# EVALUATING HAZARDOUS ROADSIDE LOCATIONS
# using the
# ROADSIDE-HAZARD-SIMULATION-MODEL
# VERSION 9 (1992)

*by*

**Paul C. de Leur**

B.Sc., University of Saskatchewan, 1988

A thesis submitted in the partial fulfilment of
the requirements for the degree of

**MASTER OF APPLIED SCIENCE**

*in*

THE FACULTY of GRADUATE STUDIES
DEPARTMENT of CIVIL ENGINEERING

We accept this thesis as conforming
to the required standard

... ..........

... ..........

.... ..........

..........................................................................................

THE UNIVERSITY OF BRITISH COLUMBIA

September 1992

..............

Department of Civil Engineering

University of British Columbia
2324 Main Mall
Vancouver, British Columbia
Canada, V6T 1Z4

September, 1992

**ABSTRACT**

Vehicles that "run-off-the-road" and crash into a hazardous roadside are a significant problem, accounting for 14.3 percent of all highway accidents in the Province of British Columbia. The computer tool developed in this project is designed to help evaluate hazardous roadside locations and evaluate various improvement alternatives proposed to reduce the level of hazard. The hazard level at any location may be reduced by: flattening the embankment slope, installing a roadside barrier, removing hazardous objects, or any combination of the three. The evaluation tool, a computer simulation model, identifies the "best" solution from a set of improvement alternatives simulated for a hazardous location.

The computer simulation model is called the Roadside-Hazard-Simulation-Model Version 9.0 (RHSM.V9), and was developed after a great deal of effort was devoted to simply modifying and revising one of the previous versions of the model (RHSM.V5 (1978), RHSM.6-2 (1982), or RHSM.V7 (1986)). The new model was developed using the important components of the previous versions and anticipating the additional factors needed in the new model. Making the new-version user-friendly and flexible was important since previous versions were difficult to use, unforgiving in nature, and consequently rarely used.

There are a number of objectives which RHSM.V9 satisfies. First, the model simulates an errant vehicle's trajectory upon leaving the roadway. Secondly, the model is capable of accurately simulating the hazards that exist in the roadside. Third, the model simulates the

roadway conditions, as well as the errant vehicle's characteristics. The fourth objective, which is dependant upon the first three objectives, determines the consequence of the vehicle leaving the roadway and entering a hazardous roadside. Finally, the model does an economic evaluation of the improvement alternatives proposed for the location and identifies the best solution for the hazardous roadside location.

The model's performance was illustrated by performing numerous program runs and then evaluating the results produced by the model. The evaluation included a results comparison with previous versions of the model, a results evaluation for various hazardous embankment slopes and roadside objects, and a sensitivity analysis of the operational parameters and economic factors used in the model. Also included in this evaluation were four typical examples from "real-life" applications. After preliminary testing of the model, the results, and the trends in the results, appear to be valid.

The general conclusion of this thesis is that RHSM.V9 can be used to improve the engineering analysis process in evaluating hazardous roadside locations. The program is a user-friendly computer tool to assist highway safety professionals in making a decision regarding the implementation of roadside safety improvement alternatives. The final decision must be made in conjunction with sound engineering judgement. Further research and updating may be easily incorporated since the program has been structured such that as better calibration information becomes available, it can be immediately and easily included in the new model.

**TABLE OF CONTENTS:**

**TABLE OF CONTENTS (continued)** Page

**LIST OF FIGURES:**

**LIST OF FIGURES (continued)**

**LIST OF TABLES:**

**LIST OF TABLES (continued)** Page

**LIST OF TABLES (continued)** Page

**ACKNOWLEDGEMENTS**

There are many people I would like to acknowledge who provided support during the course of this research project. From the University of British Columbia, Dr. Francis Navin, who not only provided supervision and direction for this thesis, but also provided funding through his Natural Science and Engineering Research Operating grant during the early stages of my degree. Dr. Gerald Brown for his positive guidance, assistance, and evaluation of this thesis. Formerly of British Columbia Research, Mr. Paul Roer, P. Eng., for his helpful insight and experience with the development of the original simulation model.

The staff from the Ministry of Transportation and Highways, Highway Safety Branch, that I would like to acknowledge include: Mr. Lorne Holowachuk, P. Eng., for providing financial and motivational support for the research project. Dr. Walid Abdelwahab for his direct supervision and beneficial suggestions throughout the development of this research project. Mr. Brad Blaney for his technical expertise and advise at critical stages of the project.

Credit must also be given to my classmates from the University of British Columbia. I would like to acknowledge and thank my friend, Mr. Norman Stang for his extraordinary effort in helping with the programming of the simulation model. I must also acknowledge and thank Mr. Chris Nutakor, Mr. Tarek Sayed, and Mr. Mohsen Ghazel for their constructive suggestions, criticism, and friendship.

Finally, I would like to acknowledge and thank my parents, Mary and Francis de Leur for their love and support throughout my academic endeavours, Mr. Michael de Leur, my brother, for his objective criticism and research expertise, and Miss Pam Lacey for her encouragement, understanding, and sacrifice during this research project.

Paul C. de Leur

# 1.0 INTRODUCTION

## 1.1 Background

"Run-off-the-road" vehicle crashes are a significant problem in the Provence of British Columbia. There were 21874 such accidents reported from 1986 to 1991 on British Columbia Highways, representing 14.3% of the total number of reported highway accidents. Run-off-the-road accident severity in terms of property damage, level of injury, and fatality rate, are often worse than for other types of roadway accidents.

The total cost of "run-off-the-road" accidents is very high. This total cost includes: property damage, effect of injury level on income loss or earning capacity, administrative and medical costs such as police, ambulance, and hospital costs, and the societal and intangible costs associated with fatal accidents. Also, as the severity of an accident increases, the cost of the accident also increases dramatically. For example, the British Columbia Ministry of Transportation and Highways (M.o.T.H.), estimates the average cost of a property damage accident to be $4,000, a non-fatal injury accident to be $15,000, and a fatal accident to be $600,000. The British Columbia government recently announced that the annual cost of road accidents was nearly $2 billion dollars, therefore, the cost of "run-off-the-road" accidents is very high due to the high frequency and severe consequences of this type of accident. Reducing the cost of highway accidents is another objective of highway officials and researchers concerned with improving highway safety.

## 1.2 Research Objectives

The goal of this study is to develop a convenient computer tool which can be used to evaluate hazardous roadside conditions and evaluate safety improvement alternatives proposed to reduce the level of hazard. The hazard level at a particular location may be reduced by: flattening the embankment slope, installing a roadside barrier, removing hazardous objects, or any combination of the three. The evaluation tool, which is in the form of a computer program, assists highway safety professionals determine which safety improvement alternatives are warranted for an identified hazardous location.

In order to achieve the goal of this study, a number of objectives are defined below.

Objective 1: Based on the previous versions of the Roadside-Hazard-Simulation-Model (RHSM) [1], develop a new model capable of quickly and accurately assessing the hazard level for various roadside conditions.

Objective 2: Validation of RHSM.

Objective 3: Analyze the probability of consequence of a vehicle having an off-road excursion and then compare the results with the vehicle encountering the proposed improvement alternatives for the location under review.

Objective 4: Determine the optimum solution for any given location by conducting an economic analysis of roadside improvement alternatives.

Objective 5: Generate typical examples to illustrate the usefulness of the program by identifying improvement alternatives which maximize safety benefits, while minimizing the cost to implement the safety improvement alternative.

### 1.3 Problem Statement

To reduce the frequency, severity, and hence the total cost of "run-off-the-road" accidents, one of four improvement alternatives are usually recommended. These include:

1. *Do-Nothing:* Leave the adjacent roadway unprotected. This alternative is recommended for locations where no improvement alternative will decrease accident severity or be employed cost-effectively.
2. *Flatten the Slope:* Modify the terrain of the adjacent roadway, including flattening the embankment slope or rounding the terrain changes.
3. *Install a Barrier:* Install a roadside barrier. The hazard of installing the barrier must be less than the hazard associated with an off-road excursion. This will satisfy an equal severity criterion.
4. *Remove the Hazards:* Remove or relocate the hazardous elements that exist in this area, including all type of hazardous objects.

The decision to implement an improvement alternative is based on the probability of an accident's occurrence, the probability of the consequence if an accident occurs, and the benefit-cost ratio analysis and/or cost-effectiveness analysis of implementing the improvement alternative.

In the evaluation of the four improvement alternatives listed above, many factors associated with an errant vehicle having an off-road excursion must be considered. These include:

1. Road geometry, including the horizontal and vertical alignments and the cross-sectional elements of the roadway.

2. Terrain characteristics which includes embankment slope, embankment height, and hazardous features such as utility poles, sign posts, bridge abutments, rock-cuts, or any feature which would cause harm if it were struck by an errant vehicle.
3. Vehicle speed and vehicle characteristics.
4. The vehicle's encroachment angle and the location of the vehicle departure in relation to the roadside.
5. Traffic conditions and traffic composition, and the variation of these components during a specified time period.
6. The use of passenger restraint devices (seat-belts), the degree of effective braking as the motorists attempt to stop the vehicle, and the ability of the driver to recover or steer-back from a roadside encroachment.
7. Climatic conditions, including driver visibility.
8. The vehicle operator's physical ability to operate the vehicle safely such as the variation in human reflexes, poor eye-sight, driver experience (ie. new driver versus experienced driver or city driver versus country driver) or intoxication.
9. The costs of the accidents expected as a result of the implementation of any improvement alternative, and the mitigation costs required to implement the option.

The complexity and unquantifiable nature of many of these factors produce difficulty in the probability of consequence analysis of an errant vehicle leaving the roadway. To facilitate this difficult analysis, a computer program called **Roadside-Hazard-Simulation-Model** (RHSM) [1] was developed for Transport Canada by BC Research. The model is based on real accident data from research studies and the results from full-scale crash testing. The analysis estimates the change in vehicle velocity and the abruptness of velocity change or deceleration when the vehicle experiences an off-road excursion. This quantity may be expressed in terms of power loss which is defined as the amount of dissipated energy during a specified time interval, and subsequently, a severity index can be established based on this rate of power loss. The severity index represents the accident occurrence (in terms of a probability) and is divided into four categories: no damage (ND), property damage only (PDO), personal injury (INJ), and fatality (FAT). Each category represents a different level of power loss, with small changes in power loss indicating a minor accident and large power dissipation indicating a severe accident.

Numerous revisions to the RHSM program have occurred over the years, however a reasonable, recent working version of the program has not been found. One of the earlier versions of the program, Version 5, appeared to show the most promise for enhancement according to a Ministry of Transportation and Highways review. A later version, Version 6.2, incorporated various new factors into the program but the results appeared to be unrealistic. The latest version, Version 7, incorporated even more factors into the program and as a result the program became too complicated, and the changes were not validated due to numerous programming errors. A thorough review of the model was made and it was determined that a new model had to be developed in order to obtain accurate and trustworthy results.

Once an accurate and running version of the RHSM computer program was developed, the next problem was to determine the consequences of an errant vehicle leaving the roadway for a variety of roadside configurations, hazards, and conditions. To check the validity of the simulation model, the results of a test location are compared to a location where actual accident data is available. A good correlation between the program results and expected results was accepted as validating the simulation model.

The economic analysis of the consequences of an errant vehicle leaving the roadway forms the final component of the new version of RHSM. Once the validation of the simulation model is complete and the probability of consequence has been determined, an economic priority ranking system can be established to evaluate roadside safety improvements. Both a benefit-cost ratio approach and a cost-effectiveness approach has been taken to evaluate the different improvement alternatives, with the alternative that offers the greatest "return" in terms of safety and cost-effectiveness, chosen as the optimal solution. The main problem in this aspect of the project is to accurately define the costs associated with each improvement alternative.

The completion of the economic analysis leads to the final problem to be completed: to illustrate the application of the model for "real-life" situations on British Columbia's highway system. The model's effectiveness will be shown by providing an example of how each of the four improvement alternatives can be warranted for typical British Columbia highway conditions.

## 1.4 Solution Strategy

In order to successfully achieve the project objectives and to solve the research problems, an effective solution strategy must be adopted. Figure 1.1 below, shows a flow-chart illustrating the solution strategy used for this project.

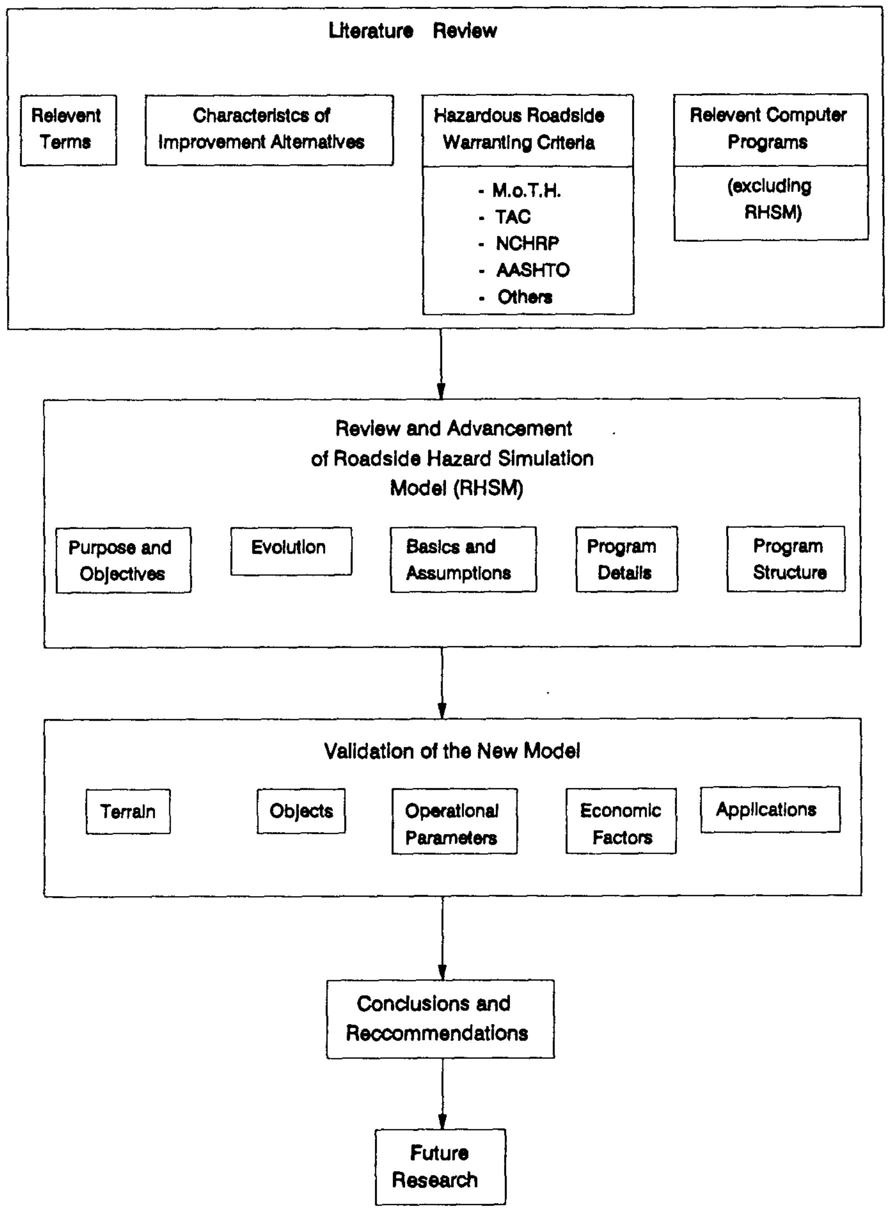



Figure 1.1: Flow Chart of Solution Strategy

### 1.5 Scope of the Project

This research project is divided into six parts. This first chapter is an introduction to the project and gives the purpose, the objectives, the problem, the solution strategy, and the scope of the work. The second chapter is the literature review of the information related to roadside improvements, barrier warranting, and off-road hazards as well as other roadside safety computer programs. The third chapter details the review and advancement of the RHSM program, providing a discussion of all the components of the model including the economic evaluation used in the model. The fourth chapter details the evaluation of the new model, reviewing the probability of consequence of an errant vehicle having an off-road excursion for the various proposed improvement alternatives. This is completed for many typical hazardous locations. Also included in chapter four is a sensitivity analysis of all the variables used in the new version of RHSM. The fifth chapter provides a series of conclusions drawn from this research project and discusses the application of the model for use to evaluate hazardous locations on British Columbia's highways. Finally, the sixth chapter suggests further research to enhance the work completed in this project.

## 2.0 LITERATURE REVIEW

This chapter provides a detailed description and review of the literature which is relevant to the topic of off-road accidents including: barrier warrants, slope flattening, and the removal of hazardous objects from the roadside. Research on the need to improve hazardous roadsides began as early as the 1920's, however, it was not until the 1950's that significant research was reported. Although much of this review may appear to deal specifically with roadside barriers, improvement options such as slope flattening or object removal are considered within the barrier warrant review.

### 2.1 Characteristics of Improvement Alternatives for Hazardous Roadsides

Slope Reduction

In many instances the best solution for a hazardous roadside may include the modification of the embankment slope geometry. This includes either reducing the severity of the embankment slope or the rounding of abrupt changes in roadside terrain slope. The main hazard to errant vehicles caused by a steep embankment slope is the high probability of vehicle roll-over. By reducing or rounding the roadside slope, the probability of roll-over reduces. The greater the flattening of the roadside slope or the more gradual the rounding, the less chance there is of roll-over and thus, the less severe the accident consequences.

Barrier Installation

The general requirement for any type of traffic barrier is to make the highway safer by reducing accident severity [2] since barriers often increase the frequency of accidents. The functions and performance characteristics for a longitudinal barrier include:

1. To prevent an errant vehicle from penetrating into a hazardous off-road location.
2. Redirect errant vehicles into a direction that is parallel to traffic flow, thus minimizing the danger for following and nearby traffic.
3. Minimizing the hazard for the vehicle occupants during impact such that vehicle occupants and nearby traffic are not endangered by a collision with the barrier. Vehicle or barrier fragments can be hazardous if allowed to enter into the passenger compartment of the vehicle or if fragments are deposited on roadway, they become a hazard for other traffic not previously involved in the accident [3].
4. The barrier should be resistive to impact damage upon collision of an errant vehicle.
5. The barrier should be economical to construct, install, and maintain.
6. The barrier should be aesthetically pleasing and be visible under any conditions.

Hazardous Object Removal

Any object which could be encountered by an errant vehicle travelling into a roadside is considered a hazard. The degree of hazard is dependant upon the probability of striking the hazard and the stiffness of the object. The greater the probability of striking the object and the greater the stiffness of the object, the greater the hazard to the vehicle's occupants. Some hazardous objects can be made such that they pose little or no hazard to errant vehicles such as breakaway poles and signs. However, many man-made hazardous roadside objects cannot be made breakaway, not to mention the natural roadside objects such as trees or rock-outcrops that to be shielded from roadway traffic or removed completely.

### 2.2 Warranting Criteria for Hazardous Roadsides

Much of the literature related to a hazardous roadside deals specifically with the warranting criteria for the installation of longitudinal traffic barriers. The components related to flattening the embankment slope and removing hazardous objects are dealt with directly within the barrier warranting criteria. This section reviews the procedures used by five different agencies in Canada, the United Stated, and parts of Europe.

#### 2.2.1 M.o.T.H.: Ministry of Transportation and Highways

*British Columbia's Design Standards Manual*

The province of British Columbia's Ministry of Transportation and Highways has compiled a Design Standards Manual [4] for many aspects of highway design considerations. Included in the manual is a roadside barrier index warrant, labelled as design manual No. B.2-11, developed in February 1982 and revised in June 1987.

The roadside barrier warrant is presented in the form of a nomograph. The range of various factors utilized in the nomograph is presented in Table 2.1, and the nomograph and an example are shown in Figure 2.1. This is the standard currently being used by M.o.T.H. in determining the need for a barrier installation at a hazardous location.

To illustrate how the nomograph works consider the following example drawn on Figure 2.1. Given a design speed of 100 kph, an outside curve radius of 380 m, a fill height of 2.4 m, a shoulder width of 3.0 m, a summer average daily traffic of 7000 vpd, and moderate freezing conditions, the resulting barrier need index from the nomograph is 110. With an f-factor of 0.127 and the effective fill height is 12.0 m the first point on the nomograph is identified and then followed through each step of the nomograph until a value of 110 is read. According to M.o.T.H standards, barrier is warranted at a index score of 90 or above.

Table 2.1 Factors Considered by M.o.T.H Nomograph

| Factor | Range and Effect on Barrier Need Index | |
|---|---|---|
| Outside Curve/ Design Speed | The combination of these factors will produce a lateral friction factor (f) which identifies the origin on the nomograph. | |
| Effective Height of Fill | range:<br>effect: | below 3.0 meters to more than 21.0 m.<br>as the fill height increases, the barrier need index increases. |
| Shoulder Width | range:<br>effect: | less than 1.2 m. to 6.1 m.<br>as the shoulder width increases, the barrier need index decreases. |
| Summer Average Daily Traffic | range:<br>effect: | from 1000 or less to 9000 or more.<br>as S.A.D.T increases, barrier need index increases. |
| Road Gradient | range:<br>effect: | from -6% grade to +6% grade.<br>as grade increases, barrier need index decreases. |
| Fill-Slope | range:<br>effect: | from 4:1 to 1.25:1.<br>as fill-slope steepens, barrier index increases. |
| Climatic Conditions | range:<br>effect: | from significant freezing to no freezing<br>as the climatic conditions become less severe, the barrier need index decreases |

Source: BC Ministry of Transportation and Highways Design Standards Manual (1991)

Although the use of the nomograph provides a clear and discrete indication of whether a barrier should be used at a particular location, it lacks detail to gain overwhelming confidence in the results. Many more factors should be considered in determining whether a barrier is warranted such as the encroachment rate, accident consequence, and the economics of a barrier installation. Another problem is the inability to accurately manoeuvre through the nomograph without loosing accuracy.

## BARRIER USUALLY NOT WARRANTED

1. When in a cut or on a fill with less than 3m effective height.
2. When overall shoulder width is greater than 6m.
3. When fill slope is flatter than 4 to1.
4. When Barrier Need Index is less than 90.

Exceptions to these restrictions may be made with approval of the Highway Safety Engineer.

### OUTSIDE CURVES

Design Speed 50 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 330* | .060 | .040 | .020 |
| 300 | .066 | .042 | .024 |
| 250 | .079 | .048 | .031 |
| 220 | .089 | .051 | .038 |
| 190 | .104 | .056 | .048 |
| 170 | .116 | .059 | .057 |
| 150 | .131 | .063 | .068 |
| 130 | .151 | .067 | .084 |
| 110 | .179 | .072 | .107 |
| 90 | .219 | .078 | .141 |
| *80 | .246 | .080 | .166 |
| 75 | .262 | .080 | .182 |
| 70 | .281 | .080 | .201 |

Design Speed 60 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 475* | .060 | .040 | .020 |
| 360 | .079 | .048 | .031 |
| 300 | .094 | .053 | .041 |
| 250 | .113 | .059 | .054 |
| 220 | .129 | .063 | .066 |
| 190 | .149 | .067 | .082 |
| 170 | .167 | .070 | .097 |
| 150 | .189 | .074 | .115 |
| 140 | .202 | .076 | .126 |
| 130 | .218 | .078 | .140 |
| *120 | .236 | .080 | .156 |
| 110 | .258 | .080 | .178 |
| 100 | .283 | .080 | .203 |

Design Speed 70 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 630* | .061 | .041 | .020 |
| 450 | .086 | .051 | .035 |
| 360 | .107 | .057 | .050 |
| 270 | .143 | .066 | .077 |
| 230 | .168 | .071 | .097 |
| 190 | .203 | .077 | .126 |
| *170 | .227 | .080 | .147 |
| 160 | .241 | .080 | .161 |
| 150 | .250 | .080 | .177 |

Design Speed 80 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 800* | .062 | .042 | .020 |
| 600 | .084 | .050 | .034 |
| 450 | .112 | .059 | .053 |
| 360 | .140 | .066 | .074 |
| 300 | .168 | .072 | .096 |
| 250 | .202 | .077 | .125 |
| *230 | .219 | .080 | .139 |
| 190 | .265 | .080 | .185 |
| 170 | .296 | .080 | .216 |

Design Speed 90 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 1050* | .061 | .041 | .020 |
| 800 | .080 | .049 | .031 |
| 600 | .106 | .058 | .048 |
| 450 | .142 | .067 | .075 |
| 380 | .168 | .073 | .095 |
| 320 | .199 | .078 | .121 |
| *300 | .213 | .080 | .133 |
| 250 | .255 | .080 | .175 |
| 230 | .277 | .080 | .197 |

Design Speed 100 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 1250* | .063 | .043 | .020 |
| 1000 | .079 | .050 | .029 |
| 800 | .098 | .057 | .041 |
| 600 | .131 | .067 | .064 |
| 450 | .175 | .076 | .099 |
| *400 | .197 | .080 | .117 |
| 380 | .207 | .080 | .127 |
| 340 | .232 | .080 | .152 |
| 300 | .262 | .080 | .182 |

Design Speed 110 km/h

| Radius | e+f | e | f |
|---|---|---|---|
| 1500* | .064 | .044 | .020 |
| 1000 | .095 | .056 | .039 |
| 800 | .119 | .064 | .055 |
| 600 | .159 | .074 | .085 |
| 550 | .173 | .077 | .096 |
| *500 | .191 | .080 | .111 |
| 450 | .212 | .080 | .132 |
| 380 | .251 | .080 | .171 |
| 360 | .265 | .080 | .185 |

* These curve radii are minimum values for new highway design.

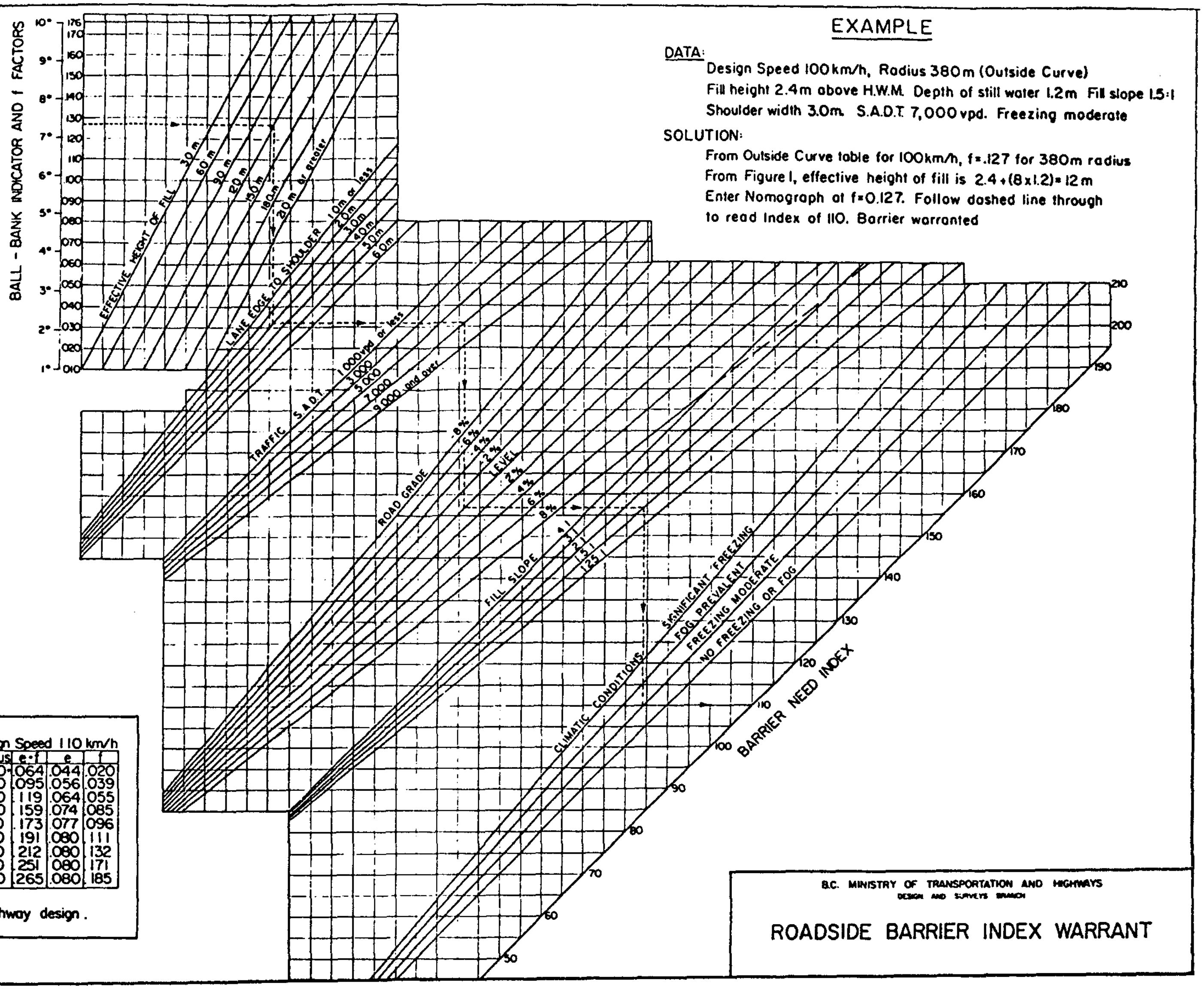



Figure 2.1 M.o.T.H. Roadside Barrier Index Warrant Nomograph

Source: BC Ministry of Transportation and Highways Design Standards Manual (1991)

### 2.2.2 TAC: Transportation Association of Canada.

*Manual of Geometric Design Standards for Canadian Roads*

TAC's (formerly RTAC) Manual of Geometric Design Standards for Canadian Roads (1986 Metric Edition) [5] specifies that warrants must satisfy an equal-severity criterion, in that a barrier will only be installed if it is less dangerous than the hazardous feature which the barrier is intended to shield. TAC has derived warrant procedures for the following general situations.

1. Steep embankment slopes.
2. Hazardous roadside objects.

TAC considers the following factors in the development of barrier warrants for the two general situations defined above.

1. Clear-Zone Identification.
2. Accident Severity Index (SI).
3. Encroachment Rates (ER).
4. Collision Frequency (CF).
5. Alignment Adjustment Factors (AF).

TAC's warrant system ranks the installation of barriers in terms of the severity of the hazard and the frequency that the hazard is struck or traversed by an errant vehicle. The two warrant systems presented include: one for steep embankment slopes and one for hazardous roadside objects.

**1. TAC's Barrier Warrant: Steep Embankment Slopes (slopes > 3:1)**

To decide if a barrier on an embankment slope is warranted, the severity index (SI) must be determined. The severity index can be obtained from one of three sources:

1) Table 2.2: Severity index for non-traversable fill slopes, developed from NCHRP's "Guide for Selecting, Locating, and Designing Traffic Barriers [6], used when embankment heights are greater than 3.0 meters.

