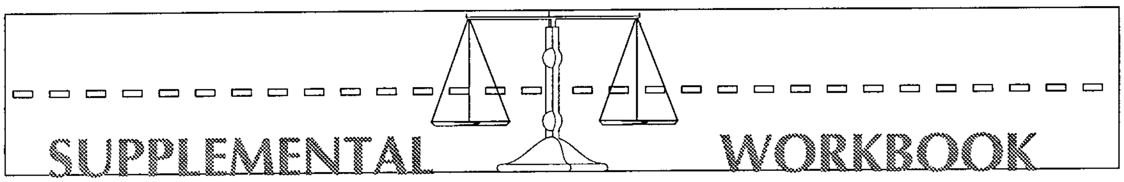
PB99-115438

FINAL
CONTRACT REPORT

A TOOL TO AID THE COMPARISON OF IMPROVEMENT PROJECTS FOR THE VIRGINIA DEPARTMENT OF TRANSPORTATION



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SUPPLEMENTAL WORKBOOK

A TOOL TO AID THE COMPARISON OF IMPROVEMENT PROJECTS FOR THE VIRGINIA DEPARTMENT OF TRANSPORTATION

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agency)

Contract Research Sponsored by
Virginia Transportation Research Council

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

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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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Acknowledgments

The team at the Center for Risk Management of Engineering Systems would like to thank the Steering Committee and the staff at the Virginia Transportation Research Council for their support and encouragement throughout the project. The team is particularly indebted to Jeff Hores for his advice and furnishing many of the datasets. Moreover, the team would like to thank the staff at the Virginia Department of Transportation for being receptive to the project effort and providing assistance along the way. In addition, the Project Team would like to thank the reviewers, those identified on the previous page as well as several unidentified persons, for their helpful comments on earlier versions of this document.

Workbook

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SUPPLEMENTAL WORKBOOK

A TOOL TO AID THE COMPARISON OF IMPROVEMENT PROJECTS OF THE VIRGINIA DEPARTMENT OF TRANSPORTATION

EXECUTIVE SUMMARY

The aim of this Workbook is to assist the Virginia Department of Transportation (VDOT) in improving the comparison in planning of potential primary and secondary roadway improvement projects. It is an outcome of an effort to:

1. Develop a comparison tool to present effectively the tradeoffs among crash-risk reduction, performance gain, and cost for roadway improvements;
2. Ensure that the experience and judgment of VDOT personnel are fundamental to the estimation of crash risk, performance, and cost;
3. Adopt existing models for estimating the crash-risk reduction and the performance gain for roadway improvements, as appropriate to supplement and complement the input of experts;
4. Work closely with a pilot VDOT district in the development, calibration, and workshop-demonstration of the developed methodology;
5. Understand and accommodate the needs of VDOT districts in their selection of projects for the Six-Year Plan; and
6. Provide that the support for decision-making is: Comprehensive, adherent to evidence (e.g., MIS 2000), logically sound, practical and politically acceptable, open to evaluation, based on explicit assumptions and premises, compatible with institutions, conducive to learning, attuned to principles of risk communication, and innovative.

This Workbook explains the steps in a process for comparing prospective projects based on estimates of crash risk reduction, performance gain, and cost. The estimation methodologies implemented here are adopted from current practice. The comparison is performed using a multiobjective chart and supporting tables. The analysis does not replace or duplicate other traditional methods of traffic engineering nor can it evaluate every project objective. The approach aims to *aid* and *supplement* the current project decision-making process with regards to cost, performance gain and crash risk reduction, it aims to assist in communicating to the public and help VDOT evaluate both past choices of projects and the efficacy of future projects. The methodology presented here does not intend to, and in fact cannot, produce decisions. Many variables that influence the decision process are not covered in this document; VDOT's decisions should, however, encompass all of them, and decisions will always be made by human decision-makers. In addition, the methodology presented here can only help VDOT make the best of the information that is available; it cannot replace real data or detailed knowledge about proposed projects.

Throughout this document, historical projects that have been implemented or were considered for implementation in the past have been used for examples etc. Historical data was used in order to allow for a comparison of the predictions produced with the methodology presented here and the actual, observed outcome. In the operational phase, however, VDOT would use current data to make inferences about future results of project implementation.

In this document, propositions are made on how to estimate the cost, performance gain and crash risk reduction of future roadway projects. It should be noted, however, that the main focus is on presenting the trade-offs among these criteria. If, in a particular case, more accurate and/or appropriate data is available on one or more of these criteria (e.g. from a simulation study that has been performed), then this information can easily be used to supplement or replace the estimations proposed here.

It should be kept in mind that the analyses introduced here can be applied to a wide range of sets of projects. For example, attention may be limited to those projects among which decision-makers find it particularly difficult to choose. Other criteria for inclusion in the analysis may be the type of funding, location etc.

Undoubtedly, the public and politicians will question the new methodology as it is taken to field implementation, even under pilot test conditions. Hence, it is important that those who will use and defend it have a firm understanding of the process and confidence in the data used to support the assumptions. It is therefore considered essential that the users be well trained and familiar with the concepts presented here, if an early abandonment is to be avoided. This study was undertaken in an effort to be proactive and to anticipate the need for a process that can effectively demonstrate the various trade-offs that invariably accompany every real-life decision. This proactiveness can only pay off if the necessary next steps are taken in order to familiarize VDOT personnel with the ideas presented in this document and to fine-tune the methodology as required based on feed-back from the field.

Overview of Project Comparison Tool

A variety of factors are important to the selection of highway improvement projects: Travel and construction time, cost, accident data, available resources, technology, public concern, political pressure, and many others. The Project Comparison Tool combines three major decisionmaking attributes in project selection: Crash risk, performance, and project cost. By quantifying these attributes across a number of proposed highway improvement projects, projects can more readily be compared to one another, and a more holistic view of potential projects is achieved. This is an important step when choosing a portfolio of projects each year.

In order to compare projects, attributes are quantified in the following manner for planning level decisions. Crash Risk Reduction is calculated as the **number of crashes *avoided* per year** at the project site. Particular roadway improvements are typically assumed to decrease the expected number of crashes by a statistically determinated and pretabulated percentage. Performance Gain is quantified by the **vehicle minutes of travel time avoided in the peak hour**. Finally, Cost is modeled as **the sum of preliminary engineering, right of way and construction costs**.

Once the objectives are quantified, they can be graphically displayed in a Project Comparison Chart. The vehicle minutes saved is mapped onto the horizontal axis. Projects that appear farther out on the horizontal axis are therefore preferable.

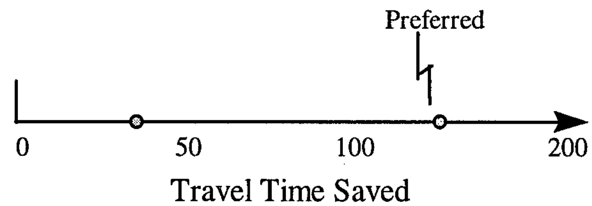


Figure 0.1

Crashes avoided per year are likewise represented on the vertical axis. Projects that appear further out on this axis are preferred.

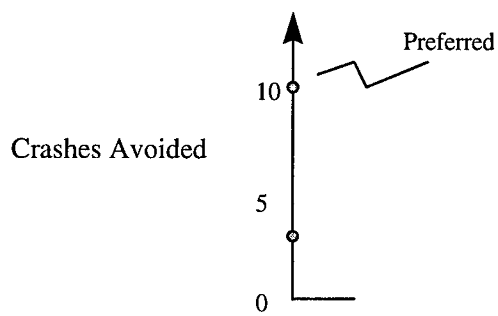


Figure 0.2

Cost is represented by the size of the project marker. A larger marker translates to a larger cost. A dot that has twice the area of another dot indicates a project with twice the cost of the other.

Figure 0.3

Combining these elements into a single chart:

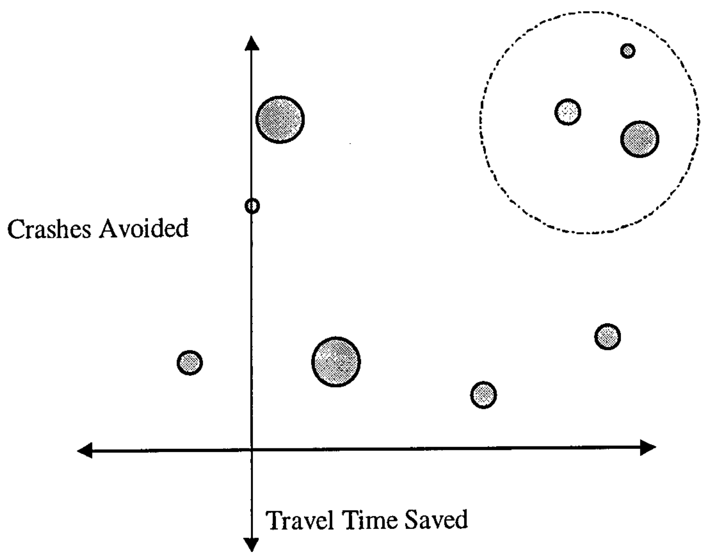


Figure 0.4

Projects shown within the dashed circle may be preferred for their large crash reduction, travel time saved, and low to medium costs. The charts show that even if a project is driven by capacity concerns, at the same time it affects the safety of the roadway. There are many different strategies for choosing a portfolio of projects: Maximizing total crashes avoided, minimizing cost, or choosing several projects which save time and others which reduce crash risk without necessary overlap. Attributes that are not charted such as environmental or pedestrian concerns can also drive project selection.

The above analysis contains point estimates, however, at the time of evaluation, projects are at different stages of development. Thus there is varying confidence in estimates of their efficacy and cost. Precision of the estimates is therefore represented as "error bars" or confidence intervals in the display of estimates.

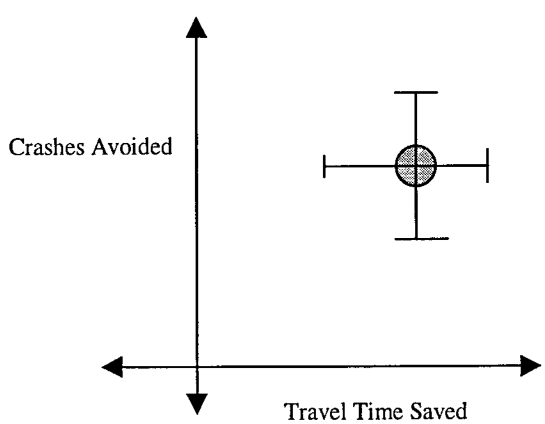


Figure 0.5

These bars represent a range in which the true annual number of crashes avoided and minutes saved is expected to lie. Cost uncertainty can be represented in two ways: By the percentage of funds already used on the project and by its cost overrun potential. The percentage of funds already used is indicative of cost certainty, because as the project nears completion, the final cost become more certain. The projected total cost can be shaded by the percentage of funds already used.

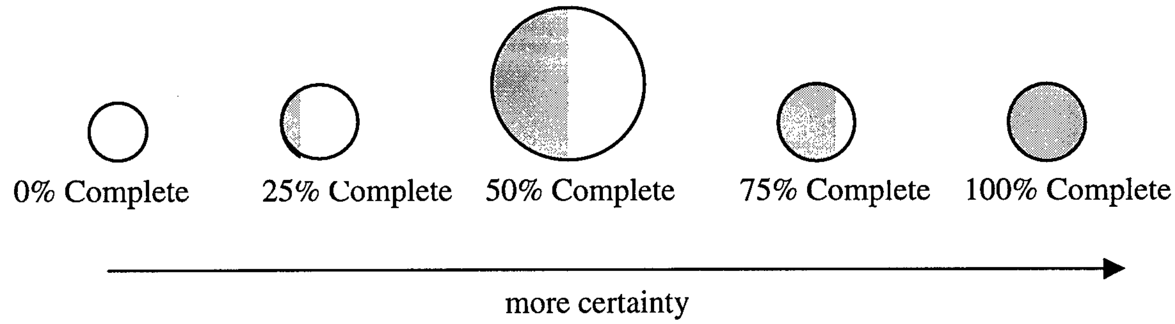


Figure 0.6

Cost overrun potential can also be estimated by engineers from analyses of completed projects. For example, a project can have a likely cost overrun of 50%. Therefore, the cost overrun would be 150% of the original cost. The cost overrun can be represented as a circle around the original marker. The areas of both markers are directly proportional to the cost in dollars .

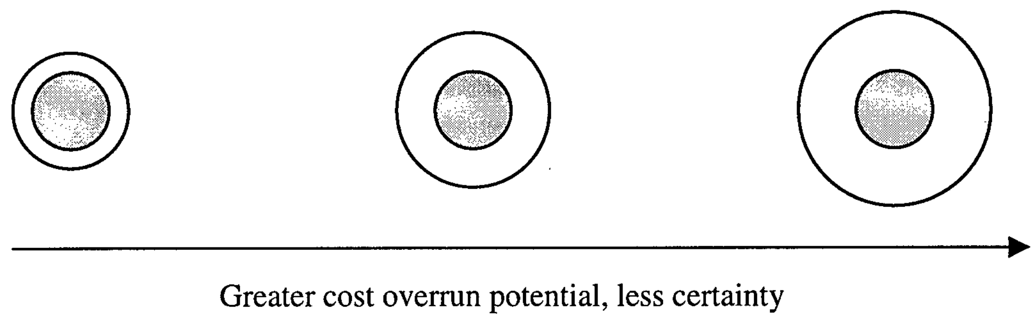


Figure 0.7

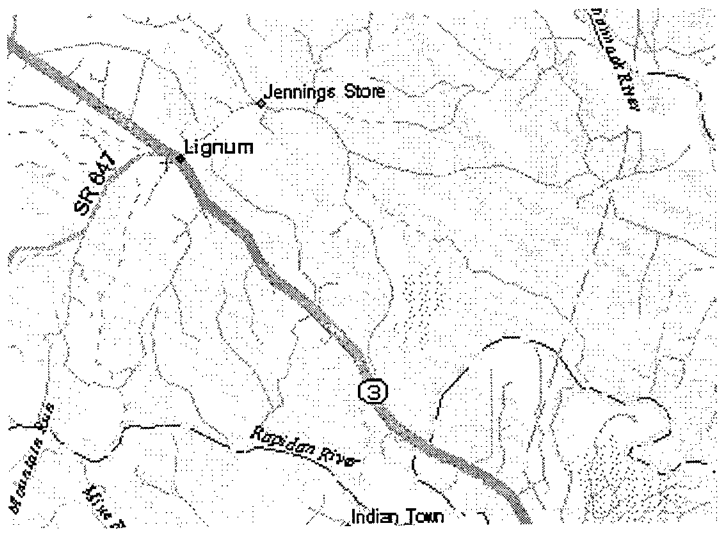
Note that the difference in size between the (inner) circle representing the expected cost and the (outer) circle representing the cost overrun potential will be visually more pronounced if the cost are chosen to be proportional to the circle radius (and not the circle area). For example, the area is doubled as the radius increases by a factor of $\sqrt{2}$. The analyst will have to decide which proportionality (area, radius) is more appropriate.

The analyst will have to decide whether to include the uncertainty information in all cases or not. For a large number of projects to be compared, the range bars may reduce readability, and the creation of two charts, one without and one with range bars, may be considered.

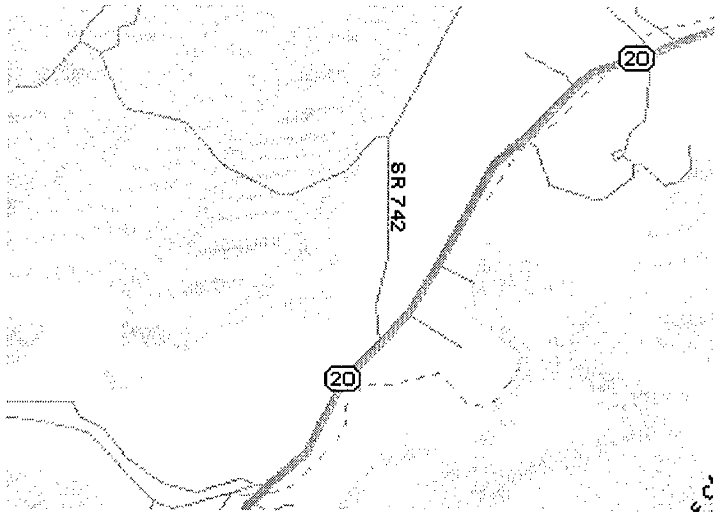
This Workbook explains the calculations for each estimate – risk, performance, and cost – and its associated uncertainty. Chapter 4 then combines these results into the project comparison chart.

Examples

Two example projects are carried out through this Workbook.



Project H: The Culpeper District widening of Route 3 from 2 to 4 lanes starting from the Orange County line west to east of Lignum. Additional project work would include alignment improvement.



Project G: The Culpeper District proposal to improve the intersection at Route 20 and Route 742. Work would include realigning Route 20 and other intersection improvements. The intersection is located 2.9 miles South of Charlottesville corporate city limits.

Note that these examples are based on real projects, but have been modified for demonstration.

Organization of Report

There are seven major parts to this Workbook: Overview (Chapter 0), Crash Risk Reduction (Chapter 1), Performance Gain (Chapter 2), Cost (Chapter 3), Comparison Tool Framework (Chapter 4), Additional Considerations (Chapter 5), Applying the Tool to Critical Rate Listings (Chapter 6). Each chapter may be employed independently of the others; however, crash risk, performance, and cost estimates must be completed before they can be charted in an appropriate framework. Chapters 1 through 3 each contain a worksheet, instructions, and one or more examples. An appendix provides a brief introduction to using HTRIS (for crash- and daily-traffic-data retrieval) and provides some tables, including one with the Accident Reduction Factors currently in use in Virginia.

The final report provides detailed background and supporting information on the project and the topics discussed in the Workbook.

CHAPTER 1
CRASH RISK REDUCTION ANALYSIS

1.1 Overview

In general, risk is a measure of the probability and severity of adverse effects, e.g. traffic accidents on the roadway. ***Crash risk*** is defined herein as the mean number of accidents per year at a given location. Further, ***crash risk reduction*** is defined as the potential reduction in the mean number of crashes per year at project site. This is equivalent to the difference of the number of crashes per year without a project and the number of crashes per year with a particular project.

This chapter contains procedures for the analysis of crash risk reduction on basic roadway sections and intersections using Accident Reduction Factors (ARFs). The methodologies below can be applied to many improvements to roadway sections and intersections.

