greater than 6 in.	X	
Wood poles or posts with area greater than 50 in^2	X	

Figure 10 helps determine if objects are in the clear zone.

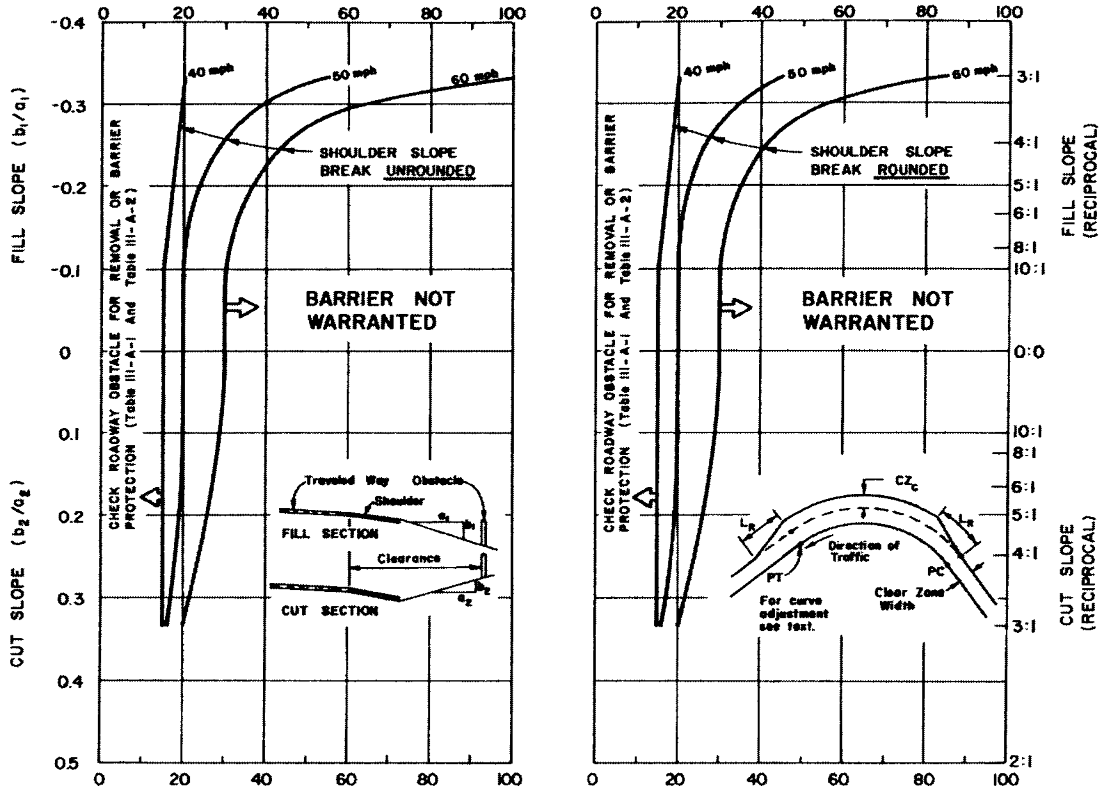

Figure 10. Additional warranting guidelines (AASHTO 1977)

An alternative chart given by AASHTO (1977), shown in Figure 11, provides step-by-step questions to determine if a guardrail upgrade project is warranted in a given location.

Step-by-step methodologies such as those in Figures 10 and 11 can be helpful in evaluating a location while avoiding numerous complex calculations.

Additional related studies include Teng and Tzang (1996), Davis (1995), Holguin-Veras (1995), Saaty (1995), Benekohal et al. (1994), Van Dam (1994), Witkowski (1988), Wattleworth and Ingram (1972), and Wildenthal et al. (1994). Multiobjective programming and planning is described by Pomerol et al. (2000), Miettinen (1999), Gal et al. (1999), and Zeleny (1982). Graphical analysis of road planning with multiple criteria has been addressed by Baker and Lambert (2001) and Frohwein et al. (1999). Such efforts rightly seek a balance among all costs, risks, and benefits in selecting a portfolio of road improvements. Risk management for engineering systems is addressed by Haimes (1998).

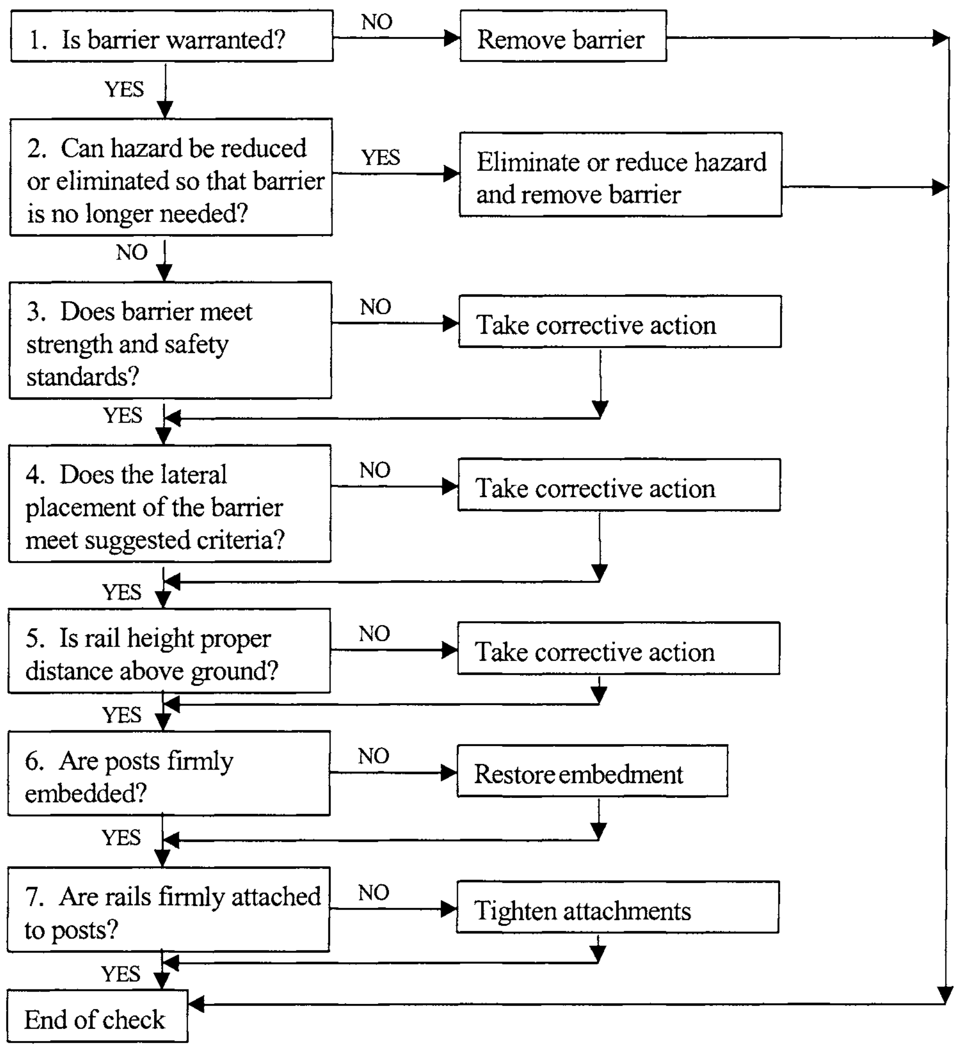

Figure 11. Flow chart used for evaluating currently installed guardrail

Informal Contact with State Transportation Agencies

A number of state departments of transportation were contacted in order to understand how highway agencies compare locations needing guardrail installations or upgrades. In general, the agencies do not formally prioritize guardrail improvements. The agencies generally use warranting methods and fund warranted projects as allowed by their budgets.

The following questions were addressed to some U.S. state departments of transportation for the purpose of understanding how states across the country allocate their funds earmarked for safety improvements, including guardrails.

1. Who in your agency, or elsewhere, has authority in the areas of funding allocation for guardrails, management of guardrail inventories, and screening of wide geographic areas for guardrail needs?

2. What recommendations do you have for a transportation agency that is faced with many needs for new installations and upgrades of guardrail but limited funding? (Please share your experiences in prioritizing your locations.)

3. Does your agency keep an inventory/database of all guardrail installations? (If so, then share your experiences in maintaining the inventory.)

4. What databases, reports, methodologies, etc., that are supportive of cost-benefit-risk analyses does your agency use for managing its inventory and needs for guardrail?

5. What standards does your agency employ to determine if guardrail is warranted (i.e., any criteria above and beyond the Roadside Design Guide)?

6. What are the factors you consider for replacement/upgrade of guardrail (e.g., obsolescence, height, new standards)?

The small number of states that do apply a process reflects the limited number of viable methodologies found in the literature. Responses to Question 1 indicate the complexity of decisions regarding allocation of guardrail funds. The changing of personnel involved in the decision makes consistency a challenge. Maintenance divisions of the agency most often manage allocation, but other involved divisions include roadway design, policy and budget, design and traffic engineers, highway safety engineers, state traffic engineers, and highway operations. New York State is divided by 11 regions, each of which is responsible for designing, constructing, and operating its own roads. Allocation of funds is managed within each region, so prioritization can be accomplished only on a regional level, and coordinating efforts across regions is difficult.

Responses to Question 2 indicate that Kentucky is one of few states that use a methodology that proactively prioritizes locations needing guardrail improvements. The Kentucky DOT builds on Pigman and Agent (1989, Section 2.5). The state of Washington uses a benefit-cost ratio to compare individual locations. Rhode Island recommends upgrading/ installing guardrail in conjunction with other scheduled projects. Indiana first evaluates areas with high accident rates and subsequently includes average daily traffic statistics.

Question 3 responses indicate about a quarter of the interviewed states maintain a database of existing guardrails. The databases track such items as the amount of guardrail installed; the guardrail type, end treatment, location, and length; and information on completed projects. Some states indicate that they are in the process of developing databases. A detailed inventory, possibly integrated with a geographic information system (GIS), is beneficial to an agency evaluating roadway locations or sections for guardrail need. Information on each location is catalogued and readily accessible, giving decision makers all of the information they need when comparing locations.

The responses to Question 4 indicate most states apply the AASHTO Roadside Design Guide to individual sites, if any methodology is used at all. The guidance of the National Cooperative Highway Research Plan (NCHRP) 350 is also used in some cases.

Question 5 responses indicate the states emphasize that the judgment and expertise of a resident engineer should be integral to the process. Georgia, among a few other states, has developed a warranting standard.

Question 6 responses indicate most states evaluate physical characteristics such as obsolescence, height, absence of block-outs, substandard end treatments, insufficient length of need, rail condition, and crash-worthiness. Some states upgrade guardrails only when another project is scheduled concurrently in the location. Accident history, presence of a 3R/4R project, compliance with NCHRP 350 requirements, and Federal Highway Administration mandates are other factors planners evaluate.

In VDOT, personnel familiar with the areas in question decide whether or not to install guardrail. A cursory evaluation of the location is performed, and if funding is available, a guardrail is installed if justified in the evaluator's eyes. Locations usually come under scrutiny as a result of identification by VDOT or through citizen complaints (VDOT 1999).

The New York State Department of Transportation (1999) also performs no prioritization of locations. Instead, each location is evaluated to determine if the clear zone is sufficient. When this is not the case, a guardrail is installed, provided funding is available. Guardrails are also installed whenever potential hazards cannot be made crash-worthy.

The Ohio DOT (1999) uses a warranting system to determine when a guardrail is justified. No prioritization of locations needing guardrail installations is performed.

The California DOT (1999) uses crash history, potential, geometrics, average daily traffic, and slope to determine when a guardrail should be installed. No prioritization technique is used.

In Minnesota, the DOT (1999) uses the AASHTO guide and evaluations by personnel to determine when guardrails are warranted. No prioritization of locations is done

The clear zone requirements of the Wyoming DOT (1999) match those of the AASHTO guide. No prioritization of locations is done.

The Alaska Department of Transportation (1999) developed an automated spreadsheet for performing a cost-effectiveness analysis. The system requires data for "Traffic Input" such as the average daily traffic, a traffic growth factor, grade, number of lanes, lane width, and highway type. There is also a section for "Roadside Model Input," which requires data on the slope rate, the offset of the slope/obstacle, and the slope/obstacle width and length. The system asks for a severity index for the hazard and a variety of cost factors and returns an accident prediction output and a project cost output. The cost output is broken down into the present worth and the annual costs.

METHODS OF ANALYSIS

The approach for the development of a decision aid for guardrail resource allocation is in three parts: (1) a database of protected and unprotected hazards is proposed; (2) a corridor-by-corridor screening is performed; and (3) a site-by-site evaluation of guardrail needs is performed.

Database of Protected and Unprotected Hazards

The development and maintenance of a database of guardrail and guardrail needs are addressed. There is yet no record or reporting format for the hazardous sites along the more than 60,000 miles of Virginia's secondary roadway system. Nor is there a process for recording locations that are protected or unprotected by guardrail or other treatments, including what type and standard of protection is afforded to the sites. A standard reporting format of hazardous sites is developed in order to capture in a database such characteristics as the location severity and the type and standard of existing guardrails. In addition, data such as daily traffic records and complaint records are associated with the respective sites. By compiling related information on hazardous sites in one database, calculations and comparisons of the sites in both an individual corridor and between different corridors can be performed readily. The database supports subsequent guardrail management approaches described here as depicted in Figure 12.

Route=	613
Length of Route=	Unknown
County/City=	NK

To Guardrail Types   To Workbook Summary Table
To Route Summary Table
To Next Route

Accident Data Covers Dates		
01/01/00	to	07/27/00

			Location						Existing					Proposed												
Include (Y or N)?	ID Number	Date Modified	Number of Lanes	Flow Direction	Right or Left	Relative to	Beginning Milepost (miles)	End Milepost (miles)	Length of Hazard (feet)	Existing Run-on Type	Existing Main Run Type	Existing Run-Off Type	Existing Other Type	Value of Existing Section	Proposed Run-on	Proposed Main Run	Proposed Run-Off	Proposed Other	Removal Cost Per Foot	Total Cost for Proposed Improvement	Severity Index	Guardrail Strikes	ADT (Vehicles per Day)	Hazard DVMT (Daily Vehicle Miles Traveled)	Number of Related Crashes	Severity of Complaints	Comments
Y	1	07/00	2	N	R	E611	1 565	1 603	201					$0	4	5	6		7	$6,207	4		258	9 8			Near Railroad, Steep Embankment
Y	2	07/00	2	N	R	E611	1 400	1 460	317	1	2	3		$3,584	4	5	6		7	$7,485	9		258	15 5			Sub GR w/Blunts
Y	3	07/00	2	N	R	E611	0 437	0 475	201					$0	4	5	6		7	$6,207	8		782	29 7			Water Hazard
N	4								0					$0						$0				0 0			
N	5								0					$0						$0				0 0			
N	6								0					$0						$0				0 0			
N	7								0					$0						$0				0 0			
N	8								0					$0						$0				0 0			
N	9								0					$0						$0				0 0			
N	10								0					$0						$0				0 0			
N	11								0					$0						$0				0 0			

Guardrail Types / Route A / Route B / Route C / Route D / Route E / Route F / Route G / Route H / Summary

Figure 12. Excerpt from the database of protected and unprotected run-off-road hazard sites, characterizing locations, lengths, severities, traffic rates, existing and proposed guardrails, costs of remedy, accident history, complaints, among other factors

Corridor-by-Corridor Screening

Over 60,000 miles of Virginia's secondary (and primary) roads are in need of screening for guardrail improvements. Figure 13 shows different attributes considered in identifying locations. It is infeasible to consider all of these possible locations together in a single funding cycle; the data collection alone would be unmanageable. Therefore, it is necessary to screen potential locations in aggregate groups that can later be analyzed in detail.

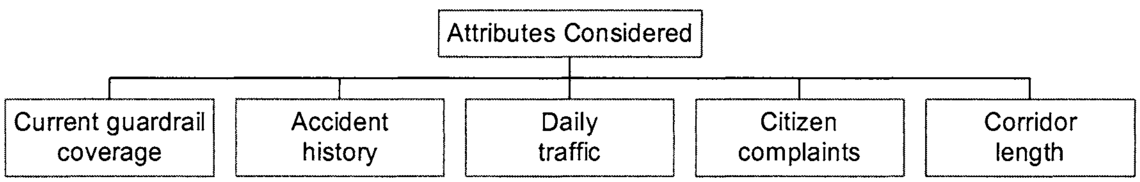

Figure 13. Attributes considered for corridor-to-corridor screening of guardrail needs

Thus, the method first entails a comparison of road corridors in broad geographic regions (e.g., counties or residencies). The data collection for comparing corridors across regions is manageable. Corridors are compared on the basis of guardrail coverage (e.g., percentage of covered hazards in a sample), guardrail condition, topography, accident history, or other relevant factors. For example, some districts of VDOT maintain a regional database with the number and condition of guardrails.

For corridor accident history, it is important to sort accidents into related and non-related incidents. Related events, which are fixed-object and run-off-road accidents, are those accidents that perhaps could have been prevented or alleviated through the use of guardrails. The type of accident designation in police reports varies in different law enforcement agencies, so it is important to define what kinds of accidents are potentially related to guardrail coverage.

An important factor in comparing corridors is the average daily traffic (ADT). The higher the ADT, the more the importance of a corridor. ADT is a measure of exposure; higher ADT leads to a greater number of guardrail-relevant accidents. With every vehicle that travels past a particular location, there is opportunity for an accident. A pilot study was conducted using data obtained from VDOT's accident databases (HTRIS) of 17 roadway corridors in the Richmond District. Figure 14 compares 17 corridors based upon their daily vehicle miles traveled (DVMT) and their accident rates over a span of 1 year. DVMT is useful for comparing corridors as it reflects (more so than ADT) the exposure to hazards. Figure 14 shows that corridors 610 and 621 have the highest accident rates and may be excellent candidates for guardrail studies. Also, Figure 14 shows that corridors 601 and 634 have the highest amount of property damage per DVMT, making them excellent candidates for guardrail studies, as well.

Use of accident data to choose guardrail sites is precarious, yet by aggregating the accidents at all sites across a corridor, reliable indicators of corridor-wide need can be developed. The uncertainty of the extreme event of an accident in any one location is diminished. The longer the corridor or the greater the ADT, the more reliable are the conclusions from accident history about the corridor need.

