Research Report
KTC-03-15/SPR250-02-1F

KENTUCKY TRANSPORTATION CENTER

College of Engineering

DEVELOPMENT OF PROCEDURES FOR IDENTIFYING HIGH-CRASH LOCATIONS AND PRIORITIZING SAFETY IMPROVEMENTS

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16. Abstract

The objectives of this study were to review and analyze the current procedures for identifying high-crash locations and evaluating and prioritizing roadway safety improvements at high-crash locations, and to recommend improved methods. Several tasks were undertaken to accomplish these objectives, including the following:

- Review of program guidelines and procedures used by other states to prioritize improvements at high-crash locations
- Review and documentation of Kentucky's current procedure
- Update of Kentucky's Crash Buildup Program software to be compatible with the 2000 crash report form
- Development of new software to assist in estimating the benefits and costs of potential projects for inclusion in the Hazard Elimination Program
- Conversion of the dynamic programming software from mainframe to PC

Results from the study include improved methods for identifying high-frequency crash locations and prioritizing those locations after preliminary analyses indicated a need to consider improvements at a crash site. Software was developed to assist in producing a generalized estimate of the benefits of potential projects for inclusion in the Hazard Elimination Program. To use the software, the user must input the improvements to be made, the current level of crashes for the highway segment, and estimated project costs. Adjustments can also be made for key factors such as discount rate and projected traffic growth. Features include a menu of types of improvement projects and related reduction factors, and benefit-cost comparisons for each project.

Revisions were recommended for updating and enhancing the Crash Buildup Program to achieve compatibility with the current crash data report form and for translating the dynamic programming module from a mainframe operation to a PC-based system. It appears that an increased level of functionality has been achieved as a result of the series of modifications and improvements.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

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- Development of new software to assist in estimating the benefits and costs of potential projects for inclusion in the Hazard Elimination Program
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The Hazard Elimination Program was established by the Federal Highway Administration in 1978 and approximately $4.8 billion have been obligated nationwide for 35,000 projects since then. In Kentucky, budgets for the Hazard Elimination Program in the past few years have been in the range of $10,000,000. At least 10 percent of available funding from each state's Federal-aid budget must be allocated to the Hazard Elimination Program or the Rail-Highway Crossing Programs. Kentucky has used a Crash Buildup Program to identify sites with a high frequency of crashes; however, a level of incompatibility resulted with the introduction of a new format for the crash report form beginning in 2000. After identification of high-frequency crash sites and analysis of those sites to determine whether improvements should be recommended, data on benefits and costs were input into a dynamic programming module for determination of priority for funding specific improvements.

Results from the study include improved methods for identifying high-frequency crash locations and prioritizing those locations after preliminary analyses indicated a need to consider improvements at a crash site. Software was developed to produce a generalized estimate of the benefits and costs of potential projects for inclusion in the Hazard Elimination Program. Features included the following: 1) a menu of types of improvement projects and related reduction factors; 2) algorithms for calculating the present worth of annual benefits from crash reductions; and 3) benefit-cost comparisons for each project. The user must enter an estimate of project costs in order to estimate the benefit-cost ratio for the proposed improvement at a highway segment.

Revisions were recommended for updating and enhancing the Crash Buildup Program to achieve compatibility with the current crash data report form and for translating the dynamic programming module from a mainframe operation to a PC-based system. It appears that an increased level of functionality has been achieved as a result of the series of modifications and improvements.

1.0 INTRODUCTION AND BACKGROUND

1.1 Research Study Objectives

The process of determining which projects to implement under a given budget and which to defer until later is central to the planning and management of highway systems. The Kentucky Transportation Cabinet's Division of Traffic must routinely evaluate and prioritize safety improvements for high crash locations. In order to effectively assign priorities to potential improvements, the benefits and costs must be determined. An improved method for identifying and prioritizing improvements for eliminating hazards increases the potential for selecting the most logical projects for implementation.

The objectives of this study were to review and analyze the current procedures for identifying high-crash locations and evaluating and prioritizing roadway safety improvements at these locations, and to recommend improved methods. Several tasks were undertaken to accomplish these objectives, including the following:

- Review of program guidelines and procedures used by other states to prioritize improvements at high-crash locations
- Review and documentation of Kentucky's current procedures
- Update of Kentucky's Crash Buildup Program software to be compatible with the 2000 crash report form
- Development of new software to assist in estimating the benefits and costs of potential projects for inclusion in the Hazard Elimination Program
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1.2 Hazard Elimination Program and FHWA Guidelines

The Hazard Elimination Program (HEP) was established by Section 168 of the Surface Transportation Assistance Act of 1978. It replaced the combined High-Hazard Locations/Elimination of Roadside Obstacles program and provided Federal funds for highway safety improvements projects on all Federal-aid systems, except the Interstate System. The Surface Transportation Assistance Act of 1982 expanded the Hazard Elimination Program to make funds available for expenditure on any public road, except the Interstate System. This exception was amended by the Transportation Equity Act for the 21st Century (TEA-21). Approximately \$4.8 billion have been obligated nationwide for 35,000 projects since the program was initiated.

In Kentucky, the FY 2000 budget for the Hazard Elimination Program was \$11,500,000. At least 10 percent of available funding from each state's Federal-aid budget must be allocated to the Hazard Elimination Program or the Rail-Highway Crossing Programs. Kentucky has for several years used a Crash Buildup Program to identify sites with a high frequency and rate of crashes as the first step in the process of implementing improvements to eliminate safety problems. However, incompatibility resulted with the introduction of a new format for the crash report form beginning in 2000 such that the Crash Buildup Program would not function with the recent crash data. In addition, the application of benefits and costs to potential improvements was cumbersome and relatively inflexible, resulting in the need for a more automated process to assess the benefits and costs. After identification of sites with a high frequency and rate of crashes, and analysis of those sites to determine whether improvements should be recommended, data on benefits and costs were input into a dynamic programming module to determine the priority for funding specific improvements. With the dynamic programming module being originally developed as a mainframe program, it was recognized that efficiency could be gained with conversion to a PC.

The Hazard Elimination Program has been expanded to include interstates (previously excluded), any public transportation surface facility, and any public bicycle pedestrian pathway or trail. In keeping with the current direction of the Federal Highway Administration, recent guidelines mention traffic calming as an eligible activity and suggest that dangers to bicyclists be included in surveys of hazardous locations. Other guidelines include the allowance for states at their discretion to identify hazards to motorists, bicyclists, pedestrians, and other users of highway facilities. Thereafter, it is expected that states will develop and implement projects and programs to address the hazards. Common state program parameters include a limit of $1,000,000 per project over a section length of one-half mile or less, and meeting criteria related to thresholds of critical rate factors.

1.3 Hazard Elimination Programs in Other States

Hazard Elimination Programs exist in other states and all programs operate under the same general guidelines as those in Kentucky. Information was obtained from several other states and all either used some form of benefit-cost analysis or critical rates to prioritize improvements. For example, Minnesota uses benefit-cost ratios for prioritization while Maine uses three years of crash data to prioritize based on critical rate factors. Similarly, the state of Washington uses a cost-effectiveness ratio to develop a prioritization scheme. In Oregon, a priority index system is used to identify sites based on history of crash data, frequency and rate of crashes, and a measure of crash severity.

1.4 Crash Reduction Factors

A common factor among the various programs in nearly all states is the application of crash reduction factors to estimate the decrease in crashes expected when safety improvements are programmed or proposed. Kentucky has been one of the leaders in the development and application of crash reduction factors. The Transportation Center at the University of Kentucky has completed two studies (1985 and 1996) in which crash reduction factors were developed for various types of highway safety improvements (1,2). Both reports were titled "Development of Accident Reduction Factors" with the 1996 report being an update of the earlier work. The primary basis for the factors included a survey of states and a review of literature. Other recent work included a compilation of reduction factors into a report titled "Countermeasure Handbook" which was developed in 1997 as part of a FHWA study performed by Dixon at Georgia Institute of Technology (3). An effort completed by Harwood, et al. in 2000 and titled "Prediction of the Expected Safety Performance of Rural Two-Lane Highways" was directed toward the objective of developing crash reduction factors that would be applicable to two-lane rural roads as input into the Interactive Highway Safety Design Model (4). A wide range of improvement types have been included in the various reports with sufficient detail to apply reduction factors to represent benefits from most improvements typically undertaken as part of Hazard Elimination Programs. The second component of a benefit-cost analysis is the cost associated with improvements proposed as part of a safety program. Specifically, an estimate must be made of the expected cost of an improvement in the preliminary stage when the relative worth of competing projects are being evaluated. This input typically relies on results from similar projects recently completed or the expertise of those who have been involved with similar projects.