The Accident Reduction Factor (ARF) method uses an expectation of the accident rate reduction to predict the effectiveness of an improvement. ARFs are factors applied to the pre-project crash rate in order to predict the number of crashes after an improvement (or countermeasure) is made. An assumption is made that a particular countermeasure will always result in a reduction of the number of accidents (x%) per vehicle regardless of the specific based on circumstances of the individual implementation. The ARF approach is based on "Before and After" studies and serves as a general guideline for expected effectiveness. Several states maintain their own list of ARFs, and for the purpose of this Workbook, the 1994 Virginia ARFs will be used. Virginia Department of Transportation has been using 30 classifications for such improvements ranging from road widening to illumination.

For example, consider that VDOT planners are exploring the effect of widening the shoulders along Route 6. Crash records show that over the past 2 years, there has been a crash rate of 10 per year. Widening the shoulders would reduce the crash rate by 30% (In other words, the new crash rate will be 70% of the original crash rate.)

> Assuming constant traffic, if no improvement is made, the engineers expect that the crash rate will continue at 10 per year.
>
> If the shoulders are widened, VDOT engineers expect that the crash rate will reduce to 7 per year, avoiding 3 crashes a year.

Table 1.1: Crashes Avoided

Initial Conditions	No Improvement	Improvement	Avoided
10	10	7	3

Confidence Intervals

Because the calculation of mean crash rate is a statistical estimate, confidence intervals for these estimates should be calculated to give a reasonable upper and lower bound.

The technique given below is taken from Bourne and Green (1972):

$$\lambda_L = \frac{\chi_{11}^2}{2\,n} \leq r \leq \frac{\chi_{22}^2}{2\,n} = \lambda_U$$

where

r	is the mean crash rate (crashes per year)
n	observation period (years)
x	number of accidents
λ_L	is the lower bound of the crash rate (crashes per year)
λ_U	is the upper bound of the crash rate (crashes per year)
χ^2_{11}	is that value which is exceeded by 100[1 - ε/2]% of values generated by a chi-square distribution with (2x) degrees of freedom,
χ^2_{22}	is that value which is exceeded by 100[ε/2]% of values generated by a chi-square distribution with (2[x+1]) degrees of freedom.

For example, assume there were 4 crashes in 2 years. The upper bound is calculated with the use of the Chi-Square Distribution.

Degrees of freedom = 2 × (number of crashes + 1) = 2 × (4 + 1) = 10

This produces the Chi-Square Distribution in Figure 1.1.

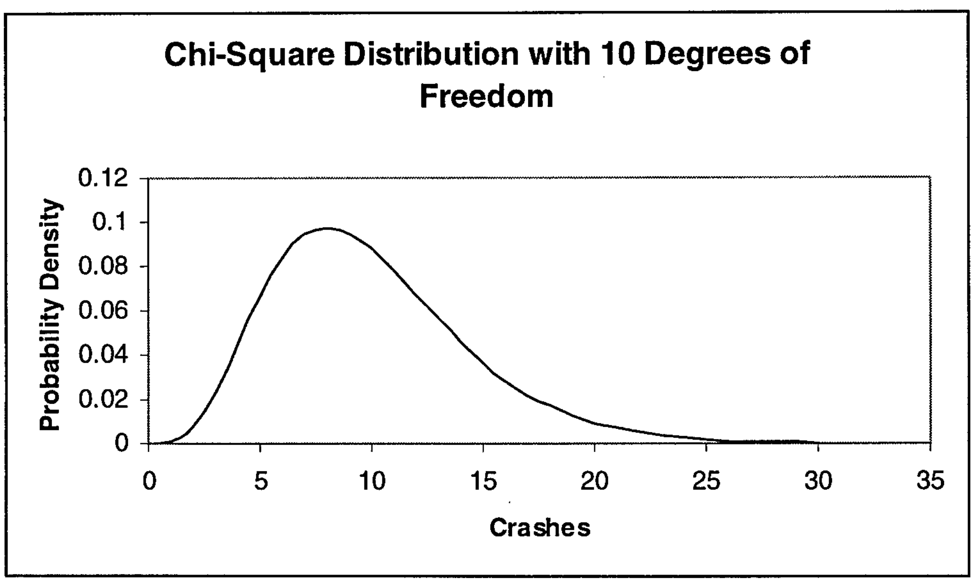


Figure 1.1: Chi-Square Distribution with 10 Degrees of Freedom

Note 95% of the distribution is less than 20.48 (This figure is found in the worksheet using a Bounds Table.) The lower bound on the crash rate is found by dividing 20.48 by twice the observation period (2 years). The lower bound is therefore $20.48 / (2 \times 2.0) = 5.12$

Statistically, the crash rate is expected to be between 0.81 and 3.25.

Growth in Traffic

Crashes Avoided under "current" traffic condition

Consider that VDOT planners are exploring the effect of widening the shoulders along Route 6. Crash records show that over the past 2 years, there has been a crash rate of 10 per year. Widening the shoulders would reduce the crash rate by 30% The new crash rate will be 70% of the original crash rate.

> Assuming constant traffic, if no improvement is made, the engineers expect that the crash rate will continue at 10 per year.
>
> If the shoulders are widened, VDOT engineers expect that the crash rate will reduce to 7 per year (70% of original crash rate), avoiding 3 crashes per year.

Crashes Avoided under a "future" traffic condition

Now, assume that traffic volumes are expected to double. If no improvement is made, the engineers expect that the present crash rate will double with twice the traffic (10 crashes per year × twice the traffic = 20 crashes per year)

If the shoulders are widened and traffic is doubled, VDOT planners would expect the new unimproved crash rate to increase to 14 per year (10 per year × twice the traffic × (1 - 0.30 Accident Reduction Factor)

Note that twice as many accidents are avoided when the improvement is made and traffic has doubled, but the observed crash rate (crashes per year) has increased.

The following worksheet will guide the user through crash risk reduction calculations. Instructions for using the worksheet and examples follow the worksheet.

1.2 Crash Risk Reduction Worksheet

Road Section: ______________________________ Date: _______
Analyst: ______________________________
Project No.: ______________________________

#1 Observation Start Date	#2 Observation End Date	#3 = #2- #1 Observation Period (years)

#4 n_P	#5 n_I

Crash Rate Calculations

#6a = **2.0** × #4 A Index	#7a Column A value	#8a = #7a / (**2.0** × #3) Lower PDO Bound	#9a = #4 / #3 r_P	#10a = (#4+ **1.0**) × **2.0** B index	#11a Column B Value	#12a = #11a / (**2.0** × #3) Upper PDO Bound
#6b = **2.0** × #5 A Index	#7b Column A value	#8b = #7b / (**2.0** × #3) Lower I&F Bound	#9b = #5 / #3 r_I	#10b = (#5+ **1.0**) × **2.0** B index	#11b Column B Value	#12b = #12b / (**2.0** × #3) Upper I&F Bound

Accident Reduction Factor Calculations

#13 **Improvement 1**	#14 **ARF$_P$**	#15 = #14	#16 **ARF$_I$**	#17 = #16
#18 **Improvement 2**	#19 **ARF$_P$**	#20 = (**1.0** – #14) × #19	#21 **ARF$_I$**	#22 = (**1.0** – #16) × #21
#23 **Improvement 3**	#24 **ARF$_P$**	#25= (**1.0**–#14) × (**1.0**–#19) × #21	#26 **ARF$_I$**	#27= (**1.0** – #16) × (**1.0** –#21) × #26
TOTAL IMPROVEMENT		#29 = #15 + #20 + #25 **ARF$_P$**		#30 = #17 + #22 + #27 **ARF$_I$**

Projected Crashes Avoided per Year

#31 = #8a × #29 Lower Bound PDO Crashes Avoided per Year	#32 = #9a × #29 Expected PDO Crashes Avoided per Year	#33 = #12a × #29 Upper Bound PDO Crashes Avoided per Year

#34 = #8b × #30 Lower Bound Injury/Fatality Crashes Avoided per Year	#35 = #9b × #30 Expected Injury/Fatality Crashes Avoided per Year	#36 = #12b × #29 Upper Bound Injury/Fatality Crashes Avoided per Year

#37 = #31 + #34 Lower Bound Total Crashes Avoided per Year	#38 = #32 + #35 Expected Total Crashes Avoided per Year	#39 = #33 + #36 Upper Bound Total Crashes Avoided per Year

1.3 How to Use the Crash Risk Reduction Worksheet

Observation dates
It is recommended that a period of 2 years (730 days) of observation data be used before a project is begun.

#1 Observation Start Date

Item #1 Observation start date
The observation start date is the beginning of the observation time period. The day, month, and year should be entered in this item.

#2 Observation End Date

Item #2 Observation end date
The observation end date is the end of the observation period. Likewise, day, month, and year should be entered in this item.

#3 = #2- #1 Observation Period (years)

Item #3 Observation period
The observation period is the amount of time between the observation start and end dates. It should entered in years (i.e. 1, 1.5, 2, etc.)

Accident Counts and Site Information
Crashes should be counted within a 300 ft. range from the center of an intersection and within project boundaries for road sections. The count range is known as the zone of influence (see Figure 1.2). The total crashes are divided into two categories: Property Damage Only (PDO) and Injury & Fatality.

Figure 1.2: Zone of Influence

#4 n_P

Item #4 n_p
n_p is the number of property damage only (**PDO**) accidents that have occurred within the zone of influence during the observation period. Any crash incident that did not result in injury will be entered in this item.

#5 n_i

Item #5 n_i
n_i is the number of injury/fatality accidents that have occurred within the zone of influence during the observation period.

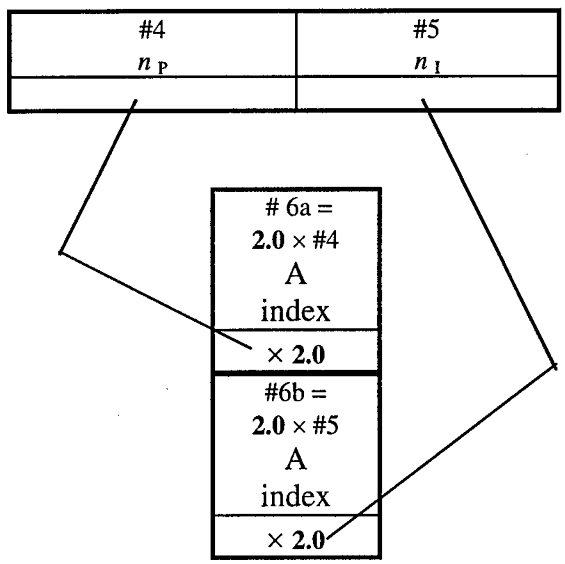
Confidence Interval and Crash Rate Calculations for Crash Occurrence per Year
Because the calculation of expected crash rate is a statistical estimate, confidence intervals for these estimates should be calculated to give a reasonable upper and lower bounds.

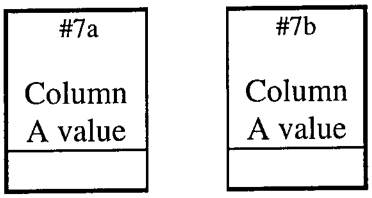
#6a = **2.0** × #4 A Index

#6b = **2.0** × #5 A index

Item #6 A index

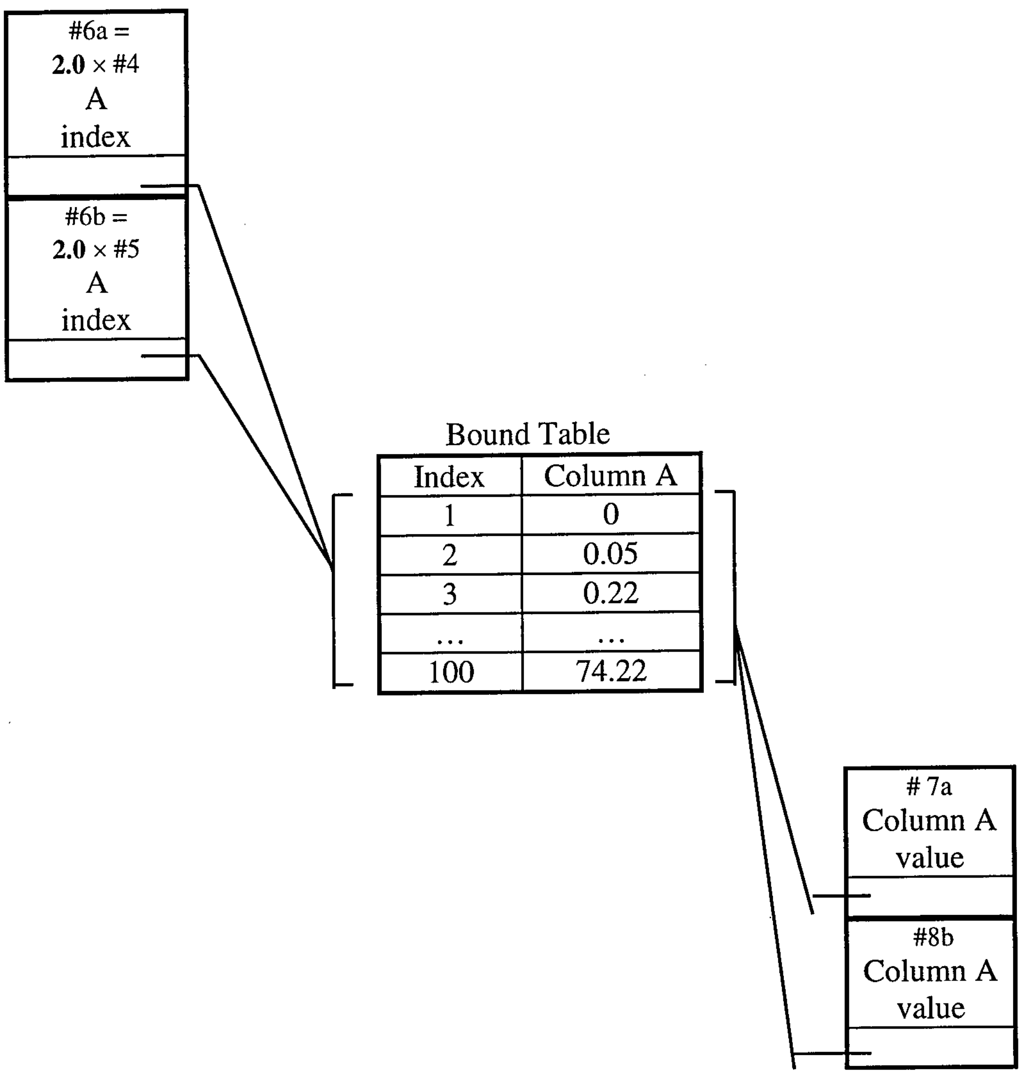
The A index is found in the Bounds Table (Table X). It represents the degrees of freedom for the distribution. For PDO calculations, it is equal to twice the number of PDO accidents n_p (Item #4). For Injury & Fatality calculations, it is equal to twice the number of Injury & Fatality crashes n_i (Item #5).





Item #7 Column A value

Column A value is taken from the Crash Bounds table. It is equal to the value in Column A next to the A index (Item #6). This represents the value which is exceeded by 95% of the observations.



Bound Table

Index	Column A
1	0
2	0.05
3	0.22
…	…
100	74.22

#8a = #7a / (**2.0** × #3) Lower PDO Bound		#8b = #7b / (**2.0** × #3) Lower I&F Bound

Item #8 Lower Bound
This is the lower bound for predicted Property Damage Only or Injury & Fatality crashes. It is calculated by dividing the Column A value (Item #8) by 2.0 and by the number of observation years (Item #3).

#9a = #4 / #3 r_P		#9b = #5 / #3 r_I

Item #9 r
Parameter r is the crash rate is expressed in crashes per year within a project section. Crash rates are computed separately for property damage only (PDO) and injury crashes. For PDO crashes, it is calculated by dividing n_p (Item #4) by the number of observation years (Item #3). For Injury & Fatality crashes, it is calculated by dividing n_i (Item #5) by the number of observation years (Item #3).

#10a = (#4+ **1.0**) × **2.0** B index		#10b = (#5+ **1.0**) × **2.0** B index

Item #10 B index
The B index is to be used in the bounds table. It represents the degrees of freedom for the upper bound. For PDO calculations, this is equal to one greater than the number of PDO crashes n_p (Item #4). For Injury & Fatality calculations, it is equal to one greater than the number of Injury & Fatality crashes (Item #5).

#11a Column B Value		#11b Column B Value

Item #11 Column B value
The Column B value is taken from the Crash Bounds table. It is equal to the value in Column B next to the B index (Item #11).

#12a = #11a / (**2.0** × #3) Upper PDO Bound

#12b = #11b / (**2.0** × #3) Upper I&F Bound

Item #12 Upper Bound
This is the upper bound for predicted PDO and Injury & Fatality crashes. It is calculated by dividing the Column A value (Item #12) by 2.0 and then multiplying by the number of observation years (Item #3).

Accident Reduction Factor (ARF) Calculations
Improvements are physical changes to the roadway which promote safety improvements. Select all appropriate improvements that apply to a specific project. There are spaces for three improvements; however, a fewer or greater number may be applied. List improvements from greatest to smallest ARF values.

#13 **Improvement 1**

Item #13, #18, #23 Improvement
Reference the Improvement with the index provided with the Improvement table (i.e., C1, C2, C3…) Only one Improvement should be listed in each item.

#14 **ARF_P**

Item #14, #19, #24 ARF_P
ARF_P is the accident reduction factor which refers to crashes involving property-damage only. Take this value from the ARF table referenced by the Improvement (Item #13, #18, or #23) index.

#16 **ARF_I**

Item #16, #21, #26 ARF_I
This accident reduction factor refers to crashes involving injuries and/or fatalities. Take this value from the ARF table referenced by the Improvement (Item #13, #18, or #23) number.

#27 = $(\mathbf{1.0} - \#16)(\mathbf{1.0} - \#21) \times \#26$

Item #17, #22, #27

Additional calculations in the chart lead to the final ARF values:

$$ARF = ARF_1 + (1-ARF_1)ARF_2 + (1-ARF_1)(1-ARF_2)ARF_3 + \ldots$$

where $ARF(i) \geq ARF\ (i + 1)$

#29 = #15 + #20 + #25 **ARF_P**	#30 = #17 + #22 + #27 **ARF_I**

Item #30, #31

The Total ARFs are summed according to the above equation.

Crashes Avoided Calculations

#33 = #9a × #29 Expected PDO Crashes Avoided per Year

Item # 33 Expected PDO Crashes Avoided per Year

Property damage only crashes avoided per year are computed as the multiplication of the PDO crash rate, the ARF, and the projected growth rate.