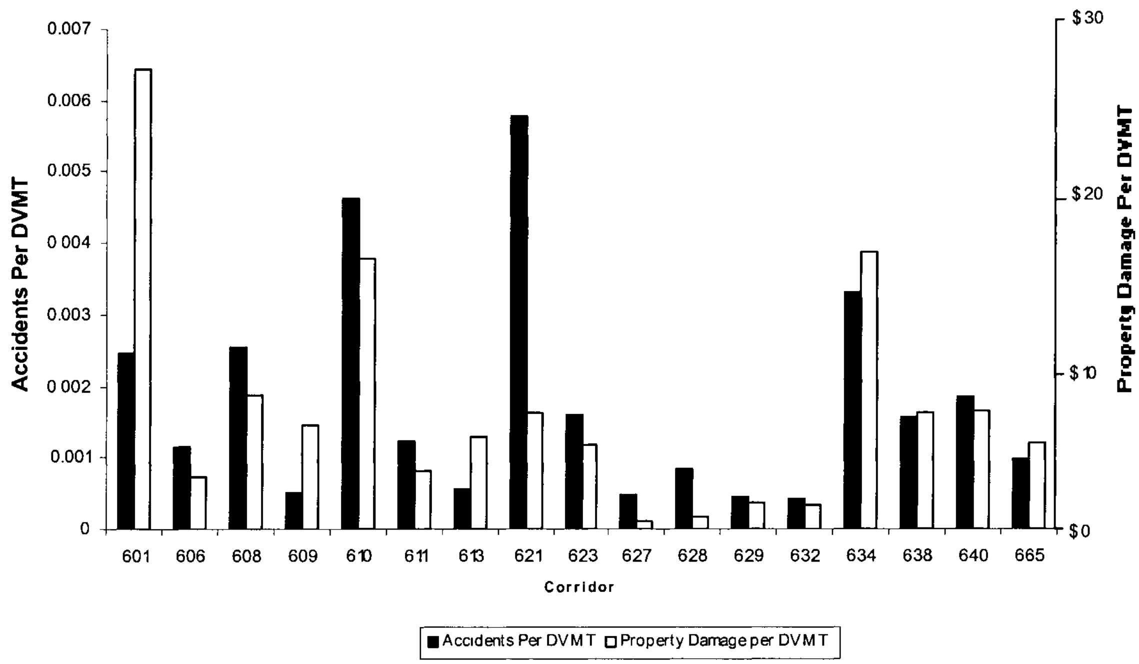

Figure 14. Number of related accidents and amount of property damage per corridor daily vehicle mile traveled (DVMT): Used for corridor-to-corridor screening

The effects as well as the number of accidents may be taken into account. Effects include the damage to persons and property associated with an accident. In Figure 14, corridors 601, 610, and 634 stand out as having high amounts of property damage associated with accidents and may heighten the concern of safety planners. The numbers of injuries and fatalities are two factors that can be considered in corridor screening. Comparisons can be made between corridors with low rates of highly severe accidents and corridors with high rates of less severe accidents.

Figure 14 provides insight as to which corridors should receive further attention. This figure is not used independently, in that insights from this figure can be supplemented with insight from another, helping the safety planner to focus on an area where further study should be applied. Following the high-level screening, an in-depth comparison of site needs follows.

Site-by-Site Evaluation

A detailed analysis is used to aid planners to select at a set of sites for allocation of funds. Benefit-cost analysis is a method for distributing limited resources as it maximizes or minimizes some objective function (the B/C ratio) while adhering to defined constraints. The approach presented here is to consider the benefits alternately in different perspectives. Figure 15 presents different objectives that are used to aid the planner in site prioritization.

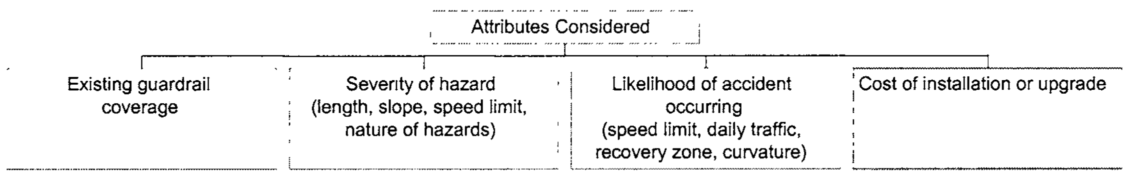

Figure 15. Attributes considered in prioritizing individual locations

In prioritizing locations needing guardrail installation or upgrade, there is a variety of useful mathematical objective functions and constraints. A planner may attempt to maximize the total length of hazardous sites protected for the largest number of people possible while staying within a monetary budget constraint. The following are examples of plausible objectives and constraints:

- *Miles protected.* A planner may wish to maximize the total length (centerline mileage) of hazardous sites protected.

- *Severity protected.* A planner may wish to maximize the hazardous sites protected based on their total severity. The severity rating of a hazard is dependent upon such factors as the roadside slope in the area, the average speed, the size of the hazard, etc. The assignment of a severity rating is performed by the surveying engineer. In the interest of consistency among raters, it is suggested that engineers train one another through case studies and attempts to reach consensus that the qualitative narrative description of the severity rating is representative of a particular site. The Roadside Design Guide (1996) is an example of the assignment of numerical severity ratings for hazards.

- *Vehicle miles protected.* The vehicle miles protected is the product of the length of the hazard and the average daily traffic at the site. It is important because the most cost-effective solutions protect the most traffic.

- *Severity miles protected.* The severity miles protected is the product of the severity index and the length of the off-road hazard.

- *Severity vehicle miles protected.* This is the product of the severity index and the daily vehicle miles (product of ADT and site length) protected at the site.

- *Cost.* Planners work with a limited budget, and thus cost is modeled as a constraint.

However, it also possible to model cost as an objective to be minimized.

A benefit-cost ratio is calculated for each site, with the benefit being one of the described objectives. The benefit-cost ratio is used to order the sites from most to least need. The planner can select sites in such order until the budget constraint is reached. The objectives and constraints listed here are not necessarily the best measures to apply to the problem of prioritizing locations. A planner can easily substitute his or her own set of objectives and constraints. The alternate use of various objectives facilitates discussion and debate among the engineers, planners, and their constituencies.

RESULTS AND DISCUSSION

An on-site visit with VDOT personnel to secondary roads in the Richmond District was supplemented by ADT data obtained from VDOT's HTRIS. The roads were selected from New Kent County by the district traffic engineer for their winding topography and proximity to the district office. The sample is not intended to be representative of the district as a whole. A sample of 10 locations for evaluation is selected to demonstrate the benefit-cost ratio formulation. Figure 16 shows the sample sites. The sample sites are located along a corridor that could have been identified using the aids described. Table 3 shows the data provided for the sites, and Table 4 shows the site severity scale 1 to 10. Table 4 was developed in consultation with field engineers who recommended that from Tables 3 and 4, the vehicle miles protected, the severity miles protected, and the severity vehicle miles protected are calculated for each location. These factors are shown in Table 5.

Tables 3, 4, and 5 are used in the program of benefit-cost ratio formulations. First, a project cost is estimated for each location. The cost typically depends only on the length of guardrail needed (a typical cost estimate is $10 per foot), the number and type of end treatments necessary (each end treatment is approximately $2,000), and whether or not the location needs an installation or an upgrade (upgrades are slightly more costly because the current guardrail on site must be removed). Table 4 was developed in the current effort to simplify a cumbersome severity assessment of Pigman and Agent (1991). Field engineers reported that application of the numerous tables and charts of Pigman and Agent (1991) was time consuming and inefficient and that Table 4 is an efficient and accurate substitute. Table 6 gives the costs assigned to each sample location.

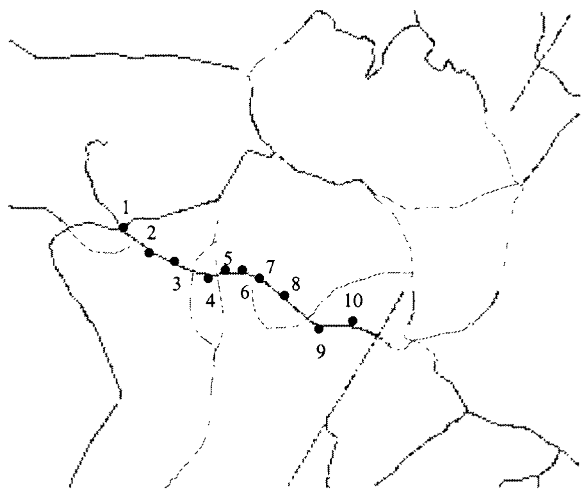

Figure 16. Sample of sites along a corridor needing guardrail improvements

Table 3. Data for Each Hazard Site under Evaluation

Location	Length of Need (miles)	Severity of Obstacle, Slope, Curvature, etc.	ADT (vehicles per day)
L1	0.038	4	258
L2	0.061	9	258
L3	0.028	8	782
L4	0.038	1	485
L5	0.057	2	485
L6	0.095	3	485
L7	0.047	6	485
L8	0.322	9	1118
L9	0.011	8	1118
L10	0.320	10	531

Table 4. Severity Scale Used to Characterize Severity of an Unprotected Hazard at Candidate Site

8 to 10	Permanent water hazards consisting of more than 2 ft of depth, slopes ratio much greater than 2:1 (indicating a high chance of vehicle rollover), fixed objects that present a clear danger to occupants of vehicles (such as the blunt "spear" ends of substandard guardrails), or areas of incidence include high potential for loss of life or property.
6 to 8	Water hazards that could potentially reach heights of over 2 ft during periods of flooding, slope ratio higher than 2:1, potential dangerous fixed objects (such as improperly mounted guardrails or a substantial number of trees with diameters greater than 4 in).
4 to 6	Slope ratio about 2:1 (marginal possibility for vehicle rollover), a small number of trees with diameters greater than 4 in).
2 to 4	Slope ratio less than 2:1, few fixed objects (such as trees with diameter greater than 4 in).
0 to 2	Area has a slope that is not likely to have vehicle rollovers occur, guardrails placed here will likely pose more of a hazard than do existing conditions, recovery zone adequate.

Table 5. Derived Factors for Each Hazard Site under Evaluation

Location	Vehicle Miles Protected	Severity Miles Protected	Severity Vehicle Miles Protected
L1	9.8	0.15	39.1
L2	15.9	0.55	142.9
L3	22.2	0.23	177.7
L4	18.4	0.04	18.4
L5	27.6	0.11	55.1
L6	45.9	0.28	137.8
L7	23.0	0.28	137.8
L8	360.2	2.90	3241.6
L9	12.7	0.09	101.6
L10	170.0	3.20	1699.6

For the 10 projects under consideration, a budget of $55,000 is assumed for the set of benefit-cost formulations where cost is a constraint, as shown in Figure 17. Each objective function is maximized in turn in Solutions 1 to 5. Table 7 gives the results when applying Microsoft Excel's solver to maximize the factors from Figure 17. In Table 7, the numbers represent the order in which the benefit-cost ratios should be funded to maximize the overall benefit, with 1 being the most recommended and 10 being the least recommended. Table 8 shows the results of applying Microsoft Excel for the various objective functions (benefits) maximized in turn subject to the above budget constraint. Note, for example, that funding locations 2, 6, 8, and 10 maximize the miles protected while remaining within the budget constraint. Table 8 gives the solutions for a sample of the additional maximization criteria discussed.

Table 6. Cost of Guardrail Project at Each Site

Location	Cost ($)
L1	$6,000
L2	$6,900
L3	$6,000
L4	$6,000
L5	$7,000
L6	$8,475
L7	$6,225
L8	$19,284
L9	$6,000
L10	$19,185

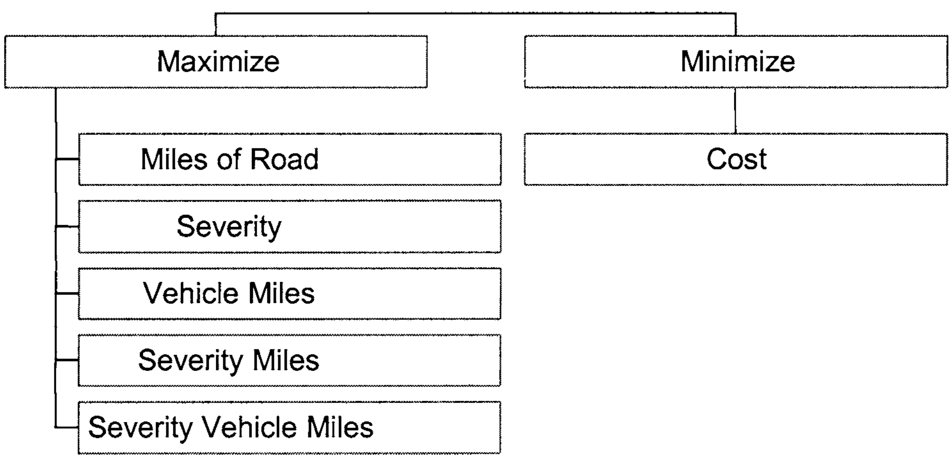

Figure 17. Criteria for site-to-site evaluation of guardrail needs along a corridor

A transportation planner is now faced with deciding what solution, or combination of solutions, to implement. Tables 7 and 8 show the several solutions that maximize one objective function or another. A planner must evaluate how the solutions compare with respect to the benefits under consideration and decide on one (or a combination) to implement. In such an iterative process, the planner discovers what benefit, or set of benefits, is most important. One comparison method is to evaluate graphically the tradeoffs the solutions provide. Table 9 summarizes the cumulative benefits for each of the optimizing solutions.

Table 7. Benefit-Cost Priorities (1-10) for Sites L1 through L10

Site Location	Solution 1 Miles Protected	Solution 2 Severity Protected	Solution 3 Vehicle Miles Protected	Solution 4 Severity Miles Protected	Solution 5 Severity Vehicle Miles Protected
L1	7	5	10	7	9
L2	4	3	8	3	5
L3	9	1	5	5	3
L4	8	10	7	10	10
L5	5	9	4	8	8
L6	3	8	3	6	7
L7	6	4	6	4	4
L8	1	7	1	2	1
L9	10	2	9	9	6
L10	2	6	2	1	2

Table 8. Benefit-Cost Funding Decisions with Budget Constraint of $55,000

Site Location	Solution 1 Miles Protected	Solution 2 Severity Protected	Solution 3 Vehicle Miles Protected	Solution 4 Severity Miles Protected	Solution 5 Severity Vehicle Miles Protected
L1		Funded			
L2	Funded	Funded		Funded	
L3		Funded			Funded
L4					
L5			Funded		
L6	Funded		Funded		
L7		Funded		Funded	Funded
L8	Funded		Funded	Funded	Funded
L9		Funded			
L10	Funded	Funded	Funded	Funded	Funded

Table 9. Cumulative Factors for Each Solution S1 through S5

Solution	Miles Protected	Severity Protected	Vehicle Miles Protected	Severity Miles Protected	Severity Vehicle Miles Protected	Cost
S1	0.80	31	592	6.94	5,222	$53,844
S2	0.51	45	254	4.51	2,299	$50,310
S3	0.79	24	604	6.50	5,134	$53,944
S4	0.75	34	569	6.94	5,222	$51,594
S5	0.72	33	575	6.61	5,257	$50,694

Figure 18 highlights the severity protected and daily vehicle miles protected by each optimizing solution, with the size of the bubble representing the cost of the solution. Figure 18 shows that the costs of all of the solutions are roughly equal (the cost of $55,000 is a binding constraint to all solutions). If a planner is most concerned with protecting severity, then Solution

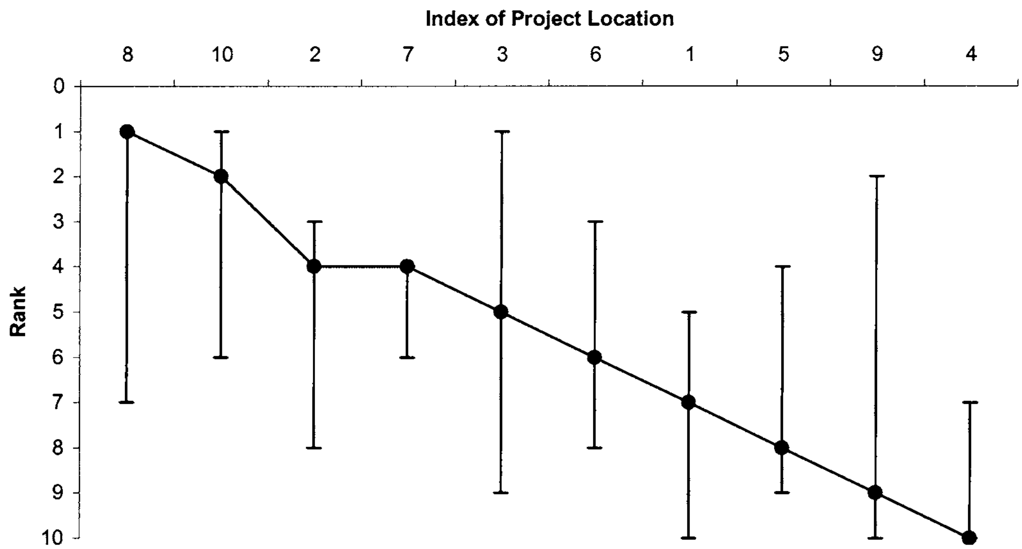

Figure 20. Lowest, median, and highest ranking of each project (L1 to L10) across the five alternate objectives

CONCLUSIONS

Two phases of analysis in support of resource allocation to roadway guardrails were developed and demonstrated. The first is a screening phase based on a high-level comparison of corridors. The screening phase compares corridors through the accident history statistics, traffic, and other factors and highlights corridors for further study for guardrail needs. The second phase makes site-by-site comparisons of the screened sites applying benefit-cost ratios to allocate the limited funds of a highway agency for guardrail projects. The two phases, together with the specified supporting database, comprise an aid to decision making, supporting discussion among planners, engineers, and the public about what benefits are important to be considered for resource allocation for guardrail needs.

RECOMMENDATIONS

The recommendations of the effort are as follows.

1. VDOT should consider the deployment of the developed database of protected and unprotected hazards, including the associated data collection.

2. VDOT should consider the deployment of the developed corridor screening tool, including the associated data collection.

3. VDOT should consider the deployment of the developed site evaluation tool and the associated data collection.

4. Workshops for resident engineers should be convened to facilitate the adoption of the developed tools.

5. The application of the tool should be considered for the primary road system (upgrading and new locations), the secondary system (new locations), and the interstate system (new locations).

6. With the new capability provided by the specified database, VDOT should consider whether to decouple the funding of new installations from the funding of upgrades to existing guardrails; the database specified in the current effort is the first to distinguish new installations from upgrades in a catalog of guardrail needs.

7. VDOT should consider supporting the maintenance of a website on its intranet for resources (including the developed softwares) relevant to guardrail installation and upgrade.

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APPENDIX

User Manual for

Risk-Based Management of Guardrails: Site Selection and Upgrade

Table of Contents

Executive Summary

The Virginia Department of Transportation's (VDOT) experiences have suggested that public and transportation-agency valuations of locations and acceptable safety standards of roadway guardrails are in need of clarification. A 1997 customer survey revealed that relative to national norms, Virginians show a high concern for adequate guardrails. The current practice in VDOT Districts for site selection for new guardrails and guardrail upgrades along secondary roads is based on citizen complaints, a general knowledge base of roadway needs from the local engineer, and accident history. Early indications are that most states consider similar factors. Notably Kentucky has developed a hazard-index point system (Kentucky Transportation Center Report KTC-89-39 "Warrants and Guidelines for Installation of Guardrail"). There are hundreds of candidate locations on the thirteen-county secondary system of Richmond District. Particular locations in New Kent County have been the focus of a related preliminary study in Richmond District.

The goal of the effort has been to develop a cost-benefit-risk tradeoff methodology to support the screening and evaluation of guardrail sites for installing and upgrading with limited available funding. There were four related objectives: (1) A review of the literature and other agencies' experience of what factors have been considered to be important in the management of guardrails; (2) Adoption of assessment methods and quantitative and qualitative factors for the comparison of costs, reductions in risk, and other metrics of guardrail performance; (3) Development of a tradeoff methodology that aids decision makers to seek an appropriate balance among the quantitative and qualitative factors/endpoints; and (4) Specification and prototype development of databases that support the assessments of costs, risks, and other factors/endpoints related to guardrails.