2) Table 2.3: A severity index which is based on a reliable accident history, either in terms of accident costs or casualties.

3) Table 2.4 and Table 2.5: Utilizing obstacle inventory codes and Severity indices also developed from NCHRP's "Guide for Selecting, Locating, and Designing Traffic Barriers [7], used when embankment heights are less than 3.0 meters.

Once the severity index has been established, the encroachment rate (ER) can be found by utilizing Table 2.6. These values, which are based on accident records, can be adjusted to correct for horizontal and vertical roadway alignments. These adjustment factors (AF) are shown in Table 2.7 (horizontal adjustments) and Table 2.8 (vertical adjustments).

The warrant index is determined using (SI), (ER), and (AF) and the following expression:

$$WI = (SI) \times (ER) \times (AF)$$

where: SI = severity index; ER = encroachment rate.

WI = warrant index. AF = adjustment factors.

TAC does not define a value for WI which locates a point to differentiate between whether or not a barrier is warranted, however, the manual states that the value obtained should be compared and ranked with similar values for other locations and a priority index should be developed based on the demands of the governing agency.

Table 2.2: Severity Indices: Non-Traversable Fill Slopes

| Slope | Severity Index |
|---|---|
| 4.0:1 | 2.6 |
| 3.5:1 | 3.5 |
| 3.0:1 | 4.0 |
| 2.5:1 | 4.5 |
| 2.0:1 | 5.0 |
| 1.0:1 | 6.0 |

Source: TAC, Manual of Geometric Design Standards (1986).

Table 2.3: Severity Index versus Casualties versus Costs

| Severity Index | % PDO Accident | % Injury Accident | % Fatal Accident | Total Accident Cost (1985 $) |
|---|---|---|---|---|
| 0 | 100 | 0 | 0 | 1,390 |
| 1 | 85 | 15 | 0 | 4,170 |
| 2 | 70 | 30 | 0 | 6,950 |
| 3 | 55 | 45 | 0 | 9,720 |
| 4 | 40 | 59 | 1 | 16,280 |
| 5 | 30 | 65 | 5 | 33,250 |
| 6 | 20 | 68 | 12 | 61,570 |
| 7 | 10 | 60 | 30 | 131,500 |
| 8 | 0 | 40 | 60 | 247,000 |
| 9 | 0 | 21 | 79 | 318,000 |
| 10 | 0 | 5 | 95 | 378,000 |

Source: TAC, Manual of Geometric Design Standards (1986).

Table 2.4: Obstacle Inventory Codes

Table 2.5: Severity Indices

| Identification Code | Descripter Code | Front Slope | Back Slope | | End Treatment Code | | Severity Index |
|---|---|---|---|---|---|---|---|
| | | | | | Beginning | Ending | |
| 14. Ditches | 1 | 6.0:1 | 6.0:1 | | 0 | 0 | 2.2 |
| | 2 | 6.0:1 | 5.0:1 | | 0 | 0 | 2.4 |
| | 3 | 6.0:1 | 3.5:1 | | 0 | 0 | 3.0 |
| | 4 | 5.0:1 | 6.0:1 | | 0 | 0 | 2.3 |
| | 5 | 5.0:1 | 5.0:1 | | 0 | 0 | 2.5 |
| | 6 | 5.0:1 | 3.5:1 | | 0 | 0 | 3.0 |
| | 7 | 4.0:1 | 6.0:1 | | 0 | 0 | 2.6 |
| | 8 | 4.0:1 | 5.0:1 | | 0 | 0 | 3.0 |
| | 9 | 4.0:1 | 3.5:1 | | 0 | 0 | 4.0 |
| | 10 | 3.6:1 | 6.0:1 | | 0 | 0 | 3.5 |
| | 11 | 3.6:1 | 5.0:1 | | 0 | 0 | 3.8 |
| | 12 | 3.6:1 | 3.5:1 | | 0 | 0 | 4.5 |
| | 13 | 3.0:1 | 6.0:1 | | 0 | 0 | 3.6 |
| | 14 | 3.0:1 | 5.0:1 | | 0 | 0 | 4.2 |
| | 15 | 3.0:1 | 3.5:1 | | 0 | 0 | 4.8 |

Notes:

Obstacles such as ditches, as shown in the table above, are not of the longitudinal class and have been given a designated code 0 for each end treatment. For the beginning and end treatment codes for longitudinal obstacles please refer to the safety treatment of the obstacle.

The table shown above represents only a partial listing of the obstacle severity codes and the corresponding severity indices. For a complete listing of all roadside obstacles identified by TAC, please refer to the manual.

Source: TAC, Manual of Geometric Design Standards (1986).

Table 2.6 Encroachment Rates

| Road Class | ADT | Design Speed (kph) | Lane Width (m) | No. of Lanes | Shoulder Width (m) | Encroachment Rate (x1000) (events/km/yr) |
|---|---|---|---|---|---|---|
| **Freeway** | | | | | | |
| Urban | | >100 | 3.7 | 4-D | 3.0-3.7 | 0.31 ADT |
| | | >100 | 3.7 | 4-D | 3.0-3.7 | 0.20 ADT |
| Rural | | >100 | 3.7 | 6-D | 3.0 | 0.07-0.12 ADT |
| | | >100 | 3.7 | 4-D | 3.0 | 0.20-0.31 ADT |
| **Arterial** | | | | | | |
| Urban | | <100 | 3.7 | 4 | 3.0 | 0.32 ADT |
| | | <100 | 3.7 | 2 | 1.2-3.0 | 0.45 ADT |
| Rural | | <100 | 3.4-3.7 | 2 | 1.2-3.7 | 0.45 ADT |
| **Collector** | | | | | | |
| | 250-400 | <50 | 3.0 | 2 | 0.6 | 0.63 ADT |
| | 400-750 | <50 | 3.0 | 2 | 0.9 | 0.45 ADT |
| | 750-4000 | <50 | 3.0 | 2 | 0.9-2.4 | 0.45 ADT |
| | 250-400 | 50-70 | 3.0 | 2 | 0.6 | 0.63 ADT |
| | 400-4000 | 50-70 | 3.4-3.7 | 2 | 0.9-2.4 | 0.45 ADT |
| | 250-400 | >70 | 3.0 | 2 | 0.6 | 0.63 ADT |
| | 400-4000 | >70 | 3.4-3.7 | 2 | 0.9-2.4 | 0.45 ADT |
| **Local** | | | | | | |
| | 50-250 | 30-50 | 2.7 | 2 | 0.6 | 1.52 ADT |
| | 250-400 | 30-50 | 2.7 | 2 | 0.6 | 0.63 ADT |
| | >400 | 30-50 | 3.0 | 2 | 1.2 | 0.45 ADT |
| | 50-400 | 70-80 | 3.0 | 2 | 0.6 | 0.63 ADT |
| | >400 | 70-80 | 3.4 | 2 | 1.2 | 0.45 ADT |

Note: D=divided Freeway under number of lanes

Source: TAC, Manual of Geometric Design Standards (1986).

Table 2.7 Horizontal Adjustment Factors

| Horizontal Curvature | Description | Horizontal Adjustment Factor |
|---|---|---|
| Tangent or Flat Curve | | 1.00 |
| Intermediate Curve (760 m) | | 1.05 |
| Inside Curve | | |
| | Minimum or near minimum , or isolated intermediate curve. | 1.10 |
| | Isolated minimum or near minimum curve, or curves with radii=170 m maximum. | 1.15 |
| Outside Curve | | |
| | Minimum or near minimum , or isolated intermediate curve. | 1.20 |
| | Isolated minimum or near minimum curve, or curves with radii=170 m maximum. | 1.25 |

Note: Minimum radii curves are those which satisfy the design requirement of speed, maximum superelevation, and road surface friction. Intermediate curves are defined as those whose radius is twice that of the minimum.

Source: TAC, Manual of Geometric Design Standards (1986).

Table 2.8 Vertical Adjustment Factor

| Downgrade or Profile Conditions | Vertical Adjustment Factor |
|---|---|
| 2% or less | 1.00 |
| 3% | 1.05 |
| 4% or moderate crest vertical curvature in combination with horizontal curve. | 1.10 |
| 5% | 1.15 |
| 6% or extreme crest vertical curvature in combination with horizontal curve. | 1.20 |
| 7% or more | 1.25 |

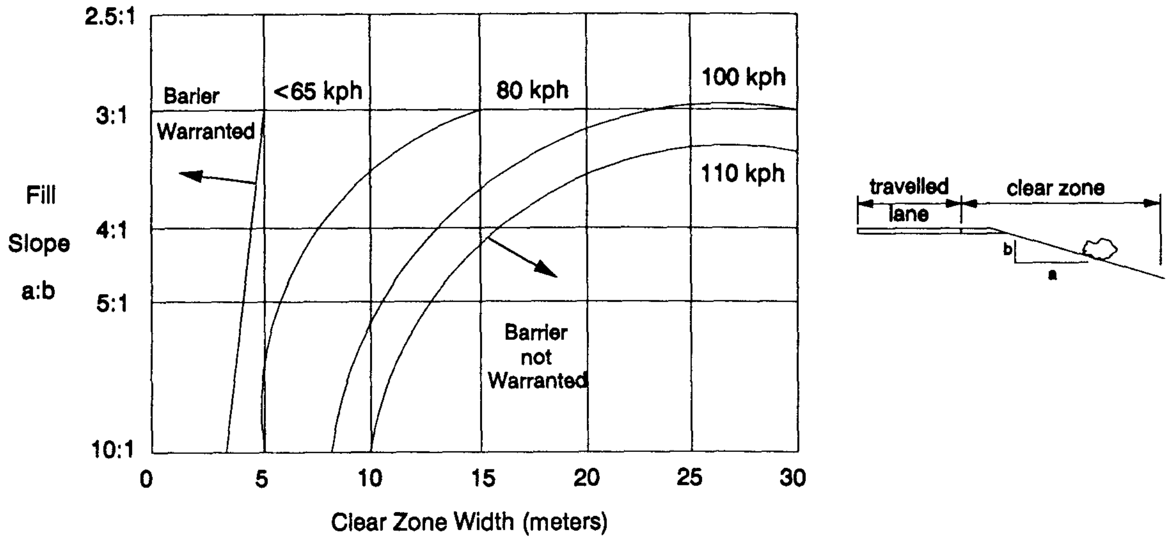
Note: A moderate vertical crest satisfies the sight distance criteria for design speed. An extreme crest is one which provides only half the required sight distance.

Source: TAC, Manual of Geometric Design Standards (1986).

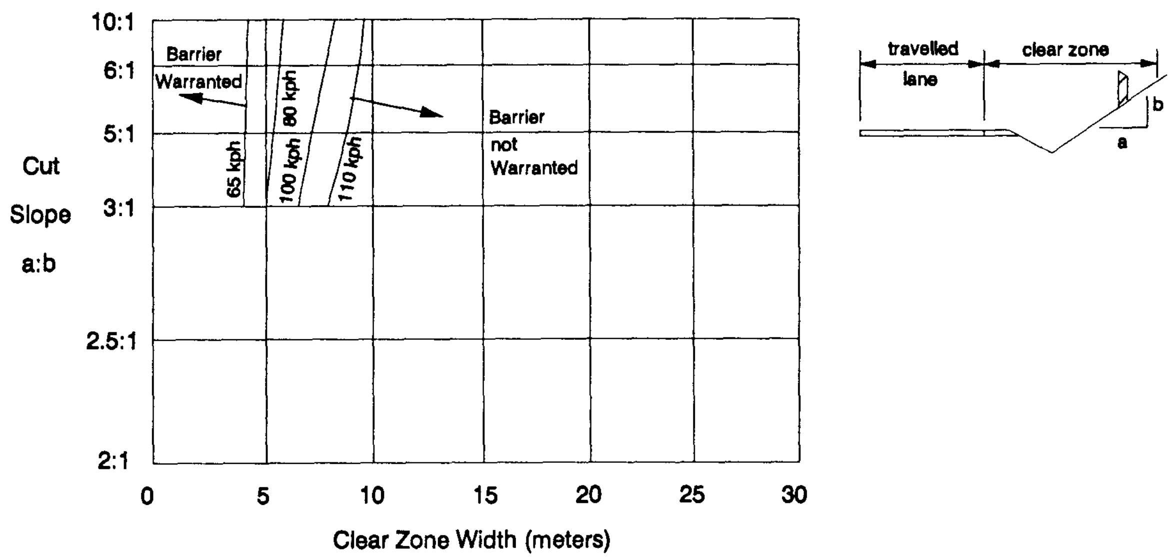
**2. TAC Barrier Warrants: Hazardous Roadside Objects**

The first step in determining a warrant for a barrier used to protect an errant vehicle from hazardous roadside objects is to determine the clear-zone. The clear-zone required can be determined given the fill/cut slope of the roadside embankment and the speed of the errant vehicle. Note that for slopes steeper than 3:1 (horizontal:vertical), the slope becomes the hazard rather than the hazardous feature. A correction factor can be applied to the amount of clear zone required to allow for the affects of horizontal curves. This correction factor is identical to the correction factors discussed for steep embankment slopes and the values of the adjustment factors were shown in Table 2.7. Once the clear-zone is determined, a conclusion can be made on whether or not a barrier should be considered for a given roadway condition, given that the location of the hazardous roadside objects are known. If the hazardous object is within the clear-zone, a barrier installation must be considered. A figure which illustrates the clear-zone requirement, as recommended by TAC, is shown in Figure 2.2.

The severity index (SI) is the next component of the warranting analysis which must be determined to evaluate the warrant index. Similar to the previous warrant procedure for steep embankment slopes, the severity index is obtained utilizing Table 2.4 (Obstacle Inventory Codes) and Table 2.5 (Severity Indices), or by using Table 2.3 (Severity Index vs Casualties versus Costs).




Fill Side Slope




Cut Back Slope

Figures 2.2: Clear Zone Width for Fill and Cut Slopes
Source: TAC, Manual of Geometric Design Standards (1986).

A collision frequency (CF) is used to determine the warrant index for hazardous roadside objects. Since the hazardous objects are often smaller or of limited size and located in an otherwise safe clear-zone, the probability of an encroaching vehicle actually striking the object is less than 100 percent. Collision frequency is introduced to relate encroachment rate to the actual number of collisions with the fixed object. Using the encroachment rate discussed earlier, with appropriate correction factors, and the lateral displacement distribution shown in Figure 2.4, the following expression can be used to calculate collision frequency.

$$C_f = \frac{E_f}{2000}\left[(L=19.2) \times P[Y \geq A] + 5.14 \sum_{J=1}^{J-W} P\left[Y \geq A + 1.8 + \frac{2J-1}{2}\right]\right]$$

Where:

| | | |
|---|---|---|
| $E_f$ | = | encroachments/km/yr. |
| L | = | horizontal length of the roadside obstacle. |
| W | = | width of roadside obstacle. |
| A | = | Lateral distance from roadside obstacle to edge of pavement. |
| Y | = | lateral displacement of the encroaching vehicle from the edge of pavement. |
| J | = | the number of 1 meter wide obstacle-width increments. |
| P[Y>] | = | probability of a vehicle's lateral displacement greater than some value. |

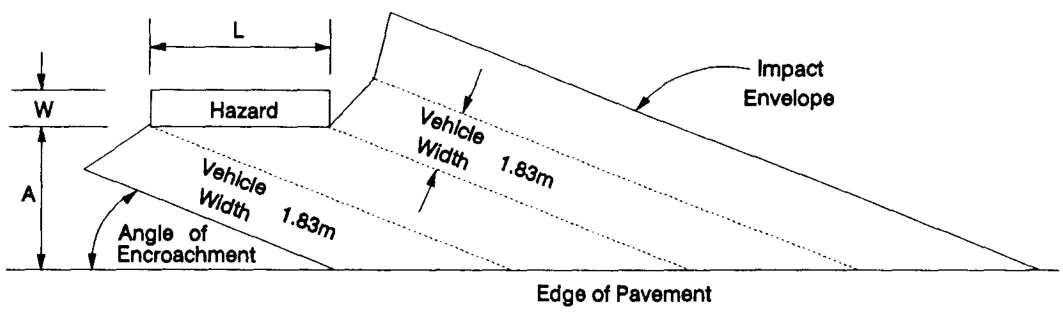



Figure 2.3: Collision Frequency.
Source: TAC, Manual of Geometric Design Standards (1986).

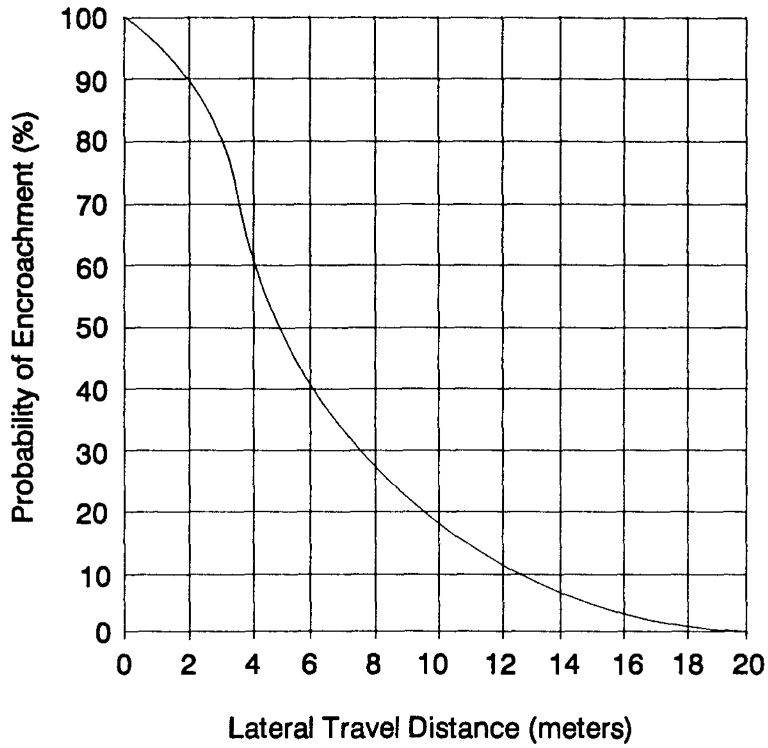



Figure 2.4: Lateral Displacement Distribution.
Source: TAC, Manual of Geometric Design Standards (1986).

Finally, the warrant index (WI) for hazardous roadside features can be found by using the following equation:

WI = (SI) x (CF) where: WI = warrant index.

SI = severity index.

CF = collision frequency.

Similar to the previous section on steep embankment slopes, TAC does not define a point on the warrant index scale which will explicitly state whether a barrier is warranted or it is not warranted. The value should be compared with others to produce a relative ranking procedure, and consequently, an installation priority.

### 2.2.3 NCHRP: National Cooperative Highway Research Program

*Report 118:* *Location, Selection, and Maintenance of Highway Traffic Barriers (1971)* *[8].*

*Report 54:* *Location, Selection, and Maintenance of Highway Traffic Barriers (1968)* *[9].*

NCHRP, which is sponsored by the American Association of State Highway Transportation Officials (AASHTO) and the Transportation Research Board (TRB), identifies two main features which may warrant a roadside traffic barrier installation. These two main features are lateral drop-off, and roadside obstacles. It should be noted that these are similar to the features identified by TAC, although some terminology may be slightly different. This is because much of the work completed by TAC is based on this work by AASHTO. Lateral drop-off is further divided into bridge structures, abrupt embankments, and sloped embankments to identify a variety of roadside conditions. Roadside obstacles are divided into non-traversable hazards and fixed objects to allow for a variety of hazardous roadside features.

To avoid repetition with TAC's description of the development of the warrants for traffic barrier installations, only the figures and tables recommended by NCHRP to determine the various barrier warrant situations are presented in this section. Figure 2.5 illustrates the barrier requirements for various embankment geometry. Table 2.9 identifies numerous roadside hazards that require a barrier installation if the hazard is located within the clear-zone. The similarities with the RTAC method are obvious.

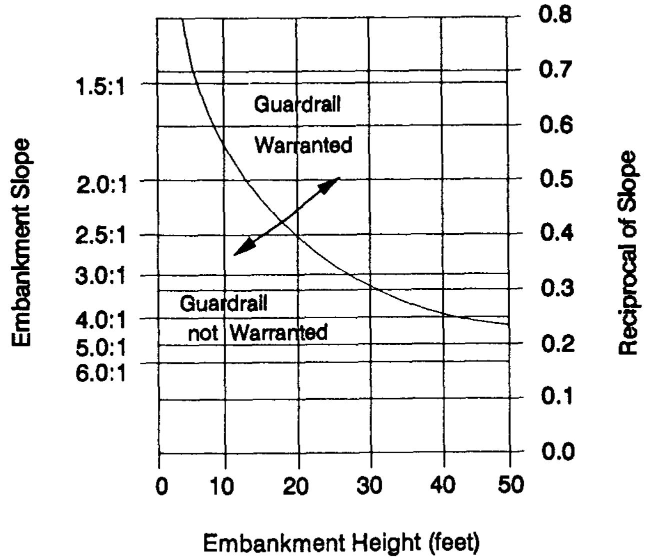



Figure 2.5: Barrier Requirements for Embankment Geometry
Source: NCHRP, Report 118 (1971).

Table 2.9: Warrants for Barrier Placement at Roadside Obstacles and Hazards.

| Roadside Objects and Hazards within 30 feet of the Roadway | Guardrail Required | |
|---|---|---|
| 1. Sign Supports [b] | Yes [a] | No |
| Posts of breakaway design | | X |
| Wood poles with area greater than 50 square inches. | X [c] | |
| Sign bridge supports | X | |
| Metal shapes with depth greater than 3.5 inches | X | |
| Concrete base 6.0 inches or more above ground. | X | |
| 2. Metal Light Poles [d] | | X |
| 3. Bridge Piers and Underpass Abutments | X | |
| 4. Retaining Wall and Culvert Head-walls | X | |
| 5. Trees with Diameter greater than 6.0 inches | X | |
| 6. Wood poles with area greater than 50 square inches | X [d] | |
| 7. Non-traversable hazards | X | |

Notes:
[a] Barrier recommended only if obstacles cannot be removed from thirty foot clear zone.
[b] Breakaway design should be used exclusively, regardless of the distance from the travelled way.
[c] The cross-sectional area of large wood members can be reduced by boring holes or notching the poles.
[d] The use of breakaway bases for metal light-poles is good practice, thus reducing the need for barrier placement

Source: NCHRP, Report 118 (1971).

### 2.2.4 AASHTO: American Association of State Highway and Transportation Officials

*Roadside Design Guide (1989)*

AASHTO's Roadside Design Guide [10] devotes an entire chapter to roadside barriers. Roadside barrier warrants are divided into two basis categories: embankments and roadside objects. AASHTO's Roadside Design Guide is intended to be used only as a guidebook and further development of the guidelines is recommended and encouraged for various locations.

As with all types of traffic barriers, roadside barriers should only be installed if it reduces the severity of potential accidents. Historically, roadside barrier warrants have been based on a subjective analysis of roadside hazards and accident potential. However, much effort has been made to quantify the subjective elements of analysis, and develop a standard warranting procedure.

Embankment Slopes

AASHTO defines the embankment height and the side slope as basic factors in determining the need for a barrier. These factors, and the corresponding barrier warrants are shown graphically in Figure 2.6. This figure assumes that the roadside is free of hazardous elements. Also, the figure does not consider the probability of the occurrence of an encroachment or the relative costs involved. This is where modifications to the presented warrants are desirable. Two examples of this are shown in Figures 2.7 and 2.8. Figure 2.7 accounts for the decreased probability on lower volume roads, and Figure 2.8 considers the cost effectiveness of a barrier for a site specific location.

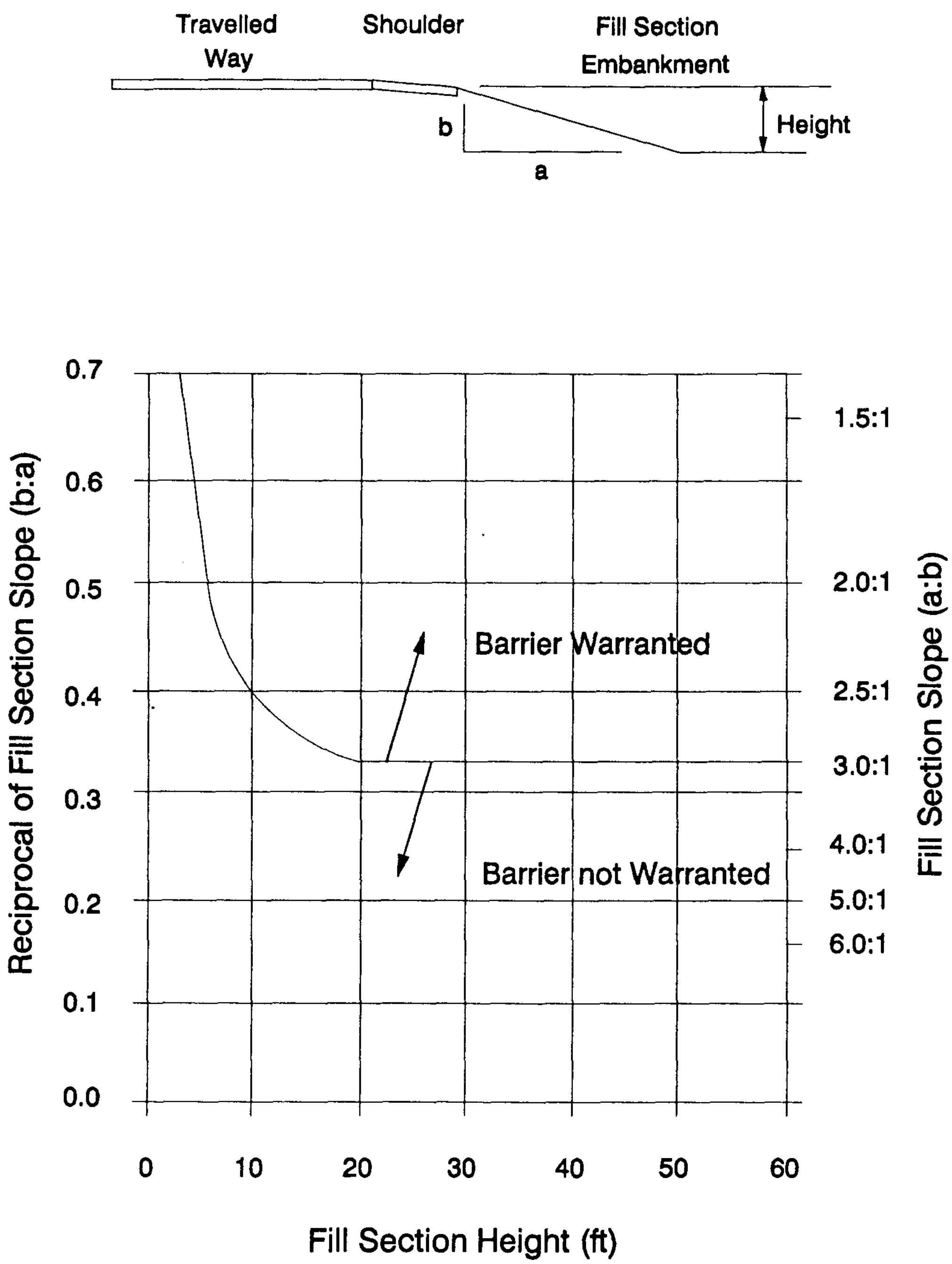



Figure 2.6: Comparative Risk Warrants for Embankments
Source: AASHTO, Roadside Design Guide (1989).

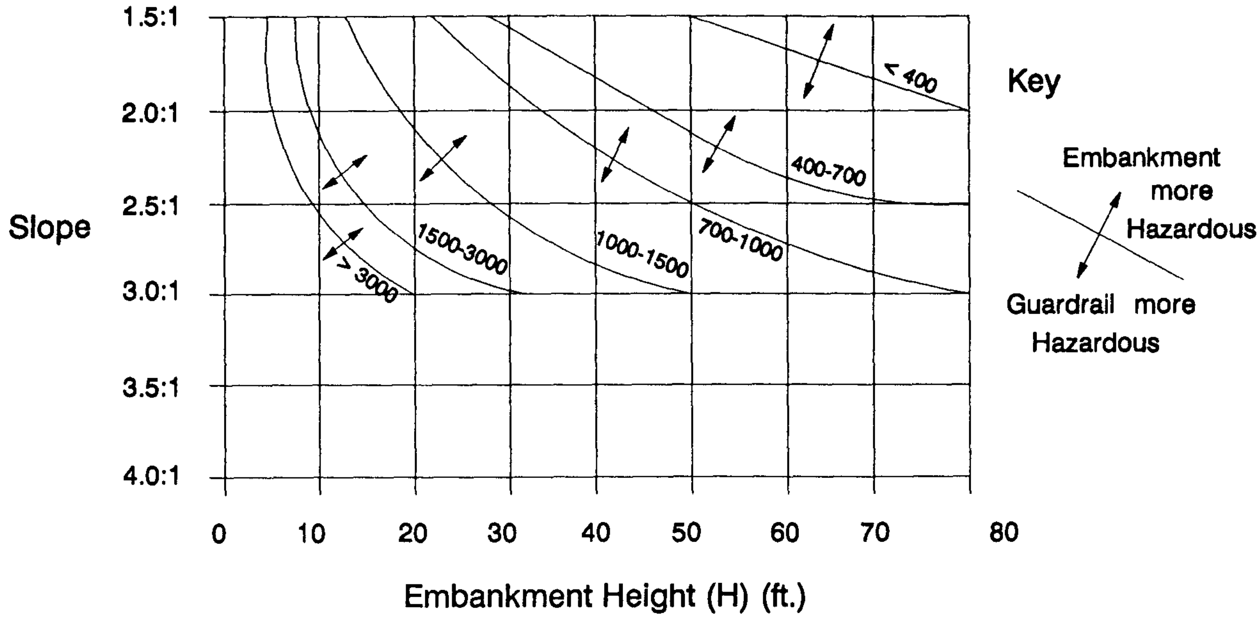



Figure 2.7: Modified Barrier Warrants for Embankments based on Traffic Volume
Source: AASHTO, Roadside Design Guide (1989).