PDO Crashes Avoided per Year $= r_P \times ARF_P$

#35 = #9b × #29 Expected Injury/Fatality Crashes Avoided per Year

Item #35 Expected Injury & Fatality Crashes Avoided per Year

Likewise, Injury/fatality crashes avoided per year:

Injury/Fatality Crashes Avoided per Year $= r_I \times ARF$

#31 = #8a × #29 Lower Bound PDO Crashes Avoided per Year

#33 = #12a × #29 Upper Bound PDO Crashes Avoided per Year

#34 = #8b × #30 Lower Bound Injury & Fatality Crashes Avoided per Year

#36 = #12b × #29 Upper Bound Injury & Fatality Crashes Avoided per Year

Item #31, #33, #34, #36
To compute the upper and lower crash avoidance range, the crash rates are substituted with the computed bounds.

#38 = #32 + #35 Expected Total Crashes Avoided per Year

Item #38 Expected Total Crashes Avoided per Year
Total crash avoidance is the summation of the PDO and Injury Figures

Total Crashes Avoided per Year = PDO Crashes Avoided per Year
+ Injury & Fatality Crashed Avoided per Year

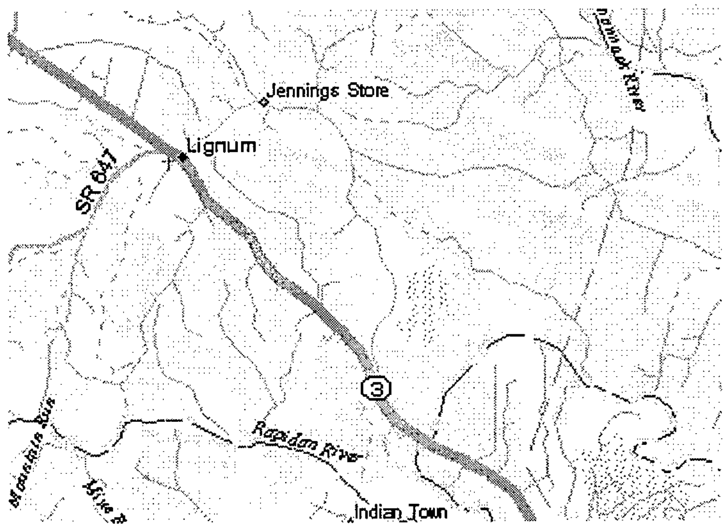
#37 = #31 + #34 Lower Bound Total Crashes Avoided per Year

#39 = #33 + #36 Upper Bound Total Crashes Avoided per Year

Item #37, #39 Lower and Upper Total Crashes Avoided per Year
Total crash avoidance for the bounds is also the summation of the PDO and Injury Figures

* Note that growth rates can be incorporated in future expected crash avoidance rates.

1.4 Example Project H



Project H: The Culpeper District would like to widen Route 3 from 2 to 4 lanes starting from the Orange County line west to east of Lignum. Additional project work would include alignment improvement.

Engineers have collected the following data through HTRIS:
Number of property-damage only crashes within the project bounds from 2/17/91-2/16/93: **4**
Number of injury/fatality crashes within the project bounds from 2/17/91-2/16/93: **12**

From this information, the following can be predicted for the improvement condition:

Total expected crashes per year avoided per year after improvement
Lower and upper bounds on total crashes per year after improvement

Expected property damage only crashes per year avoided per year after improvement

Lower and upper bounds on property damage only crashes per year after improvement

Expected Injury & Fatality crashes per year after improvement
Lower and upper bounds on total Injury and Fatality crashes per year after improvement

The Crash Reduction Worksheet for this example is given on the next page.

Example Crash Risk Reduction Calculations

#1 Observation Start Date
2/17/91

Item #1 Observation start date
The observation start date is the beginning of the observation time period. For Project H, data was gathered starting on February 17, 1991.

#2 Observation End Date
2/16/93

Item #2 Observation end date
The observation end date was February 16, 1993.

#3 = #2 - #1 Observation Period (years)
2.0

Item #3 Observation period
There were exactly 2 years of observation.

#4 n_P
4

Item #4 n_p
During the observation period, 4 crashes occurred which caused property damage only (PDO).

#5 n_I
12

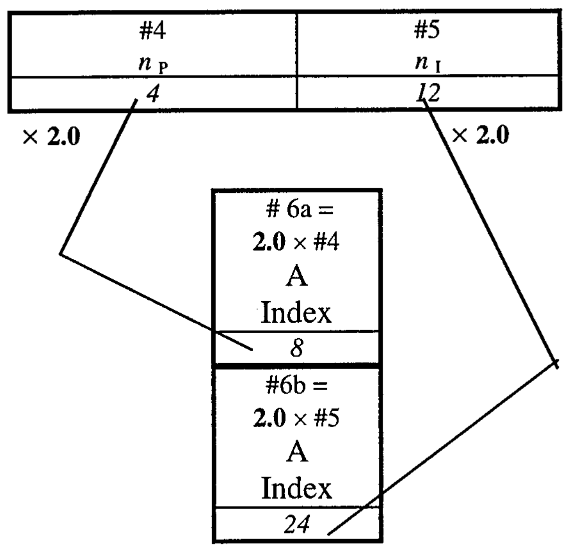
Item #5 n_i
During the observation period, 12 crashes occurred causing injuries or fatalities (I&F).

#6a = 2.0 × #4 A index	#6b = 2.0 × #5 A index
8	*24*

Item #6 A index

The A index is calculated as twice the number of crashes during the observation period. Therefore:

(PDO) Item #6a = 2.0 × 4 = 8
(I&F) Item #6b = 2.0 × 12 = 24



#7a Column A value	#7b Column A value
2.18	*12.41*

Item #7 Column A value

Column A value is taken from the Crash Bounds table. It is equal to the value in Column A next to the A index (Item #6).

Because the Bound Table does not include 24 in its index, the Column A value must be extrapolated:

1. Find the difference between the two closest index values:
   Index value 25 - Index value 20 (13.12 – 9.59)

2. Multiply this by the following fraction:

$$\frac{(\text{Desired index - Low index})}{(\text{High index - Low index})}$$

3. Add the index that is closest to and less than the desired index:
   Index 20 with value 9.59

$$\text{Column A value} = 9.59 + (13.12 - 9.59) \times \frac{(24-20)}{(25-20)} = 12.41$$

A Index

#7a = **2.0** × #4
A index
8

#7b = **2.0** × #5
A index
24

Bound Table

Index	**Column A**
1	0
2	0.05
3	0.22
4	0.48
5	0.83
6	1.24
7	1.69
8	2.18
9	2.7
10	3.25
11	3.82
12	4.4
13	5.01
14	5.63
15	6.27
16	6.91
17	7.56
18	8.23
19	8.91
20	9.59
25	13.12

#8a = #7a / (**2.0** × #3) Lower PDO Bound	#8b = #7b / (**2.0** × #3) Lower I&F Bound
0.55	*3.10*

Item #8 Lower Bound

This is the lower bound for predicted Property Damage Only or Injury/Fatality crashes.
It is calculated by dividing the Column A value (Item #8) by 2 and by the number of observation years (Item #3).

(PDO) Item #8a = 2.18 / (2 × 2) = 0.55

(I&F) Item #8b = 12.41 / (2 × 2) = 3.10

#9a = #4 / #3 r_P	#9b = #5 / #3 r_I
2.0	*6.0*

Item #9 r

Crash rates are computed separately for property damage only (PDO) and injury crashes.

(PDO) Item #9a = 4 crashes/ 2.0 years = 2.0 crashes per year

(I&F) Item #9b = 12 crashes/ 2.0 years = 6.0 crashes per year

#10a = (#4+ **1.0**) × **2.0** B index	#10b = (#5+ **1.0**) × **2.0** B index
10	*26*

Item #10 B index

The B index is to be used in the bounds table.

(PDO) Item #11a = (4 crashes +1.0) × 2.0 = 10

(I&F) Item #11b = (12 crashes +1.0) × 2.0 = 26

#11a Column B Value	#11b Column B Value
20.48	*41.92*

Item #11 Column B value

The Column B value is taken from the Crash Bounds table. It is equal to the value in Column B next to the B index (Item #10).

Again, #11b must be extrapolated:

$$\text{Column B value} = \text{Low index value} + (\text{High index value} - \text{Low index value}) \times \frac{(\text{Desired index} - \text{Low index})}{(\text{High index} - \text{Low index})}$$

$$\text{Column B value} = 40.65 + (46.98 - 40.65) \times \frac{(26-25)}{(30-25)} = 41.92$$

B Index

#11a = (#4+ **1.0**) × **2.0**
B index
10
#11b = (#5+ **1.0**) × **2.0**
B index
26

Bound Table

Index	**Column B**
1	5.02
2	7.38
3	9.35
4	11.14
5	12.38
6	14.45
7	16.01
8	17.53
9	19.02
10	20.48
11	21.92
12	23.34
13	24.74
14	26.12
15	27.49
16	28.85
17	30.19
18	31.53
19	32.85
20	34.17
25	40.65
30	46.98

#12a = #11a / (**2.0** × #3) Upper PDO Bound	#12b = #11b / (**2.0** × #3) Upper I&F Bound
5.20	*10.48*

Item #12 Upper Bound

This is the upper bound for predicted PDO or Injury/Fatality crashes. It is calculated by dividing the Column A value (Item #11) by 2.0 and then multiplying by the number of observation years (Item #3).

(PDO) Item #12a = 20.48 / (2.0 × 2.0) = 5.12

(I&F) Item #12b = 41.92 / (2.0 × 2.0) = 10.48

#13
Improvement 1
C4

Item #13, #18, #23 Improvement
In Project H, the road is to be widened from 2 to 4 lanes with additional alignment improvement. This coincides with Improvement C4 from the 1994 Virginia ARFs Table: Widen Pavement and Improve Alignment.

Table 1.1 ARFs for Virginia (VDOT, September 94)

	Improvement	**ARF_I** Injury	**ARF_P** PDO
C4	Widen Pavement and Improve Alignment	0.87	0.73

#14
ARF_P
0.73

Item #14, #19, #24 ARF_P ARF_P is the accident reduction factor which refers to crashes involving property-damage only. Take this value from the ARF table referenced by the Improvement C4.

#16
ARF_I
0.87

Item #16, #21, #26 ARF_I
This accident reduction factor refers to crashes involving injuries and/or fatalities. Take this value from the ARF table referenced by the Improvement C14.

#27 = (**1.0** - #16)(**1.0** - #21) × #26
--

Item #17, #22, #27
Additional calculations are not necessary as no other Improvements apply.

#29 = #15 + #20 + #25 **ARF_P**
0.73

#30 = #17 + #22 + #27 **ARF_I**
0.87

Item #29, #30
The Total ARFs are summed.

#33 = #9a × #29 Expected PDO Crashes Avoided per Year
1.46

Item # 33 Expected PDO Crashes Avoided per Year
Property damage only crashes avoided per year are computed as the multiplication of the PDO crash rate, the ARF, and the projected growth rate.

$$\text{PDO Crashes Avoided per Year} = r_P \times ARF_P = 2.0 \times 0.73 = 1.46$$

#35 = #9b × #29 Expected Injury & Fatality Crashes Avoided per Year
5.22

Item #35 Expected Injury & Fatality Crashes Avoided per Year
Likewise, Injury/fatality crashes avoided per year:

$$\text{Injury/Fatality Crashes Avoided per Year} = r_I \times ARF = 6.0 \times 0.87 = 5.22$$

#31 = #8a × #29 Lower Bound PDO Crashes Avoided per Year	#33 = #12a × #29 Upper Bound PDO Crashes Avoided per Year	#34 = #8b × #30 Lower Bound Injury & Fatality Crashes Avoided per Year	#36 = #12b × #29 Upper Bound Injury & Fatality Crashes Avoided per Year
0.40	*3.74*	*2.70*	*9.12*

Item #31, #33, #34, #36
To compute the upper and lower crash avoidance range, the crash rates are substituted with the computed bounds.

(PDO) Item #31 = Lower PDO Bound × ARF_P
$= 0.55 \times 0.73 = 0.40$
Item #33 = Upper PDO Bound × ARF_P
$= 5.12 \times 0.73 = 3.74$

(I&F) Item #34 = Lower I&F Bound × ARF_I
$= 3.10 \times 0.87 = 2.70$
Item #33 = Upper I&F Bound × ARF_I
$= 10.48 \times 0.87 = 9.12$

#38 = #32 + #35 Expected Total Crashes Avoided per Year
6.68

Item #38 Expected Total Crashes Avoided per Year
Total crash avoidance is the summation of the PDO and Injury Figures

Total Crashes Avoided per Year = PDO Crashes Avoided per Year + Injury/Fatality Crashed Avoided per Year

Item #38 = 1.46 + 5.22 = 6.68

#37 = #31 + #34 Lower Bound Total Crashes Avoided per Year	#39 = #33 + #36 Upper Bound Total Crashes Avoided per Year
3.10	*12.86*

Item #37, #39 Lower and Upper Total Crashes Avoided per Year
Total crash avoidance for the bounds is also the summation of the PDO and Injury Figures

Item #37 = 0.40 + 2.70 = 3.10
Item #39 = 3.74 + 9.12 = 12.86

Project H: Crash Risk Reduction Worksheet

Road Section: *Route 3 4-lane widening and alignment improvement from Orange County line west to east of Lignum Culpeper Residency* Date: *6/27/94*

Analyst: *I.N. Gineer*

Project No.: 0003-023-104

#1 Observation Start Date	#2 Observation End Date	#3 = #2- #1 Observation Period (years)
2/17/91	*2/16/93*	*2.0*

#4 n_P	#5 n_I
4	*12*

Crash Rate Calculations

#6a = **2.0** × #4 A index	#7a Column A value	#8a = #7a / (**2.0** × #3) Lower PDO Bound	#9a = #4 / #3 r_P	#10a = (#4+ **1.0**) × **2.0** B index	#11a Column B Value	#12a = #11a / (**2.0** × #3) Upper PDO Bound
8	*2.18*	*0.55*	*2.0*	*10*	*20.48*	*5.12*
#6b = **2.0** × #5 A index	#7b Column A value	#8b = #7b / (**2.0** × #3) Lower I&F Bound	#9b = #5 / #3 r_I	#10b = (#5+ **1.0**) × **2.0** B index	#11b Column B Value	#12b = #12b / (**2.0** × #3) Upper I&F Bound
24	*12.41*	*3.10*	*6.0*	*26*	*41.92*	*10.48*

Accident Reduction Factor Calculations

#13 **Improvement 1**	#14 **ARF$_P$**	#15 = #14	#16 **ARF$_I$**	#17 = #16
C4	*0.73*	*0.73*	*0.87*	*0.87*
#18 **Improvement 2**	#19 **ARF$_P$**	#20 = (**1.0** – #14) × #19	#21 **ARF$_I$**	#22 = (**1.0** – #16) × #21
#23 **Improvement 3**	#24 **ARF$_P$**	#25= (**1.0**–#14) × (**1.0**–#19) × #21	#26 **ARF$_I$**	#27= (**1.0** – #16) × (**1.0** –#21) × #26
TOTAL IMPROVEMENT		#29 = #15 + #20 + #25 **ARF$_P$**		#30 = #17 + #22 + #27 **ARF$_I$**
C4		*0.73*		*0.87*

Projected Crashes Avoided per Year

#31 = #8a × #29 Lower Bound PDO Crashes Avoided per Year	#32 = #9a × #29 Expected PDO Crashes Avoided per Year	#33 = #12a × #29 Upper Bound PDO Crashes Avoided per Year
0.40	*1.46*	*3.74*

#34 = #8b × #30 Lower Bound Injury/Fatality Crashes Avoided per Year	#35 = #9b × #30 Expected Injury/Fatality Crashes Avoided per Year	#36 = #12b × #29 Upper Bound Injury/Fatality Crashes Avoided per Year
2.70	*5.22*	*9.12*

#37 = #31 + #34 Lower Bound Total Crashes Avoided per Year	#38 = #32 + #35 Expected Total Crashes Avoided per Year	#39 = #33 + #36 Upper Bound Total Crashes Avoided per Year
3.10	*6.68*	*12.86*

From the analysis above, the improvement project is estimated to prevent 6.68 crashes per year. The lower bound (95% confidence) on this estimate is 3.1 crashes avoided per year, the upper bound is 12.86 crashes avoided per year.

CHAPTER 2
PERFORMANCE ANALYSIS

2.1 Overview

The objective for the performance modeling module is to provide a feasible and accurate means of evaluating the performance of under "without" and "with" project conditions. Given the planning-level orientation of this comparison, performance will be quantified *by travel time saved per peak-hour* under "with" project conditions as compared to "without" project conditions. To avoid confusion about the effects of the improvement project and those of a change in Daily Traffic, the following computations assume a constant Daily Traffic. It is suggested to use the Daily Traffic of the time period (year) immediately preceding project implementation, if possible. However, any other year that seems more appropriate for the particular analysis can be used as well.

The worksheet gives different approaches to determining the (anticipated) performance improvement, i.e. the total travel-time saved per peak-hour. Vehicle speeds, Levels of Service, or travel times per vehicle serve as basis for the calculations.

Both the Daily Traffic (Daily Vehicle Miles Traveled for road sections (DVMT, equal to the number of vehicles times the length of the section, Daily Entering Vehicles (DEV) for intersections) and road inventory information (e.g., 4-lane divided highway) are available through HTRIS. Further data, however, is only collected through more detailed site studies and simulations, which generally occur once some type of commitment to site improvement has been made.

The following worksheet will guide the user through performance improvement calculations. Instructions for using the worksheet and examples follow the worksheet.

2.2 Performance Improvement Worksheet

Road Section: ____ Date: _______
Analyst: ______________________________________
Project No.: __________________________________

For Road Sections, fill in #1 - #5, and either #6 - #10, #11 - #15, or #16 - #17.
For Intersections, fill in #1 - #4, and either #11 - #15, or #16 - #17.