There may be many more worthy locations for guardrails than can be addressed with available funding, however it is in the public interest to have used a sound, auditable process for determining guardrail locations rather than none at all. It may be within the rightful discretion of VDOT and local constituents to prefer small reductions in risk to large increases in cost, or to prefer smaller measurable gains to larger gains known with less precision.

The organization of this document is as follows: a.) Instructions for prototype databases b.) Example for use of prototype databases using actual survey data.

This document can serve as a user's manual for implementation of the developed system. Lambert, Baker, and Peterson (2000) describe the methodological and theoretical contribution of the effort in a more concise presentation.

Chapter 1: Hazard Catalog Tool Instructions

The purpose of this chapter is to give explicit instructions on the use of the prototype database tool called the Hazard Catalog Tool. The organization of this chapter is as follows:

a.) Overview

b.) Title

c.) Guardrail Types

d.) Route Sheets

e.) Summary Table

Overview:

The Hazard Catalog Tool is used to store data on hazard sites and guardrails along routes for use by the VDOT (Virginia Department of Transportation). With this tool, information can be readily derived from the data collected and then reformulated into other formats, most notably graphs and charts.

The Hazard Catalog Tool is available from the Center for Risk Management at UVa at the website, www.virginia.edu/~risk/guardrail/ , left click on Report and Software. The Instructions contained here are also accessible at this site. Right click where it says, underlined, "Hazard Catalog". A small gray box will appear with a list of options. Choose "Save Target As…". Now the computer will present an option of where to save the file on the user's computer. Once the selection of what folder the file is to be saved to is completed, click on the box in the lower right hand corner that says "Save" to finish. The file is now on the user's computer. To access the file on the user's computer, use a file-browsing utility such as Windows Explorer to bring up the computer's file directory. Find the folder where the file was saved and double-click on the name of the file, "Hazard.xls". Now Excel will open the file. Other tools which complement the Catalog Tool are available at the website as well.

The Hazard Catalog Tool is an Excel workbook composed of several sheets, all related to each other. The workbook automatically includes all the necessary sheets, and is opened as a singular file from a folder menu.

Throughout the Hazard Catalog, yellow cells are used as input cells. All other cells are protected and cannot be changed unless otherwise specified. By protecting cells, accidents that could cause errors in the sheets and their calculation are prevented.

Title:

The first sheet seen when the file is opened will be the title screen, shown in **Figure 1.1**.

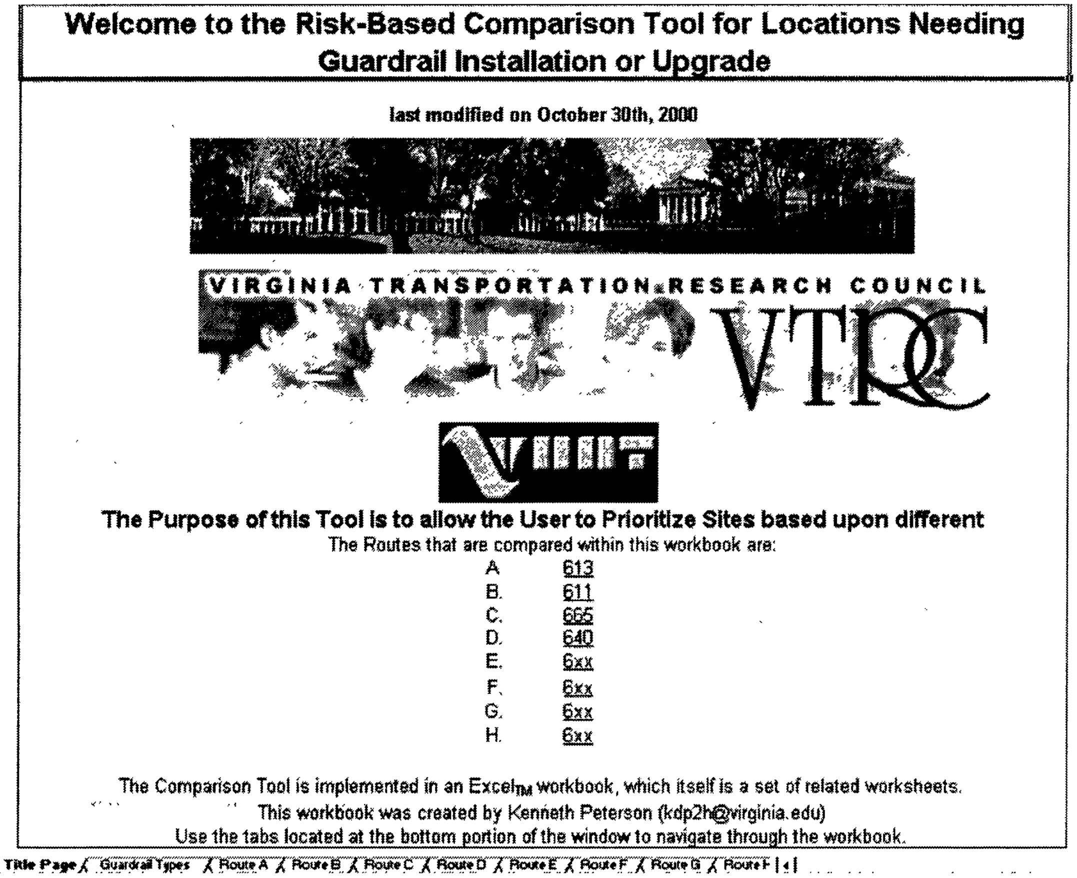

Figure 1.1 Title Sheet (from Hazard Catalog)

The tabs seen at the bottom can be used to navigate the Hazard Catalog Workbook. Finding the tab labeled **Guardrail Types** and clicking on it will bring up a screen similar to **Figure 1.2**.

Guardrail Types:

The **Guardrail Types** sheet is used to assign costs to specific numbers, which are then utilized in the subsequent **Route Sheets**. The Type, Name, and Comments columns are not used in other sheets. They are included here to help the user keep track of the number designations.

This sheet is used to keep track of the letter designations used in the Route Input Sheets. Please enter the characteristics of the letter types you wish to use in the yellow boxes

Each designation is given in terms of unit cost, except for main run types and removal costs, which are treated as cost/per foot in the Route Sheets.

Number Designation	Type	Name	Cost	Comments
1	Run-On	GRM-1	$1,000	Substandard
2	Main Run	GRM-2	$5	Substandard
3	Run-Off	GRO-3	$1,000	Substandard
4	Run-On	GRO-4	$2,000	New GR
5	Main Run		$10	New GR
6	Run-Off		$2,000	New GR
7	Removal		$1	Removal Cost per foot
8	Not Used			
9	Not Used			
10	Not Used			
11	Not Used			
12	Not Used			
13	Not Used			
14	Not Used			
15	Not Used			
16	Not Used			
17	Not Used			
18	Not Used			
19	Not Used			
20	Not Used			
21	Not Used			
22	Not Used			
23	Not Used			
24	Not Used			

Title Page | Guardrail Types | Route A | Route B | Route C | Route D | Route E | Route F | Route G | R

Figure 1.2 Guardrail Types (from Hazard Catalog)

The next sheet is the **Route A** sheet. Again, the tabs at the bottom of the screen can be used to go to the **Route A** sheet. The screen will appear as in **Figure 1.3**.

Route Sheets:

In the top-left corner of **Figure 1.3** is a box. Inside the box are three user input areas. The top one is the **Route** designation. This can be entered as letters or numbers, depending on how the route is designated. Below that is the **Length of Route**. The length of the route in miles is entered here. If the length of the route is unknown or not relevant, it can be left blank or filled in with a designation such as Unknown as shown in this example. The last input area in this box is the **County/City** designation. Enter the name of the district or city in this box.

Route=	613
Length of Route=	Unknown
County/City=	NK

To Guardrail Types — To Workbook Summary Table — To Route Summary Table — To Next Route

Accident Data Covers Dates:
01/01/00 to 07/27/00

			Location							Existing					Proposed												
Include (Y or N)?	ID Number	Date Modified	Number of Lanes	Flow Direction	Right or Left	Relative to:	Beginning Milepost (miles)	End Milepost (miles)	Length of Hazard (feet)	Existing Run-on Type	Existing Main Run Type	Existing Run-Off Type	Existing Other Type	Value of Existing Section	Proposed Run-on	Proposed Main Run	Proposed Run-Off	Proposed Other	Removal Cost Per Foot	Total Cost for Proposed Improvement	Severity Index	Guardrail Strikes	ADT (Vehicles per Day)	Hazard DVMT (Daily Vehicle Miles Traveled)	Number of Related Crashes	Severity of Complaints	Comments
Y	1	07/00	2	N	R	E611	1.565	1 603	201					$0	4	5	6		7	$6,207	4		258	9.8			Near Railroad, Steep Embankment
Y	2	07/00	2	N	R	E611	1 400	1 460	317	1	2	3		$3,584	4	5	6		7	$7,485	9		258	15.5			Sub GR w/Blunts
Y	3	07/00	2	N	R	E611	0 437	0 475	201					$0	4	5	6		7	$6,207	8		782	29.7			Water Hazard
N	4								0					$0						$0				0.0			
N	5								0					$0						$0				0.0			
N	6								0					$0						$0				0.0			
N	7								0					$0						$0				0.0			
N	8								0					$0						$0				0.0			
N	9								0					$0						$0				0.0			
N	10								0					$0						$0				0.0			
N	11								0					$0						$0				0.0			

Guardrail Types / Route A / Route B / Route C / Route D / Route E / Route F / Route G / Route H / Summary

Figure 1.3 Route A Sheet (from Hazard Catalog)

In the top middle of the screen is a menu of hyperlinks. These hyperlinks can be used as an additional method to navigating the tool, the other method being to click on the tabs at the bottom of the screen, or in the case of the **Route Summary Tables**, scrolling through the main table.

To the top-right of the main table is a user input area where the dates for which the information in the table is valid can be entered. The user input area is used for user informative use only. In the main table, moving the mouse over a header of a column, will cause a comment box to pop up with information relevant to that column.

In the main table, the first column is labeled **Include (Y or N)?**. In the user input area of this column either a **Y** is entered if that row is to be included in any analyses upon the route, or an **N** is entered if that row is not to be included in any analyses for the route. The **Include (Y or N)?** column is used as an alternative to erasing and retyping the information for a site.

The next column is the **ID Number** column. This column is used to automatically assign a number for that site, and is used for reference in later charts and analyses. The **Date Modified** column is an indicator that tells how recent the row data is.

The **Number of Lanes** column designates the number of traffic lanes present in both directions. The **Flow Direction** and **Right or Left** columns are used to designate which location on the road is under consideration. In the **Right or Left** column, **L** is used to designate the left lane, **R** is used to designate the right lane, and **B** is used to designate both sides.

The **Relative to** column is an indicator that tells where the beginning and end mileposts are on the route. It is usually the point on the route where counting of the mileage of the route (the zero point) begins. A suggested format is 0W, which stands for the westernmost point of the route, or 0S, which stands for the southernmost point of the route.

The **Beginning Milepost** and **End Milepost** columns are used to give the location and length of the hazard, and correspond to the **Relative to** column.

The **Length of Hazard** column tells the length of the hazard, and is dependent upon the entries in the **Beginning Milepost** and **End Milepost** columns.

The **Existing Guardrail** columns consist of five sub-columns. These sub-columns are used to designate a cost associated with that site. A number corresponding to a cost listed in the **Guardrail Types** sheet represents the cost. An entry may be left blank, in which case the site is presumed not to have that type of guardrail present. The **Existing Guardrail** columns consist of four user input columns and one informative column. The four user input columns are: **Existing Run-On Type**, **Existing Main-Run Type**, **Existing Run-Off Type**, and **Existing Other Type**. The informative column, **Value of Existing Section**, displays the value of the existing guardrails.

The **Proposed Guardrail** columns consist of six sub-columns. These sub-columns are used to designate a cost associated with the site being investigated by entering a number. This number relates to a cost indicated in the **Guardrail Types** sheet. An entry may be left blank, in which case the site is presumed not to have that type of guardrail present. The **Proposed Guardrail** columns consist of five user input columns and one informative column. The five user input columns are: **Proposed Run-On Type**, **Proposed Main-Run Type**, **Proposed Run-Off Type**, **Proposed Other Type**, and **Removal Cost per foot** (how much cost is associated with removing any previously existing guardrail, leave blank if there is no existing guardrail). The informative column, **Total Cost for Proposed Improvements**, displays the cost of the sites proposal (inclusive of what **Type of Improvement** is being considered for that site.)

Other Improvements can consist of actions such as removing the hazard, relocating the hazard outside of the clear zone, making the hazard yielding or breakaway, shielding the hazard with guardrail, delineating hazards, installing rumble strips, or other changes deemed necessary. The type of **Other Improvement** that is being used can be mentioned in the **Comments** section.

The **Severity Index** column has a user input based upon the on-site assessment of the severity of the site. The range is from **1** to **10**, with <u>1 being the least-severe</u> and <u>10 being</u>

the most-severe. Please refer to the **Severity Guidelines Sheet** (see Chapter 4) when assigning a severity number to a site.

The **Guardrail Strikes** column is a record of how many times a guardrail has been struck. The way to measure this quantity is to record how many dents and other damage are apparent on the existing guardrail. While not strictly quantitative to fixed-object and run-off-road accidents, it is a good indicator of the benefit derived from that particular guardrail.

The **ADT** column is the **A**verage **D**aily **T**raffic, given in Average Number of Vehicles per Day, and can be obtained using VDOT resources such as HTRIS.

The **Hazard DVMT** column is the Daily Vehicles Miles Traveled for a hazard site, and is automatically calculated using the product of the **Length of Hazard** and the **ADT**.

The **Number of Related Crashes** column has data that can be obtained using accident data databases, such as the state of Virginia's HTRIS. Related Accidents can include fixed-object crashes and run-off-road crashes.

The **Severity of Complaints** column assigns a qualitative value based on the number of citizen complaints filed. **L**(ow) is used to designate none to few citizen complaints, **M**(edium) is used to designate few to average number of complaints, and **H**(igh) is used to designate a large number of complaints.

The **Comments** column is used to add any other information which may be pertinent to a site, such as known water hazards, or any type of utility structures running through it.

That completes the main table. In the hyperlink menu at the top of the sheet, there is a menu of sites; clicking on the **To Route Summary Table** hyperlink will bring up a screen that looks like **Figure 1.4.**

Summary Table for 613

Information here only includes those sites indicated as included in Analysis   To Top of Page

Number of Sites Included	Earliest Date Modified	Latest Date Modified	Number of Sites needing Installation	Number of Sites With No Changes	Number of Sites Needing Upgrades	Value of Existing Guardrails Needing Upgrades Prior to Upgrading	Value of All Existing Guardrails	Total Cost for Proposed Installations	Total Cost for Proposed Upgrades	Summation of ADT	Summation of DVMT
3	07/01/00	07/27/00	2	0	1	$3,584	$3,584	$12,414	$7,485	1298	55

Summation of Severity Index Numbers	Summation of Collisions	Mileage of Proposed Installations	Mileage of Guardrails Needing No Change	Mileage of Guardrail to be Upgraded	Mileage Currently Protected	Mileage Protected by Proposals	Mileage Protected After Proposals
21	0	0.06	0	0.06	0	0.12	0.12

Figure 1.4 Summary Table for Route A Sheet (from Hazard Catalog)

Figure 1.4 shows the **Route Summary Table** for the route under consideration. Each route has its own **Route Summary Table** below the main entry table. Here, the summations of pertinent columns can be seen at a glance. Using this data, calculations and comparisons can be performed, as needed. Below the **Route Summary Table** is an example chart, similar to **Figure 1.5**.

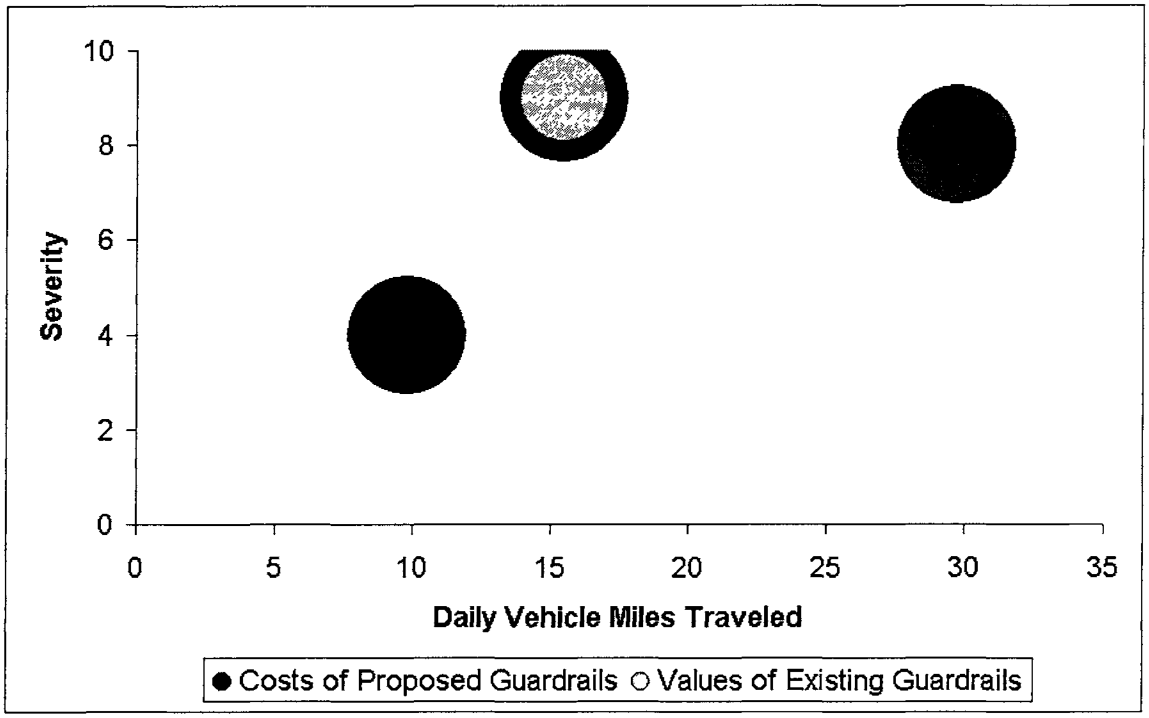

Figure 1.5 Route A Sheet Chart: Comparison of Existing Guardrails and Proposed Installations at Unprotected Sites (from Hazard Catalog)

Figure 1.5 is an example of how this sheet is used. Here is a comparison between existing guardrails and proposed installations at unprotected sites. **Figure 1.5** was created using both data from within the entry tables and also in unprotected columns to the right of the entry table.

The **Route A** through **Route H** sheets are all of the same format, they are simply contain data on different routes. Clicking on the tab at the bottom of the page that says **Summary Table** (Use the arrows to the left of the tabs) or clicking on the hyperlink labeled **To Workbook Summary Table** will bring up the corresponding sheet. A screen will appear similar to that in **Figure 1.6**.