1.5 Crash Cost Data

The use of cost data associated with reductions in injuries and fatalities is a critical component of the benefit-cost analysis used to assess the effectiveness of safety improvements. In order to determine the effect of safety improvements, a measure of reduced injuries and fatalities must be associated with the proposed safety improvements. A cost for each of the reduced injuries and fatalities has been derived from various sources in the past, including those developed by the National Safety Council, the Federal Highway Administration, and the National Highway Traffic Safety Administration (5,6,7). The costs per fatality are generally in the range from approximately $0.75 million to $3.0 million. A range of injury costs are also provided along with the costs associated with property damage only crashes. Use of these monetary values for various levels of injuries in combination with crash reduction factors permits an overall assessment of the effectiveness of safety improvements. There has not been a consensus of opinion on the appropriate crash cost data to use in the analysis.

2.0 OVERVIEW OF KENTUCKY'S HAZARD ELIMINATION PROGRAM

Kentucky's Hazard Elimination Program was established in the early 1970's after the Highway Safety Program Standards were developed as a result of the Highway Safety Act of 1966. In the US DOT publication titled "Highway Safety Program Standards" dated February 1974, there were 18 safety standards identified. Standard No. 9 was "Identification and Surveillance of Accident Locations" (8). This safety standard had as its purpose "To identify specific locations or sections of streets and highways which have high or potentially high accident experience, as a basis for establishing priorities for improvement, selective enforcement, or other operational practices that will eliminate or reduce the hazards at the locations so identified". The Standard required each state to have a program for identifying accident locations and for maintaining surveillance of those locations having high accident rates or losses.

Following is a general summary of Kentucky's Hazard Elimination Program as it is currently functioning.

Step No. 1 – Identification of High-Crash Locations

- Use statewide data to determine average crash rates and critical number of crashes for specific types of highways

- Using the Crash Buildup Program, obtain a list of locations that have a critical number of crashes
- Categorize the locations with critical numbers of crashes by type of highway and various lengths of spots and sections (current procedure uses 0.1-mile spots for three years and does not distinguish by type of highway)
- Calculate crash rates (crashes per million vehicles for spots and crashes per 100 million vehicle miles for sections) for locations having a critical number of crashes
- Calculate critical crash rates and the critical rate factor (CRF) for these locations
- Evaluate locations above a specified CRF (for example using a CFR of 1.00) or higher for further analysis (the number of locations which can be reasonably analyzed is a consideration in the selection of the cutoff CFR)

Step No. 2 – Distribute Lists of High-Crash Locations to Highway Districts

- Categorize high-crash locations (those with CRF of 1.00 or higher) by highway district
- Arrange the lists in descending order by CRF and distribute the lists to highway districts

Step No. 3 – Analyze Selected High-Crash Locations

- Review of high-crash locations by district personnel to determine locations that are candidates for detailed analysis (considering CRF, scheduled construction, sites previously reviewed, etc.)
- Obtain and analyze crash reports for locations selected for detailed review
- Visit site to determine characteristics of locations relative to types of crashes occurring
- Recommend improvements to address patterns in crashes
- Implement low-cost improvements with district personnel
- Develop list of high-cost improvements for consideration as HEP project

Step No. 4 – Select Locations for Improvements as a HEP projects

- Obtain lists from all districts for recommendations as HEP projects
- Estimate costs for recommended improvements at each site
- Estimate reduction in crashes for various improvements at each site
- Summarize estimated costs and benefits for recommended improvements at each location
- Using available funds, determine a list of improvements by highway district that should be implemented to optimize benefits (dynamic programming is an option for managing available funds to optimize benefits)

As part of the process for implementing a Hazard Elimination Program, a report titled "Optimal Highway Safety Improvement Investments" was prepared by the former research unit of the Kentucky Department of Highways (9). This report addressed the need to effectively use available funds for safety improvements by implementing an optimization process.

3.0 UPDATE AND REVISIONS OF SOFTWARE FOR KENTUCKY'S CRASH BUILDUP PROGRAM

3.1 Methodology for Identification of High Crash Locations

High crash locations are unique in that they are identified as sections of roadways that have clusters of crashes within a relatively short distance. Traditional crash identification has been limited to identifying intersections or single milepoints. A Fortran program was previously developed and used to identify high crash locations along all public roads in Kentucky. The CRASH database was used to create a list of the most recent three years of crash data sorted by county, route and milepoint. The database also includes the following fields:

- Crash Time
- Crash Date
- Total Fatalities
- Total Injuries
- ADT
- Functional Classification
- Rural/Urban Identifier
- Number of Lanes
- Median Type

This list was used to identify the high crash locations in Kentucky.

The Fortran program was called C2 and requires the user to input two values to identify the high crash locations. The first value is the length and this defines the search distance for the locations. For example a length of 0.3-mile will produce output listing the 0.3-mile spots of all routes in the database that have high concentrations of crashes. The lengths are divided into two categories. All lengths less than 0.4-mile are considered spots. Typical spot lengths used in the past include 0.1-mile and 0.3-mile. All lengths greater than or equal to 0.4-mile are considered sections. A 1.0- mile length is a typical section length used for analysis. The second user-defined value is the critical number of crashes. The critical number serves as a cutoff point for the number of crashes within a section or spot. For example, a critical number of 5 will produce output listing only spots or sections with 5 or more crashes within the specified length. A report produced annually by the Kentucky Transportation Center has calculated typical critical numbers for various roadway types (10). The critical numbers used are shown in Table 1.

Once the user has defined the length and critical number, the program proceeds to search for the high crash locations. As previously stated, the crash database is sorted by county, route, and milepoint. This arrangement is necessary for the program to operate properly. The program begins at the top of the database with the first record. The initial search distance is created by adding the user-defined length to the milepoint of the first record. For example, if the first crash record is KY 55 in Adair County at milepoint 9.1 then the search distance will be from 9.1 to 9.4. This range is stored and used to count all crashes in Adair County on KY 55 within 9.1 to 9.4. If 5 or more crashes are identified within the range, the county, route and milepoint range are written to an output file and the search continues at the end of the range (in this case 9.4 to 9.7). In the event that fewer than 5 crashes are discovered within the range a new range will be defined beginning with the last crash within the range. For instance, if there are two crashes between 9.1 and 9.4, one at 9.1 and the other at 9.3, then the new range will begin at 9.3 and end at 9.6. This entire process will continue until the route number or county number changes or the end of the database is reached. When a change is detected in the county or route the program resets the values and restarts the process.

Because of the design of the program, however, the spot or section with the highest number of crashes may not always be identified. By design, when the program encounters a spot or section with a critical number of crashes it will start a new search at the end of that spot or section. The program is unable to "backtrack" to determine if an overlapping spot or section has more crashes. For example, the program will identify two 1.0-mile sections if a route has 5 crashes between milepoint 1.0 and 2.0 and 5 crashes between 2.0 and 3.0. However, the program would be unable to determine if there were 9 crashes between milepoints 2.5 and 3.5. This limitation will be discussed further, later in this report.

The next step involved the calculation of a critical rate factor (CRF). The following formula was used to calculate a critical rate.

$$C_c = C_a + K\sqrt{\frac{C_a}{M}} + \frac{1}{2M}$$

C_c	= critical crash rate
C_a	= average crash rate
K	= constant related to level of statistical significance selected (a probability of 0.995 was used wherein K = 2.576)
M	= exposure (for sections, M was in terms of 100 million vehicle miles (100 MVM); for spots, M was in terms of million vehicles (MV)

The average crash rate used for each spot or section is dependent on the roadway type, number of lanes and median type. The most frequently occurring characteristics for crashes occurring within a spot or section were used in the event that the roadway characteristics change within the spot or section. A conservative approach was used in the unusual case in which there were an equal number of two or more characteristics within a spot or section. In this case the highway type with the lowest average rate was used to calculate the critical rate, since a lower average rate results in lower critical rate (given constant exposure) the critical rate is inversely proportional to the critical rate factor. The average rates for different roadway types have been previously calculated in another report produced annually by the Kentucky Transportation Center (10). The average rates used are shown in Table 2. These rates were calculated for each roadway type based on all crashes occurring between 1999 and 2001.

The next step was to calculate the actual crash rate for each spot or section identified as having a critical number of crashes. The rate is calculated using the number of crashes divided by the exposure, which is calculated based on traffic volume. The actual rate is divided by the critical rate to determine the Critical Rate Factor (CRF). The program then calculates a CRF for each spot or section identified as having a critical number of crashes.

All of the results were written to an output text file in tabular form. The 0.3-mile spots with a CRF of 5.0 or more are presented in Table 3. This output is for 0.3-mile spots with a critical number of 3 and is ordered by CRF. The data were for crashes occurring between 1999 and 2001. The following information is given on the printout.

Field Name	**Description**
HD	Highway district number
CO	County number
RT	Route number
# CRASHES	Number of crashes
BMP	Beginning milepoint
EMP	Ending milepoint
NK	Number of crashes involving a fatality
NI	Number of crashes involving an injury
ADT	Average daily traffic
RU	Rural/urban classification
NL	Number of lanes
MT	Type of median
FC	Functional classification
Cact	Actual crash rate
Crate	Critical crash rate
CRF	Critical rate factor

In addition to this output, a summary file was created. This file summarized the spots or sections identified and included the total number of locations, the total number in each county, and the total number in each highway district. A summary of the 0.3-mile spots with a CRF of 1.0 or more (1999-2001) is given in Figure 1.