#1 Daily Traffic for Year of Comparison	#2 = **0.8** × #1	#3 = **1.2** × #1	#4 Fraction of Daily Traffic during Peak-Hour	#5 Length of Section (miles)

(Road Sections Only)

#6 Avg. Speed (mph) Without Project Implementation during Peak-Hour *(most likely)*	#7 Avg. Speed (mph) With Project Implementation during Peak-Hour *(most likely)*	#8 = (#5 / #6) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) Without Project *(most likely)*	#9 = (#5 / #7) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) With Projec *(most likely)*
#6a *(lower bound)*	#7a *(lower bound)*	#8a = (#5 / #6b) × 60 × #2 × #4 *(lower bound)*	#9a = (#5 / #7b) × 60 × #2 × #4 *(lower bound)*
#6b *(upper bound)*	#7b *(upper bound)*	#8b = (#5 / #6a) × 60 × #3 × #4 *(upper bound)*	#9b = (#5 / #7a) × 60 × #3 × #4 *(upper bound)*

#10 = #8 - #9 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*
#10a = #8a - #9a *(lower bound)*
#10b = #8b - #9b *(upper bound)*

OR (Road Sections and Intersections)

#11 Avg. Travel Time Without Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#12 Avg. Travel Time With Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#13 = #11 × #1 × #4 Avg. Total Travel Time Without Project per Peak-Hour (minutes/peak_h) *(most likely)*	#14 = #12 × #1 × #4 Avg. Total Travel Time With Project per Peak-Hour (minutes/peak_h) *(most likely)*
#11a = #6 × **0.8** *(lower bound)*	#12a = #12 × **0.8** *(lower bound)*	#13a = #11a × #2 × #4 *(lower bound)*	#14a = #12a × #2 × #4 *(lower bound)*
#11b = #11 × **1.2** *(upper bound)*	#12b = #12 × **1.2** *(upper bound)*	#13b = #11b × #3 × #4 *(upper bound)*	#14b = #12b × #3 × #4 *(upper bound)*

#15 = #13 - #14 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*
#15a = #13a - #14a *(lower bound)*
#15b = #13b - #14b *(upper bound)*

OR (Road Sections and Intersections)

#16 Avg. Travel Time Saved Due to Project Implementation during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#17 $= \#16 \times \#1 \times \#4$ Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*
#16a $= \#16 \times \mathbf{0.8}$ *(lower bound)*	#17a $= \#16a \times \#2 \times \#4$ *(lower bound)*
#16b $= \#16 \times \mathbf{1.2}$ *(upper bound)*	#17b $= \#16b \times \#3 \times \#4$ *(upper bound)*

2.3 How to Use the Performance Improvement Worksheet

#1 Daily Traffic for Year of Comparison

Item #1 Daily Traffic for Year of Comparison

For intersections, the Daily Traffic is the number of Daily Entering Vehicles (DEV). For road sections, the Daily Traffic is the number of Daily Vehicle Miles Traveled (DVMT).

#2 = **0.8** × #1	#3 = **1.2** × #1

Item #2 and Item #3 Daily Traffic for Year of Comparison (lower bound and upper bound)

In Items #2 and #3, a lower (#2) and an upper (#3) bound for the Daily Traffic (Item #1) is calculated, assuming that the Daily Traffic is not known exactly. A range of ±20% is suggested here, but any other number that appears more appropriate may be used as well.

#4 Fraction of Daily Traffic during Peak-Hour

Item #4 Fraction of Daily Traffic during Peak-Hour

The Fraction of Daily Traffic during Peak-Hour is the percentage (expressed as a decimal number between "0" and "1") of the Daily Traffic that passes through the site during the peak-hour. A rule-of-thumb value is "0.1" (corresponding to 10%).

#5 Length of Section (miles)

Item #5 Length of Section (miles)

The length of the section applies to road sections only, and should be entered in miles.

#6 Avg. Speed (mph) Without Project Implementation during Peak-Hour *(most likely)*	#7 Avg. Speed (mph) With Project Implementation during Peak-Hour *(most likely)*

Item #6/a/b and Item #7/a/b Avg. Speed Without (With) Project Implementation during Peak-Hour

Speed Without (With) Project Implementation during Peak-Hour denote those average speeds in miles per hour that have either been measured or estimated for the site, under the current conditions, or assuming the implementation of the project, respectively.

Speeds may not be known to the exact mile per hour, and items #6a/b and #7a/b can be used to perform computations based on lower and upper bounds of the speeds.

Items #6/a/b and #7/a/b apply to road-sections only, not intersections.

<u>A Note on Obtaining Performance-Related Data through Estimation</u>

<u>Direct Point Estimation of Performance Indicators</u>

In direct point estimation, a single estimate (the point estimate, i.e. the expected value) of the desired information (average speed, travel time, etc.) is obtained from, for example, a traffic or construction engineer.

<u>Range Estimation</u>

Range estimation involves assessments from the engineers, but made with "maximum", "minimum", and "most likely" values rather than a point estimate. This is a more robust approach that allows for the uncertainty of the estimates, while still providing useful quantitative information.

Typical questions used for range estimation are:

1. What is the most likely travel time with (without) the project? or What is the most likely average speed with (without) the project?

2. What is the "best case" travel time with (without) the project? or What is the "best case" average speed with (without) the project? (upper bound)

3. What is the "worst case" travel time with (without) the project? or What is the "worst case" average speed with (without) the project? (lower bound)

Indirect Estimation

If direct speed measurements or estimates are not available, approximate speeds can be derived from the following table, based on a (presumably known) Level of Service (see Table 2.2).

Table 2.1: Speeds for different Road Sections and different Levels of Service (LOS) (Garber and Hoel, 1997)

	Basic Freeway Segment				2-Lane, 2-Way Rural Highway
LOS	Free-Flow Speed = 70mph	Free-Flow Speed = 65mph	Free-Flow Speed = 60mph	Free-Flow Speed = 55mph	
A	> 70.0	> 65.0	> 60.0	> 55.0	60.0
B	>70.0	> 65.0	> 60.0	> 55.0	55.0
C	> 68.5	> 64.5	> 60.0	> 55.0	> 52.0
D	> 63.0	> 61.0	> 57.0	> 54.8	50.0
E	> 59.0	> 54.5	> 51.5	> 49.0	< 50.0
F	var.	var.	var.	var.	n/a

#8 = (#5 / #6) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) Without Project *(most likely)*	#9 = (#5 / #7) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) With Project *(most likely)*

Item #8 and Item #9 Avg. Travel Time (minutes/peak_h) Without (With) Project (most likely)

The most likely Average Travel Time in minutes per peak_h without (or with) the project is based on the "most likely" estimates of speeds and Daily Traffic.

In Items #8a/b and #9a/b, the lower and upper bounds for Travel Time Without or With Project can be calculated with the information on the lower and upper bounds for speeds and Daily Traffic.

A Note on Obtaining Performance-Related Data

Stop Watch Approach

Travel-time data can be gathered by using the "stop-watch approach", i.e. by traversing a given site several times and recording the time it takes to travel through the site.

#10 = #8 - #9 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*

Item #10 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h)
With the previously computed Average Travel Times Without and With Project, the Average Travel Time Saved in minutes per Peak-Hour can be determined.

If range information has been used in the previous steps, Items #10a/b can be used to compute lower and upper ranges for the travel time saved.

#11 Avg. Travel Time Without Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#12 Avg. Travel Time With Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*

Item #11 and Item #12 Avg. Travel Time Without (With) Project during Peak-Hour (most likely)
Average Travel Time Without (With) Project during Peak-Hour allow the use of a measured or estimated travel time per vehicle in minutes without and with project implementation.

If Items #11 and #12 are used for *road-sections*, then the "travel time" is equal to the time that a vehicle needs to traverse the site in full length. For *intersections*, the "travel time" is equal to the time that a vehicle has to wait in the queue at the intersection, since the actual intersection can usually be traversed in a short time.

If direct measurements or estimates for the time spent in the queue at an intersection are not available, but the Level of Service is known, then the following table can provide some information.

Table 2.2: Time in Queue (sec.) for Signalized Intersections at different Levels of Service (Garber and Hoel, 1997)

LOS	Signalized Intersection
A	≤ 5.0
B	5.0…15.0
C	15.0…25.0
D	25.0…40.0
E	40.0…60.0
F	> 60.0

In Items #11a/b and #12a/b, lower and upper bounds for the Travel Time Without or With Project during Peak-Hour can be computed. A range of ±20% is suggested to be used, but another appropriate confidence rate can be selected.

#13 = #11 × #1 × #4 Avg. Total Travel Time Without Project per Peak-Hour (minutes/peak_h) *(most likely)*	#14 = #12 × #1 × #4 Avg. Total Travel Time With Project per Peak-Hour (minutes/peak_h) *(most likely)*

#15 = #13 - #14 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*

Item #13 and Item #14 Avg. Total Travel Time Without (With) Project per Peak-Hour (minutes/peak_h) (most likely)
Item #15 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) (most likely)
The Average Total Travel Times Without and With Project per Peak-Hour are calculated based on the previously provided travel time information for individual vehicles and the Daily Traffic. Once the Total Travel Times "Without" and "With" Project (#13, #14) are known, the difference can be taken to establish the Total Travel Time Saved (#15).

In Items #13a/b, #14a/b and #15a/b, the range information that is possibly available on travel times without and with project and Daily Traffic can be used to compute lower and upper bounds for total travel times without or with project and finally lower and upper bounds for the Total Travel Time Saved per Peak-Hour.

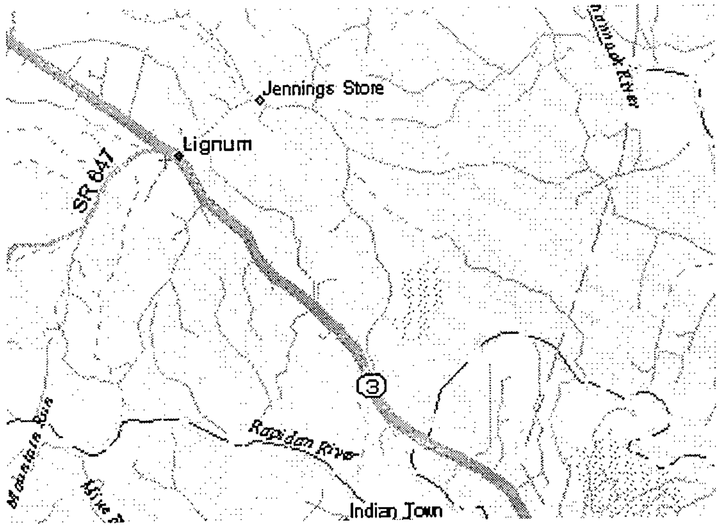
#16 Avg. Travel Time Saved Due to Project Implementation during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#17 = #16 × #1 × #4 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*

Item #16 Avg. Travel Time Saved Due to Project Implementation during Peak-Hour (per Vehicle) (minutes/peak_h) (most likely),
Item #17 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) (most likely)
If a direct estimate of the Average Travel Time Saved Due to Project Implementation during Peak-Hour exists on a per-vehicle basis (in minutes), then the Average Total Travel Time Saved per Peak-Hour is straightforward to calculate, according to the formula for item #17.

Items #16a/b and #17a/b can be used to calculate a range for the total travel time saved, rather than just using a point estimate, using range information on the travel time saved per vehicle and the Daily Traffic.

If items #16, #16a/b and #17, #17a/b are used for *road-sections*, then "travel time" refers to the time that a vehicle needs to traverse the site in full length. For *intersections*, "travel time" refers to the time that a vehicle has to wait in the queue at the intersection.

2.4 Example Project H



Project H: The Culpeper District would like to widen Route 3 from 2 to 4 lanes starting from the Orange County line west to east of Lignum. Additional project work would include alignment improvement.

The following data have been collected:

Project length (miles):	**2.2**
DVMT in the two years preceding construction start (02/17/93):	**13086**
Average Speed during Peak-Hour Without Project (mph) (most likely):	**58**
Average Speed during Peak-Hour With Project (mph) (most likely):	**64**

Example Performance Calculations

#1 Daily Traffic for Year of Comparison
5650

Item #1 Daily Traffic for Year of Comparison
The Daily Traffic equals the quotient of DVMT and section length (in miles):

Daily Traffic = DVMT / length = 13086 / 2.2 = 5650

#2 = **0.8** × #1	#3 = **1.2** × #1
4520	*6780*

Item #2 and Item #3 Daily Traffic for Year of Comparison (lower bound and upper bound)
Lower and upper bounds for the Daily Traffic are found by multiplying the number in Item #1 by 0.8, or 1.2, respectively.

Lower bound = 0.8 × 5650 = 4520
Upper bound = 1.2 × 5650 = 6780

#4 Fraction of Daily Traffic during Peak-Hour
0.1

Item #4 Fraction of Daily Traffic during Peak-Hour
For a lack of more specific information, it is assumed that 10% of the Daily Traffic occur during the peak-hour.

#5 Length of Section (miles)
2.2

Item #5 Length of Section (miles)
The length of the section is 2.2 miles.

#6 Avg. Speed (mph) Without Project Implementation during Peak-Hour *(most likely)*	#7 Avg. Speed (mph) With Project Implementation during Peak-Hour *(most likely)*
58	*64*

Item #6/a/b and Item #7/a/b Avg. Speed Without (With) Project Implementation during Peak-Hour

The most likely estimates of the average speed without, or with, project implementation are 58 mph and 64 mph, respectively. In this example, it was decided that the lower and upper bounds for the speeds can be found by subtracting or adding, respectively, 2 mph to the "most likely" speeds.

#8 $= (\#5 / \#6) \times 60 \times \#1 \times \#4$ Avg. Travel Time (minutes/peak_h) Without Project *(most likely)*	#9 $= (\#5 / \#7) \times 60 \times \#1 \times \#4$ Avg. Travel Time (minutes/peak_h) With Project *(most likely)*

Item #8 and Item #9 Avg. Travel Time (minutes/peak_h) Without (With) Project (most likely)

The average travel time during peak-hour can be found using the following calculations:

Without Project:

Most likely: $(2.2 / 58) \times 60 \times 5650 \times 0.1 = 1286$ minutes per peak-hour
(The factor 60 converts units from hours to minutes)

Lower bound: $(2.2 / 60) \times 60 \times 4520 \times 0.1 = 994$ minutes per peak-hour
(The travel time will be minimal using the *upper* bound for the speed and the *lower* bound for the Daily Traffic.)

Upper bound: $(2.2 / 56) \times 60 \times 6780 \times 0.1 = 1598$ minutes per peak-hour
(The travel time will be maximal using the *lower* bound for the speed and the *upper* bound for the Daily Traffic.)

With Project:

Most likely: $(2.2 / 64) \times 60 \times 5650 \times 0.1 = 1165$ minutes per peak-hour

Lower bound: $(2.2 / 66) \times 60 \times 4520 \times 0.1 = 904$ minutes per peak-hour

Upper bound: $(2.2 / 62) \times 60 \times 6780 \times 0.1 = 1444$ minutes per peak-hour

#10 = #8 - #9 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*

Item #10 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h)

The travel time saved is found by subtracting the "with" project travel time from the "without" project travel time, separately for the most likely value, the lower bound and the upper bound.

Most Likely: 1286 – 1165 = 121 minutes per peak-h
Lower bound: 994 – 904 = 90 minutes per peak-h
Upper bound: 1598 – 1444 = 154 minutes per peak-h

Project H: Performance Improvement Worksheet

Road Section: *Route 3: Route 3 4-lane widening from Orange County line west to east of Lignum - Culpeper Residency* Date: *2/17/93*
Analyst: *I.N. Gineer*
Project No.: *0003-023-104, Pe103, RW203, C503*

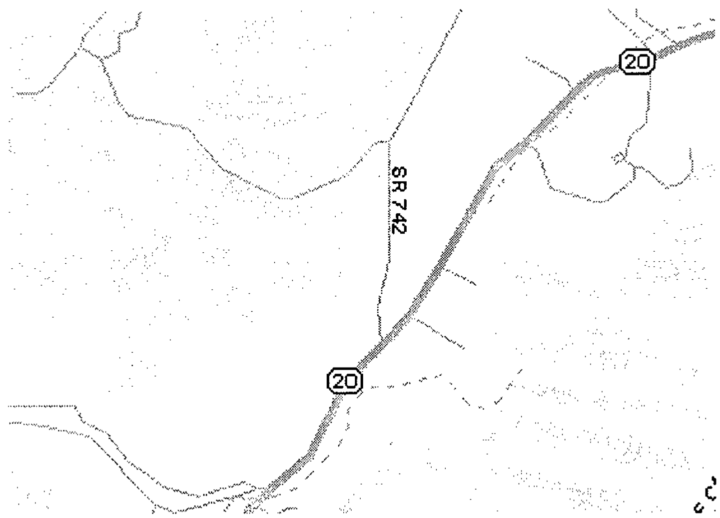
[Note: Only those Items that are applicable to the calculations are shown.]

#1 Daily Traffic for Year of Comparison	#2 = **0.8** × #1	#3 = **1.2** × #1	#4 Fraction of Daily Traffic during Peak-Hour	#5 Length of Section (miles)
5650	*4520*	*6780*	*0.1*	2.2

#6 Avg. Speed (mph) Without Project Implementation during Peak-Hour *(most likely)*	#7 Avg. Speed (mph) With Project Implementation during Peak-Hour *(most likely)*	#8 = (#5 / #6) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) Without Project *(most likely)*	#9 = (#5 / #7) × 60 × #1 × #4 Avg. Travel Time (minutes/peak_h) With Project *(most likely)*
58	*64*	*1286*	*1165*
#6a *(lower bound)*	#7a *(lower bound)*	#8a = (#5 / #6b) × 60 × #2 × #4 *(lower bound)*	#9a = (#5 / #7b) × 60 × #2 × #4 *(lower bound)*
56	*62*	*994*	*904*
#6b *(upper bound)*	#7b *(upper bound)*	#8b = (#5 / #6a) × 60 × #3 × #4 *(upper bound)*	#9b = (#5 / #7a) × 60 × #3 × #4 *(upper bound)*
60	*66*	*1598*	*1444*

#10 = #8 - #9 Avg. Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*
121
#10a = #8a - #9a *(lower bound)*
90
#10b = #8b - #9b *(upper bound)*
154

2.5 Example Project G



Project G: The Culpeper District considers improving the intersection between Route 20 and Route 742; this work includes a realignment of Route 20.

The following data have been gathered:

Project length (miles):	**n/a**
DEV (= Daily Traffic) in the two years preceding construction start (07/20/92):	**5609**
Average Time in Queue during Peak-Hour Without Project (per vehicle) (most likely):	**1 min.**
Average Time in Queue during Peak-Hour With Project (per vehicle) (most likely):	**0.75 min. (=45 sec.)**

Example Performance Calculations

#1 Daily Traffic for Year of Comparison
5609

Item #1 Daily Traffic for Year of Comparison
The Daily Traffic is the DEV number: 5609

#2 = **0.8** × #1	#3 = **1.2** × #1
4487	*6731*

Item #2 and Item #3 Daily Traffic for Year of Comparison (lower bound and upper bound)
Lower and upper bounds for the Daily Traffic are found by multiplying the number in Item #1 by 0.8, or 1.2, respectively.

Lower bound = 0.8 × 5609 = 4487
Upper bound = 1.2 × 5609 = 6731

#4 Fraction of Daily Traffic during Peak-Hour
0.1

Item #4 Fraction of Daily Traffic during Peak-Hour
For a lack of more specific information, it is assumed that 10% of the Daily Traffic occur during the peak-hour.

#5 Length of Section (miles)
--

Item #5 Length of Section (miles)
Item #5 is not applicable to intersections.