<u>Summary Table:</u>

The box at the top of **Figure 1.6** is a hyperlink menu, which provides an alternative to clicking on the tabs at the bottom of this page. The box underneath the hyperlink menu in **Figure 1.6** is an example display derived from the information from the Route Sheets. Using the data contained in the box, the following chart in **Figure 1.7** can be created:

Summarization Tables:

Individual Route Summaries:

To: 613	To:	613 Summary
To: 611	To:	611 Summary
To: 665	To:	665 Summary
To: 640	To:	640 Summary
To: 6xx	To:	6xx Summary
To: 6xx	To:	6xx Summary
To: 6xx	To:	6xx Summary
To: 6xx	To:	6xx Summary

Tab Name	Route	Include?	Summation DVMT (x-axis)	Summation Severity (y-axis)	Summation Proposed Costs (Size)
Route A	613	Y	55	21	$7,485
Route B	611	Y	110.58	6	$16,828
Route C	665	Y	76.024	4	$7,949
Route D	640	Y	62.556	17	$10,505
Route E	6xx	N	0	0	$0
Route F	6xx	N	0	0	$0
Route G	6xx	N	0	0	$0
Route H	6xx	N	0	0	$0

Figure 1.6 Summary Table (from Hazard Catalog)

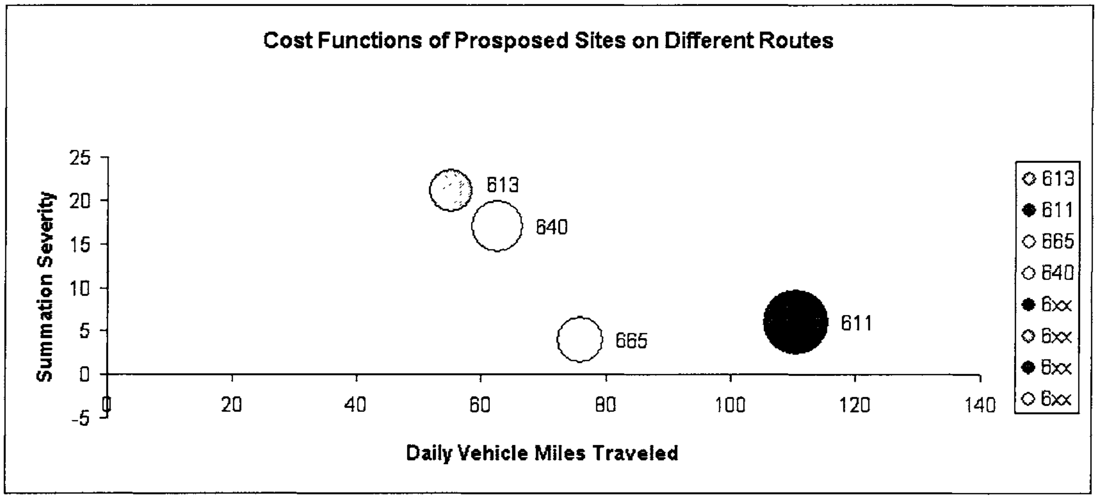

Figure 1.7 Example Chart in Summary Table (from Hazard Catalog)

Figure 1.7 is an example of a comparison of the four routes included in the Summary Table. The bubbles represent all the proposals in that route. The size of the bubble represents the cost associated with the proposal (a larger bubble indicating a higher cost). Route 611 might be chosen as a candidate route because it protects the most DVMT (Daily Vehicle Miles Traveled). On the other hand, Route 665 could also be chosen. It is not quite as effective as Route 613 at covering DVMT, but it costs substantially less.

Route	Length of Hazard (miles)	ADT	DVMT (x-axis)	Severity (y-axis)	Value of Existing Guardrails (size)	Cost of Proposed Installation (size)
613	0.038	258	9.804	4	$0	$1,315
613	0.062	258	15.996	9	$1,212	$0
613	0.028	782	21.896	8	$0	$1,315
611	0.038	485	18.43	1	$0	$1,315
611	0.057	485	27.645	2	$0	$1,315
611	0.095	485	46.075	3	$1,219	$0
611	0.047	485	22.795	6	$1,211	$0
665	0.32	1118	357.76	10	$1,214	$0
640	0.322	531	170.982	9	$1,222	$0
640	0.011	1028	11.308	8	$0	$1,301

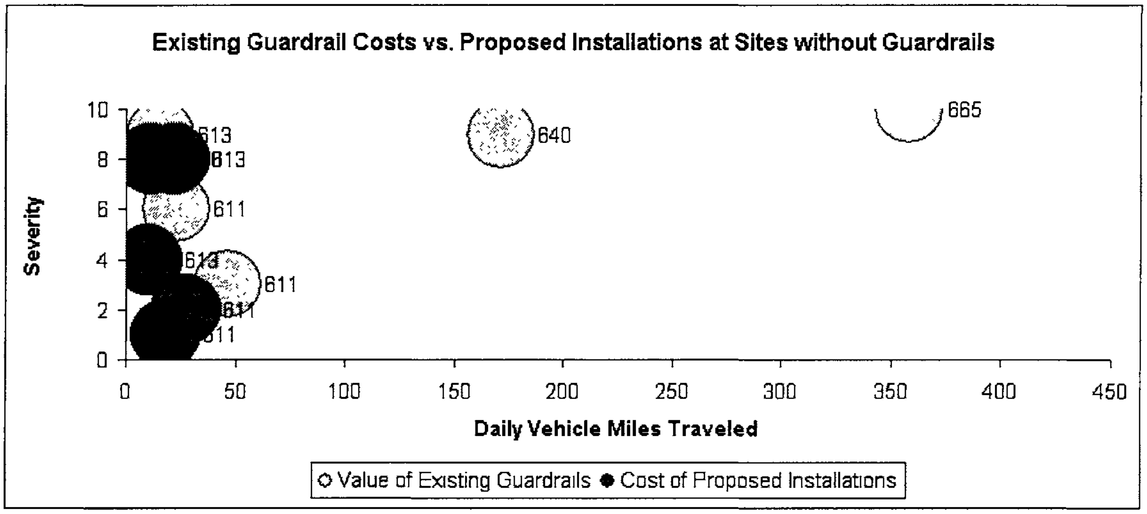

Figure 1.8 Another Example Chart in Summary Table (from Hazard Catalog)

Figure 1.8 is an example of raw data being used to create a chart. The data in the table at the top of **Figure 1.8** is used to create the chart below the table. The chart contrasts the values of the existing guardrails with the proposed installations at sites without guardrails. It is similar to **Figure 1.5** shown earlier, but whereas **Figure 1.5** only displayed one route, **Figure 1.8** shows all the proposals of all the routes.

Chapter 2: Corridor Screening Tool Instructions

The purpose of this chapter is to give explicit instructions on the use of the prototype database tool called the Corridor Screening Tool. The organization of this chapter is as follows:

a.) Overview

b.) Title

c.) Input Worksheet

d.) Summary Statistics

e.) Summary Table

Overview:

The purpose of the Corridor Screening Tool is to help the user easily analyze accident site data of different corridors and determine which sites require future attention concerning improvements such as guardrails.

The Site Prioritization Tool and the corresponding instructions are available at the Center for Risk Management website, www.virginia.edu/~risk/guardrail/database.html. The instructions for the Corridor Screening Tool are also available at this site. Right click where it says, underlined, "Corridor Screening". A small gray box will appear with a list of options. Choose "Save Target As…". Now the computer will present an option of where to save the file on the user's computer. Once the selection of what folder the file is to be saved to is complete, click on the box in the lower right hand corner that says "Save". The file is now on the user's computer. To access the file on the user's computer, use a file-browsing utility such as Windows Explorer to bring up the computer's file directory. Find the folder where the file was saved and double-click on the name of the file, "Corridor.xls". Now Excel will open the file.

The Corridor Screening Tool is presented in an Excel workbook format. An Excel workbook is a compilation of related Excel sheets that can take information from each other and use it to perform calculations. To properly use this tool, the workbook should always be opened as a collection, and not individually. Excel automatically opens an Excel workbook and includes all the sheets associated with it. The workbook is viewed as one file by a computer.

All of the workbooks are protected except for some parts of the Input Worksheet. This means that you cannot accidentally change portions of the workbook needed to run calculations. If changes to the workbook are needed or desired, go to the Tools selection on the toolbar and select **Protection -> Unprotect Worksheet**. It is not suggested this be done unless the user is familiar with Excel and its associated Macros and Visual Basic.

Title:

Figure 2.1 is the first sheet seen when the workbook is opened.

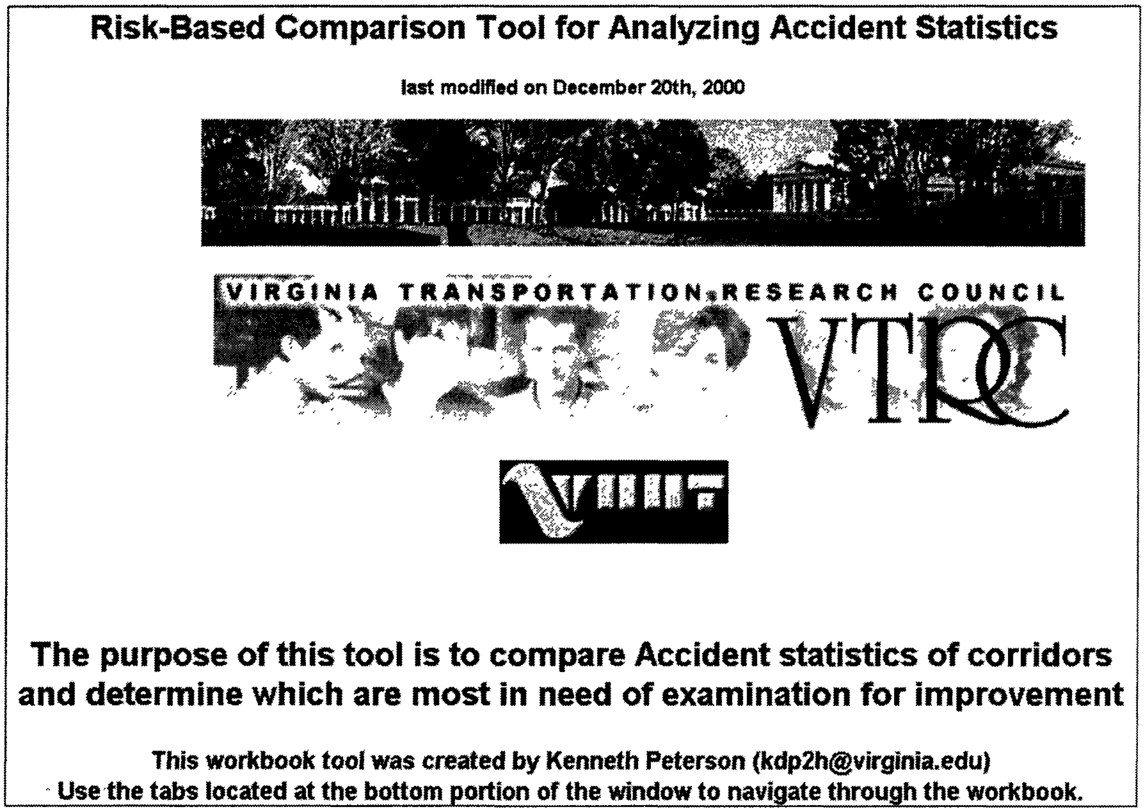

Figure 2.1 Title Sheet (from Corridor Screening)

The tabs located at the bottom of the window can be used to navigate within the workbook. In the lower-left hand corner of the window there will be a list of sheet names from left to right. Clicking on the tab named **Input Worksheet** will take you to the next page.

Input Worksheet:

When you bring up the **Input Worksheet**, a screen like **Figure 2.2** will appear.

Input Worksheet

Yellow Filled Cells Indicate User Input Areas

Corridor Comparison Tool Input Area											
Include (Y or N)?	Corridor	Referenced to	Beginning Milepost	End Milepost	Length in Miles	ADT	DVMT	Number of Related Crashes	Number of Related Injuries	Number of Related Fatalities	Amount of Related Property Damage
Y	601	N/A	0.00	2.58	2.58	253	653	1	1	0	$11,200
Y	606	N/A	0.00	7.40	7.40	761	5631	4	3	0	$11,000
Y	608	N/A	0.00	7.24	7.24	263	1904	3	1	0	$9,500
Y	609	N/A	0.00	3.96	3.96	786	3113	1	0	0	$12,000
Y	610	N/A	0.00	3.01	3.01	231	695	2	4	0	$7,000
Y	611	N/A	0.00	5.29	5.29	733	3878	3	3	1	$8,500
Y	613	N/A	0.00	3.76	3.76	782	2940	1	1	0	$10,000
Y	621	N/A	0.00	1.20	1.20	232	278	1	0	0	$1,200
Y	623	N/A	0.00	7.40	7.40	137	1014	1	1	0	$3,200
Y	627	N/A	0.00	10.44	10.44	952	9939	3	3	0	$3,100
Y	628	N/A	0.00	6.78	6.78	282	1912	1	2	1	$633
Y	629	N/A	0.00	3.78	3.78	959	3625	1	0	0	$3,500
Y	632	N/A	0.00	6.94	6.94	552	3831	1	3	0	$3,500
Y	634	N/A	0.00	5.30	5.30	92	488	1	1	0	$5,000
Y	638	N/A	0.00	4.30	4.30	481	2068	2	0	0	$9,000
Y	640	N/A	0.00	5.07	5.07	1028	5212	6	6	0	$22,850
N	658	N/A	0.00	0.50	0.50	87	44	1	1	0	$3,000
Y	665	N/A	0.00	2.90	2.90	1118	3242	2	0	0	$10,500
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				
N					0.00		0				

Figure 2.2 Input Worksheet (from Corridor Screening)

For the purposes of this example, the table is filled with sample data. For users who would like to follow along with our example, this data can be entered into the **Input Worksheet**.

The sheet represented in **Figure 2.2** enables the user to enter values and quickly analyze them. The **Include (Y or N)?** column takes as input either a **Y** or **N**. A **Y** signifies that the calculations and analyses performed upon this table of values will include that row of values. An **N** signifies that that row will be excluded from calculations and analyses performed upon the table. It is important to remember that the inputs need to be uppercase. If anything other than a **Y** is entered, the workbook will treat that row of values as if it were not included in the Summary Tables.

The **Corridor** column assigns a user defined identifier to the row data, allowing the corridor to be tracked in subsequent worksheets. A suggested format is to enter the numerical number of a route (e.g. for Route 613, enter 613 into the cell).

The **Referenced To** column signifies where the **Beginning** and **End Mileposts** are. Usually, the **Referenced To** column signifies the start of the route, where the mileage starts being counted from zero. If the corridor is a route, than "N/A" is suggested as input. If a section(s) of a route is being considered, then enter the route or routes the corridor covers.

The **Beginning** and **End Milepost** give the location of the site on some corridor. This is helpful in determining the real world position of the corridor. These columns are also used in calculating the length (in miles) of the corridor under inspection in the **Length in Miles** column. The **Length in Miles** column is used in calculating statistics on a per mile basis.

The **ADT** column shows the Average Number of Vehicles per day for that corridor. This column is used to calculate **DVMT** (Daily Vehicle Miles Traveled).

The **DVMT** column shows the Daily Vehicle Miles Traveled for that corridor. DVMT is automatically calculated as the product of the value in the **Length in Miles** column and the value in the **ADT** column. The **DVMT** column is used in calculating statistics on a **per DVMT** basis.

The **Number of Related Accidents**, **Number of Related Injuries**, **Number of Related Fatalities**, and **Amount of Related Property Damage** columns show the total number of accidents, injuries, fatalities, and property damage (in dollars), respectively, that occurred on that corridor for accidents related to the characteristic being studied (e.g. fixed object accidents and run-off-road accidents).

<u>Summary Statistics:</u>

The **Summary Statistics** sheet appears as in **Figure 2.3**, based on data entered in the Input Worksheet (**Figure 2.2**). The summary statistics are useful in comparing sets of corridors. For example, the corridors of a particular county may be found to have a higher rate of accidents than corridors of adjacent counties.

Summary Statistics

All Tables include only those rows that were marked as **Included in Summary**
If a cell has a "-" in it, then that cell is lacking something in the Input Worksheet.

Length Included in Analysis (miles):	87.85
DVMT Included in Analysis:	50466.52

Accident Counts		Sum	Mean	Max	Min	Standard Deviation
Total accidents		35.00	1.94	6.00	1.00	1.39
Injuries		30.00	1.67	6.00	0.00	1.68
Fatalities		2.00	0.11	1.00	0.00	0.32
Property Damage		$134,883	$7,494	$22,850	$833	$5,342

Accidents Per Mile			Mean	Max	Min	Standard Deviation
Total Accidents Per Mile			0.524	2.000	0.135	0.461
Injuries Per Mile			0.423	2.000	0.000	0.547
Fatalities Per Mile			0.019	0.189	0.000	0.055
Property Damage Per Mile			$2,067	$6,000	$123	$1,666

Accidents Per DVMT			Mean	Max	Min	Standard Deviation
Total Accidents Per DVMT			0.00232	0.02299	0.00026	0.00524
Injuries Per DVMT			0.00215	0.02299	0.00000	0.00537
Fatalities Per DVMT			0.00004	0.00052	0.00000	0.00013
Property Damage Per DVMT			$8.05	$68.97	$0.31	$15.77

Figure 2.3 Summary Statistics (from Corridor Screening)

The Summary Statistics sheet, represented in **Figure 2.3**, is provided so the user can see at a glance the values the next worksheet, the **Summary Table** sheet, uses.

Summary Table:

Again, using the example values from **Figure 3.2**, the **Summary Table** sheet will appear as in **Figures 2.4-2.5**. The **Summary Table's** sheet is used to compare the selected corridors and to select certain corridors based upon such statistics as number of accidents, injuries per mile, and fatalities per DVMT. By comparing these corridors, the user can concentrate efforts upon particular corridors that are deemed in need of corrective attention.