3.2 Development of Interface for High Crash Location Process

As previously noted, a program used to identify high crash locations was developed for internal use by the Kentucky Transportation Center as part of other research activities. This previously described program called C2 was programmed in Fortran. The program involved the editing of text files for input and converting text files into spreadsheets for analysis and sorting capabilities. It was decided that a more “user friendly” interface should be developed to simplify the process of identifying high crash locations. In addition, the inability of the FORTRAN program to back check for the highest possible number of crashes in a spot or section was rectified.

The program was converted into Visual Basic linked to an Access database comprised of crashes between 1999 and 2001. The program can more effectively search for the highest number of crashes per spot or section by linking to an Access database. A visual "front end" was included to allow the user to select from several conditions to identify the high crash locations. The program also allows the user to display the results in tabular form or as a summary. The program is self-contained and can be run from an executable.

The program begins by allowing the user to choose a spot or section analysis. In the spot analysis, options can be selected for either 0.1- or 0.3-mile spots. The user can also choose to analyze one of the 12 highway districts or all highway districts (default option). The user must enter a critical number (any integer greater than one) and has the option to choose severity. The severity options include: all crashes, fatal crashes only, or fatal and injury crashes only. The small number of fatal crashes limits the use of only fatal crashes in this analysis. Once these options are chosen, the user clicks a submit button and the data can be viewed in one of two ways. With the first option, the user can choose "Display Details" to view an Excel spreadsheet of all the identified spots. The data fields are similar to that of the output from the original C2 program as shown in Table 3. The second option allows the user to display the data in summary by choosing "Display Summary." This option opens a Word document summarizing the results. The format is identical to the output provided by the original C2 program and can be seen in Figure 1. A step-by-step procedure of the program is outlined in Appendix A.

4.0 DEVELOPMENT OF SOFTWARE FOR ESTIMATING BENEFITS AND COSTS OF IMPROVEMENT PROJECTS

The benefit cost estimation software is designed to allow the user to make an estimate of the safety benefits of a proposed HEP project, and also to estimate a benefit cost ratio for such a project. It is envisioned that the software could be used by planners and traffic engineers at the district level as projects are considered for submittal to the HEP program.

To operate the software, the user needs to enter information about the type(s) of improvements to be made and the current level of crashes at the relevant highway segment. The user also would have the option to adjust default values for a number of key factors such as the discount rate and projected traffic growth. Based on this information, the software would calculate the benefits of the project. The user also would be expected to enter estimated project costs. Once this is done, a benefit-cost ratio comparison can be made.

A discussion of the model is provided below. The data entry section discusses the types of selections that must be made, or data that might be entered. Each section also discusses the approach behind safety benefit estimates and benefit cost comparisons. Subsequent sections discuss key values for particular projects such as the crash reduction rate or expected project life. The last section discusses how benefit values and benefit cost ratios are calculated.

4.1 Data Entry

Use of the software requires that the user enter data for the several following factors, which are also listed in Table 4. The user must select the types of improvements to be made at a particular site. A list of potential improvements is available from a window in the software. The user also must enter the number of fatal crashes, injury crashes, and property-damage only crashes that have occurred at a site on average over the last three years. Selecting the project types and entering the number of crashes will be sufficient to calculate annual project benefits and the present value of project benefits.

The user also must enter an estimate of project costs. Entering the cost estimate will make it possible to estimate and benefit cost ratio for the proposed improvement or improvements at a highway segment.

An improvement type must be selected and crash data and costs must be entered in order for the benefit cost software to operate. A benefit cost ratio is estimated under default assumptions about the discount rate and the value of fatal crashes, non-injury crashes, and property damage only crashes. The user, however, will have the option of altering these default assumptions. The default real discount rate is 7 percent and the default traffic growth rate is 3 percent.

4.2 Improvement Types

The first step in developing the software for estimating benefit-cost ratio was to develop a list of potential improvements that could be made. Included were improvements typically applied to upgrade the safety of a road segment. Projects also had to be expensive enough to be included in the HEP program so small projects such as adding stop signs or other signage were not included. Lastly, types of improvements where crucial information on crash reductions and project life were available were chosen from previous research in Kentucky and other states (1,2). The result was the list of over 60 potential types of improvements listed in Table 5.

The software user would select which type of improvement or improvements is planned for a particular safety evaluation. Note that users would have the option of choosing from several improvement options in Table 5 in order to simulate projects where multiple improvements are made in order to improve safety at a particular road segment.

4.3 Crash Reduction

The principal goal in making improvements to a high crash highway segment is to reduce the number of crashes, and in some cases, the number of severe crashes in particular. Estimating the reduction in such crashes; therefore, is a key element in estimating the benefits that result from a particular improvement or set of improvements on a highway segment.

Civil engineers and other traffic safety experts have developed estimates of the likely reduction in crashes for each of the highway improvements listed in Table 5. Utilized in this research were reduction factors from the FHWA and estimates resulting from research studies by the University of Kentucky Transportation Center (1,2). The mean value from each set of estimates was utilized. In a few cases, a particular type of crash was only addressed in one of the reports, so that single value was used. Crash reduction factors are presented in Table 6.

4.4 Life of Project

Data on the projected life of safety improvements were taken from estimates developed by the California Office of Traffic Safety (11). This data source had project life estimates for many of the improvement types listed in Table 5. In cases where no project life information was available, the default value of 20 years was utilized. Project life estimates also are presented in Table 6.

4.5 The Magnitude of Crash Costs

Crash cost estimates are an important factor in benefit-cost analysis. Reductions in the number of crashes are the key benefit flowing from the HEP program improvement. Thus, the value assigned to each crash reduction has a large effect on the benefits of each improvement.

Crash cost values are estimated for three types of crashes – fatal crashes, all injury crashes, and property damage only (PDO) crashes. Estimates of economic and comprehensive costs are listed in Table 7. Note that valuations of economic costs of crashes include costs such as lost wages, hospitalization and other health care and crash site costs. The cost estimates for comprehensive costs include those used for economic costs in addition to a cost value associated with crash victim pain and suffering. The source for the values as of 1988 is from a report titled "The Costs of Highway Crashes" (6). Costs were updated from 1988 to 2002 using the implicit price deflator.

4.6 Present Value of Benefits Calculation

The software program automatically calculates an estimate of project benefits once all of the data is entered and relevant selections are made. The benefit calculation works as follows:

$$\text{Benefit}_t = \Sigma_i \ [\text{ Cumulative percent traffic growth}_t * \text{number of crashes in base year}_i * \text{Crash Reduction Factor}_{ik} * \text{Value per crash}_i]$$

where

- Benefit is the benefits in year t,
- Cumulative percent traffic growth is the growth in traffic between year t and the base year (mid-year of the 3-year period when crash data was collected). The default is a 3 percent annual growth rate, so that the cumulative increase in any give year is $1.03^{(t-b)}$
- number of crashes_i is the average number of annual crashes in the base year b (the year's when crash data was collected), where i denotes the type of crash (fatal crash, non-fatal injury crash, and property damage only crash).

- Crash Reduction Factor_{ik} is the reduction in crashes for type of crash i for highway segment improvement k.
- Value per crash_i is the value of each crash avoided (i.e., cost saved) by type of crash i.

The benefit from the segment improvement in any year t is the cost saved by avoiding fatal, non-fatal injury, and property damage only crashes in that year. The number of crashes avoided is a function of the predicted total crashes in that future year i plus the crash reduction factor due to the highway segment improvement k. The predicted number of crashes is the average annual crashes in the base year b times the accumulated increase in traffic between the years of b and t. This approach assumes the crashes rise linearly with traffic.

The number of crashes avoided in future year t is the number of crashes by type i multiplied by the crash reduction factor for each type of crash k. This crash reduction factor varies with the type of highway improvement. A particular highway improvement also often has a different reduction effect on fatal versus non-fatal injury versus property damage only crashes.

Valuation is possible after calculating the number of crashes avoided in year t. The number of fatal, non-fatal injury, and property damage only crashes avoided is simply multiplied by the value of each type of crash. These valuations are listed in Table 6.

The total safety benefit in each year t from avoided crashes is the basis for overall benefit calculations. The total benefit from the project is the sum of the benefits in each year over the life of the highway improvement, subject to discounting. Discounting accounts for the fact that benefits in future years are valued less than benefits in the current year. The default discount rate for the analysis is a 7 percent real (inflation-adjusted) rate. The sum of the discounted annual benefits is the Net Present Value of Safety Benefits of the project, as seen in the equation below.

$$\text{Net Present Value of Safety Benefits} = \Sigma_t^L (\text{Benefit}_t)*(1+d)^{-t}$$

where t = the year, beginning with year 1,
L = the life of the project, that is, the number of years that the project is expected to last before replacement; and
d = the discount rate.

4.7 Project Costs

An estimate of project costs is the second part of benefit-cost analysis. These costs refer to any design, construction, land acquisition, utility movement, or other costs associated with making the proposed highway improvement. In the current version of the software, the software user should enter these costs. Presumably, engineers or other experts would develop these costs estimates as they evaluate each project for inclusion in the HEP program.