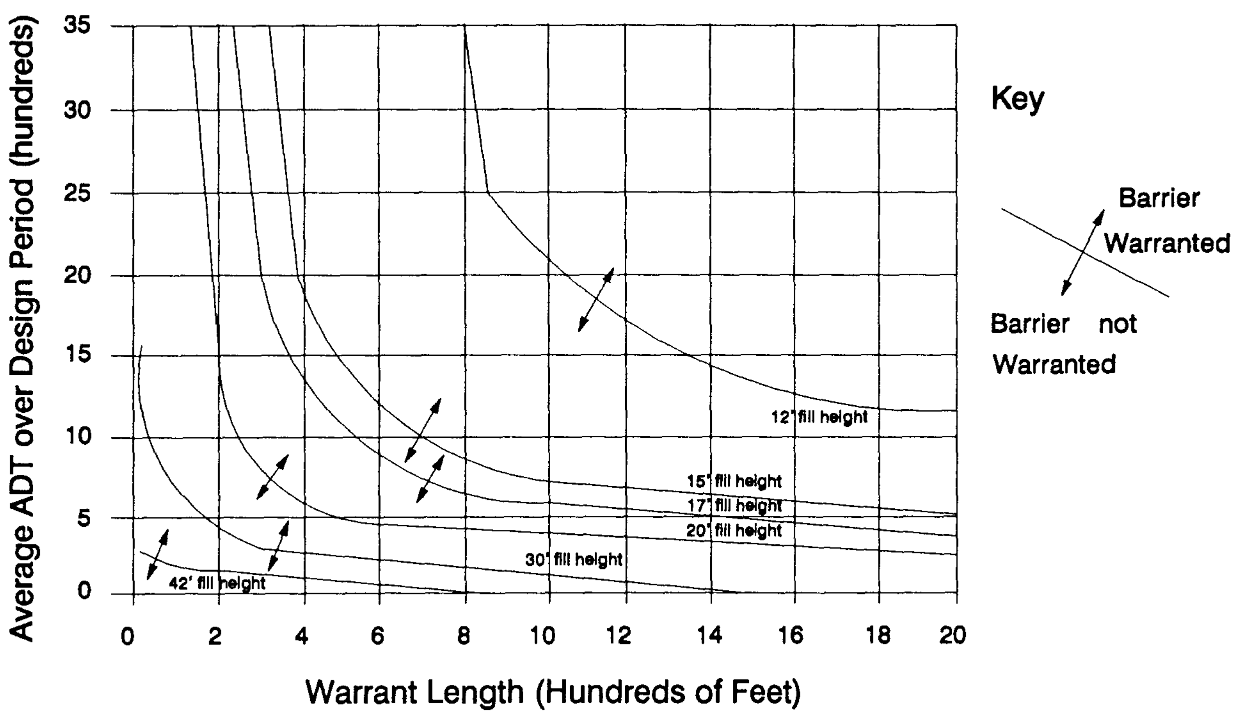



Figure 2.8: Modified Embankment Warrant considering a Cost Effectiveness Approach
Source: AASHTO, Roadside Design Guide (1989).

Roadside Objects

According to AASHTO, roadside objects account for 30% of all highway fatalities each year and therefore, these hazardous obstacles require careful consideration in the roadside barrier warrant evaluation. Table 2.10 below defines a number of hazardous roadside elements that may require shielding and Table 2.11 shows the clear zone required from the edge of the roadway based on design speed, average daily traffic (ADT), and fill/cut slopes. By consulting these two tables the engineer is able to determine if the hazard contributes a significant-enough threat to an errant vehicle (and the passengers in the vehicle) to warrant a roadside barrier.

Table 2.10: Barrier Warrants for Non-traversable Object Hazards

| Roadside Hazard | Barrier Warranting Action |
|---|---|
| bridge piers, abutments | shielding generally required |
| boulders | decision based on nature of hazard and impact likelihood |
| culverts, pipes, head-walls | decision based on size, shape, and location of hazard |
| cut slopes (smooth) | shielding generally not required |
| cut slopes (rough) | decision based on likelihood of impact |
| ditches (traverse) | shielding required if likelihood of head on impact is high |
| embankment | decision based on fill height and slope |
| retaining walls | decision based on smoothness of wall and impact angle. |
| sign/luminaire supports | shielding generally required for non-breakaway supports |
| traffic signal supports | shield isolated traffic signals within highway clear zone |
| trees | decision based on site specific circumstances |
| utility poles | shielding may be warranted on a case-by-case basis |

Notes Shielding of a non-traversable or fixed object is warranted when the hazard is in the clear zone. Marginal situations for placement/omission of a barrier, will usually be decided by accident experience. Where feasible, luminaire supports should be breakaway design regardless of distance from roadway.
Source: AASHTO, Roadside Design Guide (1989).

Table 2.11: Clear Zone Distances (in feet from the edge of driving lane)

| Design Speed | Design ADT | Fill Slopes | | | Cut Slopes | | |
|---|---|---|---|---|---|---|---|
| | | > 6:1 | 5:1-4:1 | < 3:1 | < 3:1 | 4:1-5:1 | > 6:1 |
| 40 MPH or Less | < 750 | 7-10 | 7-10 | ** | 7-10 | 7-10 | 7-10 |
| | 750-1500 | 10-12 | 12-14 | ** | 10-12 | 10-12 | 10-12 |
| | 1500-6000 | 12-14 | 14-16 | ** | 12-14 | 12-14 | 12-14 |
| | >6000 | 14-16 | 16-18 | ** | 14-16 | 14-16 | 14-16 |
| 45-50 MPH | < 750 | 10-12 | 12-14 | ** | 8-10 | 8-10 | 10-12 |
| | 750-1500 | 12-14 | 16-20 | ** | 10-12 | 12-14 | 14-16 |
| | 1500-6000 | 16-18 | 20-26 | ** | 12-14 | 14-16 | 16-18 |
| | >6000 | 18-20 | 24-28 | ** | 14-16 | 18-20 | 20-22 |
| 55 MPH | <750 | 12-14 | 14-18 | ** | 8-10 | 10-12 | 10-12 |
| | 750-1500 | 16-18 | 20-24 | ** | 10-12 | 14-16 | 16-18 |
| | 1500-6000 | 20-22 | 24-30 | ** | 14-16 | 16-18 | 20-22 |
| | >6000 | 22-24 | 26-32 * | ** | 16-18 | 20-22 | 22-24 |
| 60 MPH | <750 | 16-18 | 20-24 | ** | 12-12 | 12-14 | 14-16 |
| | 750-1500 | 20-24 | 26-32 * | ** | 12-14 | 16-18 | 20-22 |
| | 1500-6000 | 26-30 | 32-40 * | ** | 14-18 | 18-22 | 24-26 |
| | >6000 | 30-32 * | 36-44 * | ** | 20-22 | 24-26 | 26-28 |
| 65-70 MPH | <750 | 18-20 | 20-26 | ** | 10-12 | 14-16 | 14-16 |
| | 750-1500 | 24-26 | 28-36 * | ** | 12-16 | 18-20 | 20-22 |
| | 1500-6000 | 28-32 * | 34-42 * | ** | 16-20 | 22-24 | 26-28 |
| | >6000 | 30-34 * | 38-46 * | ** | 22-24 | 26-30 | 28-30 |

Notes: * Where there is indication of a high probability of an accident occurrence either by detailed study or by the accident history, the clear zone should be increased to greater than 30 feet.
** Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects should not be present in the vicinity of these slopes.

Source: AASHTO, Roadside Design Guide, (1989).

### 2.2.5 Barrier Warrant Criteria used in Six European Countries

To gain a perspective of the barrier warranting criteria used in Europe, six countries have been identified and their corresponding roadside barrier warrant criteria outlined. The six countries include France, the Netherlands, Denmark, Austria, Norway, and Belgium. This information was collected by Cooper [11] in the early 1980's, by questionnaire mailed to each country. Although this information may seem somewhat dated today, the important factor to consider, is that the experience and procedures in these countries is very similar to the experience and procedures used in North America.

**France:**

**Roadside barriers** are required when the fill height exceeds 4.0 meters or where heavy, un-modifiable obstacles are present in the clear zone. For the rest of the highway system, there is no systematic program of roadside barrier installation, except where the accident experience dictates.

**Netherlands:**

**Roadside barriers** are not required where there are no un-modifiable hazards within 10.0 meters of the travelled way. Roadside barriers may be warranted in the presence of hazards such as steep embankments, fixed objects, water courses, or overpasses.

**Denmark**

**Roadside Barrier** warrants are determined based on the fill height in meters and the slope of the embankment. The various warrants for the different roadways are illustrated in Figures 2.9, 2.10, and 2.11. A barrier is also required if a minimum clear lateral distance (often referred to as the Clear zone) is not present. The following Table, Table 2.12, shows the values of the minimum clear lateral distances required.

Table 2.12: Denmark's Minimum Clear Lateral Distance (Clear Zone)

| Railway and Water Hazards | | Obstacles | |
|---|---|---|---|
| Motorways | 20.0 m | Motorways | 10.0 m |
| Highways | 10.0 m | Highways | 7.0 m |
| Local Roads | 5.0 m | Local Roads | 4.0 m |

Source: BC Research, Highway Safety Barriers (1980).

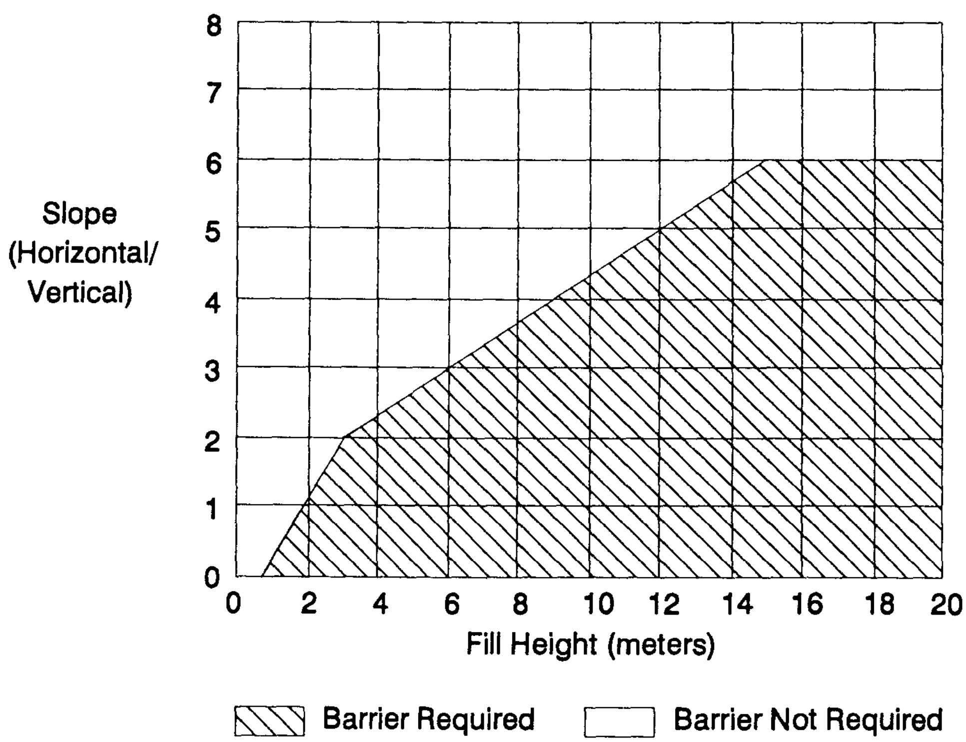



Figure 2.9: Roadside Barrier Warrant for Motorways in Denmark
Source: BC Research, Highway Safety Barriers (1980).

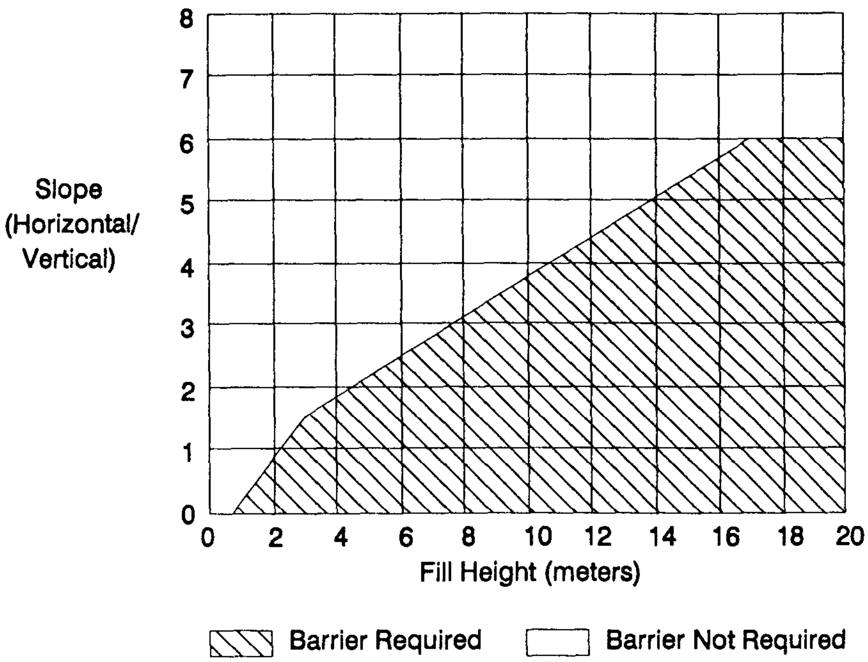



Figure 2.10: Roadside Barrier Warrant for Highways in Denmark
Source: BC Research, Highway Safety Barriers (1980).

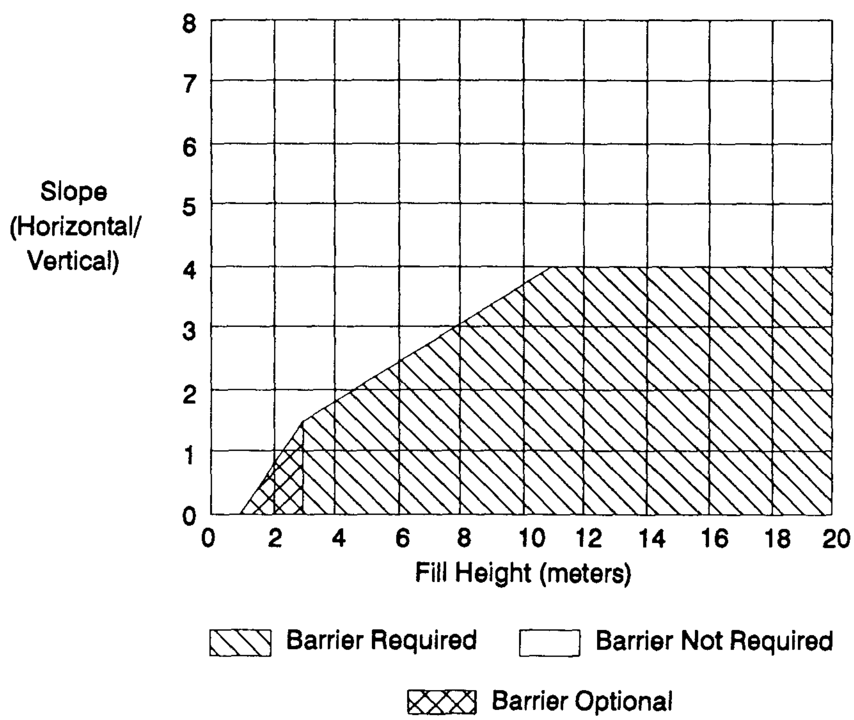



Figure 2.11: Roadside Barrier Warrant for Local Roads in Denmark
Source: BC Research, Highway Safety Barriers (1980).

**Austria**

**Roadside barriers** are required when the fill height exceeds 3.0 meters, when embankment slopes are steeper than 2:1, and at the following locations:

- retaining wall drop-offs greater than 2.0 meters.
- where obstacles are within 4.0 meters of the roadway on level terrain.
- obstacles within 8.0 meters of the roadway on terrain steeper than 3:1.
- pedestrian walkways
- short radius horizontal curves, and the ends of tight spiral curves.
- locations susceptible to icing, or strong cross winds.

**Norway**

**Roadside barriers** are required when the clear lateral distance (clear zone) available is below the value in the following table (Table 2.13), based on average daily traffic (ADT) and speed limit.

Table 2.13: Norway's Clear Lateral Distances (Clear Zones)

| Average Daily Traffic (ADT) | Speed Limits | | | |
|---|---|---|---|---|
| | 50 kph | 60 kph | 70-80 kph | 90 kph |
| < 300 | 2.0 m | 2.0 m | 3.0 m | - |
| 300-1500 | 2.0 m | 3.0 m | 3.0 m | - |
| 1500-4000 | 3.0 m | 3.0 m | 4.0 m | - |
| 4000-8000 | 3.0 m | 4.0 m | 4.0 m | - |
| 8000-12000 | 4.0 m | 4.0 m | 5.0 m | 6.0 m |
| 12000-25000 | 4.0 m | 5.0 m | 5.0 m | 6.0 m |
| > 25000 | 5.0 m | 5.0 m | 6.0 m | 6.0 m |

Note: 2.0 m can be added to clear zone distances when sharp horizontal curves are involved.
Source: BC Research, Highway Safety Barriers (1980).

**Norway (continued)**

Roadside barrier warrants in Norway are also dependant upon the embankment slope and the fill heights as illustrated in Figure 2.12 below. As well, roadside barriers may also be warranted for the following locations:

i) rock-cuts iii) hazardous roadside objects

ii) water hazards iv) poor accident history/record

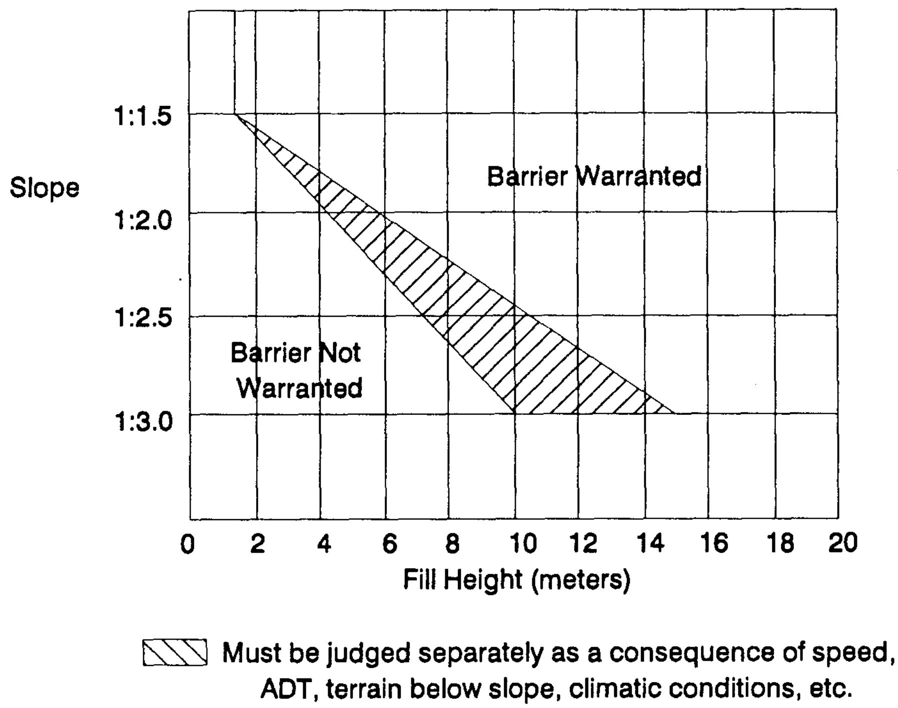



Figure 2.12: Norway's Roadside Barrier Warrants
Source: BC Research, Highway Safety Barriers (1980).

**Belgium**

**Roadside barrier** warrants are determined based on the amount of clear zone available, the speed, the fill height, and the embankment slope. The warranting criteria is illustrated in Figure 2.13 and Figure 2.14.

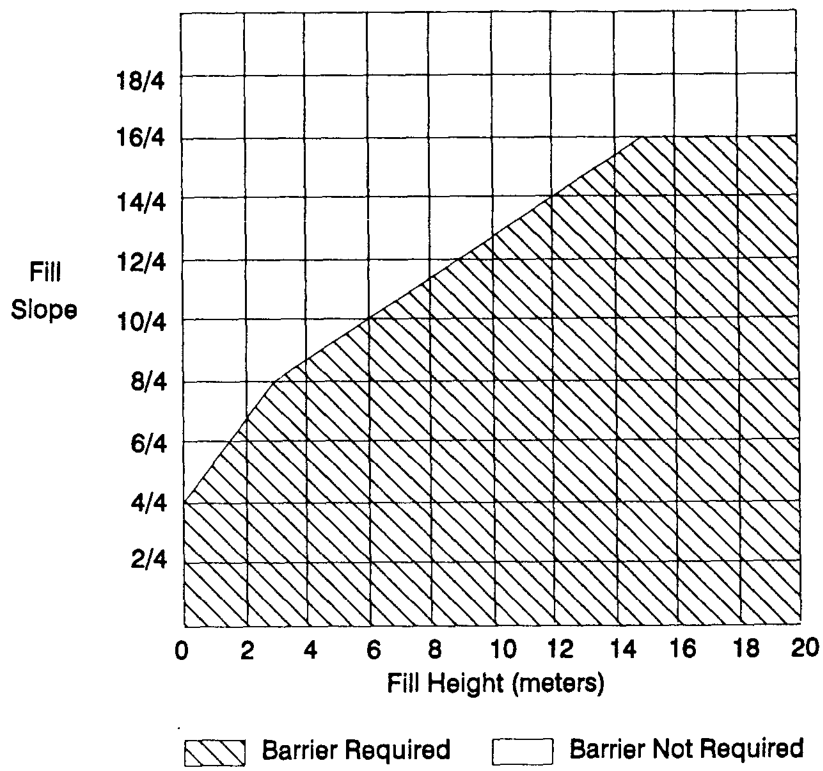



Fig 2.13 Barrier Warrant for Fill Height in Belgium
Source: BC Research, Highway Safety Barriers (1980)

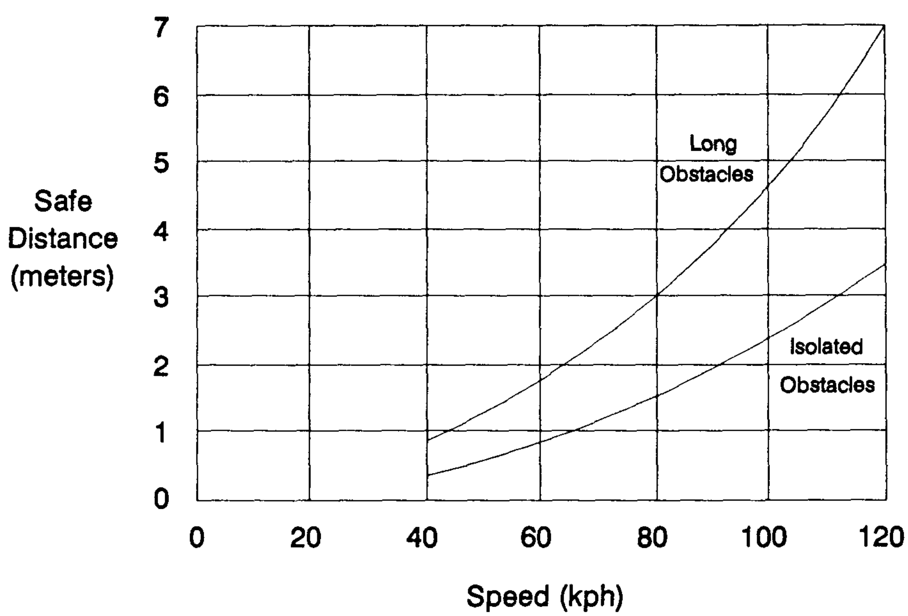



Fig 2.14 Barrier Warrant for Clear Zone in Belgium
Source: BC Research, Highway Safety Barriers (1980)

### 2.4 Computer Applications / Models

The development of computer programs to model an errant vehicle's movement and a vehicle collision with either a barrier or a roadside hazard have become more common due to an increase in the availability, speed, and capacity of computers, and because full-scale crash testing of vehicles is very expensive and time consuming. Computer simulation offers the engineer an excellent tool in analyzing any combination of roadway, vehicle, and barrier characteristics. Full-scale crash testing cannot be completely eliminated since the simulation model is calibrated using crash test results. As modifications to the roadway, the vehicles, or barriers occur, a re-calibration of the model is required using updated crash-test data. Validation of simulation models is dependant upon the quality of the calibration data.

This review describes the computer programs relevant to roadside hazards. The following programs were reviewed: HVOSM (Highway-Vehicle-Object-Simulation-Model), BARRIER VII, GUARD, ROADSIDE (AASHTO's Cost-Effectiveness Model), SAFEROAD, ROADSIDE (Expert-System), and WARRANT ADVISOR. Transport Canada's simulation program RHSM has been omitted since it is thoroughly discussed in Chapter Three.

#### 2.4.1 HVOSM: Highway-Vehicle-Object-Simulation-Model [12]

The HVOSM program is perhaps the most widely used model capable of simulating three dimensional motion for various vehicle control inputs and a wide range of terrain conditions. The model was initially developed at Calspan by McHenry and Delays [13] in 1966.

Numerous revisions and updates to the program has maintained the validity of the model. The model has been proven to accurately simulate the following situations:

1. Ride and handling motion of vehicles with dependant and/or solid axle suspension.
2. Impacts and collisions involving errant vehicles and hazardous roadside objects.
3. Effects of terrain, tire-curb contact, and wheel spin dynamics on vehicle response.
4. Torque capability of various braking systems [14].

HVOSM considers a vehicle as a sprung mass system and is capable of reproducing vehicle movements with a fair degree of accuracy. Limitations to the program include the inability to simulate impact forces during a collision, and the inability of describing barriers in detail. Since HVOSM was designed to cover a wide range or variety of roadside and vehicle conditions, it's specific application to roadside barriers is somewhat limited [15].

The input data required by HVOSM includes simulation control data, vehicle data, tire data, and the initial conditions. Unfortunately, the barrier details are too simple to be used strictly for barrier warranting analysis. The output obtained from HVOSM includes vehicle and barrier deformation, the friction forces between vehicle and barrier, and the barrier energy conservation and dissipation. The validation of HVOSM with respect to median and roadside barriers has been proven. However, because of the simple barrier representation, the results for deformable barriers are less effective than the results for rigid barriers.

### 2.4.2 BARRIER VII [16]

The BARRIER VII model was initially developed by Powell [17] in 1973 to simulate vehicle interaction with various barriers [18]. BARRIER VII is a two-dimensional motion simulation program based on elastic-plastic theory of material behaviour. The model is divided into two parts: a highly sophisticated barrier model and a somewhat simplified vehicle model. The barrier model is idealized as an assemblage of discrete structural members possessing geometric and material non-linearities [19]. The simplified vehicle model is described by a number of inelastic springs, defining contact points which the automobile may interact with the barrier.

The advantage of BARRIER VII over HVOSM is that BARRIER VII concentrates more on the safety barrier than the vehicle characteristics. The input requirements concentrate on barrier characteristics such as dimensions and material. BARRIER VII's output includes vehicle location, velocity, acceleration, and barrier deflections and forces. BARRIER VII has been more extensively validated than any other barrier simulation, thus the program has been used successfully as a design tool in the development of various barrier systems [20].

### 2.4.3 GUARD [21]

The simulation model GUARD was initially developed by Bruce and Hahn [22] for the United States Federal Highway Administration (FHWA) by the ITT Research Institute in 1976. GUARD has a three-dimensional response capability but lacks the ability to accurately simulate the friction forces developed between vehicle and barrier during impact.

However, GUARD utilizes a non-linear dynamic interaction model for vehicle impacts with longitudinal barriers. The GUARD simulation model is divided into three modules:

1. Guardrail/Barrier simulation.
2. Vehicle characteristics and behaviour.
3. Dynamic interaction of vehicle components [23].

The input requirements of GUARD can vary depending on the type of barrier application. For rigid barriers the required input is considerably reduced compared to that for flexible barriers, which require approximately the same input as the BARRIER VII simulation model. The output obtained from GUARD produces vehicle displacement, velocity, acceleration, as well as the forces on the barrier in all three dimensions. Validation of GUARD was conducted in two phases [24]. The vehicle interaction modules were validated for rigid barriers using full scale crash tests and HVOSM. Although the results were acceptable, HVOSM produced a better estimate. For flexible or semi-rigid barriers, which GUARD was designed to simulate, the model incorporated all three modules above and produced a good correlation with the results of the full scale test crashes.

#### 2.4.4 ROADSIDE (1989) Cost-Effectiveness Model Developed by AASHTO. [25]

ROADSIDE evaluates the need for a barrier based on a cost-effectiveness model. A cost-effective selection procedure predicts the total costs associated with specific traffic and roadway conditions and selects the optimum design from one or more alternatives [26].

The program requires two sets of input variables. The first set includes basic input data such as accident costs, encroachment rates, and encroachment angle. The second set describe the roadway, the roadside characteristics, and barrier related costs. The program output is in the form of a summary which identifies the expected accident costs and the cost of any improvement alternative. From this information, a decision on barrier justification can be made. This program is based on accident records from AASHTO's sources.

**2.4.5 SAFEROAD (1991)** [27]

Initially developed by P. Rosche [28] in 1991, SAFEROAD is a knowledged-based expert system designed to assist the engineer in selecting, locating, and designing traffic barriers for new construction or retrofit projects. The three main objectives of the program are given below.

1. To determine several economical barrier designs.
2. To determine data which would aid in securing conclusions.
3. To determine the basis for conclusions and recommendations.

A flow-chart of SAFEROAD is shown in Figure 2.15.

Knowledge-based expert systems can be very useful, however, updating, revising, and adding to the knowledge base must be continually undertaken. Otherwise, the faulty and obsolete data in the knowledge base will not produce valid results.