Summary Tables

"Low" signifies that the value is greater than one standard deviation **below** the average
"Moderate" signifies that the value is between a standard deviation **below** and **above** the average
"High" signifies that the value is greater than one standard deviation **above** the average
"N/A" signifies that the corridor value is not included in the analysis.
"-" signifies that none of that type was used in the analysis
These tables highlight characteristics that warrant statistical analysis to determine their precision

If Crashes Per Mile is filled with "-", then no mileage was included in Input Worksheet
If Crashes Per DVMT is filled with "-", then no mileage was included in Input Worksheet

Crashes:

Corridor Identificatio	Total Crashes	Injuries	Fatalities	Property Damage
601	Moderate	Moderate	Moderate	Low
606	High	Moderate	Moderate	Low
608	Moderate	Moderate	Moderate	Low
609	Moderate	Moderate	Moderate	Low
610	Moderate	High	Moderate	Low
611	Moderate	Moderate	High	Low
613	Moderate	Moderate	Moderate	Low
621	Moderate	Moderate	Moderate	Low
623	Moderate	Moderate	Moderate	Low
627	Moderate	Moderate	Moderate	Low
628	Moderate	Moderate	High	Low
629	Moderate	Moderate	Moderate	Low
632	Moderate	Moderate	Moderate	Low
634	Moderate	Moderate	Moderate	Low
638	Moderate	Moderate	Moderate	Low
640	High	High	Moderate	High
658	Moderate	Moderate	Moderate	Low
665	Moderate	Moderate	Moderate	Low
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High

Crashes Per Mile:

Corridor Identificatio n	Total Crashes Per Mile	Injuries Per Mile	Fatalities Per Mile	Property Damage Per Mile
601	Moderate	Moderate	Moderate	High
606	Moderate	Moderate	Moderate	Low
608	Moderate	Moderate	Moderate	Low
609	Moderate	Moderate	Moderate	Low
610	Moderate	High	Moderate	Low
611	Moderate	Moderate	High	Low
613	Moderate	Moderate	Moderate	Low
621	Moderate	Moderate	Moderate	Low
623	Moderate	Moderate	Moderate	Low
627	Moderate	Moderate	Moderate	Low
628	Moderate	Moderate	High	Low
629	Moderate	Moderate	Moderate	Low
632	Moderate	Moderate	Moderate	Low
634	Moderate	Moderate	Moderate	Low
638	Moderate	Moderate	Moderate	Low
640	High	High	Moderate	High
658	High	High	Moderate	High
665	Moderate	Moderate	Moderate	Low
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High

Figure 2.4 Summary Tables, Part 1 of 2 (from Corridor Screening)

Crashes Per DVMT:

Corridor Identification	Total Crashes Per DVMT	Injuries Per DVMT	Fatalities Per DVMT	Property Damage Per DVMT
601	Moderate	Moderate	Moderate	Moderate
606	Moderate	Moderate	Moderate	Moderate
608	Moderate	Moderate	Moderate	Moderate
609	Moderate	Moderate	Moderate	Moderate
610	Moderate	Moderate	Moderate	Moderate
611	Moderate	Moderate	High	Moderate
613	Moderate	Moderate	Moderate	Moderate
621	Moderate	Moderate	Moderate	Moderate
623	Moderate	Moderate	Moderate	Moderate
627	Moderate	Moderate	Moderate	Moderate
628	Moderate	Moderate	High	Moderate
629	Moderate	Moderate	Moderate	Moderate
632	Moderate	Moderate	Moderate	Moderate
634	Moderate	Moderate	Moderate	Moderate
638	Moderate	Moderate	Moderate	Moderate
640	Moderate	Moderate	Moderate	Moderate
658	High	High	Moderate	High
665	Moderate	Moderate	Moderate	Moderate
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High
	High	High	High	High

Figure 2.5 Summary Tables, Part 2 of 2 (from Corridor Screening)

In **Figures 2.4-2.5**, **Low** signifies that the value for that corridor is less than the mean minus the standard deviation. **Moderate** means that the value for the corridor is between a standard deviation above the mean and a standard deviation below the mean. **High** means that the value for that corridor is greater than the mean plus the standard deviation.

Below these tables are a series of charts that display the inputted information from the **Input Worksheet** in graphical form in different charts based upon the characteristic being used. These charts automatically change to reflect changes made in the **Input Worksheet**. **Figure 2.6** is an example of a chart in the **Summary Tables** sheet.

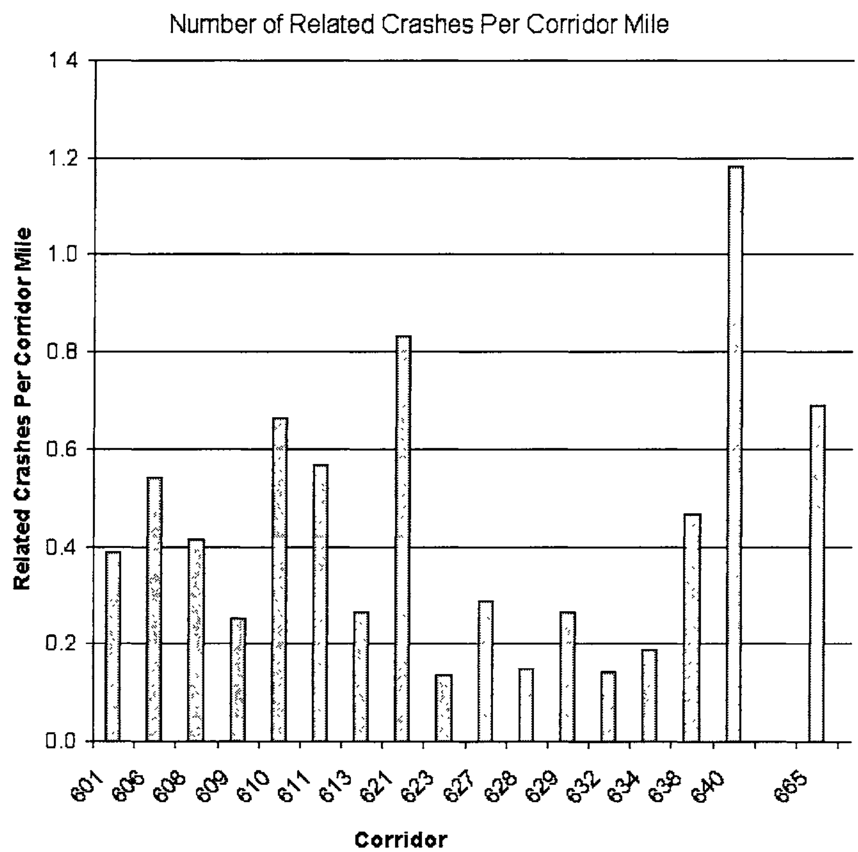

Figure 2.6 Number of Related Accidents Per Corridor Mile (from Corridor Screening)

Analyzing and comparing these charts aid the user in determining which corridors are in need of the most attention to prevent accidents and/or lessen their severity.

Chapter 3: Site Prioritization Tool Instructions

The purpose of this chapter is to give explicit instructions on the use of the prototype database tool called the Site Prioritization Tool. The organization of this chapter is as follows:

a.) Overview

b.) Title

c.) Input Worksheet

d.) Prioritizations

e.) Solution Comparison

Overview:

The purpose of the Site Prioritization Tool is to help the user prioritize and rank different sites under consideration, and determine the best usage of funds based upon different needs.

The Site Prioritization Tool and the corresponding instructions are available at the Center for Risk Management website, www.virginia.edu/~risk/guardrail/database.html. The instructions for the Site Screening Tool are also available at this site. Right click where it says, underlined, "Site Prioritization". A small gray box will appear with a list of options. Choose "Save Target As…". Now the computer will present an option of where to save the file on the user's computer. Once the selection has been made as to the folder the file is to be saved to, click on the box in the lower right hand corner that says "Save" to finish. The file is now on the user's computer. To access the file on the user's computer, use a file-browsing utility such as Windows Explorer to bring up the computer's file directory. Find the folder where the file was saved and double-click on the name of the file, "Site.xls". This Comparison Tool is presented in an Excel workbook format. An Excel workbook is simply a compilation of related Excel sheets that can take information from each other and use it to perform calculations. To properly use this tool, the workbook should always be opened as a collection, and not as individual sheets. Excel automatically opens an Excel workbook and includes all the sheets associated with it when opened.

All of the workbooks are protected except certain parts of the **Input Worksheet** and the **Guardrail Book Keeping** sheet. User input cells are designated by the yellow background of the cell. This helps to prevent accidental errors. If changes to the workbook are needed, simply go to the Tools selection on the toolbar and select **Protection -> Unprotect Worksheet**. It is not suggested this be done unless sufficient knowledge of Excel and its associated Macros and Visual Basic features is possessed.

Title:

The first sheet seen when the Site Prioritization workbook is opened is the Title Page, as seen in **Figure 3.1**.

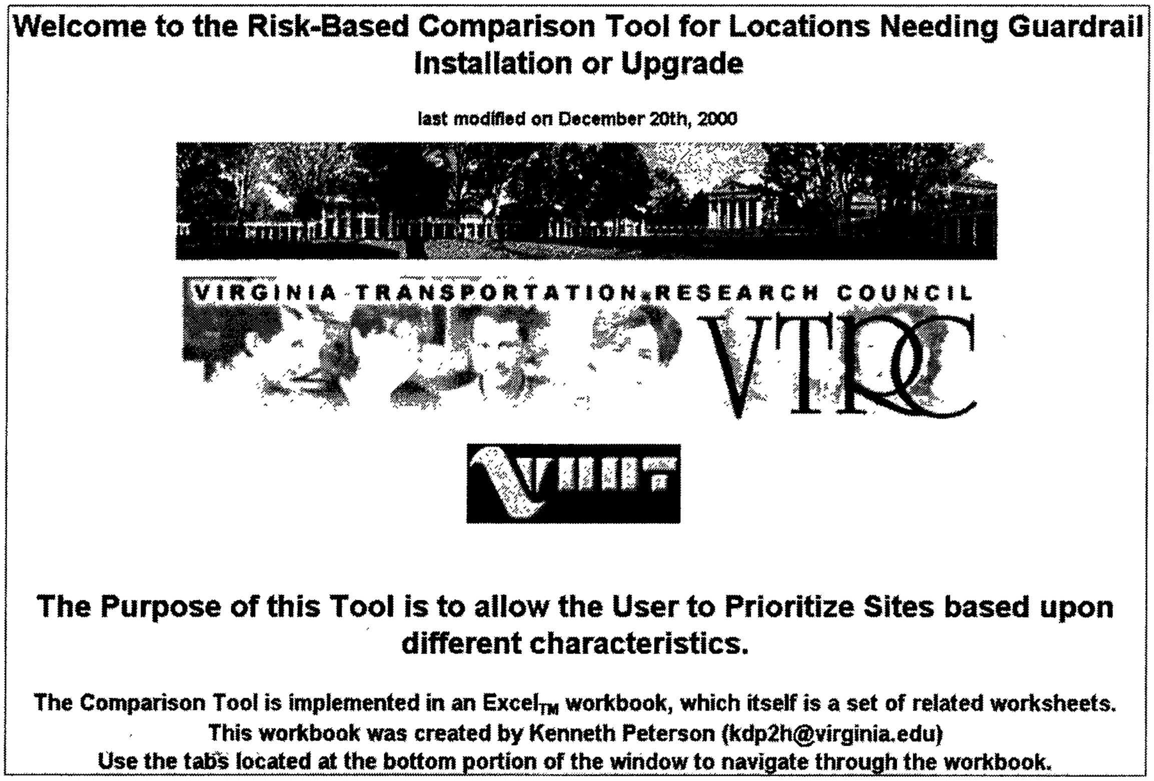

Figure 3.1 Title Sheet (from Site Prioritization)

To go to the next sheet, the **Input Worksheet**, click on the tab named **Input Worksheet** at the bottom of the page.

Input Worksheet:

Figure 3.2 shows what the Input Worksheet looks like. The **Input Worksheet** is where all the data is entered. As a reminder, all values that are defined by the user are located in the yellow cells. Everything else is non-mutable. To see the effect of changes made in the **Input Worksheet** on subsequent sheets, click on the Prioritize All button.

Input Worksheet

Prioritize All

Constants:			
Budget ($):	$50,000	Minimum Guardrail Coverage (ft):	200

Input Data Area

Include? (Y or N)	Location	Location ID #	Hazard Length (ft)	Main Run Cost ($/ft)	Run-On Cost ($)	Run-Off ($)	Other Costs ($)	Total Removal Cost ($)	Severity Index	Average Daily Traffic (Vehicles per Day)	DVMT (Daily Vehicle Miles Traveled)	Total Site Improvement Cost ($)	Comments
Y	613, E on 611, 0 04 to 0 15	1	200	$10	$2,000	$2,000	$0	$0	4	258	10	$6,000	Near Railroad, Steep Embankment
Y	613, E on 611,1 40 to 1 46	2	325	$10	$2,000	$2,000	$0	$350	9	258	16	$6,900	Substandard GR w/Blunt Ends
Y	613, E on 611,0 437 to 0 475	3	150	$10	$2,000	$2,000	$0	$0	8	782	22	$6,000	Water Hazard
Y	611, W on 670, 0 358, to 0 396	4	200	$10	$2,000	$2,000	$0	$0	1	485	18	$6,000	Optic Fiber Cable, Inside Curve
Y	611, N of 665, 1 283 to 1 321	5	300	$10	$2,000	$2,000	$0	$0	2	485	28	$7,000	High Rise, no trees
Y	611, N of 665, 1 005 to 1 10	6	500	$10	$2,000	$2,000	$0	$525	3	485	46	$8,475	Substandard GR
Y	611, N of 665, 0 553 to 0 61	7	250	$10	$2,000	$2,000	$0	$275	6	485	23	$6,225	Substandard GR, GR too low
Y	665, N of 640, 1 51 to 1 622	8	1701	$10	$2,000	$2,000	$0	$1,726	9	1118	360	$19,284	Phone Utility, Substandard GR
Y	665, N of 640, 0 225 to 0 225	9	60	$10	$2,000	$2,000	$0	$0	8	1118	13	$6,000	Water Hazard
Y	640, S of 249, 1 69 to 1 758	10	1690	$10	$2,000	$2,000	$0	$1,715	10	531	170	$19,185	Substadandard GR w/Blunt Ends
N		11	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		12	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		13	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		14	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		15	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		16	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		17	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		18	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		19	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		20	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		21	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		22	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		23	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		24	0	$0	$0	$0	$0	$0	0	0	0	$0	
N		25	0	$0	$0	$0	$0	$0	0	0	0	$0	

Figure 3.2 Input Worksheet (from Site Prioritization)

At the top of the sheet towards the middle is a box wherein lie the set values. The set values are: **Budget** and **Minimum Guardrail Coverage**. The **Budget** is used to constrain values later on in the **Solution Comparison** page. If money is not a factor, simply enter a large number in for **Budget** ($1,000,000 is a suggested number).

The **Minimum Guardrail Coverage** is used to help calculate the **Guardrail Length**. The **Minimum Guardrail Coverage** is the minimum length an entire guardrail section must be, regardless of the actual length of the hazard. If the hazard length is less than the minimum guardrail length, then the minimum guardrail length will be used for the length of the guardrail.

In the main table, the first column is **Include ? (Y or N)**. This column allows the user to designate which rows will be included in the Solution Worksheets. Rather than erasing an entire row, all that is needed is to enter a **Y** or **N** for that row. A **Y** signifies that the row will be included in the solutions, while an **N** means that the row will be excluded from the solutions and will have no bearing whatsoever in the final results. The **Include ? (Y or N)** column is case sensitive!

The **Location ID #** column gives an identification number to each row of values. In subsequent worksheets, the identification numbers show what row of values is being used or signified. The next column is **Hazard Length**. This column signifies the length of the hazard parallel with the roadway. It does NOT signify the length of the guardrail. The length of the main run guardrail is automatically calculated using the **Hazard Length** and **Minimum Guardrail Coverage** values. If the **Hazard Length** value is less than the **Minimum Guardrail Coverage** value, then the **Minimum Guardrail Coverage** value is used for the length of the main run guardrail. If the **Hazard Length** value is more than the **Minimum Guardrail Coverage**, then the **Hazard Length** value is used for the length of the main run guardrail.

There are five columns of the table that determine the values of the **Total Site Improvement Cost** column. They are **Main Run Cost**, **Run-On End Treatment Cost**, **Run-Off End Treatment Cost**, **Other Cost**, and **Total Removal Cost**. **Main Run Cost** is the cost of the intermediary guardrail (excluding Run-On End Treatment, Run-Off End Treatment, and Other costs). **Run-On End Treatment Cost** is the cost of a Run-On End Treatment. **Run-Off End Treatment Cost** is the cost of a Run-Off End Treatment, and **Other Cost** is the cost of anything else that needs to be added that does not follow under the previous categories. **Other Cost** can include improvements such as paint or reflectors. **Total Removal Cost** is the cost to remove any previously existing guardrails at that site. All the cost fields are used to calculate the **Total Site Improvement Cost**. The **Total Site Improvement Cost** plays a part in calculating the benefit/cost ratios in subsequent sheets.

The **Severity Index** refers to the **Severity Guidelines** (see Chapter 4 in this report). This sheet allows a user to find a **Severity Index number** by looking up the characteristics of a site. The **Severity Index number** will be between 1 and 10, with 1 being the least severe and 10 being the most severe. A **Severity Index Number** of 1 would represent a long unobstructed grassy meadow, while 10 would be a cliff-side with a 100 ft drop onto jagged rocks. The **Severity Index** plays a part in calculating the **Severity-Miles** and **Severity-Vehicle-Miles**.

Average Daily Traffic has values consisting of Number of Vehicles per Day. This column plays a part in calculating **Vehicle-Miles**, **Severity-Miles**, and **Severity-Vehicle-Miles**.

Rankings by:					
Location Identifier	Mileage	Severity	Vehicle-Miles	Severity-Miles	Severity-Vehicle-Miles
1	7	5	10	7	9
2	4	3	8	3	5
3	9	1	5	5	3
4	8	10	7	10	10
5	5	9	4	8	8
6	3	8	3	6	7
7	6	4	6	4	4
8	1	7	1	2	1
9	10	2	9	9	6
10	2	6	2	1	2
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
24	-	-	-	-	-
25	-	-	-	-	-

Summation:	
Total Length of Hazard Protected (ft):	5376.0
Summation of Severity Index Numbers:	60.0
Summation of Average Daily Traffic:	6005
Summation of Vehicle-Miles:	706
Summation of Severity-Miles:	7.84
Summation of Severity-Vehicle-Miles:	5752
Total Cost of Included Improvements:	$91,069

Figure 3.3 Input Worksheet Rankings and Summation (from Site Prioritization)

Figure 3.3 shows the tables that are located below the input table shown in **Figure 3.2**. The data contained within these tables is a reflection of the data entered in the above input table shown in **Figure 3.2**.The **Rankings** table underneath the main table gives the order in which the row is prioritized for each category. For example, the first row has the number 7 in the **Rankings by Mileage** column, and the number 5 in the **Ranking by Severity** column. If a decision maker were to decide to base the installation of guardrails solely upon the mileage protected, then the first row would be the seventh best project to undertake. However, if a decision-maker wanted to base the projects solely upon the severity protected, then the first row would be the fifth best project to undertake.

The **Summation** box displays a simple summation of the different characteristics of all the included sites.

Prioritizations:

The **Prioritizations** sheet, shown in **Figure 3.4**, receives as input the values entered in the **Input Worksheet (Figure 3.2)**. Each box has different values that are used to prioritize the data. The differing value each box uses is divided by cost to arrive at a ratio. The sheet then orders the ratios so as to rank them based upon those most in need of improvement.