Project Costs = Design costs + Land Acquisition Costs + Utility Movement Costs + Construction Costs + Other Costs

Costs estimates would be entered directly into a single text box in the program software. Given the size and scope of HEP program projects, it is assumed that projects can be completed during one calendar year. This initial construct year is considered to be “year 0” of the project. Thus, there is no need for discounting construction costs back to the present, and therefore, no need to enter any additional data.

4.8 Benefit Cost Calculation

Benefits and costs are compared in this software using a benefit-cost ratio. This ratio is simply the net present value of benefits divided by project costs, as seen in the equation below. The software automatically calculates this ratio based on all of the project information that the software user has entered (and internal calculations by the software).

Benefit-Cost Ratio = Net Present Value of Safety Benefits/Project Costs

The interpretation of the ratio is straightforward. A benefit-cost ratio of precisely 1.0 indicates that the project safety benefits are equivalent to project costs. A benefit-cost ratio larger than 1.0 indicates that project safety benefits exceed project costs. A benefit-cost ratio of less than 1.0 indicates that project safety benefits are less than project costs. This last condition may indicate that the project is not an economically feasible transportation investment.

Software users should use some caution, however, in interpreting the benefit-cost ratio information. As with any series of estimates, there is a margin for error in both benefit and cost calculations. This implies that there is also a margin for error in the estimate of the benefit-cost ratio itself. The software user as a result may not wish to use the precise figure of 1.0 when evaluating the economic feasibility of potential HEP program projects. The user may wish to use a value somewhat higher than 1.0 as indicating the project safety benefits are clearly greater than project costs, and a value somewhat lower than 1.0 to indicate that project costs are clearly greater. There is no set rule as to how much higher or lower these boundaries should be, so judgment is involved. As an example, a boundary of less than 0.8 might be used to suggest project costs clearly are greater than project benefits, while a boundary of greater than 1.2 might be used to suggest that project benefits are clearly greater.

5.0 CONVERSION OF THE DYNAMIC PROGRAMMING SOFTWARE FROM MAINFRAME TO PC-BASED

The University of Kentucky Center for Business and Economic Research (UK-CBER) translated the original mainframe-based dynamic programming model described in the July 1983 report “User’s Manual for Dynamic Programming for Highway Safety Improvement Program" by Mayes and Crabtree (12). The mainframe Fortran program was translated into a PC based Fortran program. The PC model maintains the features of the Fortran model. The model continues to calculate a benefit and cost ratio for each potential project, and utilizes these benefit cost ratios to find the optimal combination of projects given the size of the available program budget. This optimal allocation is driven in large part by the ranking of the projects in terms of benefits and costs, but as the available budget begins to be expended the dynamic programming feature chooses some lower ranked projects that are able to fit into budget limits. This yields a higher net benefit than a simple ranking of projects based on benefit-cost ratio because it leaves less of the project budget unexpended.

The Dynamic Programming Model also was enhanced in several important ways as it was translated to a PC framework. A menu driven system was added for model data entry. Flexibility was added for valuation of fatal crashes. A data saving system also allowed for the selection of projects within Kentucky Transportation Cabinet districts. Each of these enhancements is described below. A more detailed discussion of the methods for calculating projects costs and project benefit cost ratios is available in Section 3.0 of this report. A more detailed discussion of the dynamic programming technique is available in the report by Mayes and Crabtree (12).

5.1 Data Entry

Operation of the dynamic programming model requires the entry of a variety of both general information and information about each particular potential project. The general information for running the model includes the value placed on crashes, including fatal, non-fatal injury, and property damage only crashes. Other general information includes the discount rates used for future crashes, the expected growth rate for traffic, and the available budget. Specific information regarding each potential project includes the number of fatal, non-fatal injury, and property damage only crashes that have occurred in the last three years, the expected reduction factor for each type of crash, and expected project costs.

General information such as program budget is entered in individual cells in the window. Default information is provided for other factors such as the discount rates and expected traffic growth. Data for individual projects can be entered directly into the program. For each potential project, the user must enter the number of fatal, non-fatal injury, and property damage only crashes at a segment over the last three years. The user also must enter the expected reduction in each class of crash due to the proposed enhancement.

The user has the option of including multiple alternative improvements for a particular segment. Therefore, for a particular location, the user may enter alternative improvements. The program will not only select whether improvement of that segment is appropriate according to benefit cost criteria, but will select which alternative type of improvement is optimal.

Once entered, data can be saved for later retrieval. This is also a feature that will ease the use of this model, and allow the user to run multiple scenarios, or add additional potential projects as these come from the districts.

5.2 Fatal Crash Adjustments

Another feature of the PC framework model is its handling of the valuation of fatal crashes. In the mainframe model, all injury and fatal crashes were valued at the same rate. The logic was that there was an element of chance in the occurrence of a fatal crash in any particular highway segment. The assumption was that features of the segment would lead to a certain number of severe injury crashes, which would on occasion be fatal.

The difficulty with this approach is that some highway segments may be specifically prone to fatal crashes. Failure to count the full cost of these fatalities would tend to undermine the value of improving these segments.

The current model addresses both of these concerns with the following approach. The model values the first fatal crash that occurs in a particular highway segment over a 3-year period at the value of a non-fatal injury crash. Any additional fatal crashes are valued based on the value of a fatal crash. This approach assumes that one fatal crash in a segment is not evidence that this segment is prone to fatal crashes but that the occurrence of a second crash does. Crash costs in terms of 2002$ are presented in Table 7 for both economic and comprehensive costs. Either of these sets of costs can be used dependent upon the users desire for inclusion of all costs associated with a crash (comprehensive) or only direct costs excluding “pain and suffering” (economic).

5.3 Allocating to Regions of the State

An important issue when allocating funds within the HEP program is how those funds are allocated geographically throughout the state. In particular, there may be an interest in learning which are the best projects for selection within a particular region of the state, such as a particular Transportation Cabinet district. Such a calculation can be made with the PC based model. To do so, simply enter only the proposed projects that for the particular region of interest, and then save that file. Then, run the program only on that region and change the budget to reflect the amount of money to be allocated to that region.

6.0 SUMMARY

The objectives of this study were to review and analyze the current procedures for identifying high-crash locations and evaluating and prioritizing roadway safety improvements at these locations. As a result of these efforts, several procedures were updated and new or revised software was developed. Following is a summary of the significant accomplishments.

The history and background of the Hazard Elimination Program was documented, including guidelines of application by the Federal Highway Administration. An overview of the procedure and specific steps used in Kentucky for management and implementation of the Hazard Elimination Program was also documented.

Software used in Kentucky that is critical to the management of the Hazard Elimination Program was revised and updated to be compatible with the new crash report form implemented in 2000. This "Crash Buildup Program" was enhanced to be more efficient in operation, including the identification of overlapping spots or sections. Flexibility of application was also an outcome of the enhancements, as well as a more "user friendly" interface to simplify the process of identifying high crash locations.

The University of Kentucky Center for Business and Economic Research developed or updated two software programs for use in conducting economic analysis related to the HEP program. The first program was a PC version of an existing mainframe dynamic programming model used to select the optimal group of candidate projects for the HEP program given the program budget, and based on the relative benefits and costs of each project. In addition to converting the program to PC platform, a window to ease the process of entering input data for the program was also developed.

The second program was an original software package designed so that users could develop a benefit-cost estimate for candidate projects. This could be of use for district personnel when evaluating projects that should be pursued for more in-depth study, among other uses. Users must enter the recent accident history for the segment of interest, the proposed improvements, and the estimated costs for the improvements. The software then calculates a benefit-cost ratio for the project. Default parameters are the same for this software program and the dynamic programming program. In addition to the benefit-cost ratio as criteria for consideration as a HEP project, it was recognized that other criteria such as geographic distribution may influence the prioritization process. Prior to benefit-cost calculations, other criterion were considered in the crash buildup process including number of crashes, critical rate factor, and severity as it relates to the cost per crash.