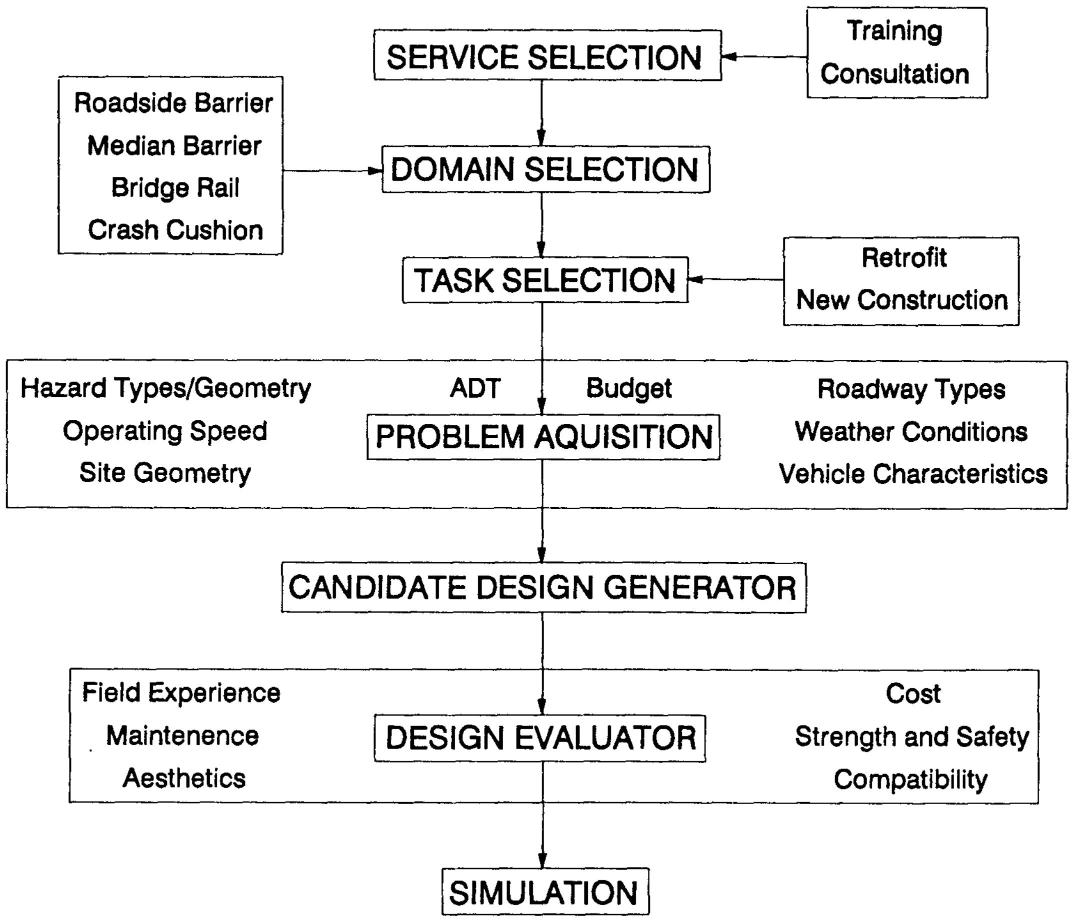



Figure 2.15 Flow-chart of Knowledge-based System SAFEROAD
Source: Advisory System for Design of Highway Safety Structures, P. Roschke (1991)

Once the service is selected, either training or consultation, the application or domain must be selected. The four applications include roadside barriers, median barriers, bridge rail, and crash cushions. The task selection identifies either new or retrofit construction. Next the problem acquisition phase identifies all the factors relevant in the barrier analysis. The candidate design generator considers the factors from the problem acquisition phase and determines whether a particular structure is warranted. Once the suitable barrier designs are identified, the design evaluator ranks the designs according to the number of evaluation criteria. Feasible, evaluated designs are sent to the last module; simulation of crash impacts.

**2.4.6 ROADSIDE (1991) Expert System for Roadside Safety.** [29]

Not to be confused with the cost-effectiveness model ROADSIDE discussed earlier, this ROADSIDE program is another microcomputer-based expert system that performs roadside safety analysis. In particular, the system has been developed to evaluate whether a traffic barrier is required at a particular site. The general framework of ROADSIDE includes three modules: user interface, inference engine, and the knowledge base. The user interface enables the user to "talk" to the computer, this includes transmitting the input and output information. The inference engine is a collection of processing procedures to find a conclusion based on the user's rules. The knowledge base is the set of rules/facts used to make decisions. Figure 2.16 shows a flow-chart of ROADSIDE.

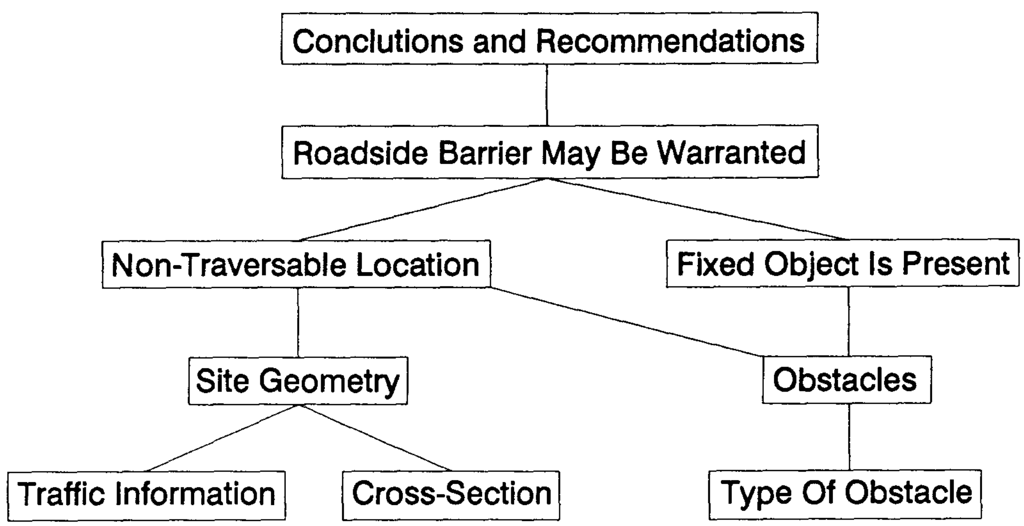



Figure 2.16 Simplified Reasoning Process used in ROADSIDE
Source: Development of Prototype Expert System for Roadside Safety, H. Zhou, D. Layton (1991).

**2.4.7 WARRANT ADVISOR (1989) Computing in Civil Eng. pp 490-497.** [31]

WARRANT ADVISOR is an object-oriented approach to warranting roadside safety hardware. Initially developed in 1989 by Ray and Logie [32], WARRANT ADVISOR's main objective is to provide a tool to explore the available alternatives in selecting roadside safety devices. The program is composed of three modules: constraint extraction, appurtenance selection, and design display. The constraint extraction module determines the constraints on the design, based on a graphical representation of the roadway site. The appurtenance selection module uses the constraints and devices obtained from the first module to determine the best device based on secondary criteria such as cost or technical feasibility. The third module, design display, produces a graphical display of the device used for the specific application. An example of the main-menu is shown in Figure 2.17.

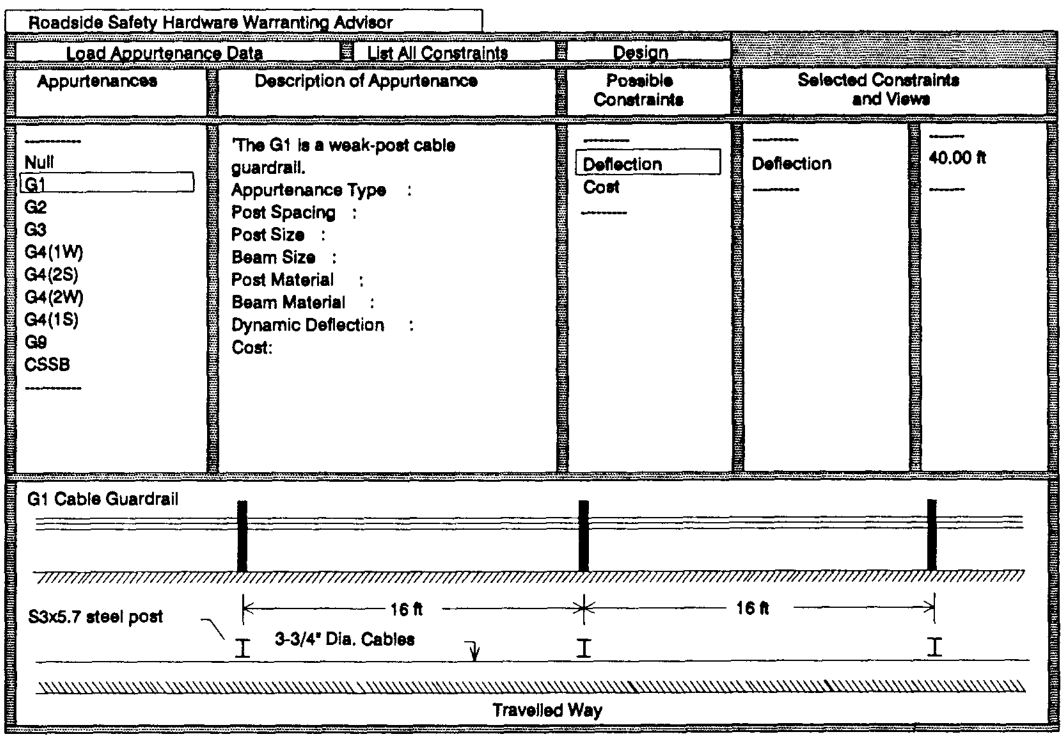



Figure 2.17 Menu Display From WARRANT ADVISOR
Source: An Object-Oriented Approach to Warranting Roadside Safety Hardware, M. Ray, D. Logie (1987).

# 3.0 ROADSIDE HAZARD SIMULATION MODEL: REVIEW and ADVANCEMENT

## 3.1 The Purpose and Objectives of RHSM.

The purpose of creating a roadside hazard simulation model is to develop a tool to assess and evaluate dangerous roadside conditions. As well, the model can be used to evaluate safety improvement alternatives.

There are a number of objectives that RHSM must satisfy. First, the model must simulate the errant vehicles trajectory upon leaving the roadway. Secondly, the model must accurately simulate the hazardous roadside, including all types of hazards. Third the model should simulate the errant vehicle's characteristics. The fourth objective, which is dependant upon the first three objectives, is to determine the consequence of a vehicle upon leaving the roadway. The final objective is to complete an economic evaluation of the improvement alternatives and identify the best solution for a hazardous roadside.

## 3.2 RHSM Evolution

Since its conception in the late 1970's, the Roadside Hazard Simulation Model (RHSM) has undergone numerous revisions. This has included various calibrations and validations of the model over the years. This review will focus on three different versions of the program: Version 5.0 (1979), Version 6.2 (1982), and Version 7.0 (1986).

The initial version of RHSM was developed in July, 1978 (ROADSIDE HAZARDS: A Methodology and Technique for Determining Accident Potential) [33], however, real data necessary to calibrate and validate the model was lacking. Shortly following this first version of RHSM, Transport Canada undertook a study of single vehicle run-off-the-road accidents collected over 4300 kilometres of roadway in five provinces [34] which provided the necessary data required to validate the model.

Version 5.0 of RHSM was developed by Cooper [35] in January 1979 under contract with Transport Canada. RHSM.V5 employed an updated probability of consequence table which reflected the results of Transport Canada's accident study. Also included was the addition of an aggregated probability of consequence output. Unfortunately, a copy of the original RHSM.V5 has not been located and a more detailed review of the program is not possible. The results produced by Version 5.0 were considered to be quite good and later versions did not produce results as favourable as the results which were obtained by Version 5.0.

RHSM Version 6-2 was developed by Lenz and Sanderson [36] for Transport Canada in August 1982. It was decided to implement a number of additional factors to the program to try to better simulate a vehicle's off-road excursion. These additions to the program included considering vehicle roll-over, vehicle steer-back (correction), and improved vehicle characteristics. Another revision included an update of the distribution of encroachment angles. Although the addition of the factors listed above seem reasonable, their addition into the model did not produce good results. The results generated from Version 6.2 were unrealistic, yielding results that were far too severe.

The latest version of was completed by Galway and Sanderson [37] in February 1986, again for Transport Canada. RHSM Version 7.0 included the additional consideration of rolling resistance in determining vehicle trajectories [38]. Other modifications include the addition of vehicle characteristics such as cornering stiffness of the tire, longitudinal stiffness of the tire, and outside diameter of the tire. These additions have made the model very complicated and the changes were not been tested due to numerous computing errors.

It appears that the evolution of the RHSM program has drifted away from its original objective; to maintain simplicity and ease in the evaluation of roadside hazards, and has become a complex and difficult program to utilize. Many revisions to the program seem reasonable in application and formulation, however, the generated results are not good. Upon a re-evaluation of the program objectives, it became apparent that a new model was required to obtain a functional and accurate model. From the users perspective, perhaps the most frustrating aspect of previous model versions is the lack of flexibility and unforgiving nature of the program.

## 3.3 Model Advancement

### 3.3.1 The Approach

After a great deal of effort was devoted to simply modifying one of the previous versions of the program, it was decided to abandon the old versions and develop a new model. Although the new model utilizes much of the theory employed in the older versions it became possible to incorporate new ideas into the program without fear of disturbing the existing code. The reason for this departure is due to the problems encountered in deciphering another person's source code and because the previous versions became difficult to interpret. With an understanding of the important aspects of the previous versions and anticipating important factors which were to be incorporated into the model, it became obvious that developing a new model was the appropriate decision.

The previous models were structured too rigidly and it was the goal of the new model to become as flexible as possible. As better model calibration information becomes available, it should be immediately and easily included into the new model. For example, if the probability of consequence table was found to be outdated, or was not relevant at a particular location, then it could be simply changed by the user to better reflect existing conditions. Older versions of the model performed like a "black box", where the user would be prompted for data and the results would somehow appear after the program was run. To have the user get "inside" the program and access all the components of the model, a greater understanding of the model will result. This is a goal of the new version of the program.

The approach taken for the new version of RHSM, called RHSM Version 9, was to consider all the interacting factors involved when an errant vehicle leaves the roadway and enters a hazardous roadside area. All the important components required to produce an effective evaluation tool were identified and then were divided into seven parts and are presented in Table 3.1.

Table 3.1 Components Considered in the Development of RHSM.V9

| | |
|---|---|
| Roadside Condition | This includes all hazardous roadside features, including hazardous embankment slopes, objects, terrain, as well as the location and characteristics of each hazardous feature. |
| Encroachment Characteristics | This includes the vehicles encroachment speed distribution and encroachment angle distributions which are based on geometric factors of the roadway under consideration. |
| Vehicle and Roadside Interaction | This includes the forces which are created when an errant vehicle encounters a hazardous roadside feature or the critical speed/embankment slope combination which will cause vehicle roll-over.<br>An understanding of the vehicle's trajectory including location, velocity, and deceleration in relation to the roadside is required to understand these interactions. |
| Accident Severity | The critical speed required to cause vehicle roll-over is calculated and compared with the simulated vehicle speed. If roll-over occurs, the simulated vehicle speed is used as the basis for the accident severity index.<br>The power loss developed when a vehicle collides with a hazardous roadside object or terrain is calculated and then is used for the basis of the accident severity index.<br>Power or critical speed levels are converted into probabilities of No Damage (ND), Property Damage Only (PDO), Injury (INJ), or Fatal (FAT) accidents.<br>The degree of passenger restraint, braking, or steer-back being used affects the outcome probabilities. |
| Aggregation | The process of combining or aggregating the consequences of all trajectories for the entire roadside environment (for each roadway configuration alternative) as well as including the possibility of more than one encroachment location. |
| Economic Evaluation | The encroachment rate, accident costs, savings in accident costs, and mitigation costs are used to evaluate a benefit-cost ratio analysis or alternatively, a cost-effectiveness approach can be employed based on user defined criteria. |
| Solution Recognition | Based on the evaluation of the different improvement alternatives for a particular hazardous roadside location, the best solution will be identified to be ranked with other improvement locations. |

**3.3.2 Model Basics and Assumptions.**

The first component of RHSM.V9 is to accurately simulate the roadside hazards and characteristics. This is done by identifying the location, dimensions, and equivalent friction coefficient for each hazard. RHSM.V9 considers a roadside area 20 meters wide, perpendicular to the roadway, and 100 meters in length, parallel to the roadway. Each hazardous roadside object can be located within this area by specifying the rectangular cartesian coordinates of the object and providing a width for the object. Each change in embankment slope can be located at any distance from the roadway edge and below the 20 meter maximum roadside lateral distance. The friction coefficients for each roadside hazard range between 0 and 100, with 0 representing no affect on the vehicles trajectory, and 100 representing a sudden stop in the vehicles trajectory (ie; a rigid wall).

The second component in RHSM.V9's development is to consider vehicle encroachment characteristics including simulating the vehicle speed and angle upon leaving the roadway. The encroachment speed probability is based on a normal distribution of occurrence about a mean speed and standard deviation as defined by the user. The encroachment angle probability is based on an empirically derived frequency distribution developed by DeLeuw Cather Canada Ltd., and ADI Limited [39] for Transport Canada in 1978. The product of the encroachment speed probability and the encroachment angle probability provides the access probability. Access probability is important since the consequence of an encroachment is not only determined by the energy dissipated in reaching that location, but also the access probability of reaching the location. For example, if two locations have the same power dissipation level, but different probabilities of being reached, it is reasonable to assume that the one with the higher probability of being reached is more hazardous [40].

The third component considered in the development of RHSM.V9 is how the vehicle and roadside features interact. Due to the great number of possible combinations of roadside, object, and vehicle characteristics, a method is needed whereby the hazard level may be estimated quickly and economically. HVOSM is capable of reproducing vehicle movements very accurately, however, the high cost and long computing time required to examine different roadside features discourage the use of this model for this type of application [41]. A simpler model was required to quickly and accurately simulate the vehicle trajectory during a roadside encroachment, thus the conception of RHSM.

RHSM considers the vehicle as a point with mass, which greatly simplifies the analysis of the vehicle's trajectory such that the location, velocity, deceleration, and power loss can be easily computed. A comparison of the results produced by assuming the vehicle is a point with mass with the results produced by HVOSM which treats the vehicle as a sprung mass, indicated that the assumption that the vehicle treated as a point mass was valid, since the results from RHSM were very similar to HVOSM. The only adjustment was for when the vehicle becomes air-borne. Correction factors have been introduced to account for air-borne landings and dive-in impacts. Once the vehicle trajectory is accurately simulated, the power loss experienced by the vehicle or the critical speed required to cause roll-over could be calculated and then the accident severity could be determined.

Proposing a suitable accident severity index is the fourth component in the development of RHSM. Statistical indices are developed based on accident records and depend on the quality of the data base to produce consistent results. An analytical index is based on physical characteristics of an accident such as vehicle damage, velocity change, or deceleration change [42]. RHSM.V9 uses the dissipation of energy over time (power) to serve as the severity index and if roll-over occurs, the velocity experienced at the time of roll-over, forms the basis for the accident severity index.

The point mass system used by RHSM.V9 provides the level of power dissipation and equates the power level into an accident severity level. The greater the power dissipation, the more severe the accident. A number of studies which utilize full-scale crash tests were chosen to derive this relationship which will be discussed in greater detail in the next section on program details. Also, the degree of passenger restraint, degree of braking, and steer-back will affect the severity of the accident. If it is determined that vehicle roll-over occurs then the severity of the accident is dependant upon the vehicle speed at the time of roll-over. The greater the roll-over speed, the greater the accident severity.

The next component in the development of RHSM is to aggregate the consequences of all vehicle trajectories. For each combination of encroachment speed and angle the power level dissipated or the roll-over speed is determined and a corresponding accident severity is assigned in terms of probability of consequence for each point along the errant vehicles's trajectory. The categories for probability of consequence are No Damage (ND), Property

Damage Only (PDO), Injury (INJ), and Fatality (FAT) accidents. The total consequence of the single trajectory is the normalized sum of each probability. By weighting each trajectory with the access probability, summing the values over the trajectory length, and normalizing the values, the consequence probabilities are obtained for the entire roadside.

The sixth component in the development of RHSM.V9 is the economic evaluation of the different safety improvement alternatives. Once a set of improvement alternatives are identified each can be subjected to an economic evaluation to determine the optimum solution for the location under review. A benefit-cost ratio and/or a cost-effectiveness evaluation can be selected by the user to evaluate the alternatives. Factors which are related to this component of the model development include encroachment rate, accident cost, the savings in accident cost, and mitigation costs.

The final component in the development of RHSM.V9 is to allow the user to compare different locations in order to define a priority ranking system. Simply stated, it would allow the user to judge the relative effectiveness of one project in relation to other projects.

### 3.4 RHSM.V9 Program Details

This discusses the relevant aspects of each component of RHSM.V9's development, providing the information, source, and justification for the conventions and procedures employed by Version 9 of RHSM. The program details are sub-divided into six sections which loosely reflect the components of the model.

The most noticeable advancement of RHSM.V9 over the previous versions is that the model is now completely menu driven allowing the user freedom to move to and from the different program components very easily and effectively. Upon activating the program, the user is greeted by a main menu which systematically suggests an order to move through the various program components. At each menu level a series of help screens are available to assist the user to make appropriate decisions. Default values are supplied whenever possible so that the user may bypass values which are not relevant or not known for a particular site. A series of keystroke conventions were adopted and maintained throughout the program. Although this may seem trivial to the operation of the model, it is tremendously important to the user who will operate the program. This section will systematically "travel" through the program to the different components or menu levels, identifying the input which is required by the program and explain the reasons/justification for each input requirement.

### 3.4.1 Roadside Simulation and Model Parameters

All of the roadside simulation features and model parameters are included in the second main menu option labelled Edit Simulation Data. From the users standpoint, this is perhaps the most important option since this is where all the operational, terrain, and object information is supplied for each improvement alternative. When Edit Simulation Data is selected, a secondary menu appears called Input Set Titles which allows the user to run up to ten different roadside improvements alternatives at one time. The first input set title is labelled 'control' which suggests simulating the existing conditions (Do-Nothing alternative). Then up to nine other input sets can be used to simulate other improvement alternatives.

Once all the improvement alternative titles are entered on the Input Set Titles screen, the user must detail the characteristics of each alternative. The user must access the Simulation Data Menu for each alternative. This sub-menu is divided into four options: Operation Data, Terrain Data, Clear-Zone Object Data, and Map of Roadside. Refer to Figure 3.1 which shows a flow-chart of the operation of the Edit Simulation Data main menu option.

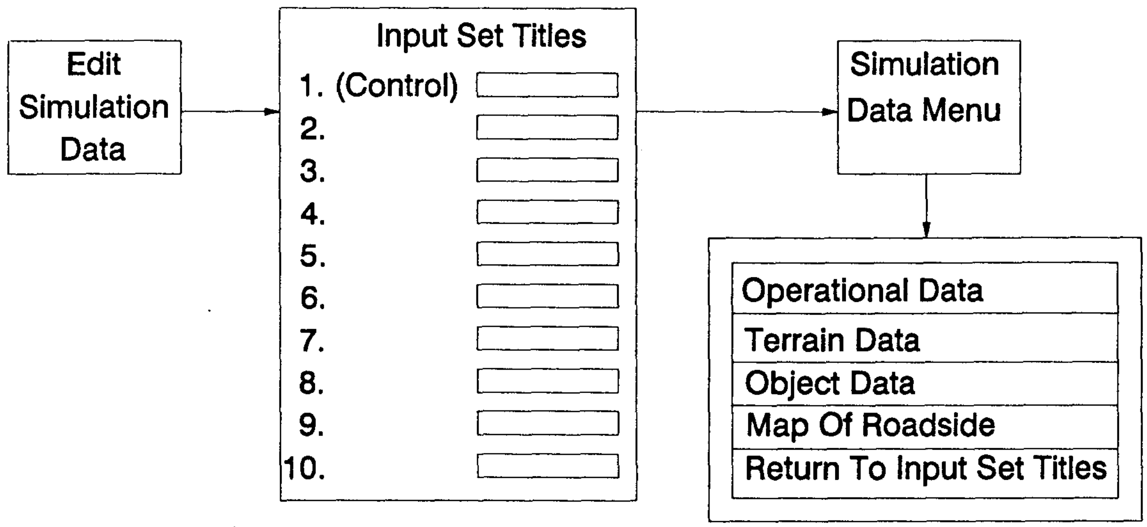



Figure 3.1 Edit Simulation Data Main Menu Options

Operation Data

There are a total of 15 different parameters which the user can specify to control the operation of the model and simulate the hazardous roadway. For ease of operation, all 15 input fields are supplied with default values. The input parameters are divided into eight groups, each representing a different component of the models operation. Below is a list of the 15 operational data parameters, divided into the eight groups, and a short description of each.

1) Horizontal Curvature

Horizontal Curvature allows the user to select a straight roadway section, a gentle curve, a moderate curve, or a severe curve. The purpose is to make an adjustment to the encroachment angle distribution due to the horizontal curvature. The greater the degree of roadway curvature, the greater the encroachment angle. These encroachment angle distributions are discussed in greater detail in a subsequent section regarding calibration and defaults.

2) Speed Increment, Angle Increment

These two input parameters control the number of trajectories which the model will consider. As the values for the speed and angle increments decrease, the model becomes more sensitive since more trajectories are considered. The purpose for these parameters is to allow the user to select values which are suitable for a particular location under review. For example, if the user wants a quick estimation of a relatively featureless roadside, values for the speed and angle increment can be quite large. Conversely, if the user wants a detailed, precise estimation of a roadside consisting of many small, detailed features, small values should be used for the speed and angle increments.

3) Time Increment of Trajectory, Maximum Time of Trajectory.

The time increment of the trajectory controls the "size" of the steps of the point mass vehicle during it's off-road excursion. The smaller the time increment, the more sensitive the model will be. The maximum time of trajectory determines how far the point mass vehicle will travel into the roadside area. The value selected should be large enough so that the vehicles travels past all roadside hazards, but not too large so that the vehicle travels far beyond the 20 meter maximum lateral distance.

4) Minimum Probability Considered

This input parameter controls the precision of the access probability. The purpose is to allow the user to select a value for access probability below which the access probability can be considered to have zero access probability. Access probability is the product of the speed probability and the angle probability.

5) Number of Encroachment Points, Encroachment Spacing

These two input parameters allow the user to specify any number and locations of encroachment points along the 100 meter length of roadway. The purpose for these parameters is to ensure that all roadside hazards will be reached in the evaluation of a particular hazardous roadside.

6) Steer-Back Correction Angle, Degree of Braking, and Degree of Restraint

These three input parameters all affect the overall probability of consequence. The purpose of these parameters is to allow the user to compensate for vehicle occupant factors which can alter the results of an off-road excursion. For example, as the values of each parameter increases, the outcome accident severity will decrease since the vehicle occupant are "protecting" themselves.

7) Average Encroach. Speed, Speed Standard Deviation, Minimum Encroach. Speed.

Average encroachment speed is self explanatory, with the probability of a certain encroachment speed is based on a normal frequency distribution. The speed standard deviation parameter allows the user to simulate the vehicle speed patterns during the encroachment. If the speed patterns vary greatly during the encroachment, then the vehicle speed standard deviation should be large. Refer to Figure 3.2 for the relationship between the average encroachment speed and the speed standard deviation.

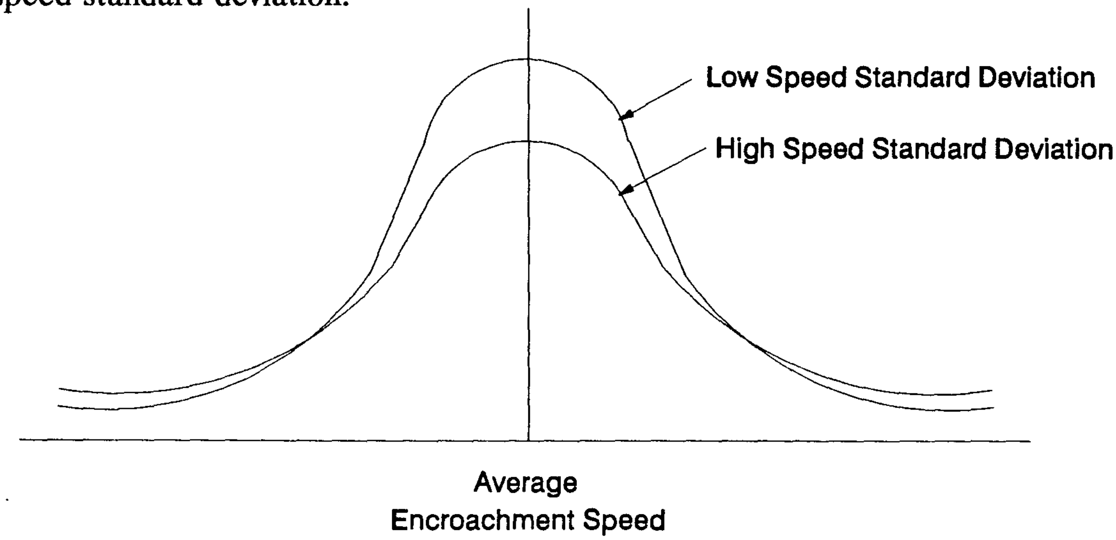



Figure 3.2 Relationship Between Encroachment Speed and Speed Standard Deviation
Source: RHSM: A Methodology and Technique to Effectively Reduce Single Vehicle Accident Potential

The minimum encroachment speed is the minimum speed in a direction parallel to the roadway that will be reached by the point mass vehicle. Velocities below this value are considered insignificant, and will not affect the program results.

8) Vehicle Model

This last operation parameter is to allow the user to select one of eight types of vehicles. The purpose of this parameter is to let the user determine the results of an improvement alternative for different types of automobiles. The exact dimensions of the vehicle models will be discussed in a subsequent section regarding calibration and defaults but it should be realized that any vehicle type can be represented.

Terrain Data

Terrain Data is the second option under the Simulate Data Menu. There are four components which are required to accurately simulate the roadside terrain; the location of the terrain change (TY), the angle of the terrain change (TA), and the coefficient of terrain resistance (TM). Each change in terrain characteristics is identified as a strip parallel to the roadway and up to 20 terrain changes are allowed within the 20 meter wide roadside area. Refer to Figure 3.3 and Table 3.2 for an illustration of how the terrain geometry and terrain characteristics are defined in RHSM.V9.

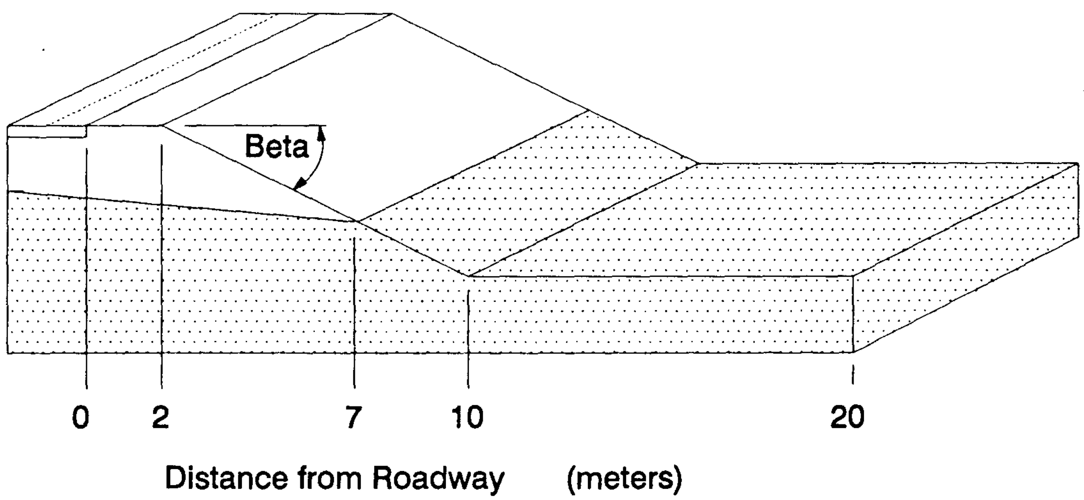



Table 3.2 Example of Roadside Terrain Description

| Distance from Road (TY) | Slope (TA) | Friction Coefficient (TR) |
|---|---|---|
| 2 | Beta | 0.70 |
| 7 | Beta | 0.55 |
| 10 | 0 | 0.55 |

Figure 3.3 and Table 3.2 Example of Roadside Terrain Description

The user inputs the distance from the edge of the pavement (TY=0) for each change in embankment slope and change in friction coefficient. The change in embankment slope is measured in degrees, with a down-slope embankment adopting a negative angle convention and an up-slope embankment adopting a positive angle convention. The terrain friction coefficient are dependant upon the type of terrain surface. The table below shows typical friction coefficients for ten different terrain surfaces.