Prioritizations

Prioritize All

Protected Mileage Prioritization			
Length (ft)/Cost ($) Ratio	Location	Cost ($)	Cumulative Cost ($)
0.08821	8	$19,284	$19,284
0.08809	10	$19,185	$38,469
0.059	6	$8,475	$46,944
0.0471	2	$6,900	$53,844
0.04286	5	$7,000	$60,844
0.04016	7	$6,225	$67,069
0.03333	1	$6,000	$73,069
0.03333	4	$6,000	$79,069
0.025	3	$6,000	$85,069
0.01	9	$6,000	$91,069
N/A	11	N/A	$91,069
N/A	12	N/A	$91,069
N/A	13	N/A	$91,069
N/A	14	N/A	$91,069
N/A	15	N/A	$91,069
N/A	16	N/A	$91,069
N/A	17	N/A	$91,069
N/A	18	N/A	$91,069
N/A	19	N/A	$91,069
N/A	20	N/A	$91,069
N/A	21	N/A	$91,069
N/A	22	N/A	$91,069
N/A	23	N/A	$91,069
N/A	24	N/A	$91,069
N/A	25	N/A	$91,069

Protected Severity Prioritization			
Severity/Cost($) Ratio	Location	Cost ($)	Cumulative Cost ($)
0.00133	3	$6,000	$6,000
0.00133	9	$6,000	$12,000
0.0013	2	$6,900	$18,900
0.00096	7	$6,225	$25,125
0.00067	1	$6,000	$31,125
0.00052	10	$19,185	$50,310
0.00047	8	$19,284	$69,594
0.00035	6	$8,475	$78,069
0.00029	5	$7,000	$85,069
0.00017	4	$6,000	$91,069
N/A	11	N/A	$91,069
N/A	12	N/A	$91,069
N/A	13	N/A	$91,069
N/A	14	N/A	$91,069
N/A	15	N/A	$91,069
N/A	16	N/A	$91,069
N/A	17	N/A	$91,069
N/A	18	N/A	$91,069
N/A	19	N/A	$91,069
N/A	20	N/A	$91,069
N/A	21	N/A	$91,069
N/A	22	N/A	$91,069
N/A	23	N/A	$91,069
N/A	24	N/A	$91,069
N/A	25	N/A	$91,069

Figure 3.4 Prioritizations (from Site Prioritization)

The **Protected Mileage Prioritization** table, shown in **Figure 3.4**, uses the length of the hazard for each row of included values and then divides that length by the cost for that improvement. The resulting number from each row of values is a mileage protected/cost ratio. The higher the ratio, the more cost effective an improvement, with regard to miles of protection provided by that improvement. The sheet arranges these ratios and orders them from highest to lowest. The purpose of the **Protected Mileage Prioritization** table is to prioritize the proposed projects based solely upon the number of miles that would be protected.

The **Protected Severity Prioritization** table, shown in **Figure 3.4,** uses the severity index number for each row of included values and then divides that length by the cost of that improvement. The resulting number from each row of values is a severity index/cost ratio. The greater the value of the ratio, the better the improvement is at protecting the severity of hazards for its cost. The sheet then arranges these ratios in order from highest to lowest. The closer the ratio is to the top of the list, the better it is in terms of getting the best value for protecting the severity of a hazard. The purpose of the **Protected Severity Prioritization** table is to prioritize the proposed projects solely upon the severity of the hazard that would be protected.

Protected Vehicle-Miles Prioritization			
Vehicle-Miles/Cost($) Ratio	Location	Cost ($)	Cumulative Cost ($)
0.01868	8	$19,284	$19,284
0.00886	10	$19,185	$38,469
0.00542	6	$8,475	$46,944
0.00394	5	$7,000	$53,944
0.0037	3	$6,000	$59,944
0.00369	7	$6,225	$66,169
0.00306	4	$6,000	$72,169
0.0023	2	$6,900	$79,069
0.00212	9	$6,000	$85,069
0.00163	1	$6,000	$91,069
N/A	11	N/A	$91,069
N/A	12	N/A	$91,069
N/A	13	N/A	$91,069
N/A	14	N/A	$91,069
N/A	15	N/A	$91,069
N/A	16	N/A	$91,069
N/A	17	N/A	$91,069
N/A	18	N/A	$91,069
N/A	19	N/A	$91,069
N/A	20	N/A	$91,069
N/A	21	N/A	$91,069
N/A	22	N/A	$91,069
N/A	23	N/A	$91,069
N/A	24	N/A	$91,069
N/A	25	N/A	$91,069

Protected Severity-Miles Prioritization			
Severity-Miles/Cost($) Ratio	Location	Cost ($)	Cumulative Cost ($)
0.00017	10	$19,185	$19,185
0.00015	8	$19,284	$38,469
8E-05	2	$6,900	$45,369
4.6E-05	7	$6,225	$51,594
3.8E-05	3	$6,000	$57,594
3.4E-05	6	$8,475	$66,069
2.5E-05	1	$6,000	$72,069
1.6E-05	5	$7,000	$79,069
1.5E-05	9	$6,000	$85,069
6.3E-06	4	$6,000	$91,069
N/A	11	N/A	$91,069
N/A	12	N/A	$91,069
N/A	13	N/A	$91,069
N/A	14	N/A	$91,069
N/A	15	N/A	$91,069
N/A	16	N/A	$91,069
N/A	17	N/A	$91,069
N/A	18	N/A	$91,069
N/A	19	N/A	$91,069
N/A	20	N/A	$91,069
N/A	21	N/A	$91,069
N/A	22	N/A	$91,069
N/A	23	N/A	$91,069
N/A	24	N/A	$91,069
N/A	25	N/A	$91,069

Figure 3.5 Prioritizations (from Site Prioritizations)

The **Protected Vehicle-Miles Prioritization** table, shown in **Figure 3.5**, uses the Average Daily Traffic multiplied by the mileage of hazard protected and then divides this value by the cost for that improvement. The resulting number from each row of included values is a vehicle-miles/cost ratio. The greater the value of the ratio, the better the improvement is at protecting traffic for a length of hazard for its cost. The sheet then arranges these ratios from highest to lowest. The closer the ratio is to the top of the list, the better it is in terms of getting a better value for protecting the vehicle-miles of a hazard. The purpose of the **Protected Vehicle-Miles Prioritization** table is to prioritize the proposed projects based upon the length of hazard exposed to an average daily number of vehicles that travel past a site.

The **Protected Severity-Miles Prioritization** table, shown in **Figure 3.5**, uses the severity index number of a hazard and multiplies it by the miles of hazard to be protected. Then that resulting number is divided by the cost of the improvement. The resulting number from each row of included values is a severity-miles/cost ratio. The greater the value of the ratio, the better the improvement is at protecting the severity of a hazard for its length along the roadside. The sheet arranges these ratios from highest to lowest. The closer the ratio is to the top of the list, the better it is in terms of getting the best value for protecting the severity-miles of hazardous sites. The purpose of the **Protected Severity-Miles Prioritization** table is to prioritize the proposed projects based upon the exposure of an average daily number of vehicles to the severity of a site.

Protected Severity-Vehicle-Miles Prioritization			
Severity-Vehicle-Miles/Cost($) Ratio	Location	Cost ($)	Cumulative Cost ($)
0.1681	8	$19,284	$19,284
0.08859	10	$19,185	$38,469
0.02962	3	$6,000	$44,469
0.02213	7	$6,225	$50,694
0.02071	2	$6,900	$57,594
0.01694	9	$6,000	$63,594
0.01626	6	$8,475	$72,069
0.00787	5	$7,000	$79,069
0.00652	1	$6,000	$85,069
0.00306	4	$6,000	$91,069
N/A	11	N/A	$91,069
N/A	12	N/A	$91,069
N/A	13	N/A	$91,069
N/A	14	N/A	$91,069
N/A	15	N/A	$91,069
N/A	16	N/A	$91,069
N/A	17	N/A	$91,069
N/A	18	N/A	$91,069
N/A	19	N/A	$91,069
N/A	20	N/A	$91,069
N/A	21	N/A	$91,069
N/A	22	N/A	$91,069
N/A	23	N/A	$91,069
N/A	24	N/A	$91,069
N/A	25	N/A	$91,069

Figure 3.6 Prioritizations (from Site Prioritizations)

The **Protected Severity-Vehicle-Miles Prioritization** table, shown in **Figure 3.6**, is the severity index of a hazard multiplied by the Average Daily Traffic multiplied by the miles of hazard to be protected. Then this value is divided by the improvement's cost. The resulting number from each row of included values is a severity-vehicle-miles/cost ratio. The greater the value of the ratio, the better an improvement will protect overall traffic from the severity of a hazard for the length of that hazard. The sheet then arranges these ratios in order from highest to lowest. The closer the ratio is to the top of the list, the better it is in terms of getting the best value for protecting the severity-vehicle-miles of a hazard. The purpose of the **Protected Severity-Vehicle-Miles Prioritization** table is to prioritize the proposed projects based upon the exposure of an average daily number of vehicles to a site with a certain severity and length.

Solution Comparison:

The **Solution Comparison** sheet, shown in **Figures 3.7-3.8**, summarizes each of the Prioritization objectives and allows the user to view the proposed site composition of each solution. The efficiency criterions for the solutions are shown in **Table 3.1**. Each solution has its own box where the locations (which correspond to the rows of values entered in the **Input Worksheet**) are prioritized. These solutions only list those sites included in the **Input Worksheet** using the **Include? (Y or N)** column and those locations beginning with the highest ratio, that fit within the **Budget**. This analysis allows you to consider each factor separately in terms of cost-efficiency. A sample of one of the solution sets is shown in **Figure 3.8.**

Table 3.1 Solution Efficiency Criterion

Solution	Efficiency Criterion
1	Length of Hazard Protected
2	Severity of Hazard
3	Length of Hazard Protected * Average Daily Traffic
4	Severity of Hazard * Length of Hazard Protected
5	Severity of Hazard * Length of Hazard Protected * Average Daily Traffic

Solution Comparison

Budget: $50,000

Prioritize All

Bubble Charts for the Solutions follow this page. Please refer to the tabs at the bottom of the screen.

	Length of Hazard Protected (miles)	Severity Protected	Average Daily Traffic (Vehicles per day)	Vehicle-Miles Protected (DVMT)	Severity-Miles Protected	Severity-Vehicle-Miles Protected
Solution 1	0.737	22	2134	576.1	6.384	5079.0
Solution 2	0.187	35	2901	83.5	1.308	599.2
Solution 3	0.737	22	2134	576.1	6.384	5079.0
Solution 4	0.704	28	1907	546.0	6.654	5084.1
Solution 5	0.671	27	2431	552.4	6.327	5118.9
Total Possible:	1.018	60	6005	705.5	7.844	5751.6

	Percentage of Possible Hazard Length Protected	Percentage of Possible Severity Protected	Percentage of Possible Average Daily Traffic (Vehicles per day)	Percentage of Possible Vehicle-Miles Protected	Percentage of Possible Severity-Miles Protected	Percentage of Possible Severity-Vehicle-Miles Protected
Solution 1	72.4%	36.7%	35.5%	81.6%	81.4%	88.3%
Solution 2	18.3%	58.3%	48.3%	11.8%	16.7%	10.4%
Solution 3	72.4%	36.7%	35.5%	81.6%	81.4%	88.3%
Solution 4	69.1%	46.7%	31.8%	77.4%	84.8%	88.4%
Solution 5	65.9%	45.0%	40.5%	78.3%	80.7%	89.0%

Figure 3.7 Solution Comparison (from Site Prioritization)

Solution 1 (Miles)								
Included?	Location	Cumulative Cost ($)	Length of Hazard Protected Per Site (miles)	Severity Protected Per Site	Average Daily Traffic (Vehicles per day) Per Site	Vehicle-Miles Protected Per Site (DVMT)	Severity-Miles Protected Per Site	Severity-Vehicle-Miles Protected Per Site
Y	8	$19,284	0.322	9	1118	360.174	2.899	3241.565
Y	10	$38,469	0 320	10	531	169.960	3.201	1699.602
Y	6	$46,944	0.095	3	485	45.928	0.284	137.784
Y	2	$0	0.000	0	0	0.000	0.000	0.000
Y	5	$0	0.000	0	0	0.000	0.000	0.000
Y	7	$0	0.000	0	0	0.000	0 000	0.000
Y	1	$0	0.000	0	0	0.000	0.000	0.000
Y	4	$0	0.000	0	0	0 000	0.000	0.000
Y	3	$0	0.000	0	0	0.000	0.000	0.000
Y	9	$0	0.000	0	0	0 000	0.000	0.000
N	11	$0	0.000	0	0	0.000	0 000	0.000
N	12	$0	0 000	0	0	0 000	0.000	0.000
N	13	$0	0.000	0	0	0.000	0.000	0.000
N	14	$0	0.000	0	0	0 000	0 000	0.000
N	15	$0	0.000	0	0	0 000	0.000	0 000
N	16	$0	0.000	0	0	0.000	0 000	0.000
N	17	$0	0 000	0	0	0.000	0.000	0.000
N	18	$0	0.000	0	0	0.000	0 000	0.000
N	19	$0	0.000	0	0	0.000	0 000	0.000
N	20	$0	0.000	0	0	0 000	0 000	0.000
N	21	$0	0.000	0	0	0.000	0.000	0 000
N	22	$0	0.000	0	0	0 000	0.000	0 000
N	23	$0	0.000	0	0	0.000	0 000	0 000
N	24	$0	0.000	0	0	0 000	0.000	0.000
N	25	$0	0.000	0	0	0.000	0.000	0 000
Total:		$46,944	0.736931818	22	2134	576.062	6.384	5078.951

Figure 3.8 Sample Solution Comparison (from Site Prioritization)

Beneath the Solution sets are a series of graphs that summarize the solutions and present them graphically. **Figure 3.9** is an example of one of the graphs. The x-axis represents the Daily Vehicle Miles Traveled; the y-axis represents the severity of the site, and the size of the bubbles represents the cost of the proposed improvement.

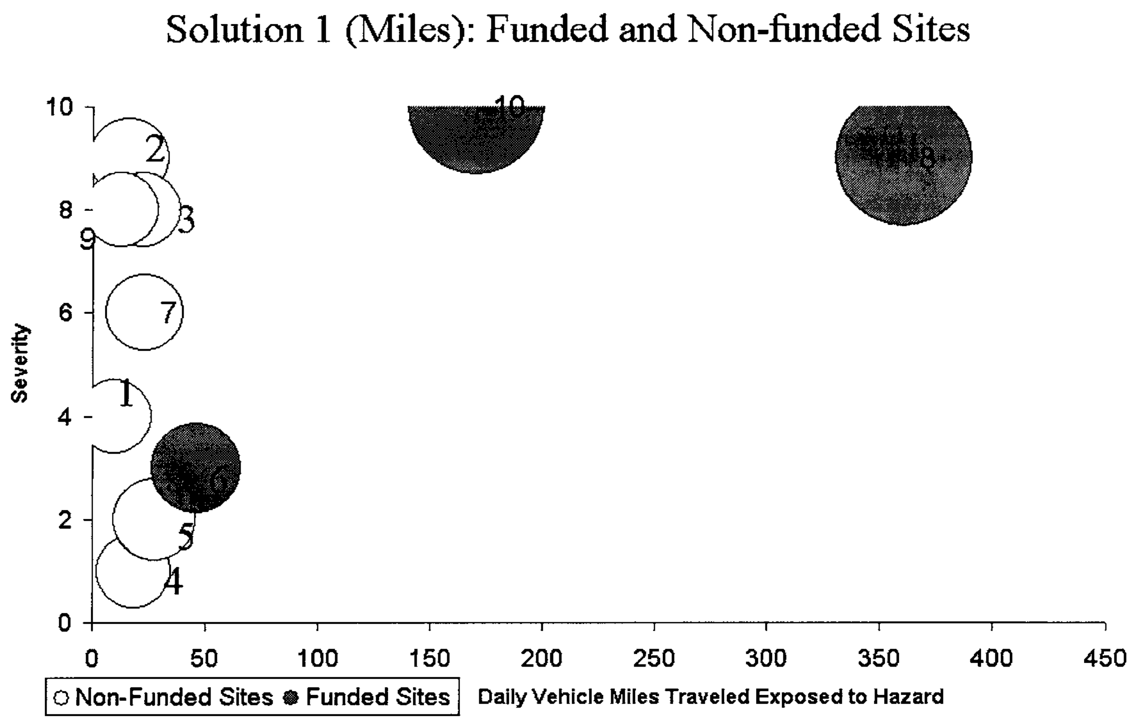

Figure 3.9 Solution Comparison of Miles (from Site Prioritization)

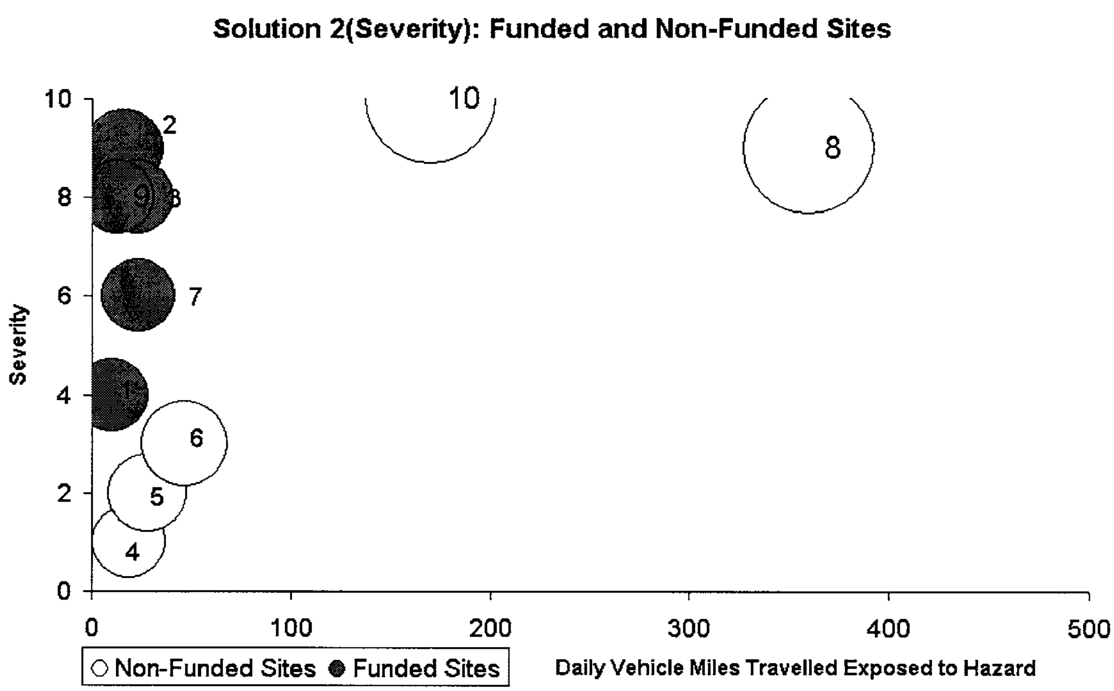

Figure 3.10 Solution Comparison of Severity (from Site Prioritization)