7.0 REFERENCES

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Table 1

Critical Numbers for All Crashes in Kentucky (1999 – 2001)

	TYPE	SPOT/SECTION LENGTH (mile)		
		0.1	0.3	1
Rural	*All*	2	3	6
	2-Lane	2	3	5
	4-Lane	3	5	10
	Interstate	4	7	14
	Parkway	3	6	13
Urban	*All*	5	9	19
	2-Lane	3	6	12
	4-Lane Undivided	6	12	29
	4-Lane Divided	7	13	33
	Interstate	7	15	32

Table 2

Average Rates for All Crashes in Kentucky (1999 – 2001)

LENGTH	0.1-mile*		0.3-mile*		≥ 0.4-mile**	
	Rural	Urban	Rural	Urban	Rural	Urban
1-Lane	0.12	*N/A*	0.37	*N/A*	123	*N/A*
2-Lane	0.25	0.31	0.75	0.92	248	306
3-Lane	0.2	0.49	0.6	1.46	202	487
4-Lane Undivided	0.27	0.5	0.81	1.5	269	501
4-Lane Divided	0.12	0.31	0.36	0.94	120	313
Interstate	0.05	0.09	0.15	0.28	49	92
Parkway	0.05	0.1	0.16	0.3	55	160

* crashes per million vehicles
** crashes per 100 million vehicle miles

Table 3

All Three-Tenth Mile High Crash Locations with a CRF Greater than 5.0 Using a Critical Number of Three (1999 – 2001)

HD	CO	RT	SU	# CRASHES	BMP	EMP	NK	NI	ADT	RU	NL	MT	FC	Cact	Crate	CRF
5	56	9071		80	0	0.3	0	15	4530	Urban	2	mixed	17 C 1	6.128	0.993	16.244
3	71	79		44	11.695	11.995	0	10	901	Rural	2	None	7 MajC 4	4.598	3.503	12.732
4	47	31	W	48	1.2	1.5	0	12	1354	Rural	2	None	9 Local 3	2.375	2.919	11.09
6	59	17		106	23.09	23.39	0	44	4327	Urban	2	None	14 PA Non 2	2.372	2.161	10.354
7	3	9002		74	58.69	58.99	0	15	14546	Rural	4	Unprot	2 PA oth	4.646	0.45	10.334
7	11	2324		27	0	0.3	0	5	511	Urban	2	None	17 C 4	8.253	5.117	9.431
6	59	17		95	23.4	23.7	0	24	4327	Urban	2	None	14 PA Non 2	0.05	2.161	9.28
3	71	79		30	10.71	11.01	0	12	901	Rural	2	None	7 MajC 3	0.408	3.503	8.681
9	10	60		76	0	0.3	1	42	4256	Rural	2	Unprot	7 MajC 1	6.308	1.891	8.625
5	56	9264		173	0	0.3	1	50	39100	Urban	4	Unprot	11 PA Int	4.041	0.5	8.081
6	19	27		139	21.454	21.754	0	26	10012	Urban	2	None	14 PA Non 1	2.679	1.712	7.407
6	19	27		127	21.759	22.059	0	20	8896	Urban	2	None	14 PA Non 1	3.038	1.763	7.395
7	76	25		64	1.36	1.66	2	18	4420	Rural	2	None	7 MajC 1	3.223	1.867	7.081
1	79	641		89	8.35	8.65	0	32	7689	Rural	2	None	2 PA oth 1	0.571	1.578	6.698
3	71	79		23	12.01	12.31	0	8	901	Rural	2	None	7 MajC 2	3.313	3.503	6.655
6	41	22		75	10.86	11.16	0	19	13029	Rural	4	Curbed	7 MajC	5.257	0.804	6.537
5	56	9264		214	7.36	7.66	0	87	69498	Urban	6	Pos Bar	11 PA Int	2.812	0.443	6.35
6	59	17		65	22.778	23.078	0	23	4327	Urban	2	None	14 PA Non 1	3.719	2.161	6.349
6	59	17		90	22.47	22.77	0	30	6920	Urban	2	None	14 PA Non 1	1.877	1.884	6.306
6	59	8		120	6.75	7.05	0	35	10462	Urban	3	None	14 PA Non 1	0.475	1.694	6.185
6	59	17		29	0	0.3	0	9	1590	Rural	2	None	7 MajC 1	6.657	2.728	6.106
3	114	231		54	0.99	1.29	0	20	4710	Rural	2	None	2 PA oth 1	0.47	1.829	5.724
6	59	17		69	22.16	22.46	0	16	5486	Urban	2	None	14 PA Non 1	1.486	2.011	5.711
3	71	79		19	11.327	11.627	0	9	901	Rural	2	None	7 MajC 1	9.258	3.503	5.498
3	114	231		50	0.67	0.97	0	23	4710	Rural	2	None	2 PA oth	9.695	1.829	5.3
2	54	70		61	18.929	19.229	0	16	5134	Urban	2	None	16 MA 1	0.851	2.051	5.29
1	79	641		57	8.05	8.35	0	19	5824	Rural	2	None	2 PA oth	8.938	1.712	5.221
5	56	1020		56	10.68	10.98	0	16	4650	Urban	2	None	14 PA Non 1	0.998	2.113	5.205
1	42	45		24	16.82	17.12	0	4	1281	Urban	2	None	16 MA 1	7.11	3.363	5.088
7	34	68		274	2.88	3.18	0	93	36537	Urban	4	Unprot	14 PA Non	6.849	1.347	5.083
5	37	9064		57	57.57	57.87	1	20	30613	Rural	4	Unprot	1 PA Int	1.7	0.337	5.042
7	11	127		64	5.05	5.35	0	19	5920	Urban	2	None	14 PA Non	9.873	1.968	5.018

Table 4

Data Entry Requirements	
Data That Must Be Entered	
	• Type of Improvement or Improvements at Site
	• # of Crashes at Site Last 3 Years by Accident Type (Fatal, Injury, PDO)
	• Estimated Project Costs
Optional Data Entry (Default Values Exist)	
	• Discount Rate
	• Benefit Value by Accident Type (Fatal, Injury, PDO)
	• Projected traffic

Table 5

Improvement Options in Benefit Cost Ratio Estimation Software
Traffic Signals - Signal Upgrade – General
Traffic Signals - Signal Upgrade – Remove Unwarranted Signal
Traffic Signals - Signal Phasing – General
Traffic Signals - Signal Phasing – Add Exclusive Left Turn Phase
Traffic Signals - Signal Phasing – Add Protected/Permissive Left Turn Phase
Traffic Signals - Signal Phasing – Improve Timing
Traffic Signals - Signal Phasing – Add Pedestrian Phase
Traffic Signals - Signal Phasing - Add All-Red Interval/Increase
Traffic Signals - Signal Phasing – Interconnect Traffic Signals
Traffic Signals - Flashing Beacon – General
Traffic Signals - Flashing Beacon – Install at Intersection
Traffic Signals - Flashing Beacon – Intersection Advance Warning Flasher
Traffic Signals - Flashing Beacon – General Advance Warning Flasher
Pavement Markings - Raised Pavement Markers in Horizontal Curve
Pavement Markings - Raised Pavement Markers in Tangent Curve
Pavement Markings - Raised Pavement Markers in Horizontal Curve
Lighting – General
Lighting – Roadway Segment
Lighting – Intersection
Lighting – Interchange
Channelization – General Intersection
Channelization – Left Turn Lane With Signal
Channelization – Left Turn Lane Without Signal
Channelization – Right Turn Lane
Channelization – Increase Turn Lane Length
Pavement Treatment – General
Pavement Treatment – Resurfacing
Pavement Treatment – Pavement Grooving
Pavement Treatment – Rumble Strips (Horizontal Curve)
Pavement Treatment – Rumble Strips (Intersection)
Pavement Treatment – Rumble Strips (At Bridge)
Pavement Treatment – Shoulder Grooving
Roadside Improvement – Install Guardrail
Roadside Improvement – Upgrade Guardrail
Roadside Improvement – Install Median Barrier
Roadside Improvement – Impact Attenuator
Roadside Improvement – Remove Fixed Objects
Roadside Improvement – Relocate Fixed Objects
Roadside Improvement – Flatten Side Slopes
Roadside Improvement – Convert Hardware to Breakaway
Roadside Improvement – Upgrade Bridge Railing
Roadside Improvement – Gore Improvements
Construction/Reconstruction – Realignment-Horizontal Realignment/Curve Reconstruction
Construction/Reconstruction – Realignment-Vertical Realignment
Construction/Reconstruction – Realignment-Modify Horizontal/Vertical Realignment
Construction/Reconstruction – Realignmen-Realign Intersection
Construction/Reconstruction – Realignment-Modify Superelevation
Construction/Reconstruction – Realignment (Sight Distance Improvement on Horizontal Curve)
Construction/Reconstruction – Realignment (Sight Distance Improvement at Intersection)

Table 5 (continued)

Improvement Options in Benefit Cost Ratio Estimation Software
Construction/Reconstruction – Realignment (Sight Distance Improvement on Horizontal Curve)
Construction/Reconstruction – Realignment (Sight Distance Improvement at Intersection)
Construction/Reconstruction – Pavement Widening-Widen Pavement (Sections)
Construction/Reconstruction – Pavement Widening-Widen Pavement (Curves)
Construction/Reconstruction – Pavement Widening-Widen Shoulder 4ft or less
Construction/Reconstruction – Pavement Widening-Widen Shoulder Over 4 ft
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Tangent)
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Horizontal Curve)
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Intersection)
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Tangent)
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Horizontal Curve)
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Intersection)
Construction/Reconstruction – Additional Lanes-Add Passing/Climbing Lane
Construction/Reconstruction – Additional Lanes-Add Acceleration/Deceleration Lane
Construction//Reconstruction – Additional Lanes-Add Left-turn Lane
Construction//Reconstruction – Additional Lanes-Add Right-turn Lane
Construction//Reconstruction – Additional Lanes-Add Two-Way-Left-turn Lane
Construction/Reconstruction – Median- Add Mountable Median
Construction/Reconstruction – Median-Add Non-moutable Median
Construction/Reconstruction – Bridge-Widen Bridge
Construction/Reconstruction – Bridge-Replace Bridge
Construction/Reconstruction – Bridge- Bridge Deck Repair
Construction/Reconstruction – Intersection-Increase Turning Radii
Construction/Reconstruction – Intersection-Sight Distance Improvement
Construction/Reconstruction – Freeway - Consruct Interchange
Construction/Reconstruction – Freeway-Modify Entrance/Exit Ramp
Construction/Reconstruction – Freeway (Frontage Road)
Construction/Reconstruction – Freeway (Glare Screen)
Construction/Reconstruction – Other-Drainage Improvements