Table 3.2 Friction Coefficients for Typical Terrain Surfaces

| Surface Type | Coefficient of Friction |
|---|---|
| rubber on dry asphalt or concrete | 0.71 |
| rubber on wet concrete | 0.70 |
| rubber on wet asphalt | 0.45 - 0.81 |
| rubber on gravel | 0.55 |
| rubber on sand | 0.55 |
| rubber on dry dirt | 0.65 |
| rubber on wet dirt | 0.40 - 0.50 |
| rubber on snow | 0.15 |
| rubber on sleet | 0.07 |
| rubber on ice | 0.06 |

Source: M. Lenz, RHSM, for Transport Canada (1984)

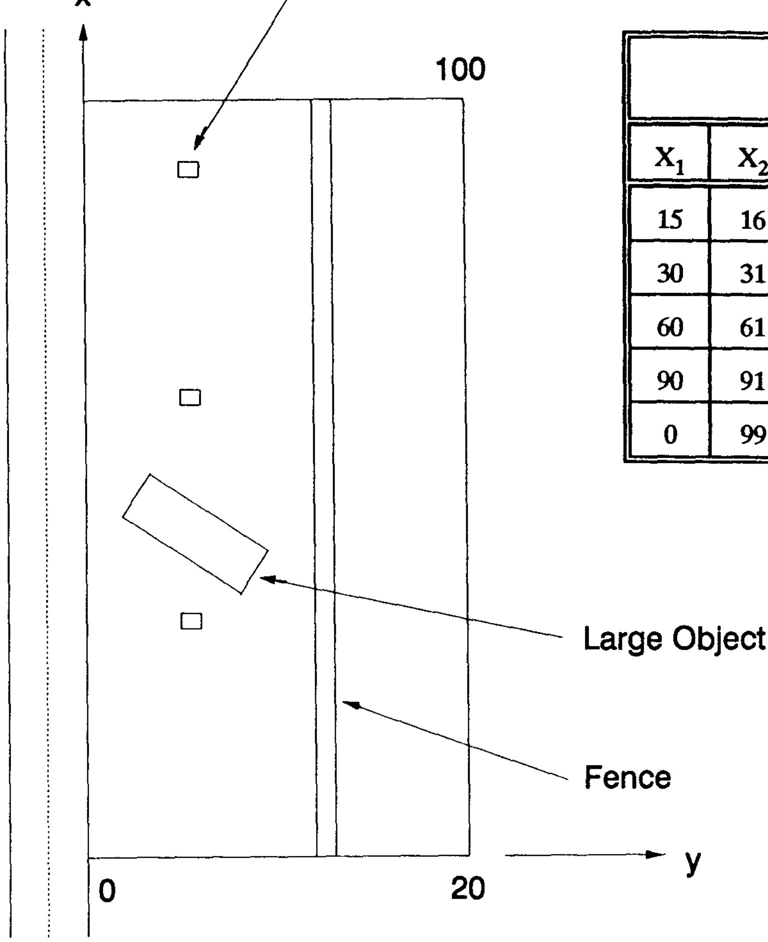
Another feature under this menu selection is to allow the user to visually check the cross section of the embankment slope. This is to ensure that the embankment slope features have been simulated accurately.

Object Data

The Object Data is the third option under the Simulation Data Menu. There are seven input requirements to accurately simulate any hazardous roadside object. The first four input requirements are to define the rectangular cartesian coordinates for the two nearest corners of the hazardous object in relation to the edge of the roadway and the start of the hazardous roadside zone. The fifth input requirement is the width of the object. All five input requirements are entered in meters. The sixth input requirement is to enter the type of object, either a rigid object, a deformable object, or a passable object. Finally, the relative rigidity or the friction coefficient of the object is entered, with zero representing an object which has no effect on a vehicles trajectory, and one-hundred representing a sudden stop in the vehicle's trajectory (such as a rigid wall). Refer to Table 3.4 which shows the object identification coding system and Table 3.5 and Figure 3.4 which shows how a variety of hazardous roadside objects can be located and simulated in the roadside area.

Table 3.4 Object identification Coding System

| Object Identification Coding | |
|---|---|
| Hazardous Object Type | Relative Rigidity (Friction Coefficient) of Object |
| R = rigid barrier | 0 - 100 defines the limits of relative rigidity.<br>0 = representing the least rigid object.<br>100 = representing the most rigid object. |
| D = deformable barrier | |
| P = passible barrier | |




| Object Identification | | | | | | |
|---|---|---|---|---|---|---|
| $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | Width | Type | $U_f$ |
| 15 | 16 | 5 | 10 | 3.0 | R | 100 |
| 30 | 31 | 5 | 6 | 1.0 | D | 75 |
| 60 | 61 | 5 | 6 | 1.0 | D | 75 |
| 90 | 91 | 5 | 6 | 1.0 | D | 75 |
| 0 | 99 | 12 | 13 | 0.5 | D | 20 |

Notes:
$X_1$ = object starting x-coordinate
$X_2$ = object ending x-coordinate
$Y_1$ = object starting y-coordinate
$Y_2$ = object ending y-coordinate
$U_f$ = object's coefficient of friction

Figure 3.4 and Table 3.5 Example of Roadside Object Identification

## Map of Roadside

The roadside map is the fourth option under the Simulation Data Menu. If the user selects this option, a topographic map of the roadside will be drawn on the screen which shows the terrain changes in different coloured strips (parallel to the roadway), the hazardous roadside objects are represented by white rectangular boxes, and the encroachment point locations shown by vehicles leaving the roadway. The purpose of this option is to give the user a visual check to ensure that the roadside hazards have been represented accurately.

### 3.4.2 Economic Evaluation of Improvement Alternatives

The third option of RHSM.V9 main menu is Alternative Simulation Data. This option controls the economic evaluation for each improvement alternative. Upon selecting this option, the user is presented with a screen which provides two options available to complete the economic evaluation: a benefit-cost ratio analysis and/or a cost effectiveness analysis.

Benefit Cost Analysis

If Benefit-Cost Analysis is selected by the user, another menu screen titled Benefit-Cost Analysis appears which consists of four components of the benefit-cost evaluation. These four components include the Encroachment Rate Factors, Accident Costs, Mitigation Costs, and Present Value/Capital Recovery Factors.

The Encroachment Rate Factors option is the first component of the Benefit-Cost analysis. The encroachment rate can be entered directly or if it is not known, then the program will calculate it based on a number of factors selected by the user. To calculate the encroachment rate the user must enter the average daily traffic (ADT) and then select a number of encroachment adjustment rate factors. The factors affecting the encroachment rate include the roadway classification, design speed, lane width, number of lanes, shoulder width, horizontal curvature, vertical curvature, climatic conditions, traffic composition, and sight restrictions. Each factor has 5 or 6 options which the user can select to accurately represent the roadway. The selection and values of the encroachment rate adjustment factors used in RHSM.V9 are based on RTAC [43] and M.o.T.H. [44].

The second component used in the benefit-cost evaluation is the accident costs. A sub-screen called Costs of Accidents is provided where the total cost of each type of accident is divided into two components: Direct Costs and Indirect Costs.

Direct Costs: Includes only those costs directly associated with an accident such as medical costs, property damage, lost work-time, legal costs, etc..

Indirect Cost: Includes the intangible or societal costs associated with an accident such as the value of life as well as a human being's net societal value.

There are eight input fields which the user can access: a direct and indirect cost associated with each accident type (No Damage, Property Damage Only, Injury, Fatality). The reason for this division in accident costs is to emphasize the difference in the total value of accident costs when indirect costs are considered. For example, the M.O.T.H., Highway Safety Branch has recently updated the value used for the cost of a fatal accident from approximately \$500,000 per fatality (based on direct costs) to approximately \$3,000,000 per fatality (based on direct and indirect costs). This 600 percent increase will have a tremendous impact on the results of the evaluation of improvement alternatives. Default values for the accident costs are supplied, however, these values can be modified if new or better accident cost data becomes available.

Mitigation Costs is the third component used in the benefit-cost analysis. Unlike the encroachment rate and accident cost components which are valid for all improvement alternatives, the mitigation cost component varies dependant upon the improvement alternative. For each improvement alternative, there are five components which may or may not contribute to the mitigation cost, including barrier costs, embankment slope flattening, object removal, maintenance costs, or right of way acquisition. If barrier is required, the installation cost in dollars must be input as well as the maintenance cost for the roadside area in dollars per year. If slope flattening is required, the cost of the cut or fill in dollars per cubic meter must be entered. The volume of the cut or fill required is calculated by determining the difference between cross-sectional profiles of the Do Nothing Alternative and subsequent improvement alternatives and then multiplying by the length of the roadway. Also, the cost of cut removal and the cost of adding fill must be entered. If object relocation or removal is required, then the number of objects and the cost of removal of each type of object must be entered. Finally, if right of way acquisition is required, the total cost of the right of way acquisition should be entered. Each improvement alternative can have any combination of mitigative factors.

The fourth and last component of the benefit-cost analysis is the Present Value/Capital Recovery Factors. This component has two input requirements: the interest rate suitable for public works investment, and the analysis period in years suitable for the project under review. The purpose of these values is to allow the economic evaluation to be presented in terms of an annual project cost and a total project cost. Annual project cost will discount all the initial construction costs into annual payments (Capital Recover Factor), and the total project cost will sum all the future annual costs into a present value of the total cost (Uniform Series, Present Worth Factor). Default values are supplied to assist the user in making a selection for the interest rate and analysis period.

Figure 3.5 shows a flow-chart summarizing the benefit-cost evaluation used by RHSM.V9.

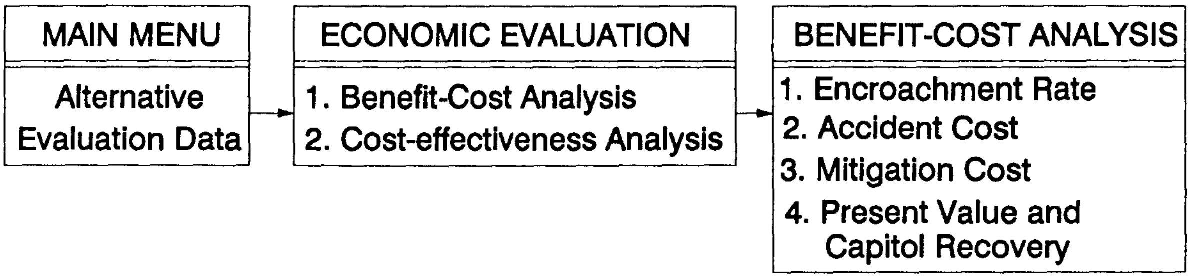



Figure 3.5 RHSM's Benefit-Cost Ratio Economic Evaluation

For each improvement alternative, the probability of consequence results obtained from the simulation run are multiplied by the encroachment rate to obtain the expected number of accident types per year. The number of accidents of each type (ND, PDO, INJ, FAT) is multiplied by the corresponding cost of each accident type and then summed to a total cost for each improvement alternative. The mitigative costs of each improvement alternative is calculated and the present value/capital recovery factors are used to evaluate accident costs and mitigative costs on an annual and total cost basis. The equations which calculate the annual cost (capital recovery) and the total cost (present value) are:

Annual Costs: $C_R = i(1+i)^n / [(1+i)^n-1)]$ Total Costs: $P_V = [(1+i)^n-1] / (i(1+i)^n]$

The **benefit** associated with any alternative is the savings in accident cost, which is calculated by determining the difference between the accident cost for the Do-Nothing alternative and the accident costs for the subsequent alternatives. The **cost** associated with the benefit-cost ratio is the relative increase in the total mitigative costs of each improvement alternative with respect to the Do-Nothing alternative. The benefit-cost ratio is then calculated and the improvement alternative with the largest benefit-cost ratio is the "best" alternative.

Cost-Effectiveness Analysis

The cost-effectiveness analysis is the second type of economic evaluation. Cost-effectiveness does not consider any of the benefits realized by a particular improvement alternative, instead, the effectiveness of each alternative is determined based on the cost of implementing a particular alternative. The two components of the cost-effectiveness analysis Criteria Weighting and Mitigative Costs.

A cost-effective approach must consider the cost of each improvement alternative. Therefore a procedure identical to that used for the benefit-cost analysis is used to determine the mitigation cost for each improvement alternative.

Criteria Weighting is the second component of the cost-effectiveness analysis. The four effectiveness criteria that the model considers are the accident consequence categories, namely ND, PDO, INJ, and FAT. This allows the user to specify the relative importance of each effectiveness criteria. The importance or weight of each criteria is provided in terms of a subjective index with any scale. For example, if the user is only concerned with fatalities (FAT), the subjective weight for the other effectiveness criteria (ND, PDO, INJ) would be set to zero. Since the user specified zero for all other effectiveness criteria, any value greater than zero could be used for FAT and still carry 100% of the importance.

For each improvement alternative, the probability of consequence value of ND, PDO, INJ, and FAT are multiplied by the corresponding user defined weight for ND, PDO, INJ, and

FAT and then summed together to determine the severity of the alternative. The alternative with the largest value represents the most severe or dangerous alternative.

The relative increase in the mitigation costs with respect to the first improvement alternative (the Do-Nothing alternative) is the value required to determine which alternative is the most cost-effective. To illustrate how the model determines which alternative is the best solution, refer to Figure 3.6 and Table 3.6. Six improvement alternatives are shown. The best alternative from a safety perspective is alternative #6, since it yields the least severity, however, it is a very costly alternative. Less costly alternative such as #3 or #4 represent better options from a cost-effective perspective even though the severities are slightly higher, the mitigation costs are significantly lower. Sound engineering judgement must be used to determine the optimum alternative for specific individual conditions.

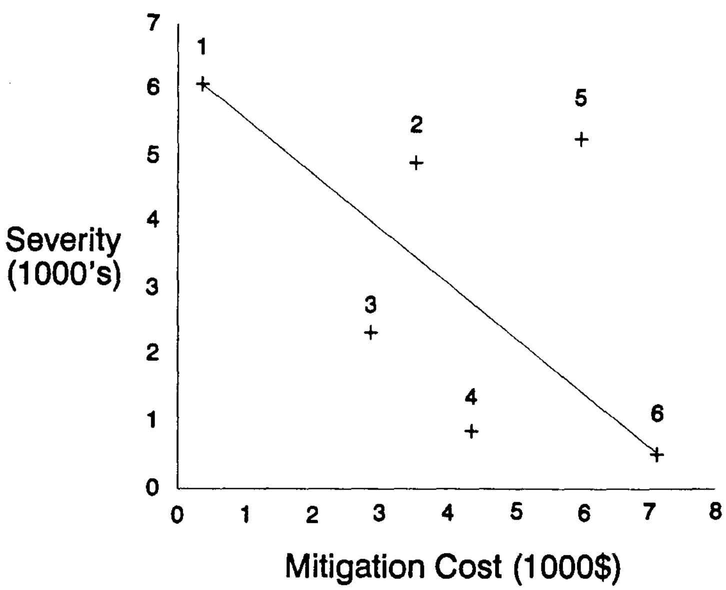



Table 3.6 Cost-Effectiveness Evaluation

| Alternative | Severity | Mitigation Cost |
|---|---|---|
| 1 | 6050 | 300 |
| 2 | 4950 | 3500 |
| 3 | 2300 | 2850 |
| 4 | 950 | 4350 |
| 5 | 5250 | 6000 |
| 6 | 500 | 7100 |

Figure 3.6 and Table 3.6 RHSM's Cost-Effectiveness Economic Evaluation

### 3.4.3 Vehicle-Roadside Interaction Details (Simulation Details)

This section details all the factors concerning the analysis of the vehicle-roadside interaction. These factors include: the encroachment characteristics, the vehicle trajectory, vehicle roll-over, the consequences of a vehicle leaving the road including critical roll-over speed and power level dissipated, the accident severity level, and the aggregation of all the factors into a useful result.

Encroachment Characteristics

There are three encroachment characteristics used in RHSM.V9 including: the encroachment locations as specified by the user, the vehicle encroachment speed probability, and the encroachment angle probability. The probability of an encroachment speed is based on a normal frequency distribution, with a mean speed and a standard deviation defined by the user. The probability of an encroachment angle is based on an empirically derived distribution [45] and is dependant upon the horizontal curvature of the roadway.

Vehicle Trajectory

The second step in analyzing the vehicle-roadside interaction is to determine the location, velocity, and deceleration of the vehicle as it progresses along the various trajectories. As the vehicle progresses along the trajectory, all the factors which tend to alter the motion of the vehicle are encountered and the affects on the vehicle trajectory is calculated. Factors which affect the vehicle's trajectory include: terrain changes, objects, roll-over, braking, dive-in impacts or air borne landings, and steer-back correction. In general terms, a vehicle moving on a surface with a friction coefficient (MU) decelerates at a rate of a=(MU)g, where g=the acceleration due to gravity.

Also included in analyzing the trajectory of the vehicle is the vehicle elevation with respect to the ground in order to determine if the vehicle becomes airborne. Adjustment factors are required to compensate for dive-in impacts and air-borne landings. The method for obtaining the adjustment factors for air-borne landings and dive-in impacts was described by Koike [46] for version 6.2 of RHSM. The simulation model HVOSM was used to simulate the movement of a vehicle starting at flat terrain and landing on different downgrade slopes for air-borne landings and upgrade slopes for dive-in impacts. The simulation for each case was run for a range of speed and power levels, and then a regression analysis was used to derive the relationship between speed, embankment slope angle, and the ratio of the power generated by the impact to the nominal power. This power ratio, which represents the terrain adjustment factor, was used to determine friction coefficients used for either air-borne landings or dive-in impacts. The two equations for calculating the friction coefficients are shown below.

Air-Borne Landing: $F = 0.8662 - 0.1852(V*\tan(A)) + 0.256(V*\tan(A))^2$

Dive-In Impacts: $F = 0.8637 + 0.4961(V*\tan(A)) + 0.07288(V*\tan(A))^2$

where F = adjustment factor for friction coefficient

V = pre-crush speed (meters per second)

A = embankment slope angle (degrees)

Vehicle Roll-Over

The final component that must be addressed in the analysis of the vehicle trajectory is to examine the occurrence of vehicle roll-over including dynamic roll-over and static roll-over. Although the vehicle is treated as a point with mass for the analysis of the trajectory, to determine if roll-over occurs, the vehicle is given four dimensions (wheelbase, track-width, height, and centre of gravity) and mass.

Dynamic roll-over occurs at terrain changes where a sudden drop-off is experienced by the outside wheels and the overhanging weight of the vehicle causes a torque about the centre of gravity which tend to cause vehicle rotation. Refer to Figure 3.7 which illustrates the occurrence of dynamic roll-over. The over-hanging weight of the vehicle is dependant upon the dimensions of the vehicle and the angle of encroachment.

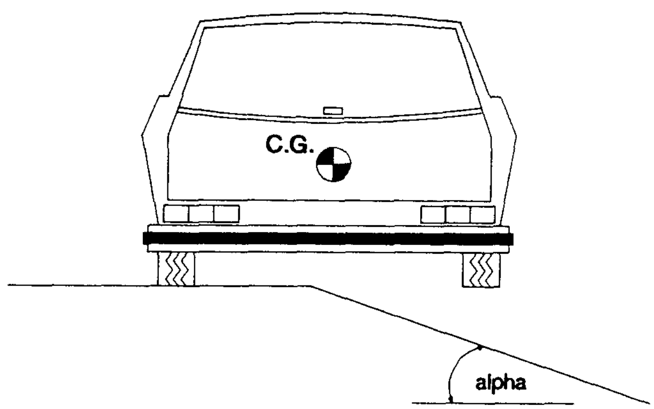



Figure 3.7 Schematic of Dynamic Vehicle Roll-Over
Source: RHSM: A Methodology and Technique to Effectively Reduce Single Vehicle Accident Potential,1984

Static Roll-over can occur when a vehicle is on a steep embankment slope, or when a steer-back manoeuvre is attempted, causing a radial force which may cause a vehicle to roll-over.

By referring to Figure 3.8, for static roll-over to occur, the centre of gravity of the vehicle goes through a transition (z) caused by the forces acting on the vehicle. To determine when the static roll-over occurs, the moments about the points of contact of the down-slope wheels are calculated. The forces which cause the vehicle to roll are the weight component (W) acting parallel to the embankment slope and the force due to radial acceleration (P).

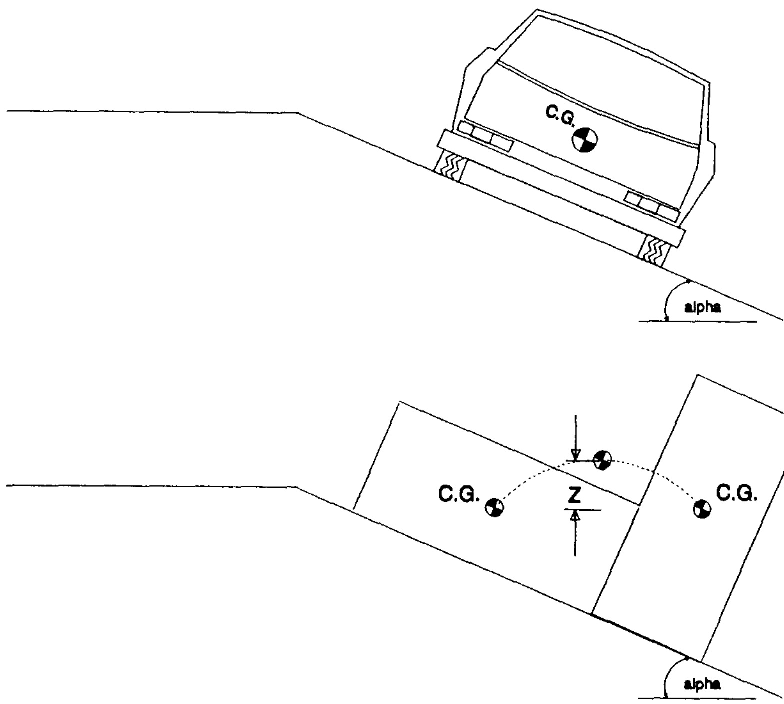



Figure 3.8 Schematic of Static Vehicle Roll-Over
Source: RHSM:A Methodology and Technique to Effectively Reduce Single Vehicle Accident Potential, 1984

Encroachment Consequences

The next step in analyzing the vehicle-roadside interaction is to determine the consequences of a vehicle leaving the roadway. There are two consequences which determine the hazard level subjected on a vehicle during an encroachment: the vehicle be subjected to factors which will alter the motion of the vehicle or the vehicle will roll. If the vehicle rolls, the speed at which the roll-over occurred is the basis for the probability of consequence severity index, otherwise the power level dissipated forms the basis for the consequence index.

Once the vehicle speed exceeds the critical roll-over speed the vehicle will roll and the roll-over speed is translated into an accident severity index. The severity index will categorize accidents in terms of No Damage (ND), Property Damage Only (PDO), Injury (INJ), and Fatalities (FAT). In the case of vehicle roll-over, the probability of ND does not exist. Table 3.7 is used by RHSM.V9 to provide the relationship between vehicle roll-over speed and probability of consequence.

Table 3.7 Roll-Over Speed versus Accident Consequence Probability

| Vehicle Roll-Over Speed | Restrained Occupants | | | Unrestrained Occupants | | |
|---|---|---|---|---|---|---|
| | PDO | INJ | FAT | PDO | INJ | FAT |
| 20 | 0.79 | 0.16 | 0.05 | 0.92 | 0.07 | 0.01 |
| 60 | 0.70 | 0.25 | 0.05 | 0.92 | 0.07 | 0.01 |
| 70 | 0.68 | 0.24 | 0.08 | 0.89 | 0.08 | 0.03 |
| 80 | 0.59 | 0.25 | 0.16 | 0.80 | 0.14 | 0.06 |
| 85 | 0.45 | 0.23 | 0.22 | 0.65 | 0.26 | 0.09 |
| 90 | 0.10 | 0.62 | 0.28 | 0.40 | 0.48 | 0.12 |
| 95 | 0.01 | 0.66 | 0.33 | 0.18 | 0.68 | 0.14 |
| 100 | 0.00 | 0.62 | 0.38 | 0.10 | 0.75 | 0.15 |
| 110 | 0.00 | 0.55 | 0.45 | 0.04 | 0.77 | 0.19 |
| 120 | 0.00 | 0.52 | 0.48 | 0.02 | 0.78 | 0.20 |
| 150 | 0.00 | 0.48 | 0.52 | 0.00 | 0.78 | 0.22 |

Source:RHSM, A Methodology and Technique to Effectively Reduce Single Vehicle Accident Potential, 1984.

The other consequence possibility of a vehicle's roadside encroachment is that the vehicle will not roll, but will traverse the roadside. RHSM.V9 calculates the power level dissipated at various points along the vehicle's trajectory by simply multiplying the velocity and the acceleration experienced by the vehicle during a specified time span. The power level is only an intermediate result which is translated into the same severity index categories used for the vehicle roll-over (ND, PDO, INJ, FAT). A number of barrier crash experiments were used to establish the relationship between power and accident severity level. A study done at the University of Saskatchewan [47] attempted to relate the AIS level (Abbreviated Injury Scale) and the CDC (Centre for Disease Control) extent number. Another study done by Campbell [48] establishes the relationship between speed and crash distance in rigid barrier crashes. When the result of these studies are combined (Table 3.8), the relationship between power level and accident severity level can be determined.

Table 3.8 Dissipated Power Level Versus Accident Severity

| Power Dissipated (W/kg) | No Damage (ND) | Unrestrained Occupants | | | Restrained Occupants | | |
|---|---|---|---|---|---|---|---|
| | | PDO | INJ | FAT | PDO | INJ | FAT |
| 200 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 300 | 0.50 | 0.50 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 |
| 432 | 0.01 | 0.98 | 0.009 | 0.001 | 0.99 | 0.009 | 0.0001 |
| 1459 | 0.00 | 0.85 | 0.14 | 0.01 | 0.95 | 0.0495 | 0.0005 |
| 3092 | 0.00 | 0.60 | 0.37 | 0.03 | 0.88 | 0.119 | 0.001 |
| 5331 | 0.00 | 0.26 | 0.62 | 0.12 | 0.74 | 0.25 | 0.01 |
| 11628 | 0.00 | 0.00 | 0.55 | 0.45 | 0.02 | 0.93 | 0.05 |
| 15685 | 0.00 | 0.00 | 0.15 | 0.85 | 0.00 | 0.63 | 0.37 |
| 20348 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 |

Source:RHSM, A Methodology and Technique to Effectively Reduce Single Vehicle Accident Potential, 1984

The degree of restraint acts as an adjustment to the various accident severity categories. A linear interpolation between the two extreme cases is assumed, however, since relatively little is known about the relationship between power dissipation and accident consequence, the relationships are somewhat crude and subject to future modifications and improvements.

The final component in analyzing the vehicle-roadside interaction is to aggregate all the components of the simulation. The accident severity results obtained from each trajectory is accumulated in the roadside grid matrix until all trajectories have been executed, with the final result being one value for each accident severity category.

### 3.4.4 Calibration and Defaults

The last option of RHSM.V9's main menu is labelled Calibration and Defaults and is provided to make the program as flexible as possible. Once selected, a secondary menu appears called Calibration Data Menu which has nine options to choose from. The nine options include Operational Data, Departure Angle, Probability of Consequence Data, Roll Consequences, Vehicle Characteristics, Encroachment Rate Calibration, Encroachment Rate Defaults, Unit-Cost/Interest Rate/Analysis Period Defaults, and Save Data to Default File. Calibration and Defaults provides the ability to update the model as new and better information becomes available or to correct for unique site locations.

1) Operational Data

All 15 operational parameters used by RHSM can be accessed and changed as required. The current defaulted values represent "average" or "typical" conditions, with relatively quick program run-time considered important. The defaulted values currently employed by the program are shown in Table 3.9.

Table 3.9 Operational Parameters Default Values

| Operational Parameter | Default Value | Operational Parameter | Default Value |
|---|---|---|---|
| Horizontal Curvature | Straight | Angle Increment | 4 degrees |
| Time Increment | 0.05 seconds | Speed Increment | 2.0 mps |
| Maximum Time | 10.0 seconds | Minimum Probability | 0.0000 |
| Number of Encroachments | One | Degree of Restraint | 50% |
| Location of Encroachments | X=0, Y=0 | Degree of Braking | 0% |
| Mean Speed | 80 kph | Degree of Steer-back | 0 degrees |
| Speed Std. Deviation | 10 kph | Vehicle Type | 4 |
| Minimum Speed | 1.0 mps | | |

2) Departure Angle

Departure Angle is used to determine the probability that a certain encroachment angle will be taken. The probability is based on an empirically derived frequency distribution ranging from a 2 degree encroachment angle to a 70 degree encroachment angle. Also included in this Calibration Data option is the angle frequency distributions for the different horizontal curves (gentle curve, moderate curve, and severe curve). Each departure angle distribution can be changed to better simulate a particular location. A graph is available to view the frequency distributions to ensure the they are suitable. The four default departure angle distributions are shown in Figure 3.9. The distribution for the straight roadway section is from on Transport Canada's study of off-road accidents [49].