#11 Avg. Travel Time Without Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#12 Avg. Travel Time With Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*
1.0	*0.75*

Item #11 and Item #12 Avg. Travel Time Without (With) Project during Peak-Hour (most likely)

The most likely Average Travel Time Without (With) Project during Peak-Hour was estimated to be 1 minute under the current conditions (without project) and 45 seconds (0.75 minutes) with the project in place. This is the time that a vehicle spends waiting before it can traverse the intersection (on average). An error range of ±20% is used here to compute the lower and upper bounds:

Without:
Lower bound: $1.0 \times 0.8 = 0.8$ minutes
Upper bound: $1.0 \times 1.2 = 1.2$ minutes

With:
Lower bound: $0.75 \times 0.8 = 0.6$ minutes
Upper bound: $0.75 \times 1.2 = 0.9$ minutes

#13 = #11 × #1 × #4 Avg. Total Travel Time Without Project per Peak-Hour (minutes/peak_h) *(most likely)*	#14 = #12 × #1 × #4 Avg. Total Travel Time With Project per Peak-Hour (minutes/peak_h) *(most likely)*

#15 = #13 - #14 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*

Item #13 and Item #14 Avg. Total Travel Time Without (With) Project per Peak-Hour (minutes/peak_h) (most likely)

Item #15 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) (most likely)

The Average Total Travel Times Without and With Project per Peak-Hour are found by multiplying the individual travel times from Items #11 and #12 by the number of vehicles that use the intersection during the peak-hour (i.e. 10% of all Daily Entering Vehicles):

Without (Item #13):
Most likely: $1.0 \times 5609 \times 0.1 = 561$ minutes per peak-hour
Lower bound: $0.8 \times 4487 \times 0.1 = 359$ minutes per peak-hour
Upper bound: $1.2 \times 6731 \times 0.1 = 808$ minutes per peak-hour

With (Item #14):
Most likely: $0.75 \times 5609 \times 0.1 = 421$ minutes per peak-hour
Lower bound: $0.6 \times 4487 \times 0.1 = 269$ minutes per peak-hour
Upper bound: $0.9 \times 6731 \times 0.1 = 606$ minutes per peak-hour

The Average Total Travel Time Saved during Peak-Hour is found as the difference of the total "without" and "with" travel times:

Most likely: $561 - 421 = 140$ minutes per peak-hour
Lower bound: $359 - 269 = 90$ minutes per peak-hour
Upper bound: $808 - 606 = 202$ minutes per peak-hour

Project G: Performance Improvement Worksheet

Road Section: *At route 20 at Intersection Route 742 (Avon St. extended) Realign Route 20 and improve intersection* Date: *7/20/92*
Analyst: *I.N. Gineer*
Project No.: *0020-002-s17, pe101, rw201, c501*

[Note: Only those Items which are applicable to the calculations are shown.]

#1 Daily Traffic for Year of Comparison	#2 = **0.8** × #1	#3 = **1.2** × #1	#4 Fraction of Daily Traffic during Peak-Hour	#5 Length of Section (miles)
5609	*4487*	*6731*	*0.1*	--

#11 Avg. Travel Time Without Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#12 Avg. Travel Time With Project during Peak-Hour (per vehicle) (minutes/peak_h) *(most likely)*	#13 = #11 × #1 × #4 Avg. Total Travel Time Without Project per Peak-Hour (minutes/peak_h) *(most likely)*	#14 = #12 × #1 × #4 Avg. Total Travel Time With Project per Peak-Hour (minutes/peak_h) *(most likely)*
1.0	*0.75*	*561*	*421*
#11a = #6 × **0.8** *(lower bound)*	#12a = #12 × **0.8** *(lower bound)*	#13a = #11a × #2 × #4 *(lower bound)*	#14a = #12a × #2 × #4 *(lower bound)*
0.8	*0.6*	*359*	*269*
#11b = #11 × **1.2** *(upper bound)*	#12b = #12 × **1.2** *(upper bound)*	#13b = #11b × #3 × #4 *(upper bound)*	#14b = #12b × #3 × #4 *(upper bound)*
1.2	*0.9*	*808*	*606*

#15 = #13 - #14 Avg. Total Travel Time Saved per Peak-Hour (minutes/peak_h) *(most likely)*
140
#15a = #13a - #14a *(lower bound)*
90
#15b = #13b - #14b *(upper bound)*
202

CHAPTER 3
COST ANALYSIS

3.1 Overview

Cost is a measure of the present dollar value of funds required for an improvement project. Total project cost is defined herein as the sum of the preliminary engineering, right of way, and construction costs. Cost estimations at the planning level are based on past projects and cost per mile averages. It must be noted that at the time of budget allocations, many project specifications are incomplete and contractor bids are uncertain. The tables provided here serve as guidelines and additional cost planning information should be obtained if possible.

This chapter contains general guidelines for cost estimates used for road section, intersection, bridge, and railroad overpass improvement projects. For planning purposes, these estimates are based on a cost per mile. Note that the following references are used as a starting point, for much of the cost estimations are based upon project-specific considerations.

Project Cost = Preliminary Engineering Cost + Construction Cost + Right of Way Cost

The following worksheet will guide the user through crash risk reduction calculations. Instructions for using the worksheet and examples follow the worksheet.

3.2 Project Cost Worksheet

Road Section: ______________________________ Date: ________
Analyst: ______________________________
Project No.: ______________________________

Road Section

#1 Typical Section	#2 Average Improvement Cost/Mile ($/mile)	#3 Length (mile)	#4 = #2 × #3 Construction Costs ($)	#5 CN Adjustment	#6 = #4 + #5 Total CN ($)

#7 Land Designation	#8 Percentage RW	#9 = #6 × #8 RW Cost ($)	#10 RW Adjustment	#11= #9 + #10 Total RW

#12 = #6 × 0.15 PE Cost ($)	#13 PE Adjustment	#14 #12 + #13 Total PE

#15 = #6 + #11 + #14 Total Cost

Intersection

#16 Improvement 1	#17 Flat Cost	#18 Average Improvement Cost/Mile	#19 Length (mile)	#20 = #17 + #18 × #19 Cost ($)	#21 Adjustment	#22 = #20 + #21 Total Cost ($)

#23 Improvement 2	#24 Flat Cost	#25 Average Improvement Cost/Mile	#26 Length (mile)	#27 = #24 + #25 × #26 Construction Costs ($)	#28 Adjustment	#29 = #27 + #28 Total ($)

#30 Improvement 3	#31 Flat Cost	#32 Average Improvement Cost/Mile	#33 Length (mile)	#34 = #31 + #32× #33 Construction Costs ($)	#35 Adjustment	#36 = #34 + #35 Total ($)

#27 = #20 + #29 + #26 Total Cost

RR Overpass

#28 Overpassed Roadway Typical Section	#29 Railroad No. of Tracks	#30 Cost ($)	#31 Adjustment	#32 = #30 + #31 Total Cost ($)

Bridge

#33 Area (ft^2)	#34 Average Improvement Cost/Feet^2 ($\$/ft^2$)	#35 = #33 × #34 Cost	#36 Adjustment	#37 = #35 + #36 Total Cost ($)

Uncertainty Analysis

#38 = #15 + #27 + #32 + #37 Total Cost	#39 = Percentage Uncertainty	#40 = #38 – (#39 × 100.00) Lower Cost Bound	#41 = #38 + (#39 × 100.00) Upper Cost Bound

Workspace for Adjustment Calculations

3.3 How to Use the Project Cost Worksheet

Construction costs form the backbone for planning level project cost estimations. These are made primarily on the basis of cost per mile calculations. However, it may be appropriate to adjust the cost with historical or project-specific information.

#1 Type of Section

Item #1 Type of section
If the project is a roadway, abbreviations are defined in the Statewide Plan Cost Estimates and Default Values Table (Table 3.1). If the project is a bridge overpass, use the abbreviation given in Table 3.2: Statewide Plan Update Estimated Costs for Replacing Railroad Underpasses. Else, if the project is an intersection or bridge, indicate this in the item box.

#2 Average Cost/Mile ($/mile)

Item #2 Average Cost per Mile
Average Cost per Mile is the average centerline cost per mile found in the Statewide Plan Cost Estimates and Default Values Table (Table 3.1). This value should be associated with the type of section.

#3 Length (mile)

Item #3 Length
This is the length of the improvement project section in miles.

#4 = #2 × #3 Construction Costs ($)

Item #4 Construction Cost
The construction cost is the Avg. Cost per Mile (Item #2) multiplied by the Length (Item #3).

#5 CN Adjustment

Item #5 CN Adjustment
Construction Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#6 = #4 + #5 Total CN

Item #6 Total CN Cost
Total Construction Cost is the final construction cost with the adjustment factor. It is the sum of the original Construction Cost (Item #4) and the Construction Adjustment factor (Item #5).

#7 Land Designation

Item # 7 Land Designation
Land Designation is defined in the Right of Way Costs Table (Table 3.5). Insert the appropriate designation for environmental land use types.

#8 Percentage RW

Item # 8 Percentage RW
Percentage of the Right of Way Cost is the estimated as a percentage of the construction cost found above. Enter the associated percentage for the Land Designation (Item #7).

#9 = #6 × #8 RW Cost

Item #9 RW Cost
RW Cost is the estimated Right of Way cost found by multiplying the Final CN Cost (Item #6) with the Percentage RW (Item #8).

#10 RW Adjustment

Item #10 RW Adjustment
Right of Way Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#11= #9+ #10 Total RW

Item #11 Total RW Cost
Total RW Cost is the final right of way cost with the adjustment factor. It is the sum of the original RW Cost (Item #9) and the RW Adjustment factor (Item #10).

#12 = #6 × 0.15 PE Cost

Item #12 PE Cost
PE Cost is the preliminary engineering cost estimated as 15% of the Total CN Cost (Item #6).

#13 PE Adjustment

Item #13 PE Adjustment
Preliminary Engineering Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#14 = #12 + #13 Total PE

Item #14 Total PE Cost
Total PE Cost is the final preliminary engineering cost with the adjustment factor. It is the sum of the original PE Cost (Item #12) and the PE Adjustment factor (Item #13).

#15 = #6 + #11 + #14 Total Cost

Item # 15 Total Cost
Total Cost is the sum of the Total CN Cost (Item #6), the Total RW Cost (Item #11), and the Total PE Cost (Item #14).

#16 Improvement 1

Item #16, #23, # 30 Improvement
The improvement is a brief verbal description of the change made to the intersection. This can include adding a right turn lane, left turn lane, center turn lane, turn light, etc. The worksheet has space for three such improvements, each on its own row.

#17 Flat Cost

Item #17, #24, #31 Flat Cost
For several improvements, there is an initial cost (or flat cost) above the cost per mile. See Table 3.4.

#18 Average Improvement Cost/Mile

Item #18, #25, #32 Average Improvement Cost per Mile
See Table 3.4 for Average Improvement Cost per Mile.

#19 Length (mile)

Item #19, #26, #33
Length is the distance of the improvement.
Average right turn lanes are 0.36 miles long
Average left turn lanes are 0.41 miles long

#20 = #17 + #18 × #19 Cost ($)

Item #20, #27, #34 Cost
Cost is the summation of cost per mile figures and any associated flat cost.

#21 Adjustment

Item # 21, 28, 35 Adjustment
Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#22 = #20 + #21 Total Cost ($)

Item #22 Total Cost
Total Cost is the final improvement cost with the adjustment factor. It is the sum of the original cost (Item #20) and the Adjustment (Item #21).

#28 Overpassed Roadway Typical Section

Item #28 Overpassed Roadway Typical Section
These include the roadway types explained in Table 3.2, Year 2015 Statewide Plan Cost Estimates and Default Values. (R2, R4D, R4R, U4R, U4, R6D,R6R,U6R, R8D,R8R, U8R)

#29 Railroad No. of Tracks

Item #29 Railroad No. of Tracks
The number of railroad tracks is typically 1, 2, or 3.

#30 Cost ($)

Item #30 Cost
Each RR Overpass has a cost associated with the type of roadway being overpassed and the number of tracks. See Table 3.2.

#31 Adjustment

Item #31 Adjustment
Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#32 = #30 + #31 Total Cost

Item #32 Total Cost
Total Cost is the final improvement cost with the adjustment factor. It is the sum of the original cost (Item #30) and the Adjustment (Item #31).

#33 Area (ft^2)

Item #33 Area
This is the area of the bridge in square feet.

#34 Average Improvement Cost/Feet^2 ($\$/ft^2$)

Item #34 Average Improvement Cost per Ft^2
Each bridge has an associated cost with its length. See Table 3.3.

#35 = #33 × #34 Cost

Item #35 Cost
Cost is the product of the cost per mile and the number of miles.

#36 Adjustment

Item #36 Adjustment
Adjustment is a cost differential based upon historical or project specific information. This value may be either zero, negative (for decreased cost) or positive (for increased cost).

#37 =   #35 + #36   Total Cost   ($)

Item #37 Total Cost
Total Cost is the final improvement cost with the adjustment factor. It is the sum of the original cost (Item #35) and the Adjustment (Item #36).

#38 =   #15 + #27 + #32 + #37   Total Cost

Item #38 Total Cost
This total cost is the sum of all above costs (roadway, bridge, etc.)

#39 =   Percentage   Uncertainty

Item #39 Percentage Uncertainty
This is an *optional* item which is the percentage of uncertainty assigned to the total cost estimate. The user can assign an appropriate cost uncertainty factor.

#40 =   #38 – (#39 × 100.00)   Lower Cost Bound

Item #40 Lower Cost Bound
Lower Cost Bound is the lowest expected cost. It is computed as the total expected cost minus the product of the percentage uncertainty and the total cost.

#41 =   #38 + (#39 × 100.00)   Upper Cost Bound

Item #41 Upper Cost Bound
Upper Cost Bound is the upper expected cost. It is computed as the total expected cost plus the product of the percentage uncertainty and the total cost.

Table 3.1: Year 2015 Statewide Plan Cost Estimates and Default Values Construction Costs
(VDOT, Correspondence with Joe Orcutt, 1997)

Typical Section	Typical Section Description	1997 Average Centerline Cost/Mile ($1000)
U2	Urban 2-Lane (26'-30' Pavement)	1800
U3	Urban 3-Lane (36'-40' Pavement)	3400
U4	Urban 4-Lane (48 Pavement)	4200
U4R	Urban 4-Lane Divided W/ 16' Raised Median	4600
U6R	Urban 6-Lane Divided W/16' Raised Median	6000
U8R	Urban 8-Lane Divided W/16' Raised Median	6000
R2(18)	Rural 2-Lane, 18' Pavement	300
R2(20)	Rural 2-Lane, 20' Pavement	500
R2(22)	Rural 2-Lane, 22' Pavement	600
R2(24)	Rural 2-Lane, 24' Pavement (Reconstruction)	900
R4D	Rural 4-Lane, Divided-Dep. Median (Reconstruction)	2400
R4D-N	Rural 4-Lane, Divided-Dep. Median (New)	3500
R4D-P	Rural 4-Lane, Divided –Add Parallel Lanes	1800
R4R	Rural 4-Lane, W/16' R. Median (Reconstruction)	2600
R6D	Rural 6-Lane, Div.-Dep. Median (Reconstruction)	4400
R6D-W	Rural 6-Lane, Divided (Widen 4-6 Lanes)	3200
R8D-W	Rural 8-Lane, Divided (Widen 6-8 Lanes)	3200
R8D-W@	Rural 8-Lane, Divided Interstate or Freeway (Widen 4-8 Lanes)	6500

U - Urban Roadways with Curb and Gutter
R - Roadways with Standard shoulders and ditches
D - Divided Roadway

Table 3.2: Statewide Plan Update Estimated Costs for Replacing Railroad Underpasses
Updated July 23, 1997
(VDOT, Correspondence with Joe Orcutt, 1997)

Overpassed Roadway Typical Section	Railroad No. of Tracks	Cost $(000)
R2	1	5000
R4D, R4R, U4R, U4	1	6000
R6D,R6R,U6R	1	7000
R8D,R8R, U8R	1	8000
R2	2	6000
R4D, R4R, U4R, U4	2	7000
R6D,R6R,U6R	2	8000
R8D,R8R, U8R	2	10000
R2	3	7000
R4D, R4R, U4R, U4	3	8000
R6D,R6R,U6R	3	10000
R8D,R8R, U8R	3	11000

RR Underpass Projects in FY95 Six Year Plan used as basis for Cost Estimates
*If No. of Tracks is unknown, base cost on 2 tracks

Table 3.3: Bridge Cost Updated 1997
(VDOT, Correspondence with Joe Orcutt, 1997)

Bridge Cost	
Bridge up to 25 ft. in length	Included in the Roadway Plan Cost Estimate
Bridge from 25 ft. to 200 ft. in length	$80 per square foot
Bridge over 200 ft. in length	$100 per square foot

Table 3.4: Plan Cost Estimates for Rural Intersections July 1997
(VDOT, Correspondence with Joe Orcutt, 1997)

Four Lane Roadway	
Improvement	Flat Cost
1 Right Turn Lane	$65,000
1 Left Turn Lane	$80,000
1 Crossover	$60,000
New Crossover with 2 Right & 2 Left Turn Lanes	$350,000

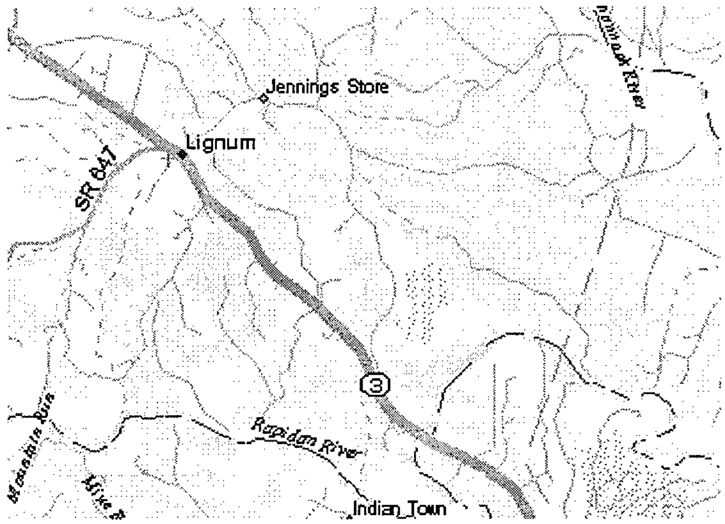
Two Lane Roadway		
Improvement	Flat Cost	Cost/mile
1 Right Turn Lane	$65,000	--
1 Left Turn Lane (.36 mi.)	--	$1,350,000
2 Left Turn Lanes (.41 mi.)	--	$1,350,000

Plan Cost estimates include engineering and contingencies.