Table 6 Accident Reduction Rates and Project Life **Type of Improvement**	**Fatal Accident Reduction Rate**	**Non-Fatal Injury Accident Reduction Rate**	**PDO Accident Reduction Rate**	**Life of Project (Years)**
Traffic Signals - Signal Upgrade – General	20%	20%	20%	10
Traffic Signals - Signal Upgrade – Remove Unwarranted Signal	50%	50%	50%	20
Traffic Signals - Signal Phasing – General	25%	25%	25%	10
Traffic Signals - Signal Phasing – Add Exclusive Left Turn Phase	25%	25%	25%	10
Traffic Signals - Signal Phasing – Add Protected/Permissive Left Turn Phase	10%	10%	10%	10
Traffic Signals - Signal Phasing – Improve Timing	10%	10%	10%	10
Traffic Signals - Signal Phasing – Add Pedestrian Phase	25%	25%	25%	10
Traffic Signals - Signal Phasing - Add All-Red Interval/Increase	15%	15%	15%	10
Traffic Signals - Signal Phasing – Interconnect Traffic Signals	15%	15%	15%	10
Traffic Signals - Flashing Beacon – General	30%	30%	30%	10
Traffic Signals - Flashing Beacon – Install at Intersection	30%	30%	30%	10
Traffic Signals - Flashing Beacon – Intersection Advance Warning Flasher	25%	25%	25%	10
Traffic Signals - Flashing Beacon – General Advance Warning Flasher	35%	35%	35%	10
Pavement Markings - Raised Pavement Markers in Horizontal Curve	5%	8%	8%	2
Pavement Markings - Raised Pavement Markers in Tangent Curve	10%	10%	10%	2
Pavement Markings - Raised Pavement Markers in Horizontal Curve	8%	8%	8%	2
Lighting – General	18%	15%	15%	15
Lighting – Roadway Segment	18%	15%	15%	15
Lighting – Intersection	23%	23%	20%	15
Lighting – Interchange	20%	20%	18%	15

Table 6 (Continued)

Type of Improvement	Fatal Accident Reduction Rate	Non-Fatal Injury Accident Reduction Rate	PDO Accident Reduction Rate	Life of Project (Years)
Channelization – General Intersection	25%	25%	25%	10
Channelization – Left Turn Lane With Signal	20%	23%	25%	10
Channelization – Left Turn Lane Without Signal	40%	45%	50%	10
Channelization – Right Turn Lane	25%	25%	25%	10
Channelization – Increase Turn Lane Length	15%	15%	15%	10
Pavement Treatment – General	25%	25%	25%	20
Pavement Treatment – Resurfacing	25%	25%	25%	20
Pavement Treatment – Pavement Grooving	25%	25%	25%	10
Pavement Treatment – Rumble Strips (Horizontal Curve)	43%	33%	25%	20
Pavement Treatment – Rumble Strips (Intersection)	38%	30%	20%	20
Pavement Treatment – Rumble Strips (At Bridge)	43%	33%	25%	20
Pavement Treatment – Shoulder Grooving	25%	25%	25%	10
Roadside Improvement – Install Guardrail	58%	28%	0%	10
Roadside Improvement – Upgrade Guardrail	50%	35%	5%	10
Roadside Improvement – Install Median Barrier	65%	40%	5%	15
Roadside Improvement – Impact Attenuator	75%	50%	5%	10
Roadside Improvement – Remove Fixed Objects	58%	55%	53%	20
Roadside Improvement – Relocate Fixed Objects	53%	50%	48%	20
Roadside Improvement – Flatten Side Slopes	53%	40%	25%	20
Roadside Improvement – Convert Hardware to Breakaway	60%	25%	-5%	10
Roadside Improvement – Upgrade Bridge Railing	60%	30%	5%	10
Roadside Improvement – Gore Improvements	25%	25%	25%	20
Construction/Reconstruction – Realignment-Horizontal Realignment/Curve Reconstruction	40%	35%	33%	10

Table 6 (Continued) Type of Improvement	Fatal Accident Reduction Rate	Non-Fatal Injury Accident Reduction Rate	PDO Accident Reduction Rate	Life of Project (Years)
Construction/Reconstruction – Realignment-Vertical Realignment	40%	40%	45%	10
Construction/Reconstruction – Realignment-Modify Horizontal/Vertical Realignment	50%	50%	50%	10
Construction/Reconstruction – Realignment-Realign Intersection	40%	40%	40%	10
Construction/Reconstruction – Realignment-Modify Superelevation	23%	25%	30%	10
Construction/Reconstruction – Realignment (Sight Distance Improvement on Horizontal Curve)	5%	5%	5%	10
Construction/Reconstruction – Realignment (Sight Distance Improvement at Intersection)	60%	50%	40%	10
Construction/Reconstruction – Pavement Widening-Widen Pavement (Sections)	8%	10%	15%	20
Construction/Reconstruction – Pavement Widening-Widen Pavement (Curves)	10%	13%	18%	20
Construction/Reconstruction – Pavement Widening-Widen Shoulder 4ft or less	20%	20%	20%	20
Construction/Reconstruction – Pavement Widening-Widen Shoulder Over 4 ft	35%	35%	35%	20
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Tangent)	13%	15%	18%	20
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Horizontal Curve)	18%	18%	18%	20
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Intersection)	15%	15%	15%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Tangent)	10%	13%	13%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Horizontal Curve)	15%	15%	15%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Intersection)	13%	13%	13%	20
Construction/Reconstruction – Additional Lanes-Add Passing/Climbing Lane	20%	18%	15%	20
Construction/Reconstruction – Additional Lanes-Add Acceleration/Deceleration Lane	10%	10%	10%	20
Construction//Reconstruction – Additional Lanes-Add Left-turn Lane	25%	25%	25%	10
Construction//Reconstruction – Additional Lanes-Add Right-turn Lane	25%	25%	25%	10
Construction//Reconstruction – Additional Lanes-Add Two-Way-Left-turn Lane	30%	30%	30%	10
Construction/Reconstruction – Median- Add Mountable Median	15%	15%	15%	15

Table 6 (Continued) Type of Improvement	Fatal Accident Reduction Rate	Non-Fatal Injury Accident Reduction Rate	PDO Accident Reduction Rate	Life of Project (Years)
Construction/Reconstruction – Median-Add Non-mountable Median	25%	25%	25%	15
Construction/Reconstruction – Bridge-Widen Bridge	45%	45%	45%	20
Construction/Reconstruction – Bridge-Replace Bridge	45%	45%	45%	20
Construction/Reconstruction – Bridge- Bridge Deck Repair	15%	15%	15%	10
Construction/Reconstruction – Intersection-Increase Turning Radii	15%	15%	15%	10
Construction/Reconstruction – Intersection-Sight Distance Improvement	30%	30%	30%	10
Construction/Reconstruction – Freeway - Construct Interchange	55%	55%	55%	20
Construction/Reconstruction – Freeway-Modify Entrance/Exit Ramp	25%	25%	25%	10
Construction/Reconstruction – Freeway (Frontage Road)	40%	40%	40%	20
Construction/Reconstruction – Freeway (Glare Screen)	15%	15%	15%	20
Construction/Reconstruction – Other-Drainage Improvements	20%	20%	20%	20
Construction/Reconstruction – Realignment-Modify Horizontal/Vertical Realignment	50%	50%	50%	10
Construction/Reconstruction – Realignment-Realign Intersection	40%	40%	40%	10
Construction/Reconstruction – Realignment-Modify Superelevation	23%	25%	30%	10
Construction/Reconstruction – Realignment (Sight Distance Improvement on Horizontal Curve)	5%	5%	5%	10
Construction/Reconstruction – Realignment (Sight Distance Improvement at Intersection)	60%	50%	40%	10
Construction/Reconstruction – Pavement Widening-Widen Pavement (Sections)	8%	10%	15%	20
Construction/Reconstruction – Pavement Widening-Widen Pavement (Curves)	10%	13%	18%	20
Construction/Reconstruction – Pavement Widening-Widen Shoulder 4ft or less	20%	20%	20%	20
Construction/Reconstruction – Pavement Widening-Widen Shoulder Over 4 ft	35%	35%	35%	20
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Tangent)	13%	15%	18%	20
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Horizontal Curve)	18%	18%	18%	20