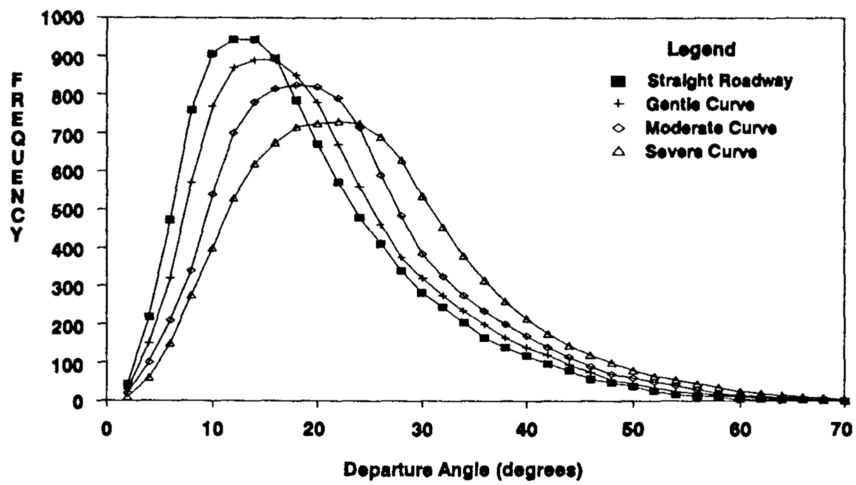



Figure 3.9 Departure Angle Frequencies

3) Probability of Consequence Table

To change the probability of consequence table a power level and the probability of each accident consequence level must be entered. The table allows up to 50 sets of power level/accident consequence probabilities, however, at the present time, only nine sets of values are used. Although better results have not been found, this aspect of the model could be up-dated allowing for further calibration of the model. A graph is available view the relationship between power level and accident severity.

4) Roll Consequences

The roll consequence table is structured identically to the probability of consequence table. The difference is that instead of power level, this table utilizes the speed at roll-over as the basis for the accident severity result. Again up to 50 sets of values can be utilized and a graphical representation of the relationship between vehicle roll-over speed and accident severity can be viewed. When new and better research becomes available, this roll-over consequence table can be immediately updated.

5) Vehicle Characteristics

The purpose of vehicle characteristics is to allow the user to modify and select the types of vehicles which are characteristic of the roadway under review. There are four factors which are used to simulate vehicles: the vehicle's centre of gravity, the track width, the wheelbase, and the vehicle mass. The eight vehicles which currently represent the default vehicles are taken from RHSM.V6.2 documentation [50], and are shown in Table 3.10.

Table 3.10 Vehicle Characteristics: Default Values

| Vehicle Type | Wheel-base (m) | Track-Width (m) | Weight (kg) | Centre of Gravity (m) |
|---|---|---|---|---|
| 1 | 2.40 | 1.30 | 922 | 0.51 |
| 2 | 2.52 | 1.42 | 979 | 0.53 |
| 3 | 2.59 | 1.42 | 1159 | 0.55 |
| 4 | 2.75 | 1.48 | 1404 | 0.58 |
| 5 | 2.95 | 1.55 | 1591 | 0.58 |
| 6 | 2.98 | 1.58 | 1859 | 0.58 |
| 7 | 2.24 | 1.30 | 636 | 0.51 |
| 8 | 2.75 | 1.48 | 1600 | 0.58 |

Source: RHSM: A Methodology and Technique to Effectively Reduce Single Vehicle Potential, 1984

6) Encroachment Rate Calibration

Encroachment rate calibration provides ten encroachment rate factors, with each factor having 5 or 6 choices to simulate the roadway under review. The values generally range from 0.80 to 1.30 for each factor and are meant to correct the encroachment rate due to the various characteristics of the roadway. The majority of the values were obtained directly from TAC [51], others were derived from M.o.T.H sources [52], and others are new to the analysis. Any of the values can be modified to better simulate unique locations.

Table 3.11 Encroachment Rate Factors

| Roadway Class | | Design Speed | | Lane Width | | Number of Lanes | | Shoulder Width | |
|---|---|---|---|---|---|---|---|---|---|
| type | value | kph | value | meters | value | number | value | meters | value |
| Highway | 1.00 | 80 | 0.90 | <3.0 | 0.90 | 2 (TW) | 1.10 | 0.0 | 0.85 |
| Urban Freeway | 1.00 | 90 | 0.95 | 3.4 | 0.95 | 4 (TW) | 1.05 | 1.0 | 0.90 |
| Rural Freeway | 0.95 | 100 | 1.00 | 3.7 | 1.00 | 4 (Div) | 1.00 | 2.0 | 0.95 |
| Urban Arterial | 1.05 | 110 | 1.05 | 4.0 | 1.05 | 6 (Div) | 0.95 | 3.0 | 1.00 |
| Rural Arterial | 1.10 | 120 | 1.10 | >4.0 | 1.10 | 8 (Div) | 0.90 | 4.0 | 1.05 |

| Horizontal Curve | Vertical Curve | Climatic Conditions | Adjust Value (each) | Traffic Composition | Adjust Value | Sight Restrict. | Adjust Value |
|---|---|---|---|---|---|---|---|
| flat | <2% | no freezing | 1.00 | 1. familiar | 1.00 | none | 1.00 |
| gentle | 3% | mod. freezing | 1.05 | 2. un-familiar | 1.10 | temporary | 1.05 |
| moderate | 4% | mod. fog | 1.10 | 3.heavy vehicles | 1.10 | periodic | 1.05 |
| severe | 5% | sig. freezing | 1.15 | 4. platooning | 1.10 | slight | 1.10 |
| moderate (outside) | 6% | sig. fog | 1.20 | combine: 2-3, 2-4, or 3-4 | 1.20 | moderate | 1.15 |
| severe (outside) | >7% | fog and freezing | 1.25 | combine: 2-3-4 | 1.30 | severe | 1.20 |

7) Encroachment Rate Defaults

This option allows the user to select the default values which will be used when the program is run. The ten encroachment rate factors, each with 5 or 6 default choices are currently set at default values of 1.0.

8) Unit Costs / Interest Rate / Analysis Period

The unit cost values which can be defaulted include barrier installation costs, barrier maintenance costs, cut/fill cost, slope maintenance cost, and the direct cost of each accident type (ND, PDO, INJ, FAT). The present value/capital recovery factors include the interest rate and the analysis period. All of these factors will vary greatly from project to project and therefore, having default values for each of the factors listed above may be difficult.

9) Save Data to Default File

The last option under the Calibration Data Menu is the Save Data to Default File option. The purpose of this option is to save the new defaults so that the next time the program is run, the new defaults will be utilized. A sub-screen will appear to verify default changes.

### 3.4.5 Display and Output Results

There are three options on RHSM.V9's main menu which relate to the displaying of the results: Display Results, Output to Printer or File, and Plot Trajectories.

1) Display Results

Once the simulation has been run, and Display Results has been selected, a sub-screen appears with two options: List Output and Graph Output. List Output will write the results of the simulation to the screen where the user can page-up or page-down to observe the results. There is one screen available for the results of each improvement alternative as well as a summary of the results from all the alternatives. For each improvement alternative, the output includes the total number of encroachment trajectories considered, the total number of vehicle roll-overs, the number and probability of roll-overs at the terrain change, the number and probability of rolls on the slope, the aggregated probability of accident consequence (ND, PDO, INJ, FAT) and the results of the economic analysis.

The second option under display results is Graph Output. The purpose of this option is to provide a visual representation of the relative hazard level of each hazardous roadside feature. When this option is selected, the improvement alternatives title screen appears for the user to select the alternative which results require visual inspection. Then the required consequence criteria (either PDO, INJ, FAT) is selected to be illustrated graphically. Finally, the vantage point in which to view the graphical output is entered. Four vantage points are provided to ensure that the 3-D graph results can be viewed accurately. Often a large peak in the foreground of the accident consequence surface will "hide" smaller contours behind. Figure 3.10 provides an example of a 3-D graph available in RHSM.V9 and identifies the various vantage points.

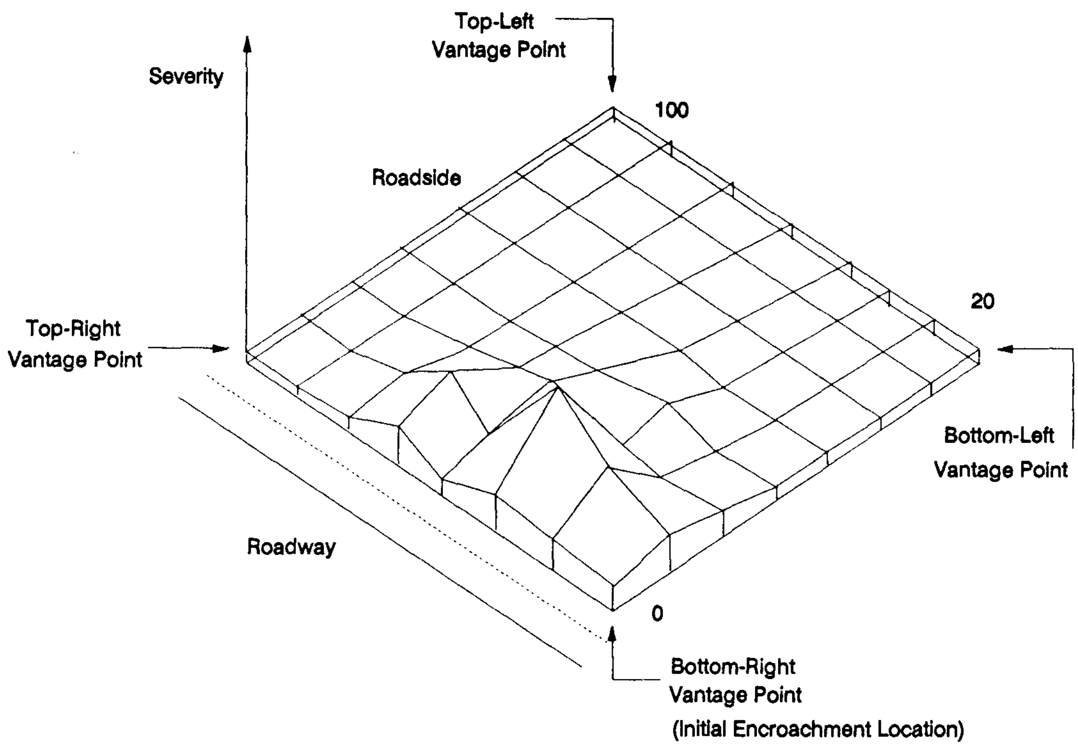



Figure 3.10 Three-Dimensional Graphic Results

2) Output to Printer or File

The purpose of the Output to Printer of File option is to either save the results of the simulation run to a file or to get a print-out of the simulation results by sending the output directly to the printer. The list of model components which can be output includes the Operational Data, Terrain Data, Clear-Zone Object Data, Departure Angle, Probability of Consequence Data, Roll Consequence Table, Vehicle Characteristics, the Results, the B/C Evaluation, and the C-E Evaluation. Each of these components has been discussed in detail in the previous sections. The user is required to answer yes (Y) or no (N) for each component to be included in the output. This option is another example which illustrates the flexibility that has been incorporated into RHSM.V9.

3) Plot Trajectories

Plot Trajectories provides a visual display of the trajectory of a vehicle during an off-road excursion. This is a check to ensure the vehicle's trajectory is simulated accurately. The information required to view the trajectory include: the encroachment number, the initial velocity of the vehicle during the roadside encroachment, and the initial encroachment angle. The trajectory plot shows a topographic view and a cross-sectional view of the roadside surface and then the vehicles trajectory will be drawn on both views and the user can observe how hazardous features in the roadside affect the vehicles trajectory. If roll-over occurs at any point along the trajectory, then a semi-circular line appears in the profile view to indicate where the vehicle roll-over occurred. An illustration of a hazardous roadside and a possible trajectory is shown in Figure 3.11.

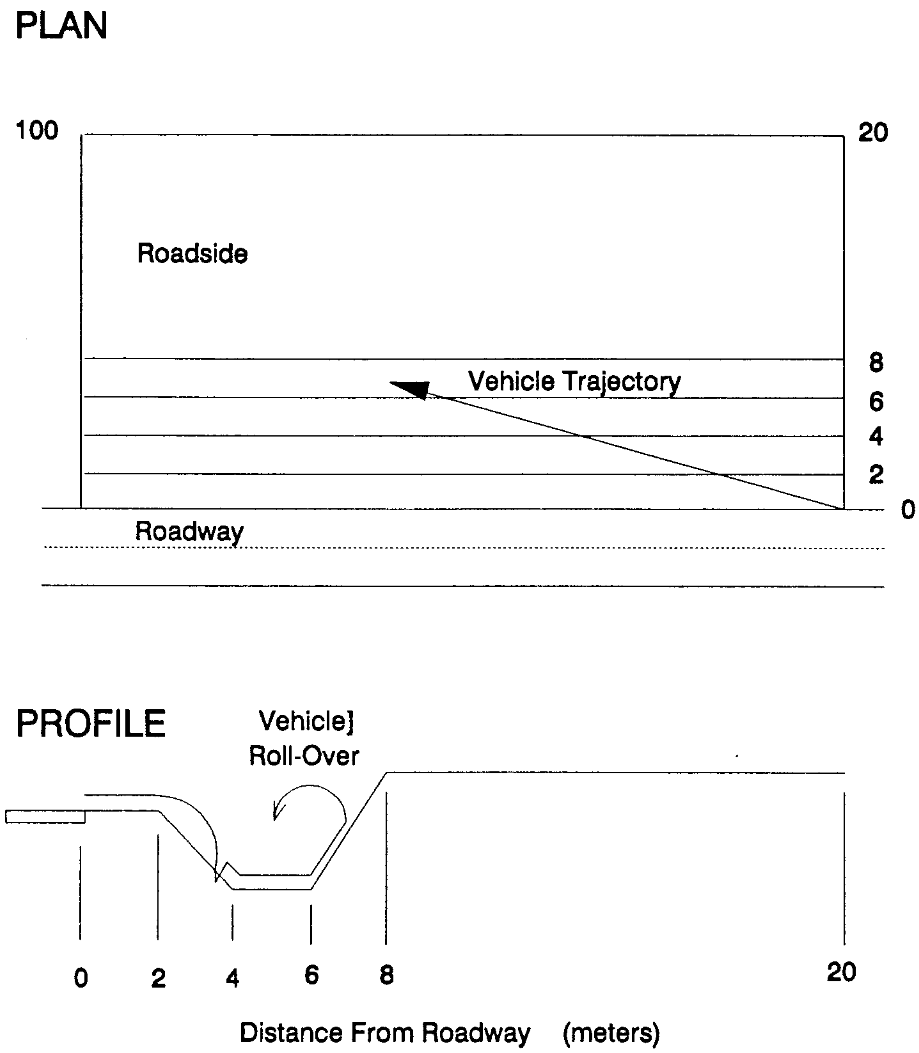



Figure 3.11 Vehicle Trajectory Plots

### 3.4.6 Information Storage and Retrieval

The final two options on RHSM.V9's main menu are called Load Input Data and Save Input Data. The purpose of these options is to save all input data including the Edit Simulation Data, Alternative Evaluation Data, and Calibration and Defaults for a particular location. These storage and retrieval components of RHSM.V9 applies to the input data only and that the storage of results produced by the program are treated separately.

### 3.5 Program Details

Since version nine of the program has been completely re-developed, the program structure, subroutine names, and variable names are unique to version nine, whereas the previous versions (5.0, 6.2, and 7.0) were all very similar in structure and variable definition. RHSM.V9 has been written in Fortran77 and utilizes Prospero's Profor2 Compiler, and Saywhat Graphics software to improve the graphic capabilities and visual presentation. Although it is possible for a user to use RHSM.V9 without having any knowledge of how the program works, it is important for the user to understand how the program flows, starting with input requirements and ending with the output results. Similar to the previous versions, RHSM.V9 utilizes a series of subroutines which separate the different components of the program. One main program called RHSM and twenty-one subroutines are used to effectively handle all the operations of the program. Figure 3.12 shows a flow-chart of the program and Appendix C provides a descriptions of the purpose of each subroutine.

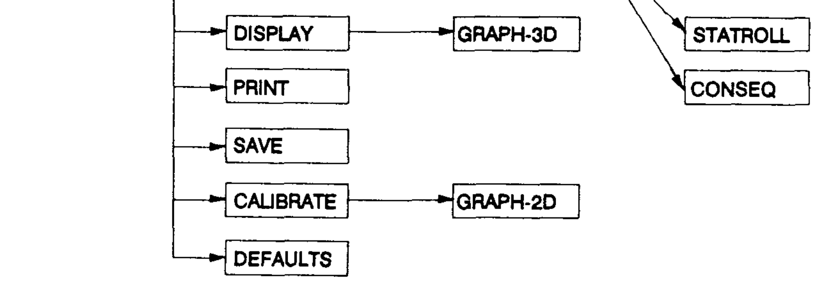



Figure 3.12 Flow-Chart of RHSM.V9

## 4.0 EVALUATION OF RHSM.V9: Results and Sensitivity Analysis

This chapter examines the results produced by RHSM.V9 and details the effectiveness of the new version of the model. The model performance will be illustrated by performing numerous program runs and comparing the results with previous results or expected results.

### 4.1 Results Comparison: RHSM.V9 with Previous Versions

Unfortunately, when reviewing the previous versions of RHSM, there is a significant lack of information relating to results produced by each earlier version (RHSM.V5, RHSM.V6.2, and RHSM.V7). However, in a M.o.T.H. publication [53] the results of each version were provided and forms the foundation of this comparison. Another problem in forming the comparison is that the operational parameters used to obtain the earlier results are not known. Therefore, for operational parameters such as speed or degree of restraint, which may greatly affect the results produced, the values had to be estimated. The value of the result, as well as the trends in the results is important in the comparison.

For this comparison, a series of typical roadside ditch configurations were utilized, including flat bottom ditches and V-shaped ditches. A flat bottom ditch has a variable front slope, but always has a one-meter wide bottom, a depth of 2.0 meters, and a 2:1 back slope for all cases. A V-ditch is a V-shaped ditch with varying front slopes, a 2:1 back slope, and a 2.0 meter depth for all cases presented. The results obtained from RHSM.V9 use a mean encroachment speed of 80 kph with 50% seat belt usage. The results of the comparison are shown in Tables 4.1, 4.2, and 4.3, one table for each previous RHSM version.

Table 4.1 RHSM.V9 versus RHSM.V5 Results Comparison

| Ditch Config. | Probability ND | | Probability PDO | | Probability INJ | | Probability FAT | | Probability Roll | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V9 | V5 | V9 | V5 | V9 | V5 | V9 | V5 | V9 | V5 |
| 4:1 FB | 0.89 | 0.64 | 0.10 | 0.33 | 0.01 | 0.03 | 0.00 | 0.00 | 0.01 | 0.11 |
| 4:1 V | 0.89 | 0.51 | 0.10 | 0.40 | 0.01 | 0.08 | 0.00 | 0.01 | 0.01 | 0.10 |
| 2:1 FB | 0.72 | 0.46 | 0.22 | 0.32 | 0.04 | 0.16 | 0.01 | 0.06 | 0.01 | 0.64 |
| 2:1 V | 0.70 | 0.24 | 0.23 | 0.52 | 0.05 | 0.18 | 0.02 | 0.07 | 0.02 | 0.64 |

Table 4.2 RHSM.V9 versus RHSM.V6.2 Results Comparison

| Ditch Config. | Probability ND | | Probability PDO | | Probability INJ | | Probability FAT | | Probability Roll | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V9 | V6.2 | V9 | V6.2 | V9 | V6.2 | V9 | V6.2 | V9 | V6.2 |
| 4:1 FB | 0.89 | 0.95 | 0.10 | 0.01 | 0.01 | 0.03 | 0.00 | 0.01 | 0.01 | 0.23 |
| 3:1 FB | 0.83 | 0.69 | 0.15 | 0.17 | 0.02 | 0.09 | 0.00 | 0.04 | 0.02 | 0.48 |
| 2:1 FB | 0.72 | 0.36 | 0.22 | 0.39 | 0.04 | 0.18 | 0.01 | 0.07 | 0.02 | 0.82 |
| 4:1 V | 0.89 | 0.03 | 0.10 | 0.69 | 0.01 | 0.21 | 0.00 | 0.07 | 0.01 | 0.71 |
| 3:1 V | 0.83 | 0.02 | 0.15 | 0.65 | 0.02 | 0.23 | 0.00 | 0.09 | 0.01 | 0.91 |
| 2:1 V | 0.70 | 0.01 | 0.23 | 0.64 | 0.05 | 0.25 | 0.02 | 0.10 | 0.01 | 0.99 |

Table 4.3 RHSM.V9 versus RHSM.V7 Results Comparison

| Ditch Config. | Probability ND | | Probability PDO | | Probability INJ | | Probability FAT | | Probability Roll | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V9 | V7 | V9 | V7 | V9 | V7 | V9 | V7 | V9 | V7 |
| 4:1 FB | 0.89 | 0.92 | 0.10 | 0.00 | 0.01 | 0.04 | 0.00 | 0.03 | 0.01 | 0.30 |
| 3:1 FB | 0.83 | 0.91 | 0.16 | 0.01 | 0.01 | 0.05 | 0.00 | 0.03 | 0.01 | 0.40 |
| 2.5:1 FB | 0.77 | 0.79 | 0.20 | 0.03 | 0.03 | 0.11 | 0.00 | 0.06 | 0.01 | 0.50 |
| 2:1 FB | 0.72 | 0.46 | 0.23 | 0.10 | 0.04 | 0.29 | 0.01 | 0.15 | 0.02 | 0.59 |

Notes: V9 - version nine V6.2 - Version 6.2 FB - Flat bottom ditch
V7 - version seven V5 - Version 5 V - V-shaped ditch

The major criticism of RHSM.V6.2 and RHSM.V7 was that the results generated from each version were far too severe. This is true, especially for the probability of vehicle roll-over, which according to M.o.T.H. standards, specifies that a 4:1 embankment slope is recoverable, or in other words, would be very unlikely to cause vehicle roll-over. This problem is overcome in Version 9 of RHSM, which produced very low roll-over probabilities. As well as the roll-over probabilities, the accident consequence probabilities are also significantly less severe than those produced by Versions 6.2 and 7, which, considering the geometric configuration of the roadside terrain, seems more realistic.

RHSM.V5 produced the "best" results of the three previous versions. RHSM.V9 produced results that were relatively close to those produced by Version 5, especially for the injury and fatality categories of accident consequence. The results produced by Version 9 are moderately less severe than those produced by Version 5. If the operational parameters such as vehicle speed, seat-belt usage, or other parameters were modified, the results produced by Version 9 could closely reflect those produced by Version 5. The trend of increasing accident severity with increases in embankment slope is valid.

### 4.2 Results Evaluation: Hazardous Roadside Terrain Slopes

There are three factors which need to be analyzed in the evaluation of when an errant vehicle encounters hazardous roadside terrain including the location of the terrain changes, the severity of the terrain changes, and the friction coefficient which is representative of the roadside terrain. To ensure consistency, all the default values for the operational parameters have been employed for each roadside terrain analyzed. Also, no hazardous roadside objects were used in the evaluation of the various roadside terrain in order to isolate the effects caused by the terrain.

The first factor which will be considered in the evaluation of the hazardous roadside terrain is the location of the terrain changes. To emphasize the effects of the location of the hazardous terrain, a severe ditch configuration has been selected which is simulated at different locations parallel to the edge of the roadway. The simulated V-shapes ditch has a 53 degree front slope, a 53 degree back slope, and a depth of 4.0 meters. For the analysis, the ditch locations start at 0.0 meters, 5.0 meters, 10.0 meters, and 15 meters from the edge of the roadway and the results have been tabulated in Table 4.4.

Table 4.4 Location of Hazardous Terrain

| Location of Terrain Hazard. (m) | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0.0 | 0.58 | 0.14 | 0.16 | 0.12 | 0.24 | 0.22 | 0.02 |
| 5.0 | 0.68 | 0.11 | 0.15 | 0.07 | 0.15 | 0.10 | 0.05 |
| 10.0 | 0.71 | 0.13 | 0.13 | 0.04 | 0.10 | 0.08 | 0.02 |
| 15.0 | 0.80 | 0.11 | 0.07 | 0.02 | 0.09 | 0.05 | 0.04 |

The results produced by RHSM.V9 for the variations in the location of the hazardous terrain appear to be quite good. The accident severity consequence probability results show that as the location of the hazardous terrain feature increases in distance from the edge of the roadway, the accident severity consequence probability decreases. This is a reasonable result since the vehicle has a greater distance in which to decelerate and therefore avoid the hazard or encounter the hazard at a lower speed. The roll-over probability results are similar, with the total roll-over probability decreasing with the distance from the edge of the road to the hazardous terrain feature. The majority of the roll-overs occur on the slope instead of at the terrain change, which is a realistic result since air-borne and dive-in roll-overs usually occur on the slope.

The second factor to be discussed in the evaluation of hazardous roadside terrain is the severity or relative magnitude of the terrain slope. For this analysis, a series of different slopes ranging from 0 degrees to 60 degrees were used for both the down-slope (negative) and up-slope (positive) directions. The terrain was simulated as flat for 2.0 meters from the roadway edge, then the variable slope was simulated for a distance which would allow for an effective fill height of 5.0 meters, and then the terrain was simulated as flat for the remaining 20.0 meter lateral distance. The results have are shown in Tables 4.5 and 4.6.

Table 4.5 Degree of Down-Slope Terrain (Negative Slope Angles)

| Terrain Slope (degrees) | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -10 | 0.98 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -20 | 0.83 | 0.16 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| -30 | 0.73 | 0.21 | 0.05 | 0.01 | 0.07 | 0.00 | 0.07 |
| -40 | 0.67 | 0.21 | 0.10 | 0.02 | 0.06 | 0.00 | 0.06 |
| -50 | 0.61 | 0.23 | 0.13 | 0.02 | 0.08 | 0.00 | 0.08 |
| -60 | 0.61 | 0.06 | 0.17 | 0.16 | 0.51 | 0.48 | 0.03 |

Table 4.6 Degree of Up-Slope Terrain (Positive Slope Angles)

| Terrain Slope (degrees) | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 1.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 |
| 30 | 0.97 | 0.03 | 0.00 | 0.00 | 0.02 | 0.00 | 0.02 |
| 40 | 0.88 | 0.07 | 0.03 | 0.01 | 0.03 | 0.00 | 0.03 |
| 50 | 0.78 | 0.17 | 0.05 | 0.01 | 0.01 | 0.00 | 0.01 |
| 60 | 0.61 | 0.06 | 0.17 | 0.16 | 0.48 | 0.48 | 0.00 |

The results produced by RHSM.V9 for variations in the severity or slope of hazardous roadside terrain also appears to be quite good. The first observation should be that the down-slope terrain is more hazardous than the up-slope terrain. This is a reasonable result since the up-slope terrain tends to slow the vehicle down and thus lessen the severity of the accident consequence probability. The exception is for the very severe slope angles (60 degrees), in which the vehicle roll-over becomes the significant factor causing similar results for both positive and negative embankment slopes. The trends in the results are also correct. For either down-slope or up-slope terrain, the accident severity increases with an increase in the embankment slope angle. For down-slope terrain, the accident severity consequence probability becomes significant near the -20 degree down-slope (approximately a 3:1 slope), which according to AASHTO and TAC, becomes the point at which a slope is unrecoverable.

The final factor which will be evaluated in the analysis of hazardous roadside terrain is the coefficient of friction used to represent various roadside terrains. These values were discussed in the previous chapter, where a table was provided which recommended values which could be used for different terrain types. For this analysis, the values for terrain resistance varied from MU=0.10 to MU=0.90. The terrain was simulated as very flat (a 2.0 degree down-slope), and no hazardous roadside objects. The results produced by RHSM.V9 have been tabulated below in Table 4.7.

Table 4.7 Level of Terrain Friction Coefficient

| Terrain Friction Coefficient (MU) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| MU=0.10 | 1.00 | 0.00 | 0.00 | 0.00 |
| MU=0.30 | 1.00 | 0.00 | 0.00 | 0.00 |
| MU=0.50 | 1.00 | 0.00 | 0.00 | 0.00 |
| MU=0.70 | 0.99 | 0.01 | 0.00 | 0.00 |
| MU=0.90 | 0.77 | 0.23 | 0.00 | 0.00 |

The results produced from RHSM.V9 for this aspect of hazardous terrain evaluations are valid. The terrain friction coefficient acts as a factor to decelerate an errant vehicle, and in so doing, reduce the severity of the accident consequence probabilities. As the vehicle decelerates according to the terrain friction coefficient specified, a power loss, based on the product of the deceleration and change in velocity, results. However, at no time should this power be large enough to cause accident resulting in injuries or fatalities. For example, if the roadside area under investigation has a surface that is asphalt, the program recommends a high value for the coefficient of friction (approximately equal to MU=0.70). Therefore, it is reasonable to assume that as the errant vehicle leaves the road onto the flat asphalt roadside terrain, it should be able to stop without serious injury or fatality, even though, power loss has occurred through the application of the brakes and the rubber tires "gripping" the asphalt surface. The program provides these results.

### 4.3 Results Evaluation: Hazardous Roadside Objects

There are three factors which need to be analyzed in the evaluation of the results produced by RHSM.V9 when a vehicle encounters hazardous roadside objects. These three factors are the type of object, the size and number of objects, and the location of the objects in relation to the roadway. For the purpose of consistency, all of the default values are used for the operational parameters, and the roadside terrain was simulated as very flat (2 degree down-slope angle), with a very low friction coefficient for the terrain resistance. Although this may appear to be an unrealistic assumption, the purpose is to isolate the hazardous objects to see the affects of varying the three factors outlined above.

The first factor considered is the type of object; either a rigid object, a deformable object, or a passable object, and the relative rigidity. The relative rigidity of an object ranges from 0 to 100 and only applies to objects specified as deformable since rigid objects have a defaulted value of 100 for the rigidity factor and passable objects have a defaulted value of 0 for the rigidity factor. In Table 4.8, the three different types of objects are presented, with the deformable objects having a rigidity factor of MU=50.

Table 4.8 Object Types

| Object Type | Rigidity Factor (MU) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|---|
| | | ND | PDO | INJ | FAT |
| Rigid | 100 | 0.65 | 0.20 | 0.13 | 0.02 |
| Deformable | 50 | 0.66 | 0.24 | 0.09 | 0.01 |
| Passable | 0 | 1.00 | 0.00 | 0.00 | 0.00 |

The results produced are as expected: the rigid object has the most severe accident probability consequence, the passable object has the least severe accident probability consequence, and the deformable object produces results between the two extremes.

It is also important to evaluate how the relative rigidity factor (MU) affects the results of the program. By simulating the same size, number, and location of objects in the roadside and varying the relative rigidity of the objects, the sensitivity of MU can be determined. One large object, 2.0 meters from the roadway, 95.0 meters by 16.0 meters in size is simulated with MU ranging from 3 to 30. The results of the analysis have been tabulated in Table 4.9. The trend in the results is correct, indicating that as the friction coefficient of the hazardous objects increase, the accident severity consequence probability also increases. The value of this component of the model is tremendously important, since many hazardous objects are considered deformable (including some roadside barriers) and obtaining a representative value for these objects will ensure accurate results. More research is required to achieve these values, some of which should become available from M.o.T.H., Highway Safety Branch sponsored research by Navin and Thomson [54] regarding concrete roadside barriers.