Table 3.5: Right of Way Costs
(VDOT, Correspondence with Joe Orcutt, 1997)

Environmental Land Use	Designation	%
Rural	RUR	25
Residential	RES	50
Suburban Low Density	SLD	50
Outlying Business District	OBD	60
Suburban High Density	SHD	60
Central Business District	CBD	100

3.4 Example Project H



Project H: The Culpeper District plans to widen Route 3 from 2 to 4 lanes starting from the Orange County line west to east of Lignum. Additional project work would include alignment improvement.

Engineers have collected the following data:

Type of Section:	Urban 2-Lane (26'-30' Pavement)
Length:	2.2 miles
Land Designation:	Rural

From this information, the following can be predicted for post-improvement:

Total expected Construction Cost
Total expected Right of Way Cost
Total expected Preliminary Engineering Cost
Total Cost

The Crash Reduction Worksheet is computed on the next page.

Project H: Project Cost Worksheet

Road Section: *Route 3 4-lane widening and alignment improvement from Orange County line west to east of Lignum Culpeper Residency* Date: *6/27/94*

Analyst: *I.N. Gineer*

Project No.: 0003-023-104

Road Section

#1 Type of Section	#2 Avg Cost/Mile ($/mi)	#3 Length (mi)	#4 = #2 * #3 Construction Costs ($)	#5 CN Adjustment	#6=#4+#5 Total CN
U2	*1,800,000*	*2.2*	*3,960,000*	*190,000*	*4,150,000*

#7 Land Designation	#8 Percentage RW	#9=#6 *#8 RW Cost ($)	#10 RW Adjustment	#11=#9+#10 Total RW
RUR	*0.25*	*1,037,500*	*-387,500*	*650,000*

#12 = #6 * 0.15 PE Cost ($)	#13 PE Adjustment	#14= #12+#13 Total PE
622,500	*-422,500*	*200,000*

#15= #6+#11+#14 Total Cost
500,000,000

Intersection

#16 Improvement 1	#17 Flat Cost	#18 Average Improvement Cost/Mile	#19 Length (mile)	#20 = #17 + #18 × #19 Cost ($)	#21 Adjustment	#22 = #20 + #21 Total Cost ($)

#23 Improvement 2	#24 Flat Cost	#25 Average Improvement Cost/Mile	#26 Length (mile)	#27 = #24 + #25 × #26 Construction Costs ($)	#28 Adjustment	#29 = #27 + #28 Total ($)

#30 Improvement 3	#31 Flat Cost	#32 Average Improvement Cost/Mile	#33 Length (mile)	#34 = #31 + #32× #33 Construction Costs ($)	#35 Adjustment	#36 = #34 + #35 Total ($)

#27 = #20 + #29 + #26 Total Cost

RR Overpass

#28 Overpassed Roadway Typical Section	#29 Railroad No. of Tracks	#30 Cost ($)	#31 Adjustment	#32 = #30 + #31 Total Cost ($)

Bridge

#33 Length (mile)	#34 Average Improvement Cost/Mile ($/mile)	#35 = #33 × #34 Cost	#36 Adjustment	#37 = #35 + #36 Total Cost ($)

Uncertainty Analysis

#38 = #15 + #27 + #32 + #37 Total Cost	#39 = Percentage Uncertainty	#40 = #38 – (#39 × 100.00) Lower Cost Bound	#41 = #38 + (#39 × 100.00) Upper Cost Bound
5,000,000	*0.20*	*4,000,000*	*6,000,000*

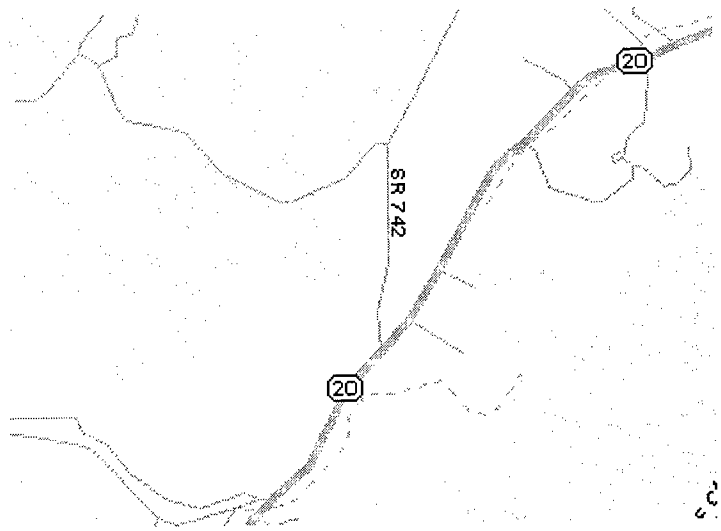
Workspace for Adjustment Calculations

Contractor bid $190,000 over

RW cost: 4 residencies x $162,500 = $650,000

PE cost: Designed similar project 2 years ago $200,000

3.5 Example Project G



Project G: The Culpeper District proposal to improve the intersection at Route 20 and Route 742. Work would include realigning Route 20 and other intersection improvements. The intersection is located 2.9 miles South of Charlottesville corporate city limits.

Engineers have collected the following data:

Type of Section:	Rural 2-Lane (20' Pavement)
Length:	intersection
Land Designation:	Rural

Intersection improvement:
From this information, the following can be predicted for post-improvement:

Total expected Construction Cost
Total expected Right of Way Cost
Total expected Preliminary Engineering Cost
Total Cost

The Crash Reduction Worksheet is computed on the next page.

Project G: Project Cost Worksheet

Road Section: *At route 20 at the intersection of Route 742 (Avon Street Extended) Realign Route 20 and improve intersection* Date: *7/20/92*
Analyst: *I.N. Gineer*
Project No.: *0020-002-s17*

Road Section

#1 Typical Section	#2 Average Improvement Cost/Mile ($/mile)	#3 Length (mile)	#4 = #2 × #3 Construction Costs ($)	#5 CN Adjustment	#6 = #4 + #5 Total CN ($)
R2(20)	*500,000*	*.1*	*50,000*	--	*50,000*

#7 Land Designation	#8 Percentage RW	#9 = #6 × #8 RW Cost ($)	#10 RW Adjustment	#11= #9 + #10 Total RW
RES	*50%*	*25,000*	--	*25,000*

#12 = #6 × 0.15 PE Cost ($)	#13 PE Adjustment	#14 #12 + #13 Total PE
7,500	--	*7,500*

#15 = #6 + #11 + #14 Total Cost
82500

Intersection

#16 Improvement 1	#17 Flat Cost	#18 Average Improvement Cost/Mile	#19 Length (mile)	#20 = #17 + #18 × #19 Cost ($)	#21 Adjustment	#22 = #20 + #21 Total Cost ($)
Right Turn Lane	*65,000*	--	--	*65,000*	--	*65,000*

#23 Improvement 2	#24 Flat Cost	#25 Average Improvement Cost/Mile	#26 Length (mile)	#27 = #24 + #25 × #26 Construction Costs ($)	#28 Adjustment	#29 = #27 + #28 Total ($)
2 Left Turn Lanes	--	*1,350,000*	*.41*	*553,500*	--	*553,500*

#30 Improvement 3	#31 Flat Cost	#32 Average Improvement Cost/Mile	#33 Length (mile)	#34 = #31 + #32× #33 Construction Costs ($)	#35 Adjustment	#36 = #34 + #35 Total ($)

#27 = #20 + #29 + #26 Total Cost
618,500

RR Overpass

#28 Overpassed Roadway Typical Section	#29 Railroad No. of Tracks	#30 Cost ($)	#31 Adjustment	#32 = #30 + #31 Total Cost ($)

Bridge

#33 Length (mile)	#34 Average Improvement Cost/Mile ($/mile)	#35 = #33 × #34 Cost	#36 Adjustment	#37 = #35 + #36 Total Cost ($)

Uncertainty Analysis

#38 = #15 + #27 + #32 + #37 Total Cost	#39 = Percentage Uncertainty	#40 = #38 – (#39 × 100.00) Lower Cost Bound	#41 = #38 + (#39 × 100.00) Upper Cost Bound
701,000	*50%*	*350,500*	*1,051,500*

Workspace for Adjustment Calculations

CHAPTER 4
COMPARISON TOOL FRAMEWORK

After all calculations have been carried out, the results can be graphically represented in a comparison chart which graphs the number of crashes avoided per year on the vertical axis, the total travel time saved per peak-hour on the horizontal axis. The basic format of the chart will be as shown in the following graph.

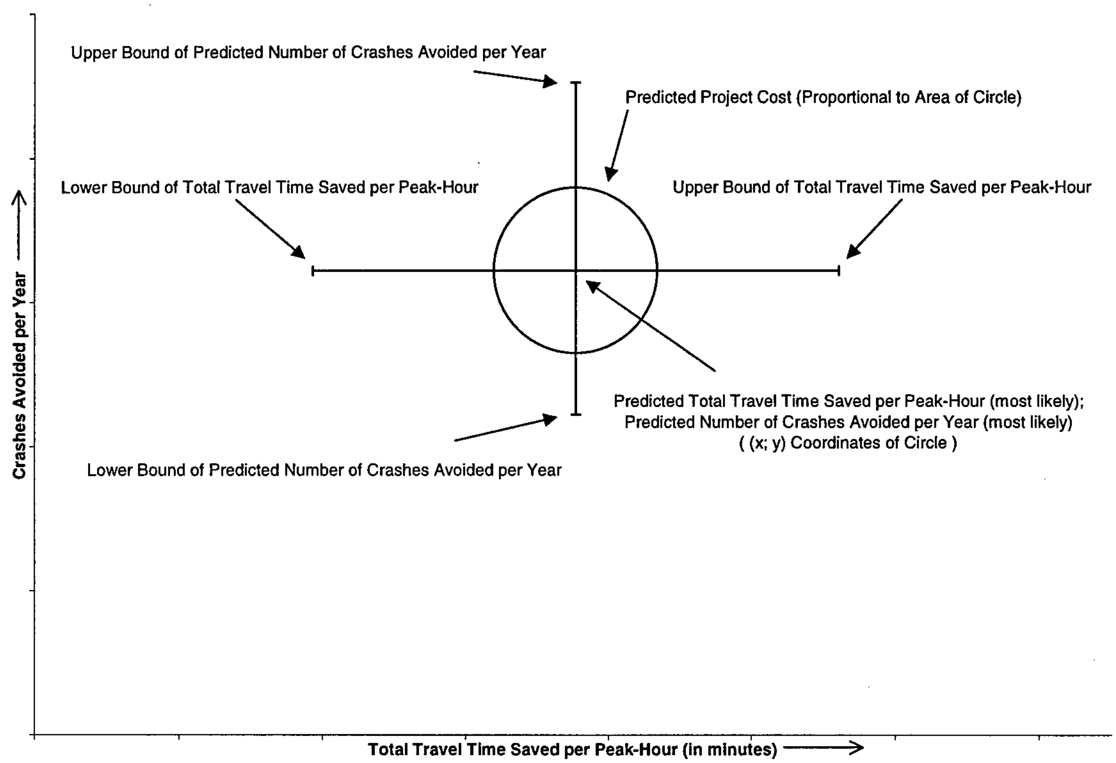


Figure 4.1: Legend to Comparison Chart

The following table summarizes the results for the two projects that have been used throughout the Workbook.

Table 4.1: Results for Example Projects

	Project H	Project G
Cost ($1,000)	5000	826
Total Travel Time Saved per Peak-hour (minutes) (most likely)	121	140
(lower bound)	90	90
(upper bound)	154	202
Crashes Avoided per Year (most likely)	6.68	3.9
(lower bound)	2.8	2.2
(upper bound)	9.7	7.1

This data could be processed using a computer spreadsheet program, such as MS Excel, in order to generate the desired chart. However, here, a stepwise procedure for manual charting is proposed.

In a first step, the results for the most likely travel time saved and crashes avoided per year are used to mark the center-points for each project.

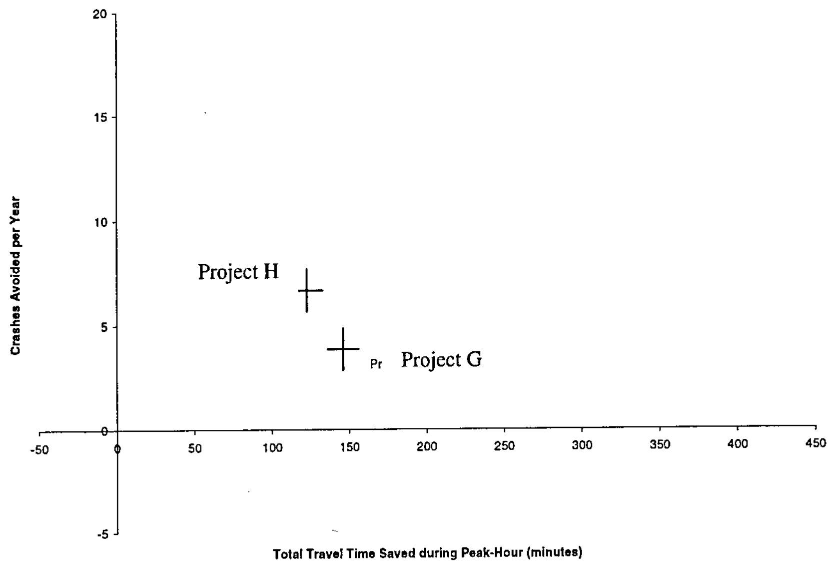


Figure 4.2: Step 1 in Creating Comparison Chart

Then, circles are added with the previously marked points as centers. The circle size should in some form represent the project cost. For example, the circle-area (or radius) should be proportional to the cost. To facilitate the procedure when manually creating these charts, an engineer's ruler could be used to draw circles of predefined size. Each circle size would then represent a certain range of project cost, with the circle-size increasing with cost. In the following chart, the circle-area is proportional to the cost.

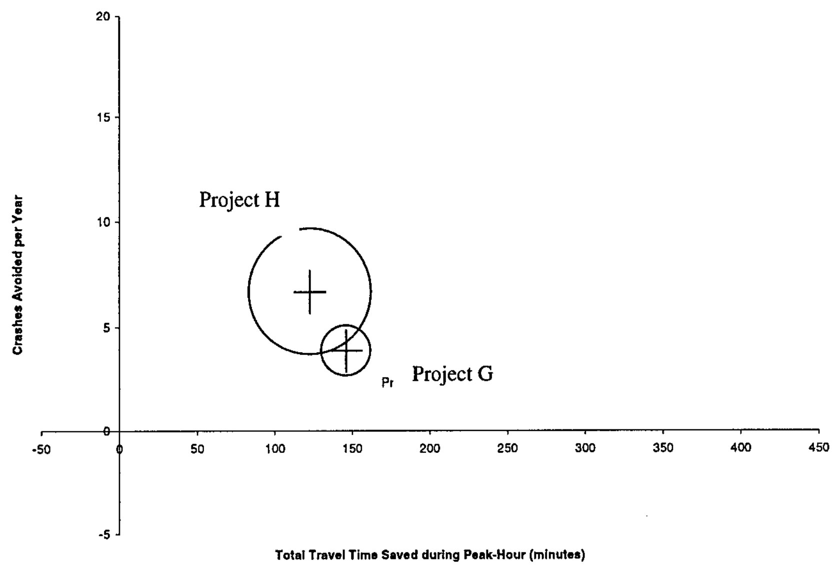


Figure 4.3: Step 2 in Creating Comparison Chart

Finally, the uncertainty information can be added in the form of range bars.

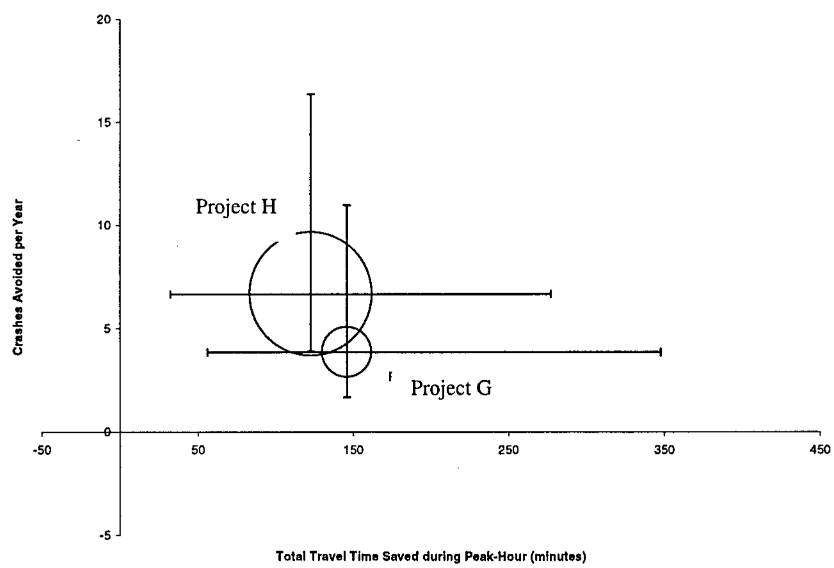


Figure 4.4: Step 3 in Creating Comparison Chart

The range bars intersect at the center of the associated circle. While the "most likely" value of the variable that is charted on the horizontal axis is indicated by the horizontal positioning of the circle-center, the left (right) end of the horizontal range bar indicates the lowest (highest) value that the variable could have for the associated project, considering the available information (lower and upper bounds). An analogous interpretation applies to the vertical range bars. Of course, the upper and lower bounds are not absolute, but are associated with a certain confidence level (and underlying distribution). For example, a 95% confidence interval and a chi-square distribution has been used to determine the bounds on the number of crashes avoided.

CHAPTER 5
ADDITIONAL CONSIDERATIONS

5.1 Selecting an Appropriate Chart

The graph that has been introduced in the previous sections (crashes avoided per year versus total travel time saved) is only one feasible chart of several. Some of the charts that will be discussed in the following passage require somewhat less processing of existing data. Also, they may be attractive to the analyst as the adopted measures (such as "daily traffic," or "accidents per vehicle") are used currently at VDOT.

In assessing the potential impacts of various highway (safety) improvement projects, it is important to consider the yearly number of crashes at the different sites. The average number of vehicles passing through these sites per day (or year) is also important. This information on the daily traffic will allow the analyst to determine how many accidents per passing vehicle occur (accident rate) and will also provide a measure of how many people (vehicles) would be affected by an improvement project. All else being equal, one would usually prefer a project that benefits a larger number of people. Of course, the cost of a project will have to be considered as well. These observations lead to two basic comparison charts: "Crashes per year" versus "daily traffic" (Figure 5.1) and "crashes per million vehicles" versus "daily traffic" (Figure 5.2). These figures depict actual projects that appeared in VDOT 6-year-plans for construction between 1992 and 1997. In the charts, the area of the circles is proportional to the project costs, which range from about $15,000 to $6,500,000 (preliminary engineering, right of way, construction engineering).