Table 6 (Continued) Type of Improvement	Fatal Accident Reduction Rate	Non-Fatal Injury Accident Reduction Rate	PDO Accident Reduction Rate	Life of Project (Years)
Construction/Reconstruction – Pavement Widening-Shoulder Stabilization (Intersection)	15%	15%	15%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Tangent)	10%	13%	13%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Horizontal Curve)	15%	15%	15%	20
Construction/Reconstruction – Pavement Widening-Pave Shoulder (Intersection)	13%	13%	13%	20
Construction/Reconstruction – Additional Lanes-Add Passing/Climbing Lane	20%	18%	15%	20
Construction/Reconstruction – Additional Lanes-Add Acceleration/Deceleration Lane	10%	10%	10%	20
Construction//Reconstruction – Additional Lanes-Add Left-turn Lane	25%	25%	25%	10
Construction//Reconstruction – Additional Lanes-Add Right-turn Lane	25%	25%	25%	10
Construction//Reconstruction – Additional Lanes-Add Two-Way-Left-turn Lane	30%	30%	30%	10
Construction/Reconstruction – Median- Add Mountable Median	15%	15%	15%	15
Construction/Reconstruction – Median-Add Non-mountable Median	25%	25%	25%	15
Construction/Reconstruction – Bridge-Widen Bridge	45%	45%	45%	20
Construction/Reconstruction – Bridge-Replace Bridge	45%	45%	45%	20
Construction/Reconstruction – Bridge- Bridge Deck Repair	15%	15%	15%	10
Construction/Reconstruction – Intersection-Increase Turning Radii	15%	15%	15%	10
Construction/Reconstruction – Intersection-Sight Distance Improvement	30%	30%	30%	10
Construction/Reconstruction – Freeway - Construct Interchange	55%	55%	55%	20
Construction/Reconstruction – Freeway-Modify Entrance/Exit Ramp	25%	25%	25%	10
Construction/Reconstruction – Freeway (Frontage Road)	40%	40%	40%	20
Construction/Reconstruction – Freeway (Glare Screen)	15%	15%	15%	20
Construction/Reconstruction – Other-Drainage Improvements	20%	20%	20%	20

Table 7

	Crash Costs in 2002$	
	Economic	Comprehensive
Fatal Crash	$1,007,276	$3,724,130
All Injury Crashes (includes fatal)	$44,896	$158,356
PDO Crash	$5,265	$6,140

Source: Miller, Ted R., J. Viner, S. Rossman, N. Pindus, W. Gellert, J. Douglass, A. Dillingham, and G. Blomquist, 1991. *The Costs of Highway Crashes.* Washington, D.C.: The Urban Institute. Updated using the implicit price deflator.

Figure 1

Summary Output of High Crash Locations

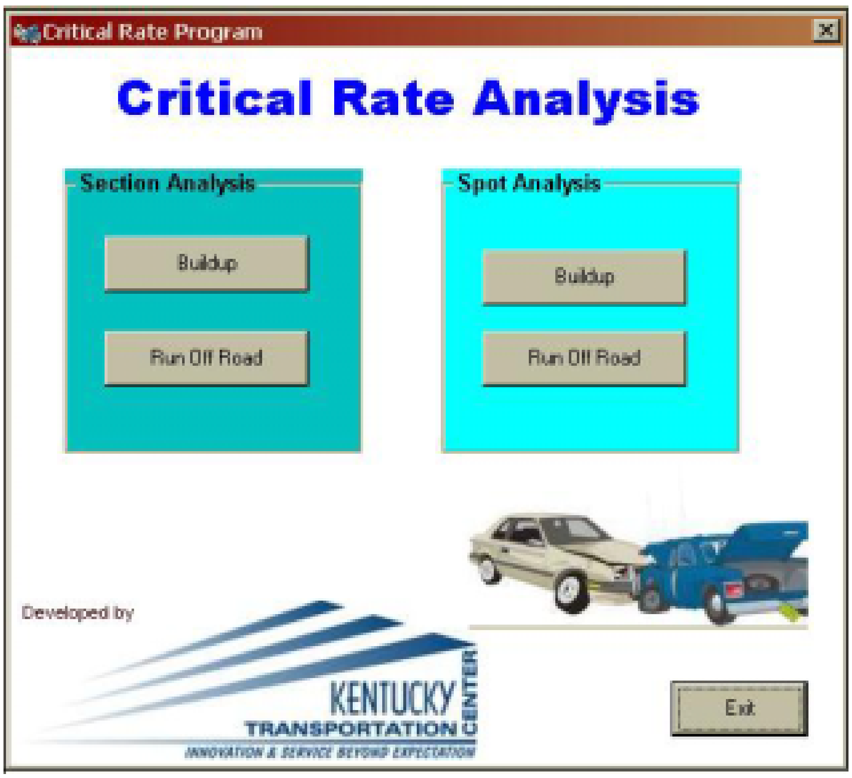
```
******** S P O T  ********
 The Length is             .300
 The Critical Number is     5
 Allcrashes in KY from 1999 to 2001

        Total Number of Spots/Sections:      10412
 Number of Spots/Sections with CRF >=1:       3532


               0.1              0.3            >=0.4
            R       U       R       U      R       U
-----------------------------------------------------
     1     .12     N/A     .37     N/A    123.     N/A
     2     .25     .31     .75     .92    248.    306.
     3     .20     .49     .60    1.46    202.    487.
    4U     .27     .50     .81    1.50    269.    501.
    4D     .12     .31     .36     .94    120.    313.
  INTS     .05     .09     .15     .28     49.     92.
   PRK     .05     .10     .16     .30     55.    160.

Total Number of Spots/Sections with a CRF>=1 by County

 1)    6|       31)    5|       61)   39|       91)    5|
 2)   10|       32)    7|       62)   19|       92)   17|
 3)   24|       33)    8|       63)   93|       93)   44|
 4)    4|       34)  136|       64)    5|       94)   13||
 5)   20|       35)   11|       65)    1|       95)    1|
 6)   18|       36)   59|       66)   10|       96)   12|
 7)    9|       37)   62|       67)   21|       97)   44|
 8)  118|       38)    1|       68)    7|       98)  102|
 9)   15|       39)    5|       69)   13|       99)   11|
10)   49|       40)   23|       70)    9|      100)   72|
11)   31|       41)   55|       71)   29|      101)    0|
12)   19|       42)   39|       72)   13|      102)   18|
13)   19|       43)   26|       73)   65|      103)   43|
14)    2|       44)    6|       74)   18|      104)    4|
15)   59|       45)   22|       75)    4|      105)   46|
16)    9|       46)    5|       76)   92|      106)   46|
17)    7|       47)   71|       77)    7|      107)   24|
18)   38|       48)   21|       78)   20|      108)    3|
19)   67|       49)   26|       79)   46|      109)   24|
20)    1|       50)    8|       80)   17|      110)   17|
21)   25|       51)   47|       81)   29|      111)   13|
22)   13|       52)   19|       82)   14|      112)    6|
23)    5|       53)    0|       83)    1|      113)   24|
24)   61|       54)   62|       84)   13|      114)   98|
25)   27|       55)    7|       85)    8|      115)   11|
26)   12|       56)  318|       86)    3|      116)   20|
27)    6|       57)   58|       87)   39|      117)   13|
28)    8|       58)   26|       88)   15|      118)   28|
29)    1|       59)  117|       89)   43|      119)   11|
30)   56|       60)   21|       90)   39|      120)   20|

Total Number of Spots/Sections with a CRF>=1 by Highway District

 1)  237
 2)  339
 3)  223
 4)  240
 5)  557
 6)  457
 7)  524
 8)  163
 9)  204
10)  118
11)  219
12)  251
```