Table 4.9 Deformable Object Rigidity Factor

| Deformable Object Rigidity Factor (MU) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| 3 | 0.61 | 0.37 | 0.02 | 0.00 |
| 6 | 0.61 | 0.35 | 0.04 | 0.00 |
| 9 | 0.61 | 0.31 | 0.07 | 0.00 |
| 12 | 0.61 | 0.28 | 0.10 | 0.01 |
| 15 | 0.61 | 0.25 | 0.13 | 0.01 |
| 18 | 0.61 | 0.22 | 0.15 | 0.01 |
| 21 | 0.61 | 0.20 | 0.17 | 0.01 |
| 24 | 0.61 | 0.19 | 0.19 | 0.02 |
| 27 | 0.61 | 0.17 | 0.20 | 0.02 |
| 30 | 0.61 | 0.16 | 0.20 | 0.02 |

The second factor to be considered in the evaluation of hazardous roadside objects is to consider the size and number of objects present in the roadside. The terrain data was consistent throughout this phase of the testing in order to isolate the object size and number. The terrain was given a very slight down-slope (2 degrees) and low friction coefficients for terrain resistance. For this analysis five different object sizes were selected: very small (0.2 x 0.2 meters), small (1.0 x 1.0 meters), medium (3.0 x 3.0 meters), large (5.0 x 5.0 meters), and very large (15.0 x 15.0 meters). The initial contact location or the corner of the object closet to the vehicle trajectory was constant, with the object size increasing perpendicularly away from this initial corner. The object type selected was rigid objects. The trend in the results produced by RHSM.V9 is valid, as shown in Table 4.10. The accident consequence severity increases as the size of the hazardous object increases. This is due to the increase in the access probability of the vehicle striking the object.

Table 4.10 Object Size

| Object Size | Object Dimensions (meters) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|---|
| | | ND | PDO | INJ | FAT |
| Very Small | 0.2 x 0.2 | 1.00 | 0.00 | 0.00 | 0.00 |
| Small | 1.0 x 1.0 | 0.87 | 0.08 | 0.04 | 0.00 |
| Medium | 3.0 x 3.0 | 0.74 | 0.15 | 0.09 | 0.01 |
| Large | 5.0 x 5.0 | 0.73 | 0.16 | 0.10 | 0.01 |
| Very Large | 15.0 x 15.0 | 0.70 | 0.17 | 0.11 | 0.01 |

In evaluating the results produced by increasing the number of hazardous roadside objects, the results are very similar to those results produced by increasing the size of the object. The terrain is similar to that specified earlier, and the simulated objects were located 5.0 meters from the edge of the road, and spaced approximately 5.0 meters apart. As expected, the trend is that as the number of objects increase, the accident severity consequence probability also increases. The reason for this is the increase in the access probability of a vehicle striking a hazardous roadside object. The results are presented in Table 4.11.

Table 4.11 Number of Objects Parallel to the Roadway

| Number of Objects | Object Dimensions (meters) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|---|
| | | ND | PDO | INJ | FAT |
| 1 | 1.2 x 1.2 | 0.87 | 0.08 | 0.04 | 0.00 |
| 2 | 1.2 x 1.2 | 0.80 | 0.12 | 0.08 | 0.01 |
| 3 | 1.2 x 1.2 | 0.73 | 0.16 | 0.10 | 0.01 |
| 4 | 1.2 x 1.2 | 0.68 | 0.18 | 0.13 | 0.01 |
| 5 | 1.2 x 1.2 | 0.68 | 0.18 | 0.13 | 0.01 |
| 10 | 1.2 x 1.2 | 0.62 | 0.22 | 0.14 | 0.02 |
| 15 | 1.2 x 1.2 | 0.62 | 0.21 | 0.15 | 0.02 |
| 20 | 1.2 x 1.2 | 0.63 | 0.21 | 0.14 | 0.02 |

The third factor considered in the evaluation of hazardous roadside objects is the location of the objects. A series of roadside objects were simulated at different locations within the roadside to evaluate the effects on the accident severity consequence probability. One run of the program was completed to evaluate the effects of moving a row of objects further from the edge of the roadway (parallel to the roadway) and a second run of the program was completed to evaluate the effects of moving a row of objects further from the start of the hazardous area (perpendicular to the roadway). The objects simulated were rigid objects with dimensions of 1 x 1 meters. In the direction parallel to the roadway, a row of 10 objects were spaced at 5 meters apart, and in a direction perpendicular to the road, a row of 6 objects were spaced 3 meters apart. The results are shown in Tables 4.12 and 4.13.

Table 4.12 Location of Objects Parallel to the Roadway

| Distance from Edge of the Road | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| 3.0 meters | 0.67 | 0.18 | 0.13 | 0.02 |
| 6.0 meters | 0.66 | 0.20 | 0.13 | 0.01 |
| 10.0 meters | 0.70 | 0.20 | 0.09 | 0.01 |
| 15.0 meters | 0.79 | 0.15 | 0.05 | 0.00 |

Table 4.13 Location of Objects Perpendicular to the Roadway

| Distance from Start of the Hazard Zone | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| 1.0 meter | 0.99 | 0.01 | 0.00 | 0.00 |
| 15.0 meters | 0.63 | 0.22 | 0.14 | 0.01 |
| 30.0 meters | 0.77 | 0.14 | 0.08 | 0.01 |
| 50.0 meters | 0.79 | 0.17 | 0.04 | 0.00 |
| 70.0 meters | 0.93 | 0.06 | 0.01 | 0.00 |

The results produced by RHSM.V9 for both object location types are valid. When the objects are parallel to the roadway, the accident severity consequence probability decreases as the objects become further away from the edge of the roadway. Similarly, when the objects are aligned perpendicular to the roadway, the accident severity consequence probability decreases as the objects get further away from the start of the start of the hazardous roadside area. The exception is for the line of objects only 1.0 meter into the hazardous zone, here, the vehicle is unable to reach these objects and the low accident probabilities are a result of a low access probability. The reason for the decrease in accident severity probability as the objects get further away is that the vehicle has more time to slow down (decelerate) and therefore the impact speed is reduced to a level which will cause a reduction in power loss and therefore, a reduction in accident severity consequence level.

**4.4 Sensitivity Analysis: Operational Parameters**

Each operational parameter will be subjected to a sensitivity analysis to determine the affects on the overall results of the program. The hazardous roadside terrain and hazardous objects have been held constant in order to compare the affects of one operational parameter in relation to the others. The hazardous roadside is shown in Figure 4.1. The operational parameters have been divided into seven groups: speed, horizontal curve, time increments, number/location of encroachments, speed/angle increments, corrective parameters, and vehicle model.

Vehicle Speed

The mean vehicle velocity ranges from a low of 70 kph to a high of 120 kph, in increments of 10 kph. The simulation of the roadside are was quite detailed with a number of terrain changes and hazardous objects. A diagram showing a three dimensional cross-sectional view and a plan view of the hazardous roadside is provided in Figure 4.1 instead of a description since the diagram is self-explanatory. The roadside area has been simulated such that the accident consequence probabilities would be quite severe in order to emphasize the affects of the operational parameters.

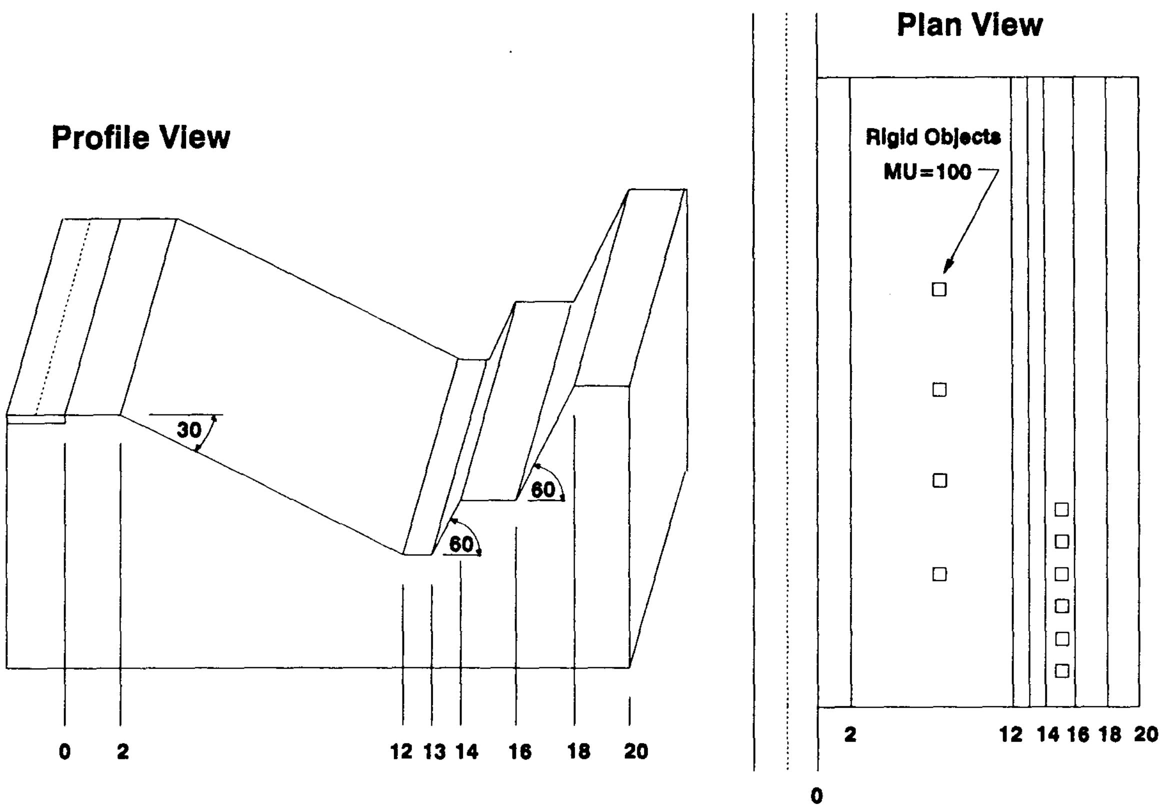



Figure 4.1 Hazardous Roadside Area: Sensitivity Analysis of Operational Parameters

The results of the sensitivity analysis for mean vehicle speed are provided in Table 4.14. The trend in the results is correct, indicating that as the mean speed is increased, the overall accident consequence probability becomes more severe. Validation of the exact values obtained from the model is difficult due to the lack of a detailed and large enough data base. The results produced by RHSM.V9 appear to be "intuitively obvious" and thus provide support in the model's validation process.

Table 4.14 Mean Vehicle Encroachment Speed

| Mean Encroachment Speed (kph) | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| 70 | 0.54 | 0.35 | 0.10 | 0.02 |
| 80 | 0.49 | 0.35 | 0.13 | 0.02 |
| 90 | 0.44 | 0.34 | 0.18 | 0.03 |
| 100 | 0.44 | 0.29 | 0.22 | 0.05 |
| 110 | 0.43 | 0.25 | 0.25 | 0.07 |
| 120 | 0.44 | 0.21 | 0.25 | 0.09 |

Horizontal Curve

The roadside terrain and hazardous objects have been simulated identically to that illustrated earlier for the mean vehicle velocity. There are four categories of horizontal curvature available to the user: a straight roadway section, a gentle curved section, a moderate curved section, and a severe curved section. As the roadway curvature increases, the angle of incidence becomes greater, and therefore the lateral vehicle velocity increases which should cause an increase in the overall accident severity consequence probability. The results produced by RHSM.V9 have substantiated this statement, shown in Table 4.15.

Table 4.15 Horizontal Curvature

| Horizontal Curvature | Accident Severity Consequence Probability | | | |
|---|---|---|---|---|
| | ND | PDO | INJ | FAT |
| Straight | 0.49 | 0.35 | 0.13 | 0.02 |
| Gentle | 0.47 | 0.36 | 0.15 | 0.03 |
| Moderate | 0.45 | 0.36 | 0.16 | 0.03 |
| Severe | 0.44 | 0.34 | 0.18 | 0.04 |

The relationship between the straight roadway section and the curved roadway section is based strictly on the geometric considerations of the curved roadway with respect to the straight roadway. More research is required to establish whether this is an accurate assumption and/or to determine if any other factors will affect the encroachment angle distribution. Once this research is completed, it is recommended that the encroachment angle distributions be updated.

## Time Increment of Trajectory

For this sensitivity analysis, the hazardous roadside which was illustrated earlier has been used to determine the affects of varying the time increment of the trajectory. The time increment varies from a low of 0.005 seconds to a high of 0.250 seconds, offering a wide range of values from the default value of 0.05 seconds. The results produced by RHSM.V9 for this component of the sensitivity analysis are presented below in Table 4.16. It should be noted that as the time increment decreases the cpu time required to run the program increases significantly.

Table 4.16 Time Increment of Trajectory

| Time Increment of Trajectory (seconds) | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0.005 | 0.52 | 0.17 | 0.21 | 0.09 | 0.37 | 0.37 | 0.00 |
| 0.010 | 0.48 | 0.17 | 0.25 | 0.10 | 0.34 | 0.34 | 0.00 |
| 0.050 | 0.49 | 0.35 | 0.13 | 0.02 | 0.15 | 0.13 | 0.02 |
| 0.100 | 0.51 | 0.23 | 0.22 | 0.03 | 0.05 | 0.03 | 0.02 |
| 0.150 | 0.64 | 0.16 | 0.14 | 0.06 | 0.07 | 0.02 | 0.05 |
| 0.200 | 0.73 | 0.19 | 0.06 | 0.02 | 0.05 | 0.01 | 0.04 |
| 0.250 | 0.69 | 0.19 | 0.08 | 0.03 | 0.06 | 0.01 | 0.05 |

It can be concluded from these results that the "best" results are those with a small time increment of trajectory. This is because at larger time increments the vehicle may not encounter the various hazardous features in the roadside. In other words, if the time increment of the vehicle is large, the vehicle may "jump" over the hazardous feature which would normally cause an increase in the accident severity consequence probability.

## Number and Location of Encroachment Points

Once again, the roadside illustrated earlier will be used for this aspect of the analysis. For this evaluation, four different situations were simulated: one encroachment at 0 meters, two encroachments at 0 meters and 25 meters, two encroachments at 0 meters and 50 meters, and three encroachments at 0 meters, 25 meters, and 50 meters. The distance is measured from the start of the hazardous roadside zone, parallel to the roadway. The results have been tabulated in Table 4.17.

Table 4.17 Encroachment Number and Location

| Encroachment Number and Locations | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 1 @ 0 m | 0.49 | 0.35 | 0.13 | 0.02 | 0.15 | 0.13 | 0.02 |
| 2 @ 0, 25 m | 0.23 | 0.19 | 0.39 | 0.18 | 0.34 | 0.34 | 0.00 |
| 2 @ 0, 50 m | 0.30 | 0.43 | 0.23 | 0.05 | 0.14 | 0.13 | 0.01 |
| 3 @ 0, 25, 50 m | 0.19 | 0.31 | 0.42 | 0.09 | 0.05 | 0.03 | 0.02 |

Recalling the hazardous roadside simulated, it can be concluded that these results are very good. The results of the first option (1 encroachment at 0 m) is less severe than the results produced by the other options with more than one encroachment location. The results of the second option (2 @ 0, 25 m) is more severe than the results of the third option (2 @ 0, 50 m) because the third option "misses" many of the hazardous objects. The results of the fourth option (3 @ 0, 25, and 50 m) are "in-between" the second and third options because the results of all three encroachment locations are normalized for the entire roadside area.

Speed/Angle Increments

For this analysis, the speed increment ranged from a low of 1 kph to a high of 4 kph, and the angle increment, ranged from a low of 2 degrees to a high of 8 degrees. Obviously, as the increment size increases, the "sensitivity" of the results produced decrease. The control roadside, illustrated at the beginning of this section, was also utilized for this component of the sensitivity analysis. The results of the analysis are shown in Table 4.18.

Table 4.18 Speed and Angle Increments

| Speed/ Angle Increments | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 1 / 2 | 0.23 | 0.44 | 0.25 | 0.08 | 0.18 | 0.17 | 0.01 |
| 2 / 4 | 0.48 | 0.17 | 0.25 | 0.10 | 0.34 | 0.34 | 0.00 |
| 3 / 6 | 0.57 | 0.32 | 0.10 | 0.01 | 0.17 | 0.17 | 0.00 |
| 4 / 8 | 0.89 | 0.06 | 0.05 | 0.01 | 0.06 | 0.06 | 0.00 |

The results produced are as expected: as the speed/angle increments increase, the sensitivity of the results worsen, with the result being, that little confidence can be given to results with large speed or angle increments. Confident results are produced when the speed/angle increments are at, or below, the default values of 2/4 respectively.

Corrective Parameters (Braking, Restraint, and Steer-back)

The next group of operational parameters to be evaluated in the sensitivity analysis are the factors which tend to "protect" the vehicle occupants. These factors include the degree of braking, the degree of restraint, and the amount of vehicle steer-back. The roadside which was illustrated earlier is, once again, used for this part of the sensitivity analysis. The first factor to be considered is the degree of vehicle braking, which has been varied from 10 percent braking to 80 percent braking. The results produced by RHSM.V9 are shown in Table 4.19, and appear to be quite good. The trend in the results agree with the expected results: as the degree of braking increases, the severity of the accident consequence probability decreases. The relative values of the results produced also appear to "intuitively" realistic.

Table 4.19 Degree of Braking

| Degree of Braking | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 10 | 0.53 | 0.33 | 0.12 | 0.02 | 0.14 | 0.10 | 0.04 |
| 20 | 0.55 | 0.31 | 0.12 | 0.02 | 0.13 | 0.10 | 0.03 |
| 30 | 0.49 | 0.39 | 0.11 | 0.02 | 0.12 | 0.09 | 0.03 |
| 40 | 0.49 | 0.40 | 0.10 | 0.01 | 0.11 | 0.09 | 0.02 |
| 50 | 0.44 | 0.46 | 0.09 | 0.01 | 0.09 | 0.08 | 0.01 |
| 60 | 0.35 | 0.56 | 0.08 | 0.01 | 0.10 | 0.08 | 0.02 |
| 70 | 0.28 | 0.63 | 0.08 | 0.01 | 0.10 | 0.09 | 0.01 |
| 80 | 0.23 | 0.69 | 0.07 | 0.01 | 0.09 | 0.08 | 0.01 |

The second component of the "protection" operational parameters being evaluated to determine the sensitivity is the degree of restraint. For this analysis, the degree of restraint ranges from a low of 0 percent restraint (no seat-beat usage) to a high of 100 percent restraint (full seat-belt usage). It is expected that as the degree of seat belt usage increases the severity of the accident consequence probability should decrease. The results of the analysis, as shown below in Table 4.20, substantiate this statement. The trend in the results are good, however, the relative value of the results seem somewhat low. Research has proven the effectiveness of restraint devices and therefore, the results produced by RHSM.V9 should clearly emphasize the effects of increased seat-belt usage. Perhaps an update of the probability of consequence table and the roll-over consequence table is required to account for the improvements in seat-belt effectiveness, especially since the consequence table is based on research that is approximately ten years old.

Table 4.20 Degree of Restraint

| Degree of Restraint | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0 | 0.49 | 0.33 | 0.14 | 0.03 | 0.15 | 0.13 | 0.02 |
| 15 | 0.49 | 0.34 | 0.14 | 0.03 | 0.15 | 0.13 | 0.02 |
| 30 | 0.49 | 0.34 | 0.14 | 0.03 | 0.15 | 0.13 | 0.02 |
| 45 | 0.49 | 0.35 | 0.14 | 0.02 | 0.15 | 0.13 | 0.02 |
| 60 | 0.49 | 0.36 | 0.13 | 0.02 | 0.15 | 0.13 | 0.02 |
| 75 | 0.49 | 0.36 | 0.13 | 0.02 | 0.15 | 0.13 | 0.02 |
| 90 | 0.49 | 0.37 | 0.13 | 0.01 | 0.15 | 0.13 | 0.02 |
| 100 | 0.49 | 0.37 | 0.13 | 0.01 | 0.15 | 0.13 | 0.02 |

The third component of the three operational parameters used to simulate a vehicle occupants ability to protect themselves is the degree of vehicle steer-back. The degree of vehicle steer-back is not the angle between the front tires of the vehicle and a longitudinal axis through the vehicle, but rather, it is the actual corrective angle which the vehicle will deviate from the normal trajectory. The range of steer-back angles ranges from a low of 0 degrees, to a high of 10 degrees. Table 4.21 presented the results below.

Table 4.21 Degree of Vehicle Steer-Back

| Degree of Steer-back (degrees) | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 0 | 0.49 | 0.35 | 0.13 | 0.02 | 0.15 | 0.13 | 0.02 |
| 2 | 0.68 | 0.18 | 0.08 | 0.06 | 0.49 | 0.47 | 0.02 |
| 4 | 0.66 | 0.06 | 0.13 | 0.15 | 0.58 | 0.56 | 0.02 |
| 6 | 0.66 | 0.04 | 0.14 | 0.16 | 0.62 | 0.60 | 0.02 |
| 8 | 0.61 | 0.05 | 0.16 | 0.18 | 0.64 | 0.63 | 0.01 |
| 10 | 0.61 | 0.05 | 0.16 | 0.18 | 0.63 | 0.62 | 0.01 |

At first inspection , the results produced for variations in steer-back angle appear to be wrong, however, further inspection lends credibility to the results. Initially, it was expected that as the steer-back angle increased, the severity of the accident consequence probability will decrease, however, the opposite is true. The reason is, that on un-recoverable slopes, such as those simulated, any correction in steer-back angle tends to increase the probability of roll-over and therefore, the accident consequence probability. This fact is substantiated by the high probability of vehicle roll-overs produced by RHSM.V9. The reason for the increase in vehicle roll-over is due to the increase in radial acceleration exerted on the vehicle as a result of attempting to deviate from the vehicle's normal trajectory.

Vehicle Type

RHSM.V9 allows up to eight different vehicle types, with the difference being, the dimensions (wheelbase, track-width, height, and centre of gravity) and the mass of the vehicle. The default vehicles range in size from a compact car to a full size sedan based on 1985 and 1990 typical vehicle models. The hazardous roadside terrain and objects have been simulated identically to the roadside illustrated earlier in this section. The results for variations in vehicle type are shown in Table 4.22.

The results of this aspect of the sensitivity analysis is somewhat difficult to interpret, and conceptually, this is true since there is a great deal of variability among vehicles with the same dimensions and mass. The results appear quite good, with the smallest vehicles (type 1 and 7) having the most severe accident consequence probability and roll-over probability.

The conclusion obtained from these results is that the vehicle types used for this analysis do not contribute to large variations in the results, which is a reasonable result since most of the vehicles are relatively close in size.

Table 4.22 Vehicle Type

| Vehicle Type | | Accident Severity Consequence Probability | | | | Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|---|
| No | Mass | ND | PDO | INJ | FAT | Total | on Slope | @ Ter. Chg. |
| 1 | 922 kg | 0.490 | 0.331 | 0.149 | 0.030 | 0.17 | 0.15 | 0.02 |
| 2 | 979 kg | 0.492 | 0.353 | 0.133 | 0.023 | 0.12 | 0.10 | 0.02 |
| 3 | 1159 kg | 0.492 | 0.353 | 0.133 | 0.023 | 0.12 | 0.10 | 0.02 |
| 4 | 1404 kg | 0.490 | 0.352 | 0.135 | 0.020 | 0.15 | 0.13 | 0.02 |
| 5 | 1591 kg | 0.486 | 0.329 | 0.161 | 0.025 | 0.12 | 0.11 | 0.01 |
| 6 | 1859 kg | 0.486 | 0.328 | 0.161 | 0.025 | 0.12 | 0.11 | 0.01 |
| 7 | 636 kg | 0.490 | 0.331 | 0.149 | 0.030 | 0.17 | 0.15 | 0.02 |
| 8 | 1600 kg | 0.484 | 0.328 | 0.160 | 0.025 | 0.16 | 0.15 | 0.01 |

### 4.5 Sensitivity Analysis: Economic Factors

This section details the sensitivity of the components which form the economic analysis of the model. The operational factors, hazardous roadside terrain, and hazardous objects remain constant throughout this aspect of the analysis in order to isolate the effects of each economic factor. There are four economic factors associated with the benefit-cost ratio analysis of the model, and only one other factor associated with the cost-effectiveness component of the model. The benefit-cost factors include the encroachment rate, the accident costs, the mitigation costs, and the interest rate/time period factors. The factor associated with the cost-effectiveness approach is weight of each effectiveness criteria.

The roadside terrain and hazardous objects simulated for the economic sensitivity analysis is shown in Figure 4.2, together with the relevant details required for the analysis.

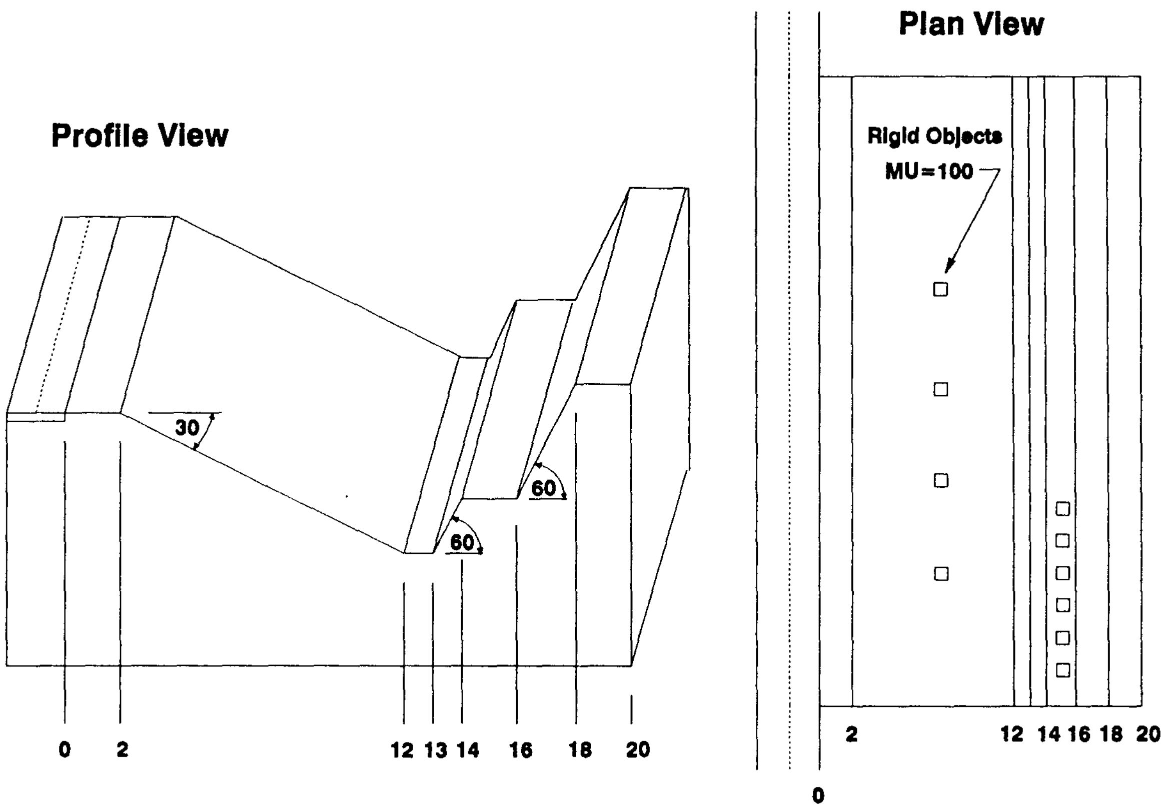



Figure 4.2 Hazardous Roadside Area: Sensitivity Analysis of Economic Factors

Benefit-Cost Analysis

The first factor associated with the benefit cost analysis used in RHSM.V9 is the encroachment rate. A total of ten different factors and the average daily traffic (ADT) are used to calculate the encroachment rate. The factors which cause the greatest and the least affect on the encroachment rate calculation have been selected to define the limits of the encroachment rate sensitivity. As well, one set of factors which represent the an "average" affect on the encroachment rate has also been chosen for a comparative evaluation. The roadway class is defined as an urban freeway and the average daily traffic is 5000 vehicles per day. The results produced by RHSM.V9 are shown in Table 4.23.

Table 4.23 Encroachment Rate

| Encroachment Scenario | Descriptive Factors | | | Expected Encroachmt Rate (events/km/yr) |
|---|---|---|---|---|
| 1. Worse Case | DS = 120 kph<br>LW < 3.0 m<br>NL = 2 (t-w) | SW < 1.0 m<br>HC = severe<br>VC > 7% | CC = severe<br>TC = unfamiliar<br>SR = severe | 5.855 |
| 2. Best Case | DS = 80 kph<br>LW > 4.0 m<br>NL = 8 (div.) | SW > 4.0 m<br>HC = flat<br>VC = flat | CC = none<br>TC = familiar<br>SR = none | 0.777 |
| 3. Average Case | DS = 100 kph<br>LW = 3.4 m<br>NL = 4 (div.) | SW = 3.0 m<br>HC = ave.<br>VC = 4% | CC = moderate<br>TC = average<br>SR = moderate | 2.013 |

notes: Please note the following abbreviations:

| | | |
|---|---|---|
| DS = design speed | SW = shoulder width | CC = climatic conditions |
| LW = lane width | HC = horizontal curve | TC = traffic composition |
| NL = no. of lanes | VC = vertical curvature | SR = sight restrictions |

The conclusion that can be drawn from the sensitivity of the encroachment rate calculation is that the encroachment rate can very significantly depending on the adjustment factors selected by the user. Encroachment rate is critical in the evaluation of any hazardous roadside location. For example, if the roadside at a particular location is very hazardous, however, there is very low encroachment rate due to a very low ADT (as an example), then the encroachment rate has a significant effect on the evaluation of the improvement alternatives.

The second factor associated with the benefit cost analysis is the accident cost. For this analysis, the accident costs will vary between the values used by M.o.T.H. for the direct costs only (ND = \$0, PDO = \$4,000, INJ = \$13,000, and FAT = \$600,000) to those values which consider both direct and indirect costs which have also been propose by M.o.T.H. (ND = \$0, PDO = \$6,000, INJ = 25,000, FAT = 3,000,000). To facilitate this analysis, a practical example with realistic improvement alternatives for the roadside described earlier, was chosen. For the given roadside, four alternatives were proposed: do nothing, flatten the slope to 3:1, install a roadside barrier 2.0 meters from the edge of the roadway, or remove the hazardous objects from the encroachment zone and flatten the slope to 3:1. The accident severity consequence probabilities produced by the program for the four alternatives is shown below in Table 4.24.