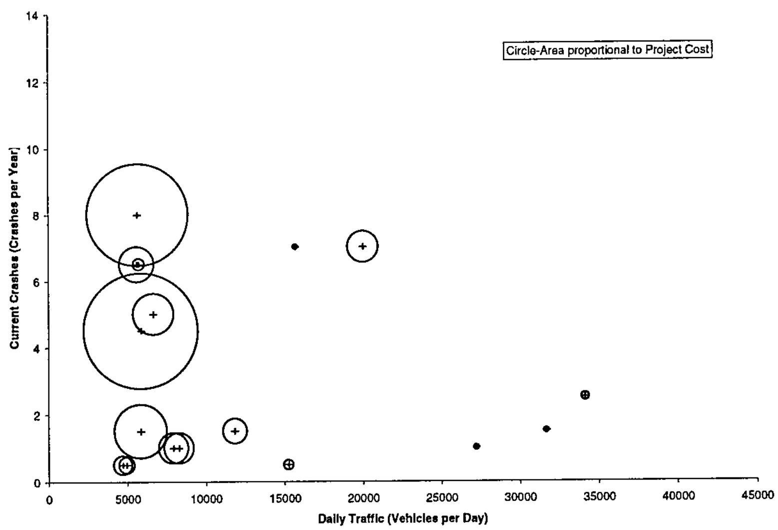


Figure 5.1: Graphical representation of sample projects; crashes per year versus daily traffic (range bars omitted for readability)

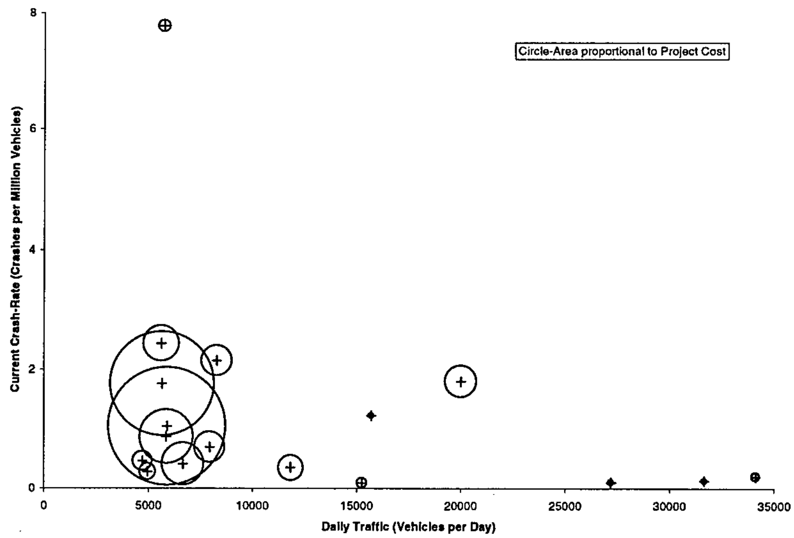


Figure 5.2: Graphical representation of sample projects; crashes per million vehicles versus daily traffic (range bars omitted for readability)

In addition, one may not only be concerned about the current number of crashes per year or per vehicles, but also about an improvement project's potential to reduce the number of accidents. The chart in Figure 5.3 illustrates this approach. The "crashes avoided per year" were obtained by multiplying the mean of the current number of crashes per year (which has already been used in Figure 5.1) by the appropriate accident reduction factor(s) (ARF) for each project.

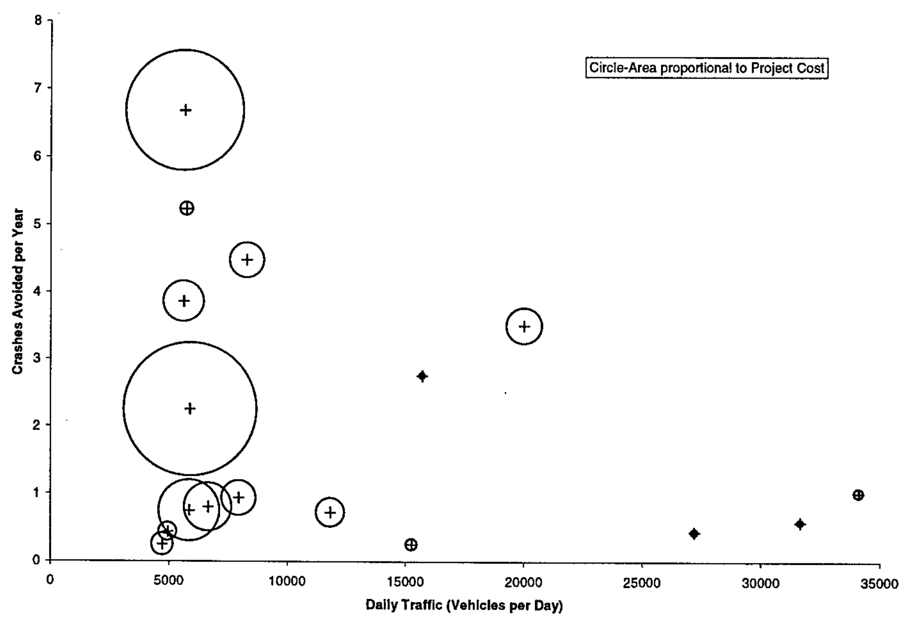


Figure 5.3: Graphical representation of sample projects; crashes avoided per year vs. daily traffic

Following the calculations outlined in this Workbook, the estimate of the number of crashes avoided cannot be negative, i.e. the number of yearly crashes is never estimated to increase from the "without" to "with" project condition. However, an increase in the yearly number of crashes certainly could be observed in practice.

The charts that have been presented up to this point focus on the safety improvement aspect of highway projects. However, any project could potentially also influence the performance of a site, no matter whether the project is classified as a "safety" or as a "performance" project. To make various kinds of projects comparable (in particular, projects at intersections and those on road sections), it is proposed here to employ "total travel time saved per peak-hour" as a measure of the performance improvement (or degradation) due to project implementation. This is the type of chart that has been introduced in the "Comparison Framework" section of the Workbook. The focus on "peak-hour" is appropriate as the peak-hour(s) will usually constitute the performance-bottleneck – an improvement in performance will in the first place affect the peak-hour situation, and may change nothing for those who use the roadway outside those times. The chart in Figure 5.4 is an example of "crashes avoided per year" versus "total travel time saved in minutes during peak-hour." The chart in Figure 5.4 also includes uncertainty information: The horizontal bars indicate that both daily traffic data and information on average speeds, or travel times, without and with project implementation are not known precisely. For both the daily traffic and the speeds or travel times without and with project implementation, a range of ±20% was used. The vertical bars acknowledge that the (current) mean number of accidents can be estimated only approximately, i.e. an average is computed over a short length of time. The average corresponds to only a sample observation of a process that is generated by the true but unknown mean rate of crash occurrence. After an upper and lower bound has been calculated for the mean number of crashes per year (using a 95% confidence interval and a chi-squared distribution), an upper and lower bound for the number of crashes avoided per year can be calculated, once again using ARFs. (Note that similar uncertainty information can be included in the previously presented graphs; it has been omitted for improved readability.)

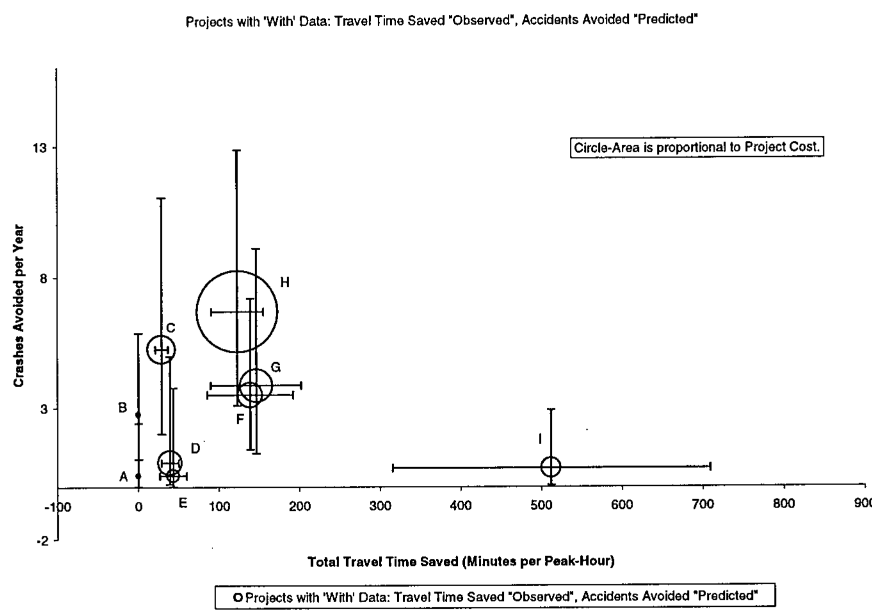


Figure 5.4: Graphical representation of sample projects; crashes avoided per year vs. total travel time saved (in a composite of the two years up to the construction start)

Table 5.1: Sample Projects depicted in Figure 5.4.

Index	Number	Description	Location	Construct Start	Construct End	Total Travel Time Saved	Accidents Saved per Year Predicted (Total)	Total Cost (in $1,000)
A	0029-056-112, pe101, n501	29- Madison Construct Right Turn Lane Northbound	@ Madison Cty. High School (Rt. 9731), 0.3 mi S of Intersection Rt. 29 Bus./Rt. 231	11/02/92	06/22/93	0	0.4	16
B	0029-023-v10, pe101, m501	29 - Culpeper Construct Right Turn Lane	@ Rt. 666	10/27/94	11/02/94	0	2.8	15
C	0020-002-s21, pe101, rw201, c501	20- Albemarle Improve Horizontal and Vertical Alignment	3.4 mi S of Rt. 53 to 3.8 mi S of Rt. 53	11/01/93	01/26/95	29	5.2	595
D	0015-056-701, pe101, rw201, m600, 0015-023-705, rw201, m400	15 - Culpeper and Madison Bridge Replacement	Crooked Run: Culpeper/Madison CL	03/22/93	12/04/93	39	0.9	440
E	0033-039-107, pe101, rw201, c501	33- Greene Improve Turning Radius	Stanardsville, Intersection Rt. 230	04/27/92	06/25/92	43	0.4	125
F	0020-002-123, pe101, rw201, m501	20 - Albemarle Extend Acceleration Lane	@ Intersection I-64	11/11/96	7/97	139	3.5	475
G	0020-002-s17, pe101, rw201, c501	At route 20 at Intersection Route 742 (Avon St. extended) Realigned Route 20 and improved intersection	2.9 mi S of Corporate City Limits C-ville	07/20/92	11/03/93	140	3.9	826
H	0003-023-104, Pe103, RW203, C503	Route 3 4-lane widening from Orange County line west to east of Lignum - Culpeper Residency	2.5 mi W of Culpeper/Orange CL to 0.3 mi W of C/O CL	02/17/93	09/28/94	121	6.7	5000
I	0033-054-106, pe101, rw201, n501	33- Louisa Install Right turn lane	Intersection Rt. 628	01/20/92	04/17/92	512	0.7	300

Note that still other charts are conceivable, such as one using "crashes avoided per million vehicles" on the vertical axis and/or "travel time saved per vehicle" on the horizontal axis.

5.2 Project Comparison Table

In the Project Comparison Charts, some criteria that are important to the project comparison are often not able to be included. However, these additional criteria (objectives) can be formatted into a table as information becomes available.

Table 5.2: Fictitious Project Comparison Table.

Project	Total Estimated Cost (in thousands)	Cost Error Range	Cost to State after Applicable Funding	Additional Maintenance Costs (annual basis)	Known Environmental Impacts	Total Mins Saved during Peak Hour	Crash Risk Reduction	Crash Severity Reduction
X	10000	3000	2000	10	none	9000	4	2
Y	4500	500	4500	0	none	2000	0	0
Z	76000	1000	0	0	air quality of residential area	5000	9	6

5.3 Different Uses for the Comparison Chart

There are several processes that conceivably involve comparison of roadway improvements, e.g. that of different sites of roadway improvements, that of design alternatives (at a given site), and that of allocating various total budgets among their constituent parts (district budget, state and/or federal budget).

Basic Project Comparison at 6 Year Plan Level
The comparison of roadway improvement projects in the development of the 6-year-plan constitutes the basic intended use of the proposed tool.

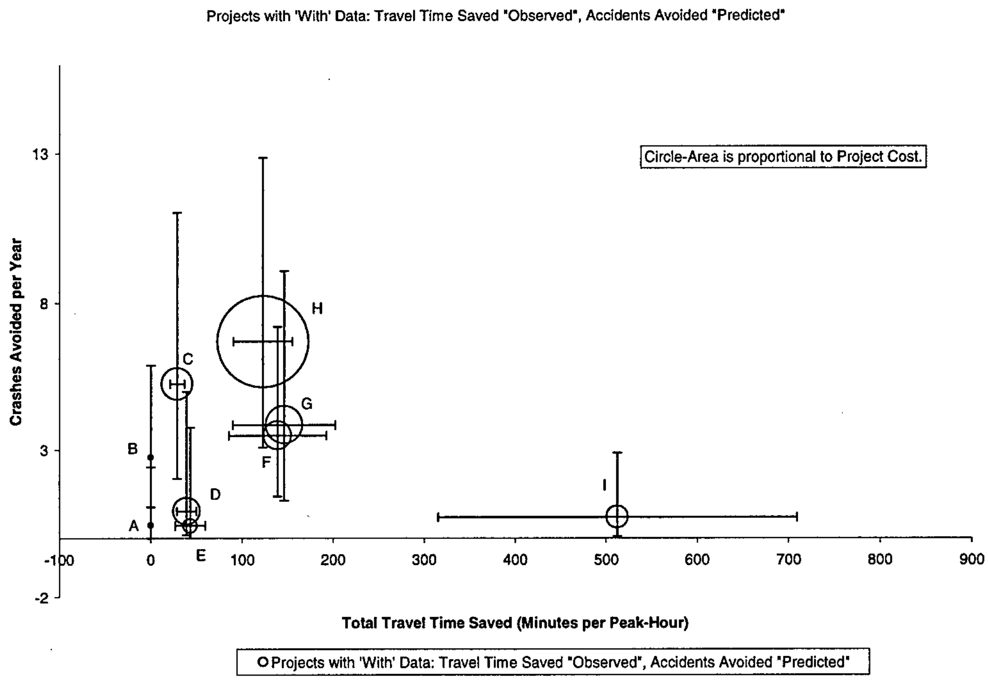


Figure 5.5: Project Comparison on 6-year-plan level

Design Alternatives Framework

Although this tool primarily focuses on planning level decisions, it can be used as a visual aid in the comparison of design alternatives. For example, if a district is considering an additional light or a turn lane for a particular intersection, it may use the Comparison Tool with these two alternatives. The differences in cost, crash risk reduction, and performance gain with uncertainty accounting measures will help make the project selection more objective in public perception and planning perspective.

District Budget Framework

Every year, the districts go through a process of prioritizing potential projects on a local level. These projects are often initiated at a district level or are directed from significant safety statistics from the state or capacity needs of residents and businesses. The projects undergo initial cost estimations and sometimes preliminary engineering. The selections go through a public hearing in order to incorporate the input of residents, government officials, and interested businesses. Each district chart will show the potential projects under the state budget.

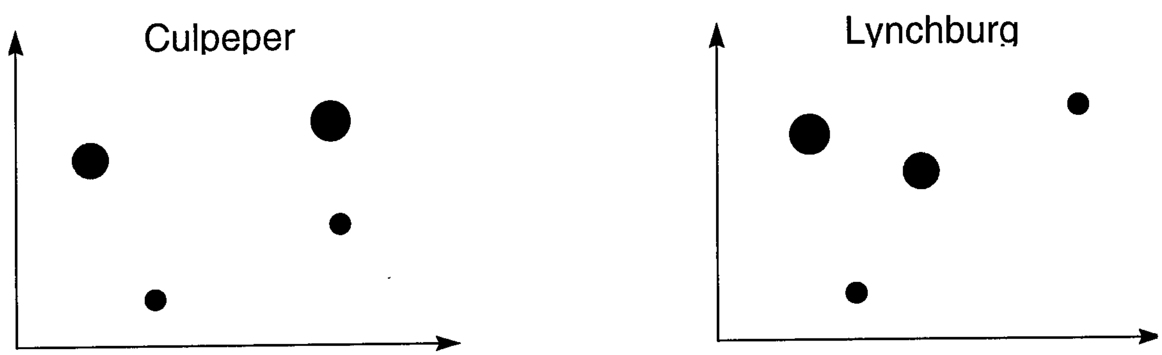


Figure 5.6: Comparison Charts by District

At this level, the Comparison Tool can act as a visual aid for both resident engineers and local officials. In a setting where politics are prominent, and additional objective tool can be used to assist local rankings of project priorities.

State/Federal Framework
The state level of prioritization takes each district budget into consideration. Calculations are performed that divide the budget according to factors such as population densities, vehicle flow, and other defined needs. The optimization incorporates the work done on the residential and district level.

Sources of Funding
Funds for improvement projects often comes from a variety of sources such as the Federal Appalachian Highway Program, Districtwide Allocations, Districtwide Safety Improvement Account, and the Federal Safety Program. The tool can be used in the framework of each funding source.

For instance, if the HES program would fund 90% of total project cost and the state would pick up the other 10%, the project would appear in the HES framework at 90% of its original size, and appear in the state budget at 10% of its original size.

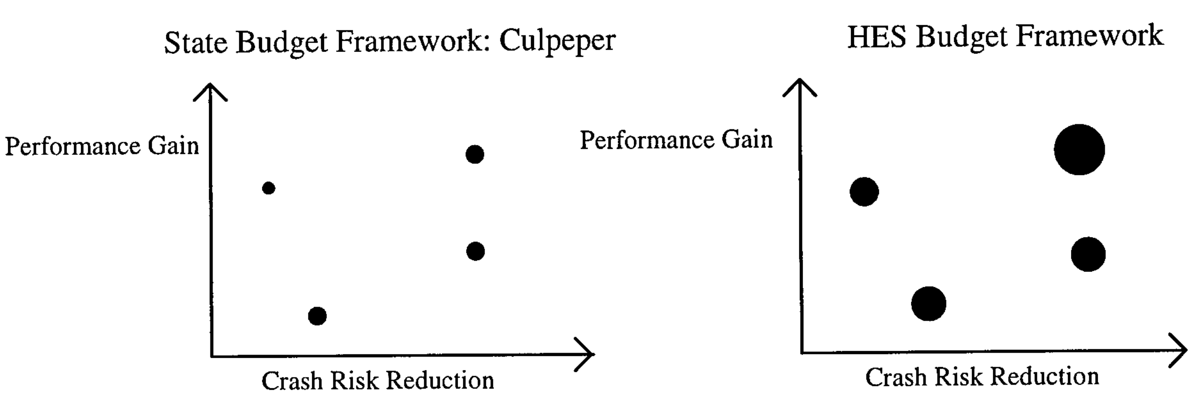


Figure 5.7: Comparison Charts by Sources of Funding

CHAPTER 6
APPLYING THE TOOL TO CRITICAL RATE LISTINGS

In addition to the various projects from the Culpeper district which have been mentioned before, information from some Critical Rate Listings (1994 and 1995) was processed and plotted in different graphs. Since the hazardous locations in the Critical Rate Listings do not represent projects (but may well be sites for future projects), only limited information was available, such as "Daily Vehicle Miles Traveled" and "length of road-section." For each year, 60 locations were identified and plotted, making a total of 120 locations, where locations may not be different, but "replicated" from 1994 to 1995.