Appendix A

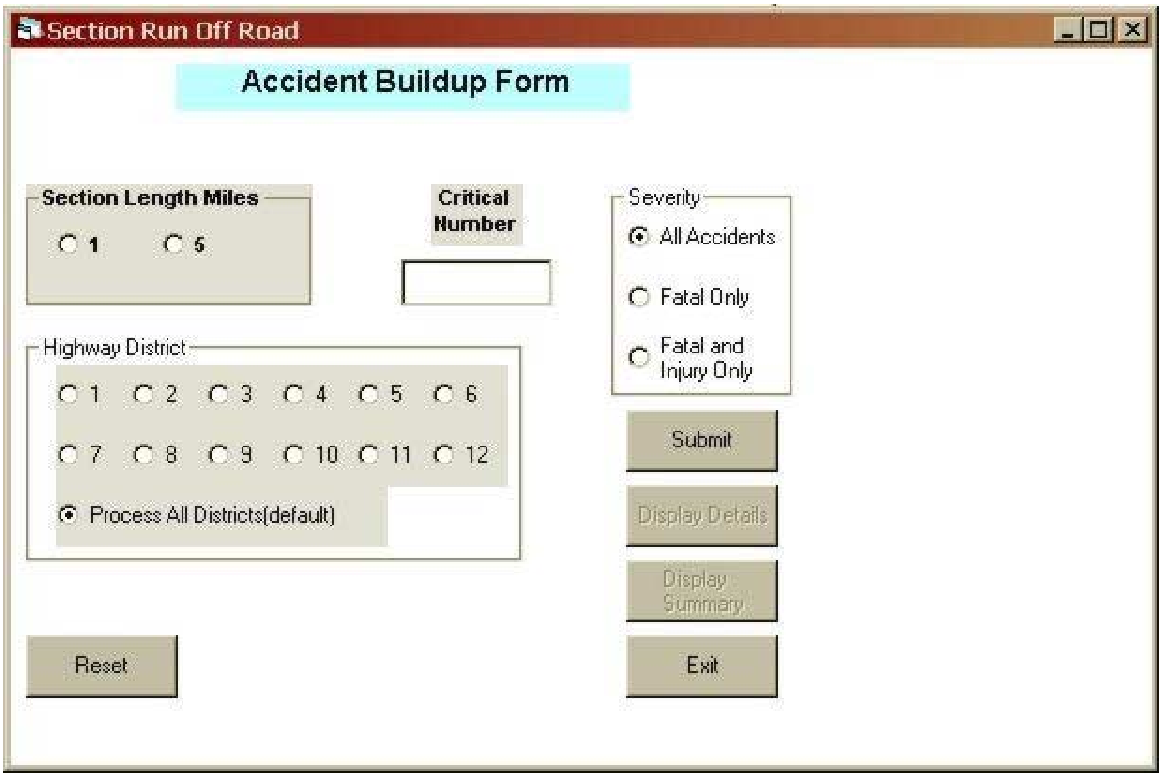
Description of High Crash Location Identification Software

The following is a description of how the software is used to identify high crash locations using crash and volume data. This may be used for instruction purposes and to understand the functions of the software.

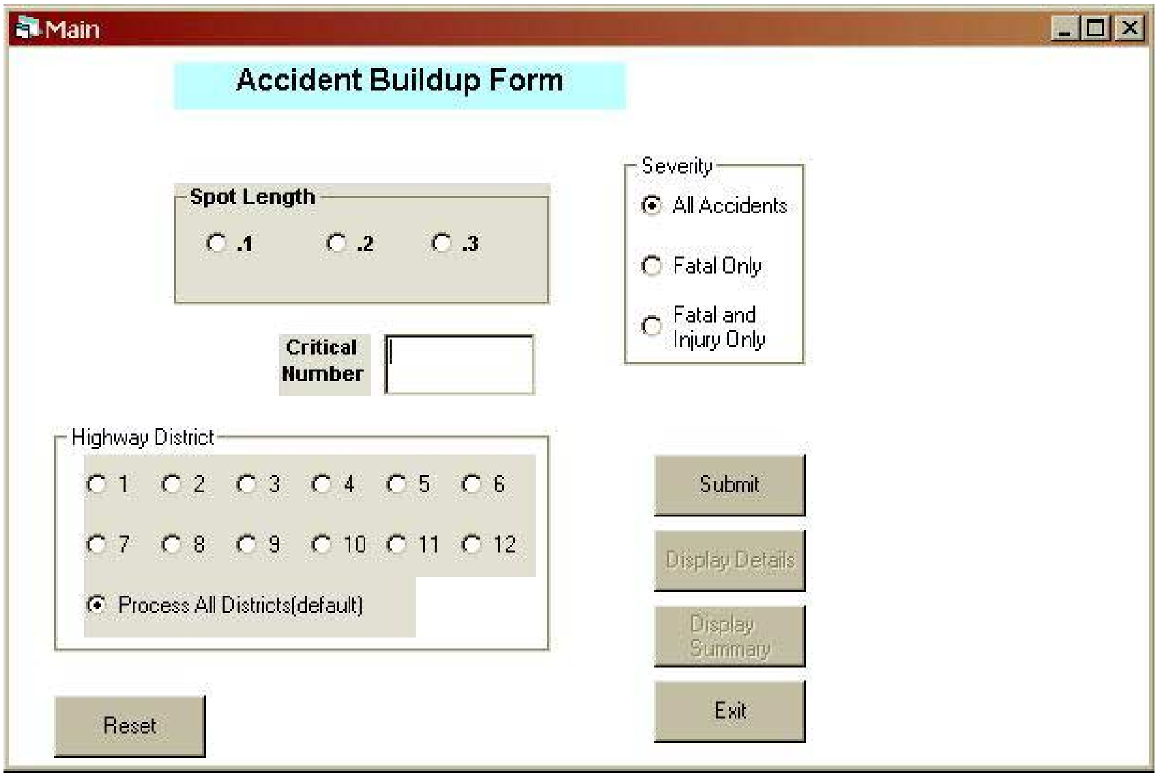
The program begins with an introduction screen allowing the user to choose either section or spot analysis. In addition the user can choose either the buildup or run-off-road analysis. Both of these options operate in the same fashion; however, the buildup option will analyze all crashes while the run-off-road option will only query crashes coded as run-off-road. The user can click any of the four buttons to begin with the chosen analysis or choose ‘exit’ to terminate the program. The following screenshot shows these options.



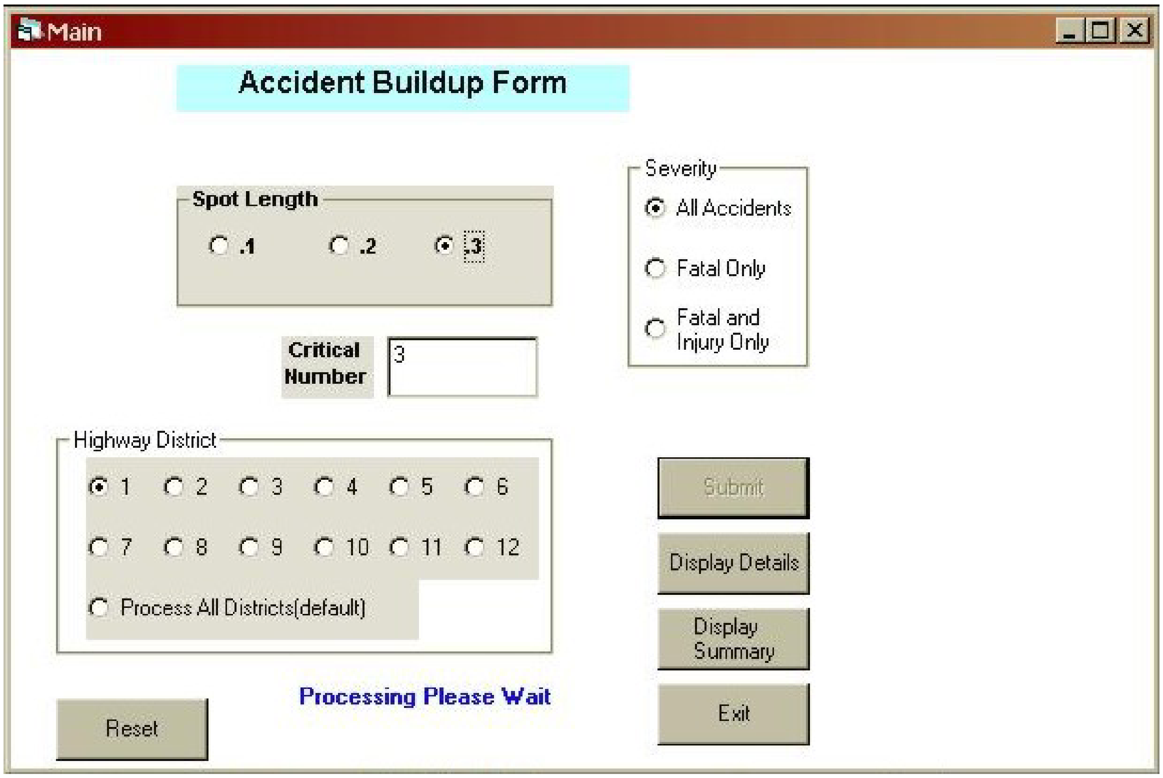
If the user chooses the section analysis a new screen is displayed. The user is prompted for the section length (either 1 or 5 miles) and the critical number (user defined). The user may also choose to analyze data from one specific highway district by simply clicking the appropriate radio button. The default analysis is 'all districts.' Additionally, the user may choose to analyze specific severity classes: All Crashes (default), Fatal Only, or Fatal and Injury Only. The following screenshot displays these options.



If the user chooses the spot analysis a different window is opened. The functions of this analysis are identical to the section analysis with the exception of the spot length. The user now chooses either a 0.1-mile, 0.2-mile or 0.3-mile spot. The following screenshot displays the spot analysis interface.



The submit button can be clicked after the user selects the appropriate options. The program will process the information. After the locations are determined two new buttons will be available. The user can now display the results in detail (a Microsoft Excel file will be executed) or in summary (a Microsoft Word document will be executed). The following screenshot shows this interface.



When the results are displayed in detail or summary, the data can be printed, sorted, or saved as with any office document. The form can also be reset to start a new query or exited. An example of the format of the "display details" is given in Table 3 and an example of the "display summary" format is given in Figure 1.