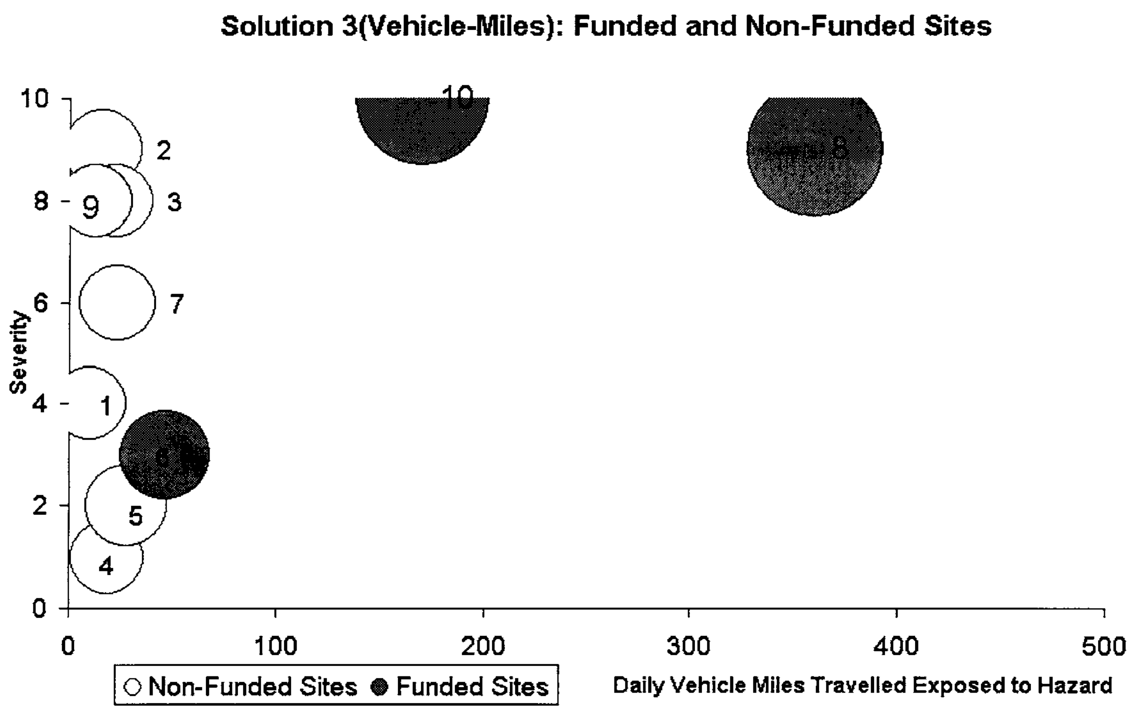

Figure 3.11 Solution Comparison of Vehicle-Miles (from Site Prioritization)

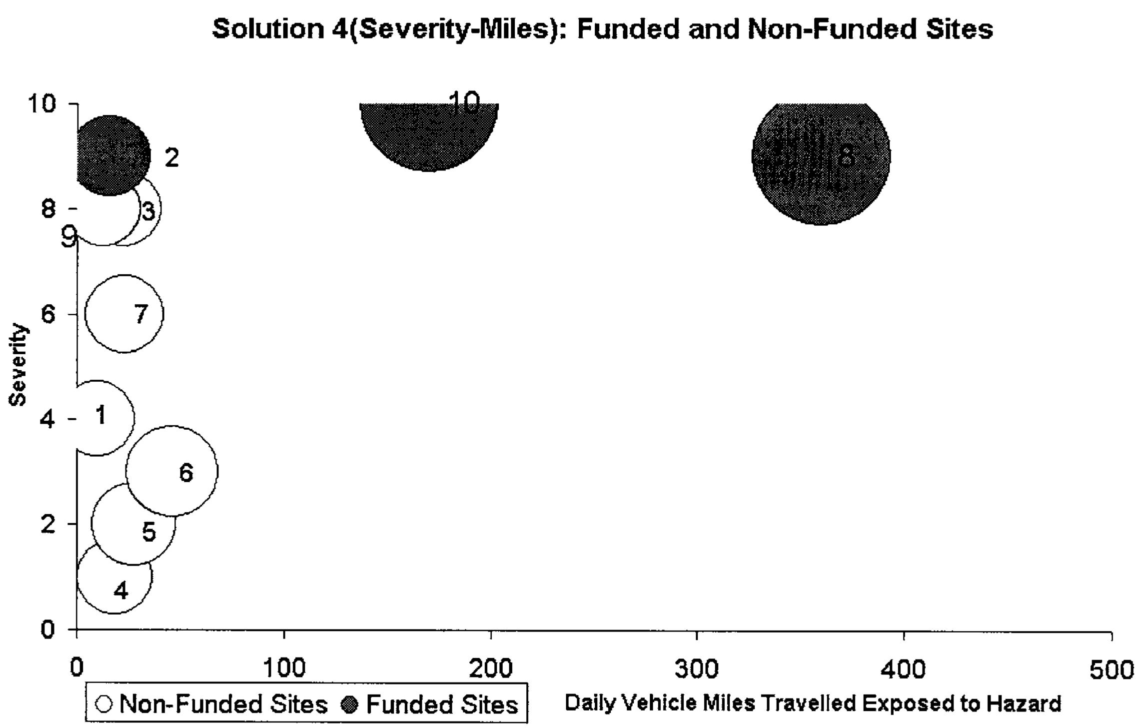

Figure 3.12 Solution Comparison of Severity-Miles (from Site Prioritization)

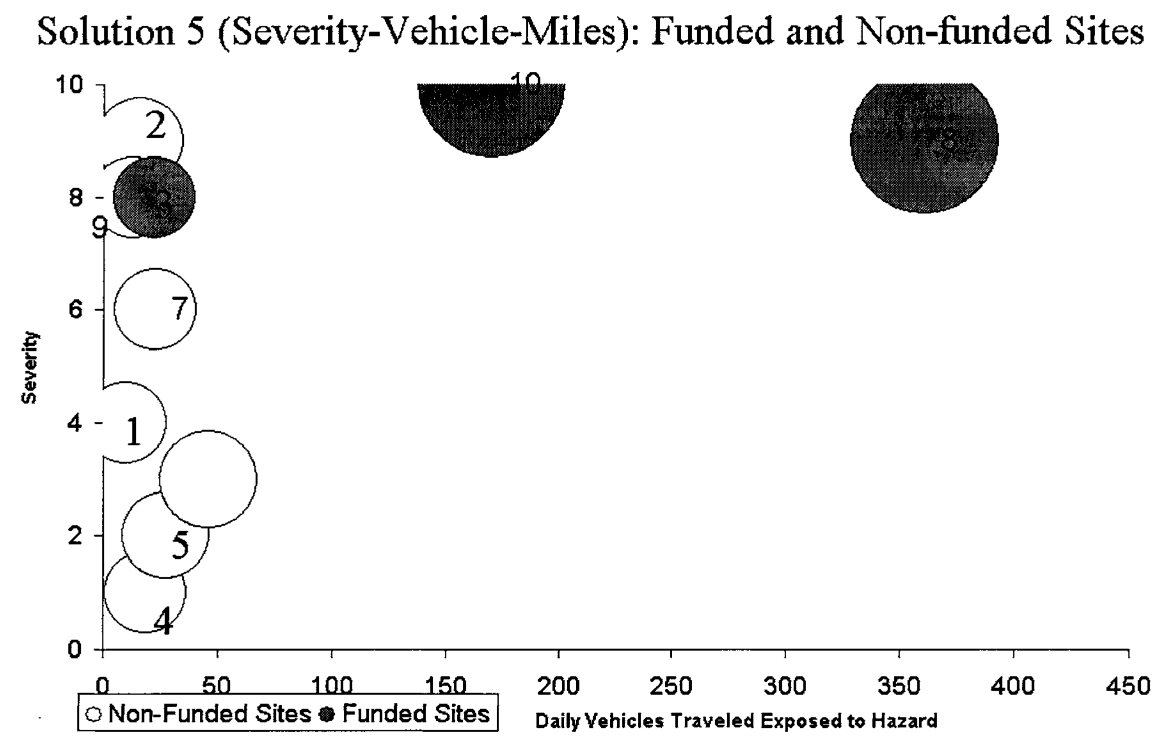

Figure 3.13 Solution Comparison (from Site Prioritization)

The solution sets are absolutes; they only take into account one characteristic and try to maximize it. It is up to the final discretion of the user to select the appropriate solution, if any. A mixture of the different solutions may result in the best overall solution. For example, the chart in **Figure 3.9** recommends funding sites 6, 8, and 10. However, another chart such as **Figure 3.13**, might recommend funding sites 3, 8, and 10. Based solely upon **Figure 3.9** and **Figure 3.13**, sites 8 and 10 would be excellent candidates for funding, and either sites 3 or 6.

Chapter 4: Severity Guidelines

The Severity Guidelines are included in the Hazard Catalog Tool and the Site Prioritization Tool. The Severity Guidelines will appear as a sheet inside these two tools, but are worth mentioning in a separate section. The Severity Guidelines were based upon field data collections. They are meant to assign a severity rating to a site, with a 1 representing the least severe site, and a 10 representing the most severe, with the numbers in between representing a progression from 1 to 10. The Guidelines will appear in the sheets like Figure 4.1.

Severity Guidelines:

<-->

1 3 5 7 10

8 to 10:	Permanent water hazards consisting of more than 2 ft of depth, slope ratio much greater than 2:1 (indicating a high chance of vehicle rollover), fixed objects that present a clear danger to occupants of vehicles (such as the blunt "spear" ends of substandard guardrails), or areas of incidence include high potential for loss of life or property
6 to 8:	Water hazards that could potentially reach heights of over 2 feet during periods of flooding, slope ratio higher than 2:1, potential dangerous fixed objects (such as improperly mounted guardrails or a substantial number of trees with diameters greater than 4 inches).
4 to 6:	Slope ratio about 2.1 (marginal possibility for vehicle rollover), a small number of trees with diameters greater than 4 inches).
2 to 4:	Slope ratio less than 2:1, few fixed objects (such as trees with diameter greater than 4 inches).
0 to 2:	Area has a slope that is not likely to have vehicle rollovers occur, guardrails placed here will likely pose more of a hazard than do existing conditions, recovery zone adequate

Figure 4.1 Severity Guidelines

Chapter 5: New Kent County Field Survey

The purpose of this chapter is to give an example of a real-world application of the prototype databases described previously, these being the Corridor Screening Tool and the Site Prioritization Tool. The organization of this chapter is as follows:

a.) Corridor Screening

b.) Site Prioritization

In the summer of 2000, a field study of run-off-road accidents was conducted in New Kent County, a part of the Richmond District of the Virginia Department of Transportation. Data was collected through various means described below and entered into software designed to facilitate examinations and selections of guardrail installation and upgrade.

Corridor Screening

The first part in the field survey involved obtaining accident history data from the year 1999 for eighteen routes in New Kent County. The criterion used for selecting these routes to examine were that there was at least one accident of a category that could have been prevented or alleviated by a guardrail (such as fixed-object and run-off-road accidents), and that the routes had significant Average Daily Traffic (ADT). The case study contained here only contains the crash history for one year. It may be desirable to obtain data for more than one year for routes with a relatively low ADT. The lower the ADT, the more likely data gathered within a small time frame is to be random. The accident data was collected using the Virginia Department of Transportation's (VDOT) on-line database, called HTRIS. For the purposes of this survey, each route was treated as a measurable length of road, called a corridor. The data characteristics of the corridors collected were: the length of the corridors, their average daily traffic (ADT), the number of related (included fixed-object and run-off-road accidents) accidents, injuries, fatalities, and the amount of property damage per corridor. Using the length of the corridor and the ADT, the daily vehicle miles traveled (DVMT) were calculated. This data is summarized in **Table 5.1**. The data here was entered into the Corridor Screening Tool.

Table 5.1 Accident Corridor Comparison Tool Data Entries for New Kent County, 1999

Corridor Comparison Tool Input Area											
Include (Y or N)?	Corridor	Referenced to	Beginning Milepost	End Milepost	Length in Miles	ADT	DVMT	Number of Related Crashes	Number of Related Injuries	Number of Related Fatalities	Amount of Related Property Damage
Y	601	N/A	0.00	2.58	2.58	253	653	1	1	0	$11,200
Y	606	N/A	0.00	7.40	7.40	761	5631	4	3	0	$11,000
Y	608	N/A	0.00	7.24	7.24	263	1904	3	1	0	$9,500
Y	609	N/A	0.00	3.96	3.96	786	3113	1	0	0	$12,000
Y	610	N/A	0.00	3.01	3.01	231	695	2	4	0	$7,000
Y	611	N/A	0.00	5.29	5.29	733	3878	3	3	1	$8,500
Y	613	N/A	0.00	3.76	3.76	782	2940	1	1	0	$10,000
Y	621	N/A	0.00	1.20	1.20	232	278	1	0	0	$1,200
Y	623	N/A	0.00	7.40	7.40	137	1014	1	1	0	$3,200
Y	627	N/A	0.00	10.44	10.44	952	9939	3	3	0	$3,100
Y	628	N/A	0.00	6.78	6.78	282	1912	1	2	1	$833
Y	629	N/A	0.00	3.78	3.78	959	3625	1	0	0	$3,500
Y	632	N/A	0.00	6.94	6.94	552	3831	1	3	0	$3,500
Y	634	N/A	0.00	5.30	5.30	92	488	1	1	0	$5,000
Y	638	N/A	0.00	4.30	4.30	481	2068	2	0	0	$9,000
Y	640	N/A	0.00	5.07	5.07	1028	5212	6	6	0	$22,850
Y	658	N/A	0.00	0.50	0.50	87	44	1	1	0	$3,000
Y	665	N/A	0.00	2.90	2.90	1118	3242	2	0	0	$10,500

Preliminary analysis revealed that one of the corridors, corridor 658, appeared to be an outlier due to its relatively small corridor length and low ADT. Corridor 658 was removed from subsequent analyses.

Also removed from consideration were the fatality characteristics. There were only two fatalities, and they were likely due to random chance. The inference was drawn that the fatality statistics are not pertinent for corridors lacking sufficient length. Thus, the corridors analyzed in the New Kent County Field Survey were not sufficient in length to make the fatality characteristic valid.

The main features of the Corridor Screening Tool that were the most relevant in drawing conclusions for this field study were the graphical representations of the corridors' DVMTs.

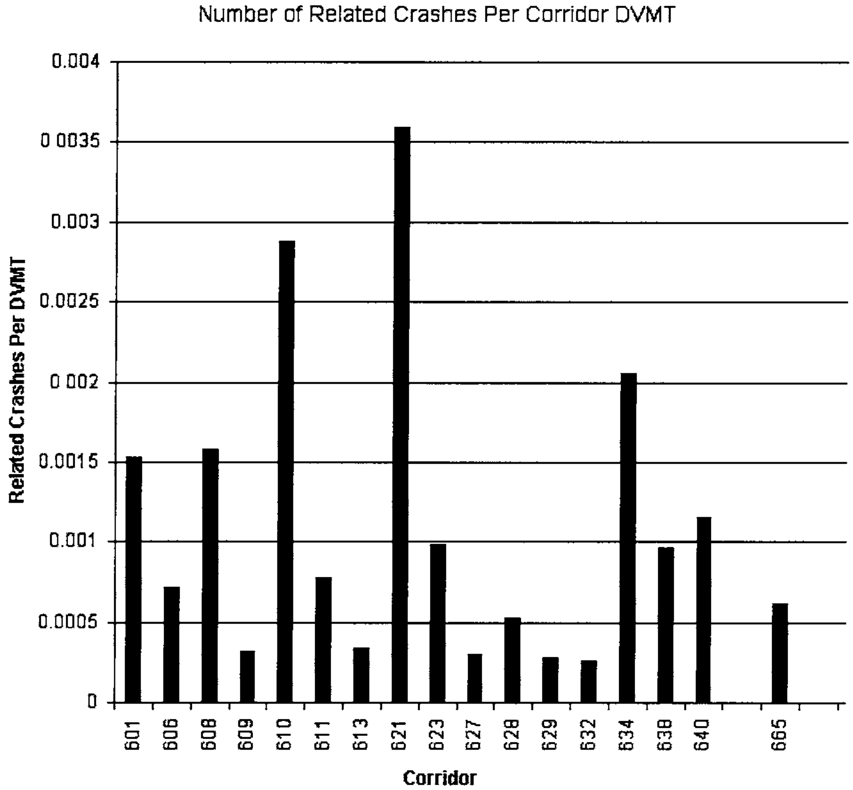

Figure 5.1 Number of Related Crashes per Corridor DVMT

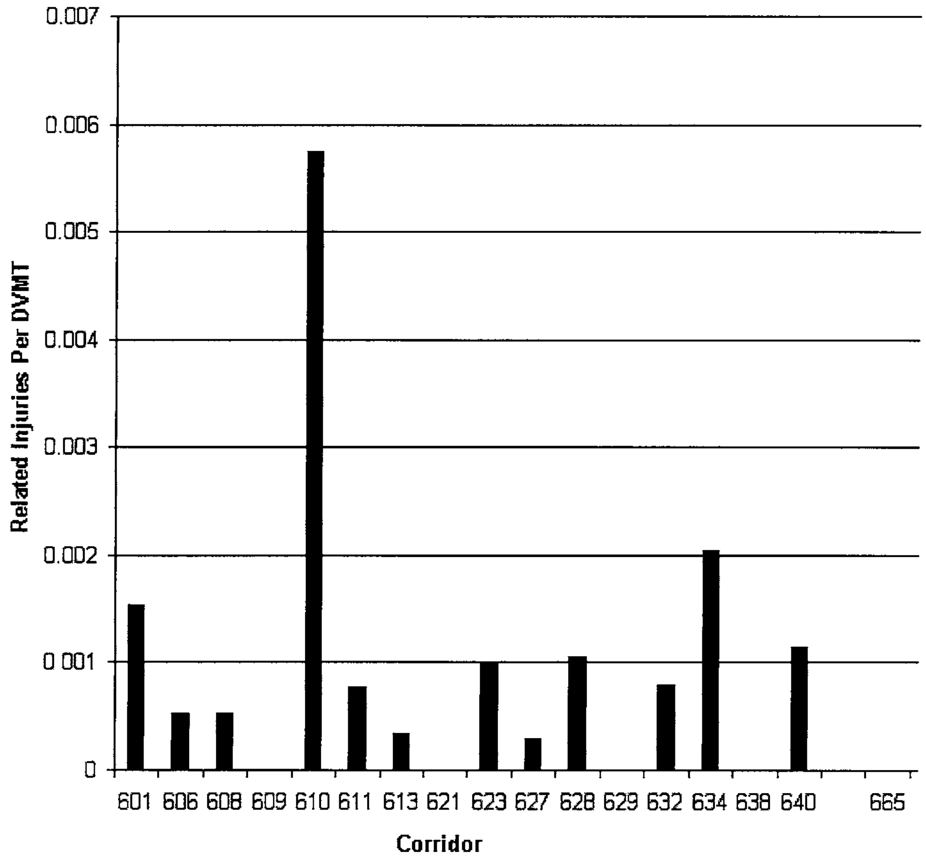

Figure 5.2 Number of Related Injuries per Corridor DVMT

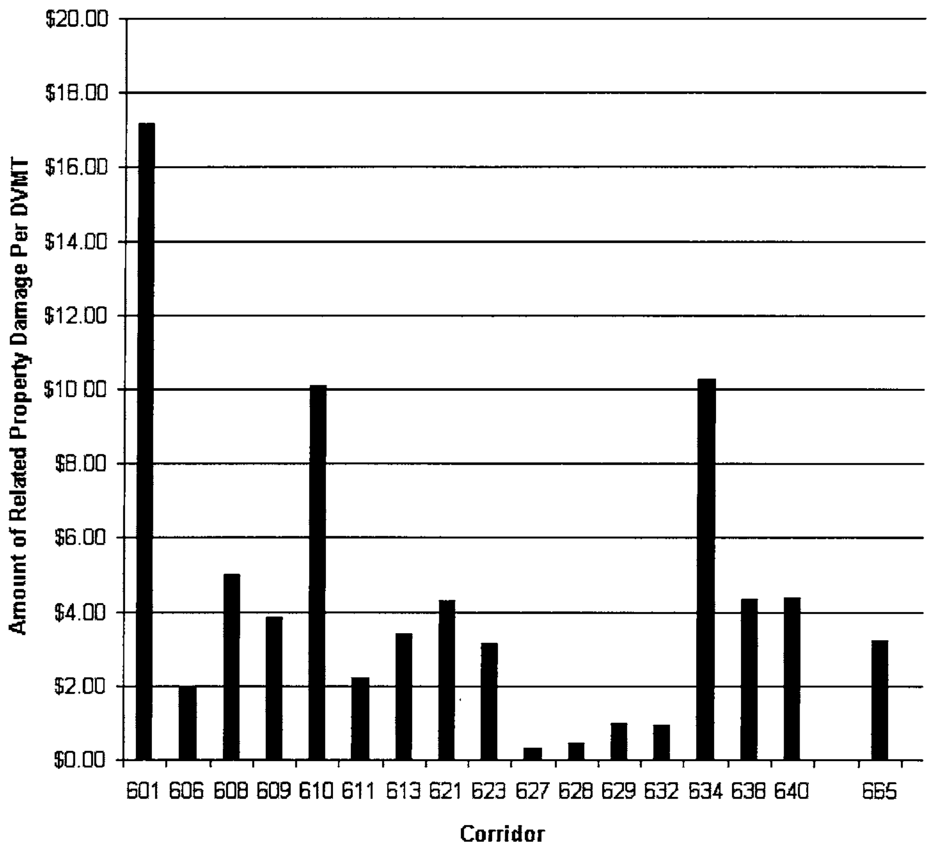

Figure 5.3 Amount of Related Property Damage per Corridor DVMT

From **Figures 5.1, 5.2,** and **5.3**, it can be seen that corridor 610 consistently suffers more damage compared to the other corridors. Corridor 610 would be an excellent candidate on which to concentrate future guardrail efforts.