In the following charts, the current number of crashes per year, or the current crash rate is plotted versus the daily traffic for the mentioned hazardous locations. Thus, these charts represent some of the "simpler" graphing options discussed in Chapter 5. It is intended to show that these charts can be easily generated with the information currently available at VDOT and provide a more intuitive insight into the available data. In Figure 6.1, the current total number of crashes is plotted versus the daily traffic. As one would expect, the number of crashes increases with daily traffic. A benefit from this chart would be to identify outliers (low daily traffic, high number of crashes, or vice versa) and investigate those. Insight gained from these outliers may be helpful in finding ways to generally reduce the number of crashes. Figure 6.2 is equal to Figure 6.1, but error bars have been added to account for uncertainties in the available data (confidence intervals (95%) for crash figures, error (± 20%) for daily traffic). It is apparent that the benefit of additional information in the graph (error bars) has to be traded-off against worse readability. Note that for Figure 6.1 through Figure 6.4, the horizontal axis is log-scaled.

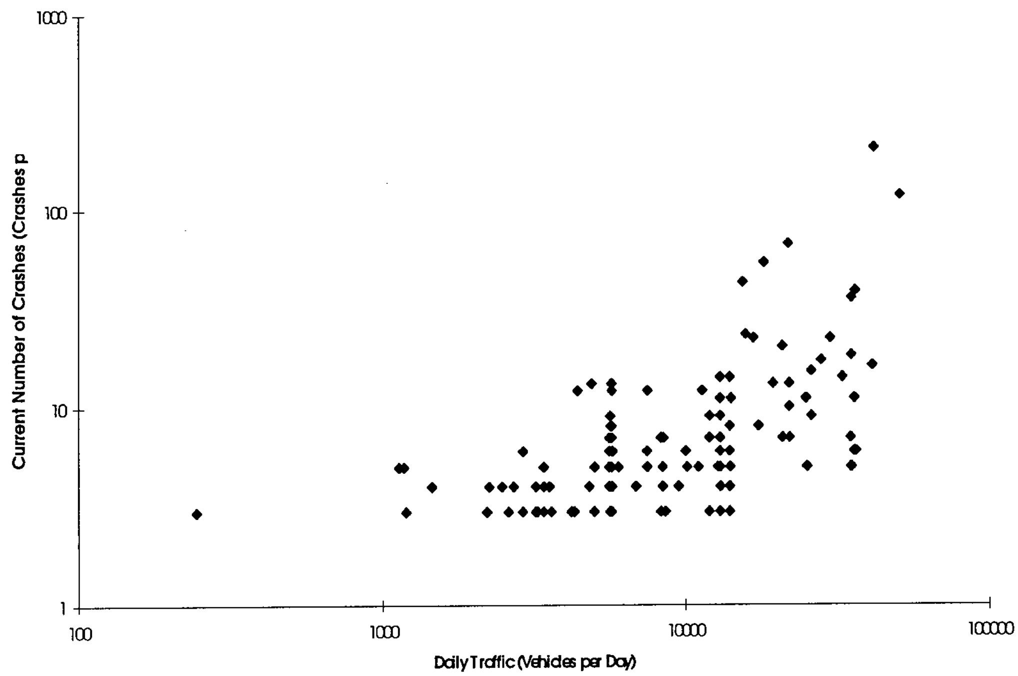


Figure 6.1. Current Total Number of Crashes vs. Daily Traffic

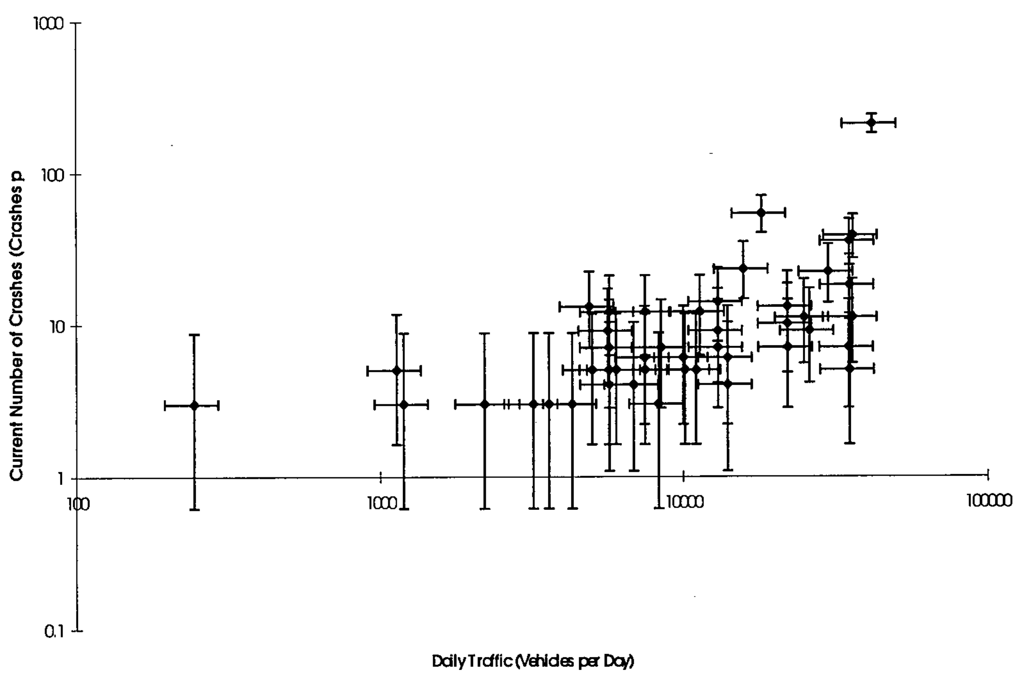


Figure 6.2. Current Total Number of Crashes vs. Daily Traffic (including error bars)

In Figure 6.3 and Figure 6.4, the current total number of crashes has been replaced by the current crash-rate. Note that the crash-rate is expressed in terms of crashes per million vehicle-miles. This measure is inappropriate for intersections, and a more suitable measure (for comparing projects of all kinds) may be "crashes per (million) entering vehicles." Again, the basic pattern follows intuitive expectation, with the crash-rate decreasing with increasing daily traffic.

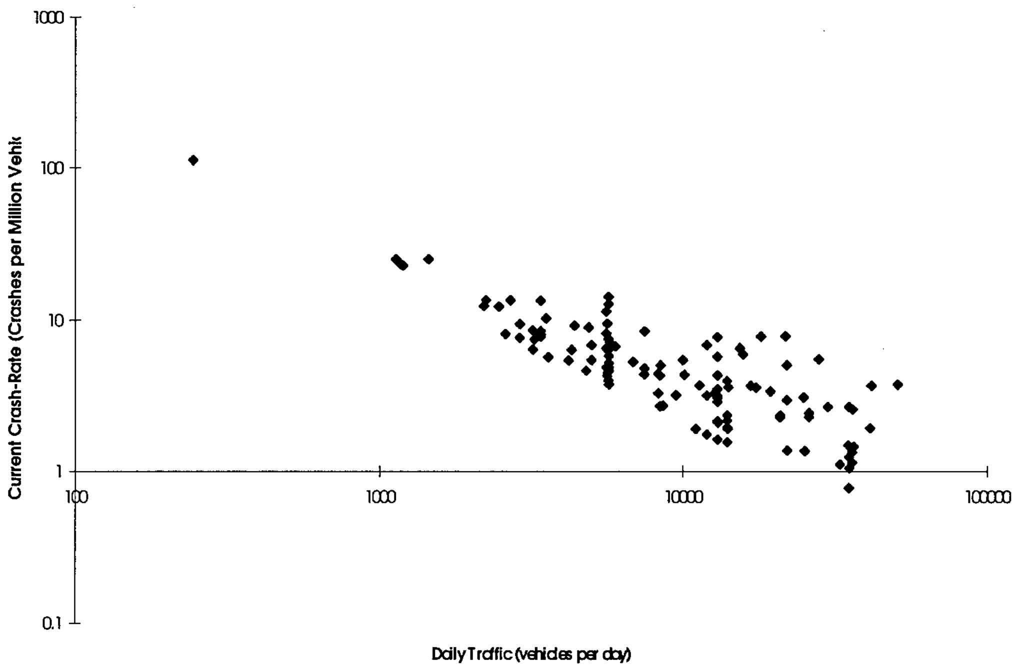


Figure 6.3 Current Crash-Rate vs. Daily Traffic

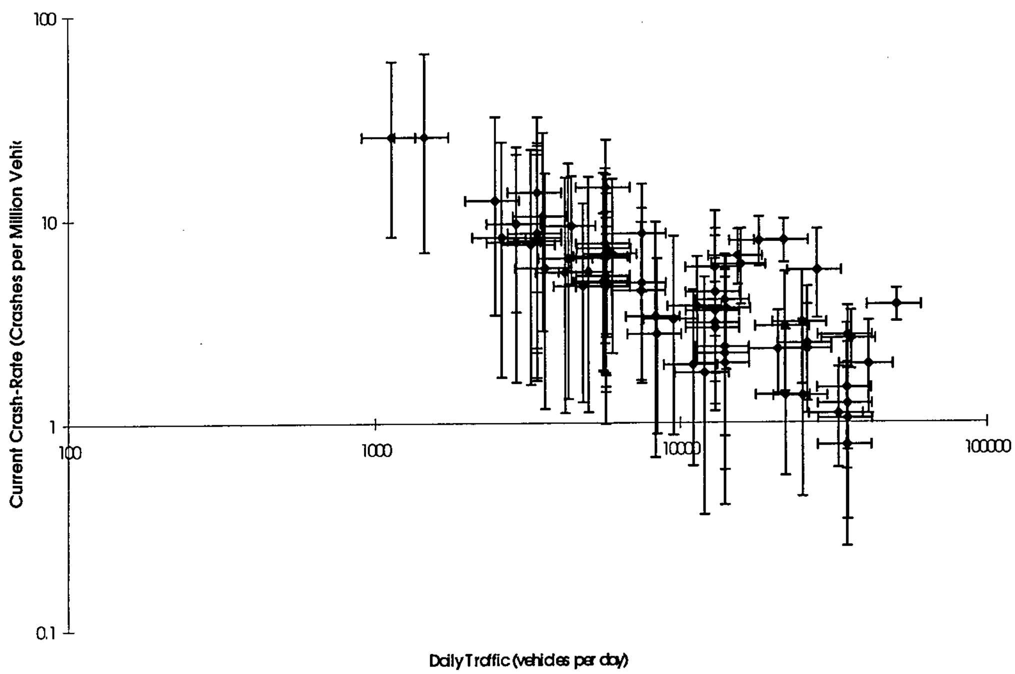


Figure 6.4 Current Crash-Rate vs. Daily Traffic (including error bars)

In Figure 6.5, only locations from the 1994 Critical Rate Listing have been used. Again, the current crash-rate has been plotted over the daily traffic (linear scale). In addition, the length of each road-section has been used as a crude indicator of the cost of a potential project that would try to "cure" this hazardous location. The area of the circles representing these locations of potential projects is proportional to the estimated cost (i.e. the section length).

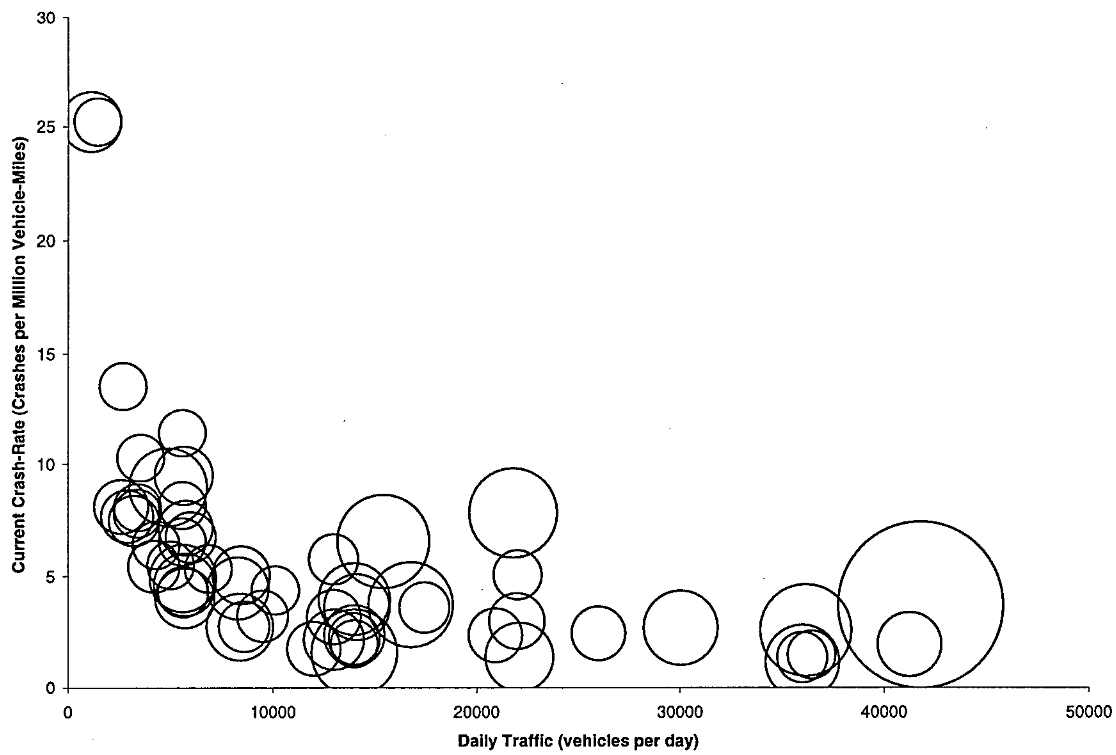


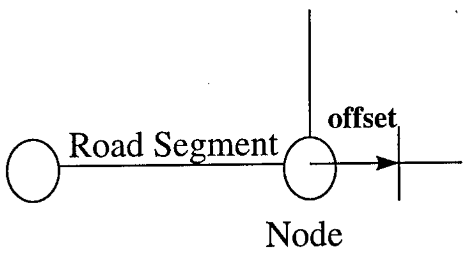
Figure 6.5. Current Crash-Rate vs. Daily Traffic (including Project Cost)

The data from the Critical Rate Listing can be found in the Appendix. However, site locations have been disguised.

APPENDIX

Gathering data through HTRIS: Hints and Tips

Each intersection is a node in the HTRIS database. Segments of roads are defined between intersections (nodes) or they can be more narrowed down using node offsets.



Follow this procedure to look up accident information on HTRIS:

1. From this point on, the enter key on the keyboard functions similarly to the Tab key; in fact, it's best not to use it at all. Once you are in the COMPLETE system, only the enter key on the numeric keypad is useful.
2. Choose option 2 for HTRIS. Press enter.
3. Choose option 3 for the Accident Submodule. Press enter.
4. Choose 3 for Accident Analysis. Press enter.
5. Note the following comments:

- The PF options can be selected by inserting the appropriate number in the bottom right blank on the screen and pressing enter.
- The locator function/node list can be very useful in determining where intersections, etc. are. Mark the beginning of a section with an X, and the end with a Y.
- This is much easier with a map. The nodes are intersections and jurisdictional lines. For things like rivers, etc. (which may be listed as project boundaries but are impossible to find in HTRIS), a map is useful to approximate the location).

Table A1: ARFs for Virginia
(VDOT, September 94)

	Improvement	ARF_I Injury	ARF_P PDO
C1	Widen Pavement	0.5	0.5
C2	Widen Pavement (Additional Lane)	0.5	0.5
C3	Widen Shoulders	0.5	0.5
C4	Widen Pavement and Improve Alignment	0.87	0.73
C5	Grooving	0.68	0.61
C6	Widen Bridge	0.92	0.95
C7	Eliminate Substandard Bridge	0.5	0.5
C8	Improve Horizontal Alignment	0.87	0.73
C9	Improve Vertical Alignment	0.87	0.73
C10	Install Railroad Protective Devices	0.5	0.5
C11	Signing	0.5	0.5
C12	Install Guardrail	0.5	0.5
C13	Median Barrier	0.5	0.5
C14	Install Roadside Delineators	0.5	0.5
C15	Impact Attenuators	0.5	0.5
C16	Channelization	0.29	0.58
	Left/Right-Turn-Lane (LTL/RTL):		
C17	LTL 2-Lane Highway	0.29	0.58
C18	LTL 4-Lane Divided Highway	0.29	0.58
C19	Extend LTL 4-Lane Divided Highway	0.29	0.58
C20	RTL 2-Lane Highway	0.29	0.58
C21	RTL 4-Lane Divided Highway	0.29	0.58
C22	Install Traffic Control Signals	0.5	0.5
C23	Modify Existing Traffic Control Signals	0.5	0.5
C24	Install Flashing Caution Signal	0.5	0.5
C25	Install Flashing Lights on Signs	0.5	0.5
C26	Improve Sight Distance	0.57	0.79
C27	Raised/Recessed Pavement Markers	0.5	0.5
C28	Illumination	0.22	0.5
C29	Bridge Approach Guardrail Transition	0.92	0.5
C30	Roadside Object	0.24	0.5

Table A2: Confidence Bounds Table
(VDOT, September 94)

Index	Column A	Column B
1	0	5.02
2	0.05	7.38
3	0.22	9.35
4	0.48	11.14
5	0.83	12.38
6	1.24	14.45
7	1.69	16.01
8	2.18	17.53
9	2.7	19.02
10	3.25	20.48
11	3.82	21.92
12	4.4	23.34
13	5.01	24.74
14	5.63	26.12
15	6.27	27.49
16	6.91	28.85
17	7.56	30.19
18	8.23	31.53
19	8.91	32.85
20	9.59	34.17
25	13.12	40.65
30	16.79	46.98
40	24.43	59.34
50	32.36	71.42
60	40.48	83.3
70	48.76	95.02
80	57.15	106.63
90	65.65	118.14
100	74.22	129.56