<u>Site Prioritization</u>

The next part of the New Kent County Survey involved HTRIS data collections and on-site investigations of candidate sites for guardrail improvements. The purpose of this next part of the field study was to discover and compare candidate sites for guardrail improvements.

A field investigation was conducted along four routes with the aid of two personnel of the Richmond District VDOT. The two personnel helped judge the severity of the sites. A total of ten sites from the four routes were analyzed in the Site Prioritization Tool (SPT). The site inspections took approximately an hour for every ten miles of roadway, with a total of around twenty miles inspected for the field study. HTRIS data was then collected for the purpose of finding the ADT's past the candidate sites. The data collected is shown in **Table 5.2**. DVMT (Daily Vehicle Miles Traveled) is equal to the product of the Hazard Length and the ADT.

Table 5.2 Summary of Field Data collected for New Kent County Survey

ID Number	Number of Lanes	Flow Direction	Right or Left	Route	Beginning Milepost (miles)	End Milepost (miles)	Length of Hazard (feet)	Substandard Guardrail?	Severity Index	ADT (Vehicles per Day)	Hazard DVMT (Daily Vehicle Miles Traveled)
1	2	N	B	613	1.565	1.603	201		4	258	9.8
2	2	N	B	613	1.400	1.460	317	Y	9	258	15.5
3	2	N	B	613	0.437	0.475	201		8	782	29.7
4	2	N	B	611	0.358	0.396	201		1	485	18.4
5	2	N	B	611	1.283	1.321	201		2	485	18.4
6	2	N	B	611	1.005	1.100	502	Y	3	485	46.1
7	2	N	B	611	0.553	0.610	301	Y	6	485	27.6
8	2	N	B	665	1.690	1.758	359	Y	4	1118	76.0
9	2	N	B	640	1.510	1.622	591	Y	9	531	59.5
10	2	N	B	640	0.225	0.228	16		8	1028	3.1

The data from Table 5.2 was then stored in the Hazard Catalog Tool (HCT) as shown in **Figure 5.4.**

Route=	613
Length of Route=	Unknown
County/City=	NK

To Guardrail Types   To Workbook Summary Table
To Route Summary Table
To Next Route

Accident Data Covers Dates:
01/01/00 to 07/27/00

			Location							Existing					Proposed												
Include (Y or N)?	ID Number	Date Modified	Number of Lanes	Flow Direction	Right or Left	Relative to:	Beginning Milepost (miles)	End Milepost (miles)	Length of Hazard (feet)	Existing Run-on Type	Existing Main Run Type	Existing Run-Off Type	Existing Other Type	Value of Existing Section	Proposed Run-on	Proposed Main Run	Proposed Run-Off	Proposed Other	Removal Cost Per Foot	Total Cost for Proposed Improvement	Severity Index	Guardrail Strikes	ADT (Vehicles per Day)	Hazard DVMT (Daily Vehicle Miles Traveled)	Number of Related Crashes	Severity of Complaints	Comments
Y	1	07/00	2	N	R	E611	1.565	1 603	201					$0	4	5	6		7	$6,207	4		258	9.8			Near Railroad, Steep Embankment
Y	2	07/00	2	N	R	E611	1.400	1 460	317	1	2	3		$3,584	4	5	6		7	$7,485	9		258	15.5			Sub GR w/Blunts
Y	3	07/00	2	N	R	E611	0.437	0 475	201					$0	4	5	6		7	$6,207	8		782	29.7			Water Hazard
N	4								0					$0						$0				0.0			
N	5								0					$0						$0				0.0			
N	6								0					$0						$0				0.0			
N	7								0					$0						$0				0.0			
N	8								0					$0						$0				0.0			
N	9								0					$0						$0				0.0			
N	10								0					$0						$0				0.0			
N	11								0					$0						$0				0.0			

Guardrail Types | Route A | Route B | Route C | Route D | Route E | Route F | Route G | Route H | Summary

Figure 5.4 Screenshot of Hazard Catalog Tool Data Entry

Figure 5.4 shows how the data from the hazard sites surveyed is entered. Here, four hazard sites from Route 611 are entered into one of the Route sheets. The number designations in the **Existing Guardrail** columns and **Proposed Guardrail** columns are used to designate a type of guardrail. In **Figure 5.4**, the numbers 1,2, and 3 are used to designate **Existing Run-On End Treatments**, **Existing Main Run Treatments**, and **Existing Run-Off End Treatments**, respectively. Also in Figure 5.4, the numbers 4, 5, 6, and 7 are used to designate **Proposed Run-On End Treatments**, **Proposed Main Run Treatments**, **Proposed Run-Off End Treatments**, and **Removal Cost Per Foot**, respectively. The user defines these numbers. For the field study, **Table 5.3** was used for guardrail definitions.

Table 5.3 Guardrail Number Designations for Hazard Catalog Tool

Number Designation	Type	Name	Cost	Comments
1	Run-On	SUB-1	$1,000	Substandard
2	Main Run	SUB-2	$5	Substandard
3	Run-Off	SUB-3	$1,000	Substandard
4	Run-On	GR-9	$2,000	New GR
5	Main Run	GR-1	$10	New GR
6	Run-Off	GR-8	$2,000	New GR
7	Removal	Removal	$1	Removal Cost per foot

The Hazard Catalog tool can be used to make comparisons among hazard sites along a route or between different routes, as shown in **Figures 5.5** and **5.6**. A one to ten scale of Severity is defined in the instructions below.

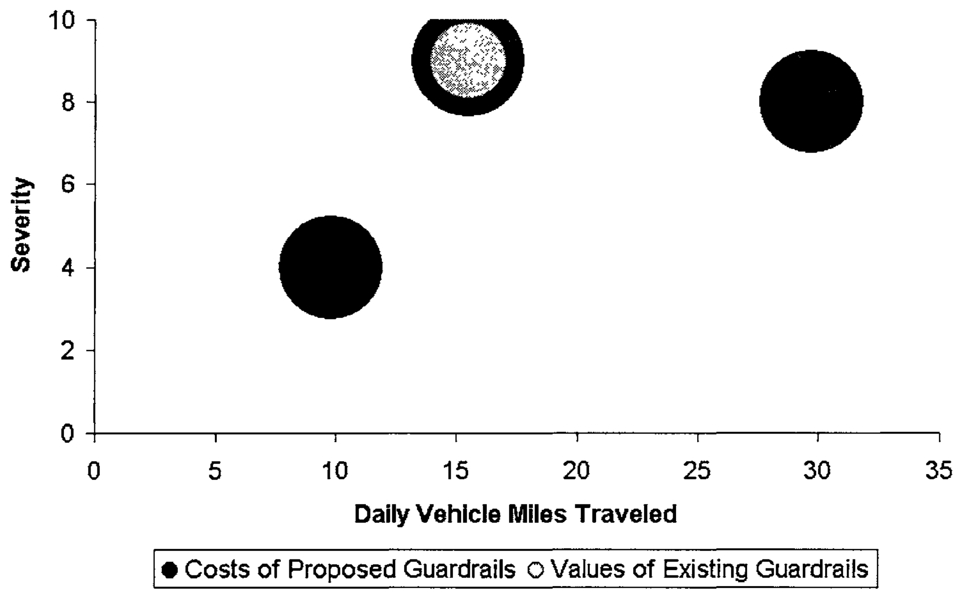

Figure 5.5 Comparison between Existing Guardrails and Proposed Installations at Unprotected Sites for Route 611 (from Hazard Catalog Tool)

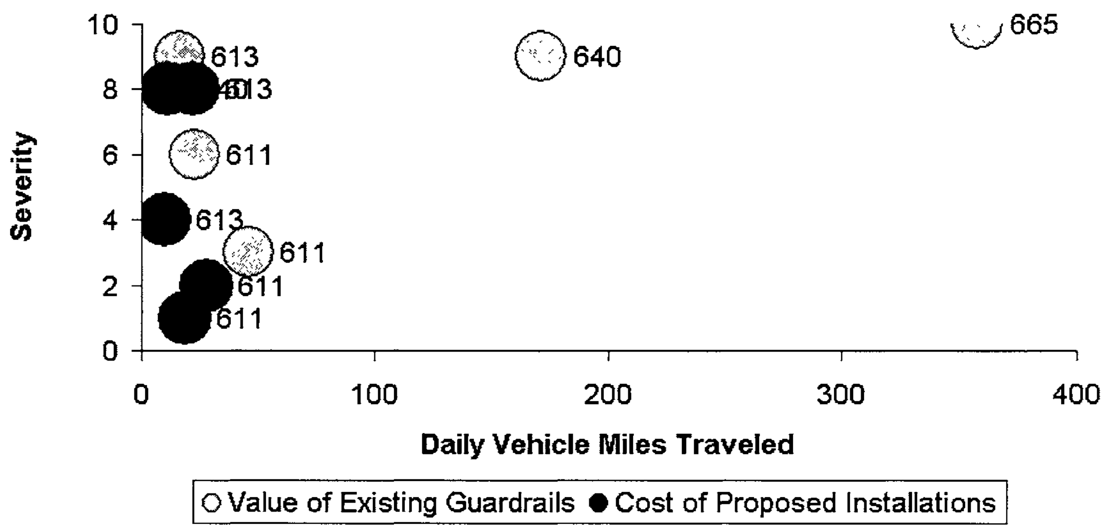

Figure 5.6 Comparison between Existing Guardrails and Proposed Installations at Non-Protected Sites for Routes 613, 611, 665, and 640 (from Hazard Catalog Tool)

The next step in analyzing the data collected (**Table 5.2**) is to enter the pertinent information into the Site Prioritization Tool. **Figure 5.7** shows the form the data would take in the Site Prioritization Tool.

Input Worksheet

Prioritize All

Constants:			
Budget ($):	$50,000	Minimum Guardrail Coverage (ft):	200

Input Data Area

Include? (Y or N)	Location	Location ID #	Hazard Length (ft)	Main Run Cost ($/ft)	Run-On Cost ($)	Run-Off ($)	Other Costs ($)	Total Removal Cost ($)	Severity Index	Average Daily Traffic (Vehicles per Day)	DVMT (Daily Vehicle Miles Traveled)	Total Site Improvement Cost ($)	Comments
Y	613, E on 611, 0.04 to 0.15	1	200	$10	$2,000	$2,000	$0	$0	4	258	10	$6,000	Near Railroad, Steep Embankment
Y	613, E on 611,1.40 to 1.46	2	325	$10	$2,000	$2,000	$0	$350	9	258	16	$6,900	Substandard GR w/Blunt Ends
Y	613, E on 611,0.437 to 0.475	3	150	$10	$2,000	$2,000	$0	$0	8	782	22	$6,000	Water Hazard
Y	611, W on 670, 0.358, to 0.396	4	200	$10	$2,000	$2,000	$0	$0	1	485	18	$6,000	Optic Fiber Cable, Inside Curve
Y	611, N of 665, 1.283 to 1.321	5	300	$10	$2,000	$2,000	$0	$0	2	485	28	$7,000	High Rise, no trees
Y	611, N of 665, 1.005 to 1.10	6	500	$10	$2,000	$2,000	$0	$525	3	485	46	$8,475	Substandard GR
Y	611, N of 665, 0.553 to 0.61	7	250	$10	$2,000	$2,000	$0	$275	6	485	23	$6,225	Substandard GR, GR too low
Y	665, N of 640, 1 51 to 1 622	8	1701	$10	$2,000	$2,000	$0	$1,726	9	1118	360	$19,284	Phone Utility, Substandard GR
Y	665, N of 640, 0.225 to 0.225	9	60	$10	$2,000	$2,000	$0	$0	8	1118	13	$6,000	Water Hazard
Y	640, S of 249, 1 69 to 1.758	10	1690	$10	$2,000	$2,000	$0	$1,715	10	531	170	$19,185	Substadandard GR w/Blunt Ends

Figure 5.7 Input Worksheet (from Site Prioritization Tool)

Once the data is entered and constraints are set, the Site Prioritization Tool generated the graphical summaries shown in **Figures 5.8** and **5.9**.

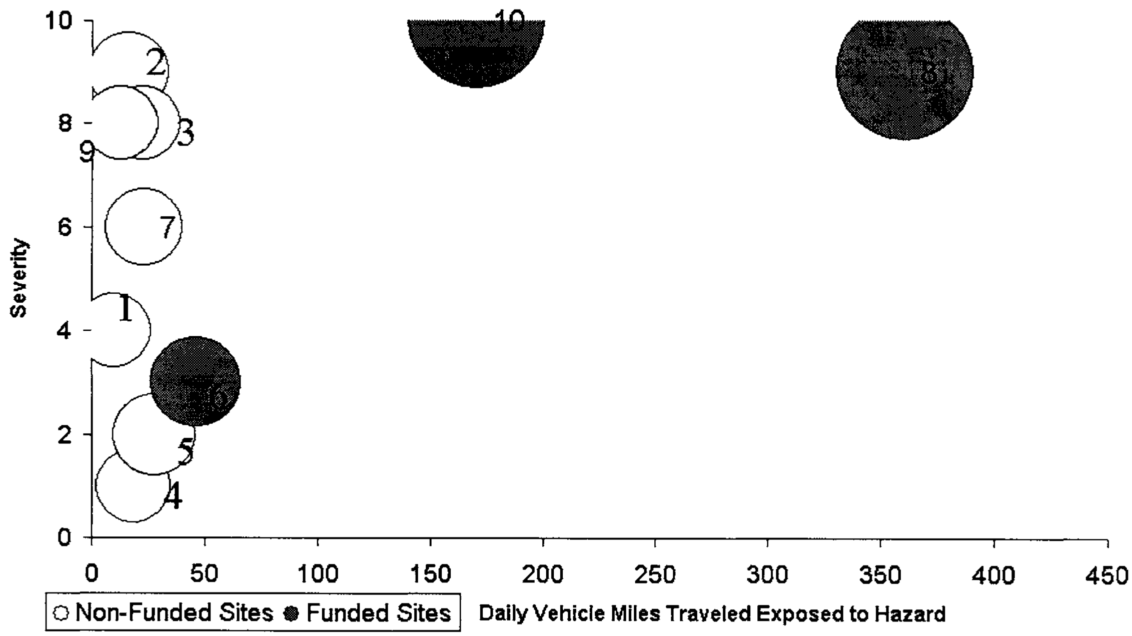

Figure 5.8 Comparison of Suggested Site Funding for Prioritizing the Length of Hazard Protected (from Site Prioritization Tool)

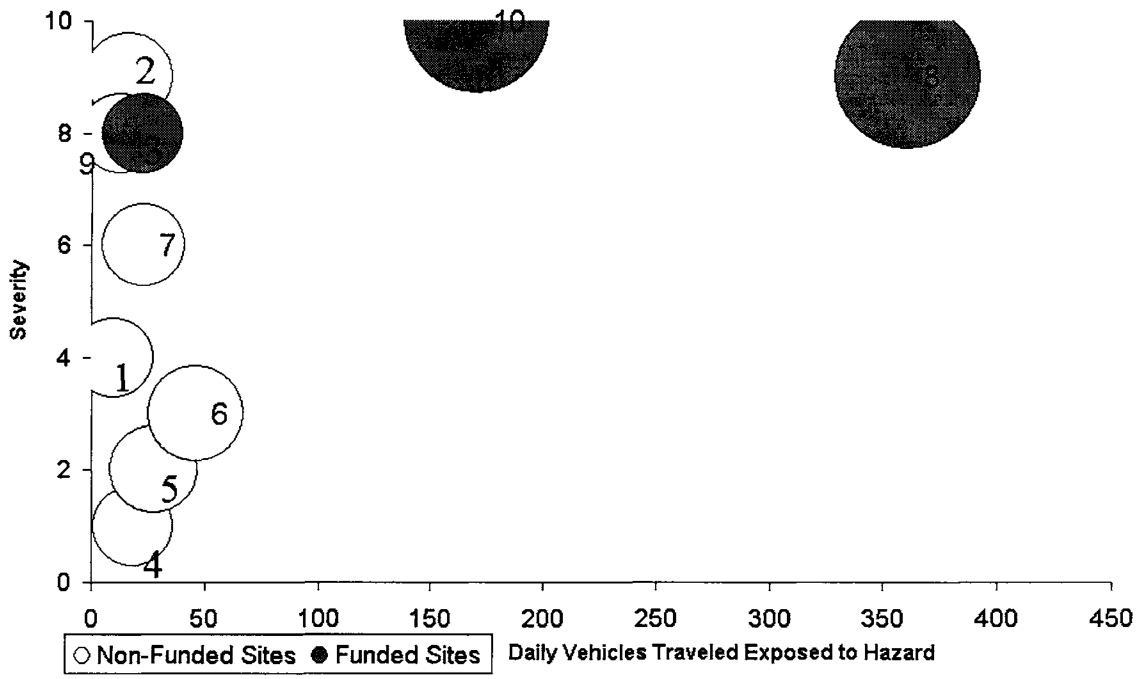

Figure 5.9 Comparison of Suggested Site Funding for Prioritizing the Severity-Vehicle-Miles Protected (from Site Prioritization Tool)

From the graphical representations from such graphs as **Figure 5.8** and **Figure 5.9**, the user of the Site Prioritization Tool can be assisted in making the decisions as to which sites to fund for guardrail improvements. For example, **Figure 5.8** selects sites 6, 8, and 10; while **Figure 5.9** selects sites 8, 9, and 10. Sites 8 and 10 are both chosen by the two Figures, and would be excellent candidates for guardrail improvement.

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