Table 4.24 Accident Severity Consequence Probability

| Improvement Alternative | Accident Severity Consequence Probability | | | | Roll-over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | Ter Chg |
| Do Nothing | 0.490 | 0.352 | 0.135 | 0.023 | 0.15 | 0.13 | 0.02 |
| Flatten Slope | 0.589 | 0.308 | 0.095 | 0.008 | 0.01 | 0.00 | 0.01 |
| Install Barrier | 0.593 | 0.252 | 0.138 | 0.017 | 0.01 | 0.00 | 0.01 |
| Remove Objects | 0.718 | 0.228 | 0.049 | 0.006 | 0.01 | 0.00 | 0.01 |

Before the sensitivity of the accident cost can be completed, a series of assumptions regarding the economic factors must be made. The encroachment rate was simulated identically to that used for the "average" case scenario for the encroachment rate sensitivity. The interest rate and project time period was left at the default values of 8% and 30 years respectively. The mitigation costs used for each alternative is provided in Table 4.25.

Table 4.25 Mitigation Factors

| Mitigation Factor | Improvement Alternative | | | |
|---|---|---|---|---|
| | Do Nothing | Flatten Slope | Install Barrier | Remove Objects |
| 1. Barrier Installation | | | | |
| Installation ($/100m) | | | 10,000 | |
| Maintenance ($/100m/yr) | | | 100 | |
| 2. Slope Flattening | | | | |
| Cost of Cut ($/m3) | | 3.00 | | |
| Cost of Fill ($/m3) | | 4.50 | | |
| Removal Cost ($/m3) | | 8.00 | | |
| Addition Cost ($/m3) | | 9.00 | | |
| 3. Maintenance Cost ($/yr) | 1500 | 1000 | 1000 | 1500 |
| 4. Object Removal ($/object) | | | | 5 at 2500<br>5 at 1500 |
| 5. ROW Acquisition ($) | | | | 50,000 |

Four different sets of accident costs were used for the sensitivity analysis and are defined as follows:

| | ND ($) | PDO ($) | INJ ($) | FAT ($) |
|---|---|---|---|---|
| Case 1: | 0 | 4,000 | 13,000 | 600,000 |
| Case 2: | 0 | 4,500 | 17,000 | 1,400,000 |
| Case 3: | 0 | 5,000 | 21,000 | 2,200,000 |
| Case 4: | 0 | 6,000 | 25,000 | 3,000,000 |

The results from the economic evaluation including the total accident cost, the total mitigation cost, the relative accident cost, the relative mitigation cost, the benefit cost ratio, and the net benefit for each case are presented in Table 4.26.

Table 4.26 Results of Mitigation Factors

| Alternative | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|
| **Case 1** | | | | | | |
| Do Nothing | 33,812 | 16,887 | | | | |
| Flatten Slope | 14,459 | 33,826 | 19,352 | 16,940 | 1.14 | 2,413 |
| Install Barrier | 26,228 | 22,384 | 7,584 | 5,497 | 1.38 | 2,087 |
| Remove Objects | 9,931 | 86,886 | 23,881 | 70,000 | 0.34 | -96,119 |
| **Case 2** | | | | | | |
| Do Nothing | 71,842 | 16,887 | | | | |
| Flatten Slope | 28,194 | 33,826 | 43,648 | 16,940 | 2.58 | 26,708 |
| Install Barrier | 55,040 | 22,384 | 16,803 | 5,497 | 3.06 | 11,306 |
| Remove Objects | 19,645 | 86,887 | 52,198 | 70,000 | 0.75 | -17,802 |
| **Case 3** | | | | | | |
| Do Nothing | 109,873 | 16,887 | | | | |
| Flatten Slope | 41,940 | 33,826 | 67,943 | 16,940 | 4.01 | 51,004 |
| Install Barrier | 83,852 | 22,384 | 26,022 | 5,497 | 4.73 | 20,525 |
| Remove Objects | 29,358 | 86,887 | 80,515 | 70,000 | 1.15 | 10515 |
| **Case 4** | | | | | | |
| Do Nothing | 148,259 | 16,887 | | | | |
| Flatten Slope | 55,976 | 33,826 | 92,283 | 16,940 | 5.45 | 75,343 |
| Install Barrier | 112,918 | 22,384 | 35,341 | 5,497 | 6.43 | 29,844 |
| Remove Objects | 39,302 | 86,887 | 108,956 | 70,000 | 1.56 | 38956 |

Notes: Please note the following abbreviations:
TAC = total accident costs    RAC = relative accident costs
TMC = total mitigation costs    RMC = relative mitigation costs
PV$ = present value dollars    B/C = benefit-cost ratio

The results of the sensitivity analysis for the accident costs indicates that the cost of accident has a profound affect on the decision whether or not to implement a particular improvement alternative. Although for this case simulated, the barrier installation is the best regardless of the cost of accidents, the readiness to accept this alternative increases as the benefit cost ratio increases, due to the increase in accident costs. The evaluation of any improvement alternative greatly depends on the actual costs of accidents. For example, the relocation of hazardous objects alternative "transforms" from an option which does not produce a favourable benefit-cost ratio (B/C<1.0: B/C=0.34) to an option which does produce a B/C ratio which would be considered favourable (B/C=1.56)

The mitigation costs are the third factor associated with the benefit-cost analysis used in RHSM.V9. Similar to the sensitivity analysis used for the accident costs, the sensitivity analysis used for the mitigation costs will utilize the same roadside environment, with the same improvement alternatives. The encroachment rate will also be identical to that used in the previous section and the accident costs will be held constant with ND=$0, PDO=$4,000, INJ=$13,000, and FAT=$600,000. The three components of mitigation costs which will be evaluated are barrier costs, the cost of flattening slopes, and the cost of removing and relocating objects. The first component to be discussed is the cost associated with installing and maintaining roadside barriers. The cost of installing the barrier ranges from a low of $5,000 per 100 meters to a high of $20,000 per 100 meters. The corresponding maintenance costs range from a low of $50 per year to a high of $1,000 per year. All other mitigation values for the other improvement alternatives are similar to those used in the previous section. The results produced by RHSM.V9 have been tabulated in Table 4.27.

Table 4.27 Roadside Barrier Costs

| Improvement Alternative | | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C ratio | Net Benefit |
|---|---|---|---|---|---|---|---|
| Do Nothing | | 33,812 | 16,887 | | | | |
| Barrier Alternatives | | | | | | | |
| Installation Cost ($) | Maintenance Cost ($) | | | | | | |
| 5,000 | 200 | 26,228 | 24,138 | 7,584 | 7,252 | 1.05 | 332 |
| 10,000 | 400 | 26,228 | 31,390 | 7,584 | 14,503 | 0.52 | -6,919 |
| 15,000 | 700 | 26,228 | 39,767 | 7,584 | 22,880 | 0.33 | -15,297 |
| 20,000 | 1,000 | 26,228 | 48,144 | 7,584 | 31,258 | 0.24 | -23,674 |

Notes: Please note the following abbreviations:
TAC = total accident costs　RAC = relative accident costs
TMC = total mitigation costs　RMC = relative mitigation costs
PV$ = present value dollars　B/C = benefit-cost ratio

The results produced by varying the mitigation costs associated with installing and maintaining roadside barriers are valid. The increase in the cost of barriers, increases the total mitigation costs and ultimately reduces the benefit-cost ratio and net benefit of the option of installing roadside barrier. After discussion with M.o.T.H. staff, it was concluded that the cost of roadside barrier could vary significantly, however, the average cost of barrier was quoted at $8,000 per 100 meters which was within the range used for the sensitivity of barrier costs.

The second component of the mitigation costs to be evaluated is the cost of flattening hazardous embankment slopes. There are four elements which are required to calculate the total mitigative cost associated with flattening an embankment slope including the cost of cut, the cost of fill, the cost of waste (cut) removal, and the cost of hauling additional fill to the location. For this analysis, four different values have been used to cover the range of values used to represent the cost of earthwork for a hazardous roadside. The different combinations of costs are detailed in Table 4.28, together with the economic results.

Table 4.28 Slope Flattening Costs

| Improvement Alternatives | | | | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|---|---|---|
| Do Nothing | | | | 33,811 | 16,887 | | | | |
| Slope Flattening | | | | | | | | | |
| Cut Cost | Fill Cost | Remove Cost | Add Cost | | | | | | |
| $ 2 | $ 3 | $ 4 | $ 5 | 14,459 | 30,099 | 19,352 | 13,312 | 1.46 | 6,140 |
| $ 4 | $ 6 | $ 8 | $ 10 | 14,459 | 43,310 | 19,352 | 26,424 | 0.73 | -7,071 |
| $ 6 | $ 9 | $ 12 | $ 15 | 14,459 | 56,522 | 19,352 | 39,636 | 0.49 | -20,283 |
| $ 8 | $ 12 | $ 20 | $ 20 | 14,459 | 69,734 | 19,352 | 52,847 | 0.37 | -33,495 |

Notes: Please note the following abbreviations:
TAC = total accident costs RAC = relative accident costs
TMC = total mitigation costs RMC = relative mitigation costs
PV$ = present value dollars B/C = benefit-cost ratio

The results which are produced appear to be quite good. An increase in the cost of earthwork, increases the total mitigative cost of the alternative, and thus, the benefit-cost ratio and net benefit decreases at a rate similar to the rate of increase in earthwork costs. The exact values of the results indicates that researching the exact values for earthwork at a particular location is essential in achieving confident results.

The fourth and final element of the mitigation costs evaluated for this sensitivity analysis is the cost of removing and/or relocating hazardous objects and the need to acquire right-of-way (ROW). For the particular roadside considered, 2 sets of 5 objects are require to be relocated, and therefore a series of scenarios have been developed detailing the different costs of relocating each type of object and the cost of the right-of-way required for each of the improvement alternatives. The results produced by RHSM.V9 for this analysis are provided in Table 4.29.

Table 4.29 Object Removal Costs

| Improvement Alternatives | | | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|---|---|
| Do Nothing | | | 33,811 | 16,887 | | | | |
| Object Removal | | | | | | | | |
| Object Type 1 ($) | Object Type 2 ($) | ROW ($) | | | | | | |
| 500 | 1,000 | 10,000 | 9,931 | 34,387 | 23,881 | 17,500 | 1.36 | 6,381 |
| 1,000 | 1,500 | 20,000 | 9,931 | 49,387 | 23,881 | 32,500 | 0.73 | -8,619 |
| 1,500 | 2,500 | 40,000 | 9,931 | 76,887 | 23,881 | 60,000 | 0.40 | -36,119 |
| 2,500 | 4,000 | 70,000 | 9,931 | 119,387 | 23,881 | 102,500 | 0.23 | -78,619 |

Notes: Please note the following abbreviations:

TAC = total accident costs
TMC = total mitigation costs
PV$ = present value dollars
ROW = Right of Way
RAC = relative accident costs
RMC = relative mitigation costs
B/C = benefit-cost ratio
($) = present dollars

The fourth factor associated with the benefit cost analysis employed by RHSM.V9 is the interest rate and time period factors. For this sensitivity analysis, the interest ranged from a low of 6% to a high of 10% while the time period remained constant at 30 years. Then the interest rate was held constant at 8% and the time period ranged from 20 years to 40 years. Abbreviated economic results for each of the four improvement alternatives are shown in Tables 4.30 and 4.31.

Table 4.30 Varying the Interest Rate (i)

| Improvement Alternative | 30 Years at 6% | | 30 Years at 8% | | 30 Years at 10% | |
|---|---|---|---|---|---|---|
| | B/C Ratio | Net Benefit | B/C Ratio | Net Benefit | B/C Ratio | Net Benefit |
| Do Nothing | | | | | | |
| Flatten Slope | 0.46 | -23,144 | 0.44 | -24,397 | 0.43 | -25,313 |
| Install Barrier | 1.69 | 3,090 | 1.38 | 2,087 | 1.22 | 1,354 |
| Remove Objects | 0.34 | -46,119 | 0.34 | -46,119 | 0.34 | -46,119 |

Table 4.31 Varying the Analysis Period (n)

| Improvement Alternative | 20 Years at 8% | | 30 Years at 8% | | 40 Years at 8% | |
|---|---|---|---|---|---|---|
| | B/C Ratio | Net Benefit | B/C Ratio | Net Benefit | B/C Ratio | Net Benefit |
| Do Nothing | | | | | | |
| Flatten Slope | 0.44 | -25,117 | 0.44 | -24,397 | 0.45 | -24,064 |
| Install Barrier | 1.25 | 1,511 | 1.38 | 2,087 | 1.45 | 2,354 |
| Remove Objects | 0.34 | -46,119 | 0.34 | -46,119 | 0.34 | -46,119 |

The range of results produced by of the model with respect to the interest rate and the analysis period for reasonable values of interest rate and time period are small. If un-realistic values are used for i and n, the results are poor.

## Cost Effectiveness Analysis

The cost-effective economic evaluation considers only the mitigation costs associated with each alternative and the accident severity based on the criteria weights input by the user. Since mitigation costs were considered previously under the benefit-cost analysis section, only the criteria weighting component of the cost-effectiveness analysis will be reviewed.

The scale used for the relative severity weighting is arbitrary, left to the discretion and knowledge of the user. For this analysis, five different severity weighting schemes have been tested for the roadside defined earlier and the corresponding improvement alternatives. Table 4.32 shows the results of each test.

Table 4.32 Criteria Weighting Schemes

| Accident Consequence | Test One Relative Weight | Test Two Relative Weight | Test Three Relative Weight | Test Four Relative Weight | Test Five Relative Weight |
|---|---|---|---|---|---|
| ND | 0 | 0 | 1 | 250 | 1250 |
| PDO | 0 | 0 | 2 | 250 | 1000 |
| INJ | 0 | 50 | 1200 | 250 | 750 |
| FAT | 100 | 50 | 70000 | 250 | 500 |
| Improvement Alternative | | | | | |
| Do Nothing | 5 | 16 | 3530 | 504 | 1668 |
| Flatten Slope | 2 | 10 | 1339 | 504 | 1753 |
| Install Barrier | 3 | 16 | 2737 | 504 | 1723 |
| Remove Objects | 1 | 5 | 915 | 504 | 1843 |

To evaluate the cost effectiveness criteria weighting, the program provides visual assistance in the form of a graph. This allows the user to judge the effectiveness of each alternative in relation to the other alternatives. A series of graphs are presented below which illustrates the usefulness of the cost effective analysis and the effects of varying the criteria weighting. Note the arbitrary nature of the severity scale and the ability of the user to "rate" the effectiveness of each alternative.

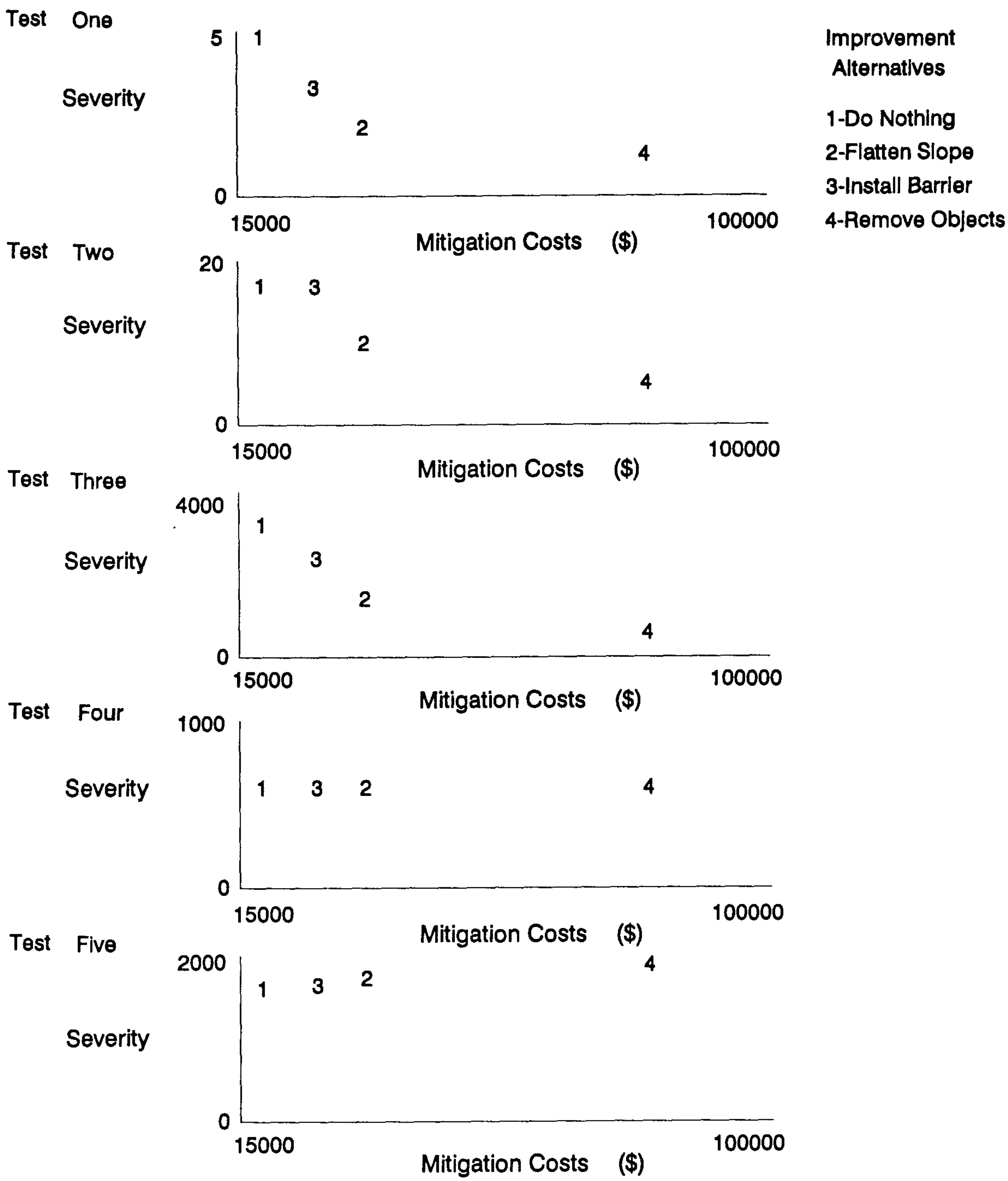


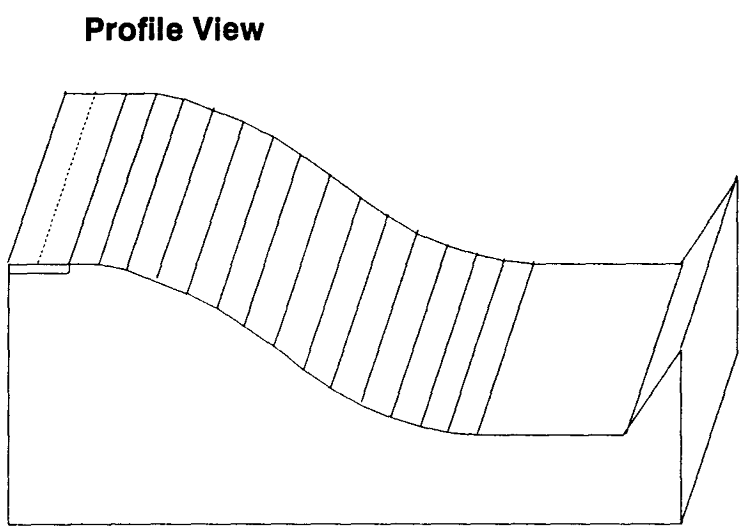

Figure 4.3 Cost-Effectiveness Graphs

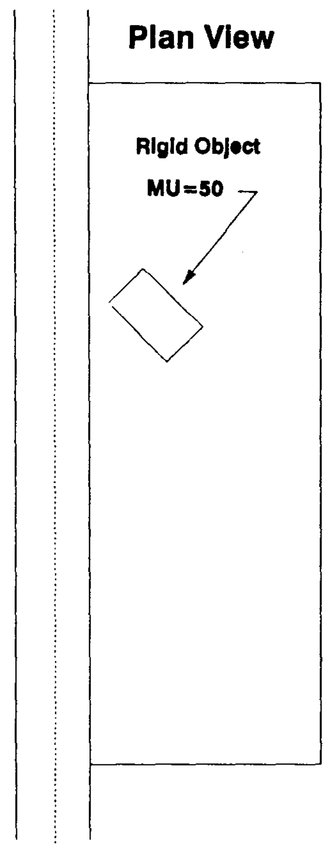
## 4.6 Model Application: Typical Example Runs

The purpose of this section is to illustrate the usefulness of the program by presenting a number of typical examples, outlining the application of the model for real-life situations. This section is divided into four sub-sections, each offering the optimum solution for each typical improvement option: do nothing, flatten slope, install barrier, and remove objects.

### 4.6.1 Leave Roadside Unprotected Warranted (Do-Nothing Alternative)

It may seem inappropriate to intentionally leave a hazardous location unprotected, however, from an engineering economic standpoint, often there may be no improvement alternative that is cost-effective. The hazardous roadside used for this analysis is shown in Figure 4.4, complete with the important details.




| Offset | Slope | Offset | Slope | Offset | Slope | Offset | Slope |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 4 | -24 | 8 | -36 | 12 | -12 |
| 1 | -6 | 5 | -30 | 9 | -30 | 13 | -6 |
| 2 | -12 | 6 | -36 | 10 | -24 | 14 | 0 |
| 3 | -18 | 7 | -42 | 11 | -18 | 18 | 50 |

Figure 4.4 Hazardous Roadside Area: Leave Roadside Unprotected Warranted

For each improvement alternative, the operational parameters were all set to the default values with the mean encroachment speed set at 80 kph. The second improvement alternative, after the do-nothing alternative, is to flatten the slope. In this case the simulated slope was flattened to only a 5 degree down-slope angle from the roadway shoulder, making the roadside very safe. The third improvement alternative, installing a barrier, simulated placing a rigid barrier at 2.0 meters from the edge of the roadway. The fourth improvement option removed the simulated object located in the hazardous roadside.

There are four groups of results which are used to evaluate the four improvement alternatives, including the accident consequence probability, the vehicle roll-over probability, the benefit-cost analysis, and the cost effectiveness analysis. The first two have been summarized together in Table 4.33. Flattening the slope appears to be the "safest" alternative , whereas installing the barrier appears to be the most hazardous. This is a reasonable conclusion since a barrier, although intended to protect errant vehicles, is in itself a roadside hazard.

Table 4.33 Unprotected Roadside: Accident Consequence Probability

| Improvement Alternatives | Accident Severity Consequence Probability | | | | Vehicle Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | Ter Chg |
| Do Nothing | 0.786 | 0.155 | 0.051 | 0.009 | 0.05 | 0.00 | 0.05 |
| Flatten Slope | 0.927 | 0.063 | 0.009 | 0.000 | 0.00 | 0.00 | 0.00 |
| Install Barrier | 0.671 | 0.176 | 0.137 | 0.017 | 0.00 | 0.00 | 0.00 |
| Remove Objects | 0.888 | 0.092 | 0.015 | 0.005 | 0.05 | 0.00 | 0.05 |

The next result to consider is the benefit-cost ratio economic evaluation. The results, which are shown in total present value dollars, are provided in Table 4.34. The values used for mitigation costs were set such that they emphasize the desired result, however, the values were not un-realistic. By observing the benefit-cost ratios calculated and the net benefit, the three improvement options are rejected. Installing a barrier is the worst improvement alternative, with the negative b/c ratio indicating that the high cost of installing a barrier would only increase the accident costs. The other two alternatives provide some accident cost savings, however the high mitigation cost required to implement these alternatives makes them unacceptable. Therefore, the best alternative is the do-nothing alternative.

Table 4.34 Unprotected Roadside: Benefit-Cost Analysis

| Improvement Alternative | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|
| Do Nothing | 6,731 | 11,258 | | | | |
| Flatten Slope | 749 | 95,571 | 5,982 | 84,314 | 0.07 | -78,332 |
| Install Barrier | 13,274 | 26,887 | -6,543 | 15,629 | -0.41 | -22,172 |
| Remove Objects | 3,395 | 51,258 | 3,336 | 40,000 | 0.08 | -36,664 |

Notes: Please note the following abbreviations:
TAC = total accident costs — RAC = relative accident costs
TMC = total mitigation costs — RMC = relative mitigation costs
PV$ = present value dollars — B/C = benefit-cost ratio

The last result to consider in the analysis of the hazardous roadside location is the cost-effectiveness evaluation. The critical weighting for each category of accident consequence were ND=2, PDO=20, INJ=200, and FAT=400,000. The results of this analysis are provided in Table 4.35 together with a graph (Figure 4.5) to illustrate the effectiveness of each improvement option. There are two options less severe that the do-nothing alternative, however, the costs associated with each are significantly greater than the do-nothing alternative. Remember that the recommendations are based on engineering judgement and economics, there may be the need from a safety or political basis (for example) to reduce the accidents regardless of the cost. This decision must be made by the user, familiar with their particular requirements and constraints.

Table 4.35: Cost-Effectiveness Analysis

| Improvement Alternative | Mitigation Costs (PV$) | Severity |
|---|---|---|
| Do Nothing | 11,258 | 4094 |
| Flatten Slope | 95,571 | 235 |
| Install Barrier | 26,887 | 8054 |
| Remove Objects | 51,258 | 2159 |

Notes: Please note the following abbreviation: PV$ = present value dollars

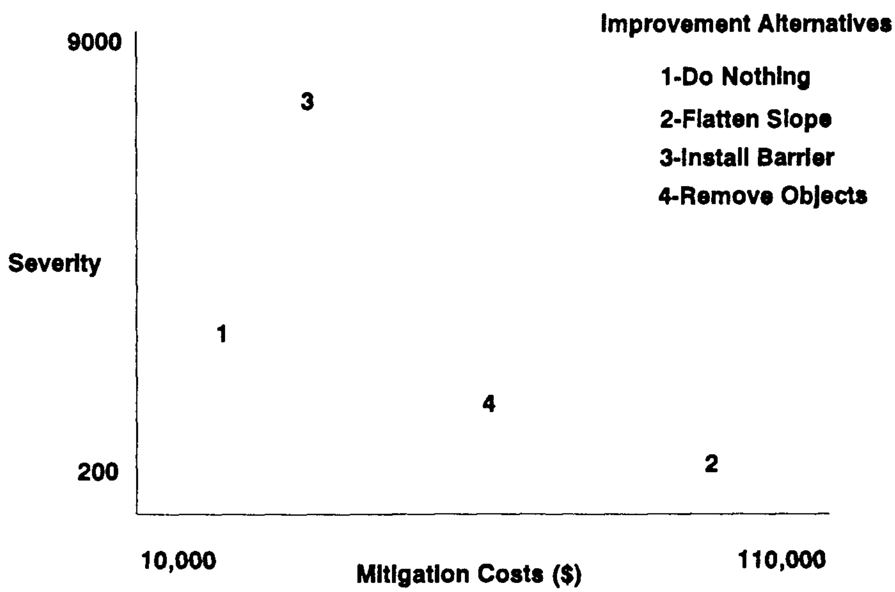



Figure 4.5 Cost-Effectiveness Graph: Leave Roadside Unprotected Warranted

### 4.6.2 Flattening Embankment Slope Warranted

The second typical situation to be modeled represents the case where the best alternative would be to flatten the roadside terrain. The hazardous roadside terrain is shown below in Figure 4.6. Except for a severe ditch near the road, the terrain is relatively flat and safe, with only one hazardous object.

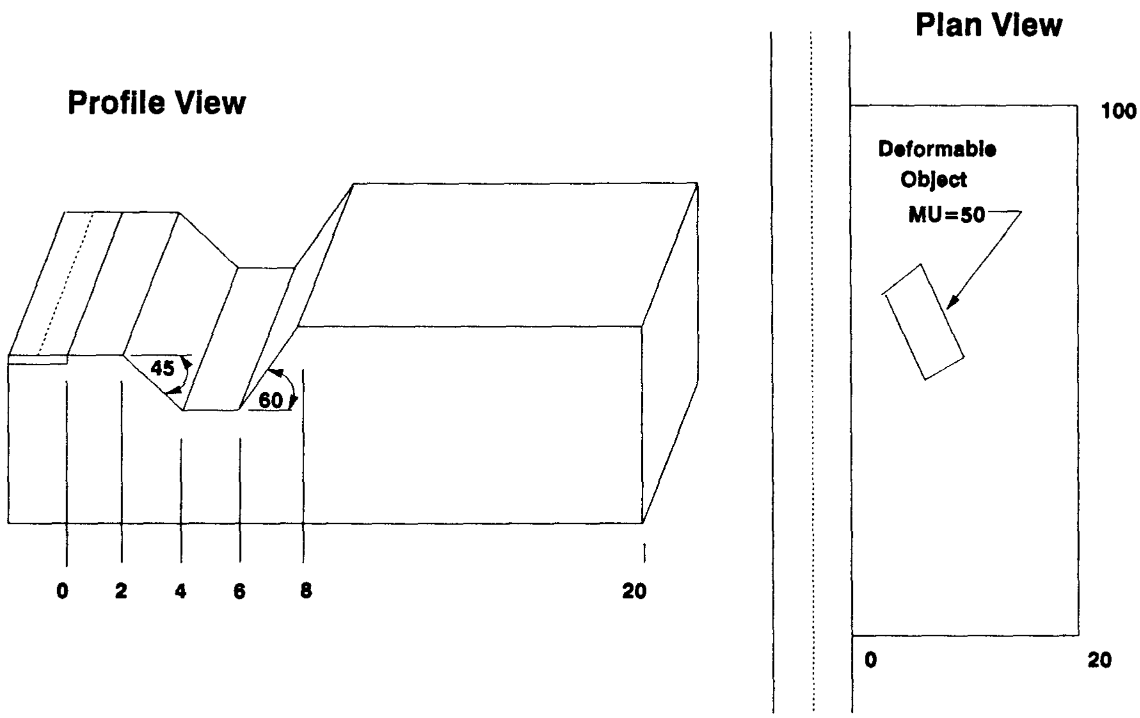



Figure 4.6 Hazardous Roadside Area: Flattening Embankment Slope Warranted

The flattening the slope improvement alternative simply fills in the ditch thus having a gentle uphill increase in the slope from 2.0 meters to 8.0 meters from the roadway edge. The installing a barrier option simulates a deformable barrier with a friction coefficient (MU) equal to 50, 2.0 meters from the roadways edge. Removing the hazardous object alternative is identical to the do-nothing alternative, except no objects are simulated.

The accident severity consequence probability of the four alternatives are summarized in Table 4.36, together with the vehicle roll-over probabilities. The results indicate that the flattening the slope alternative is the "best" alternative from a safety perspective. This is reflected in the vehicle roll-over probability, where there is zero probability of vehicle roll-over if the slope is flattened as simulated.

Table 4.36 Flattening Slope: Accident Consequence Probability

| Improvement Alternatives | Accident Severity Consequence Probability | | | | Vehicle Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | Ter Chg |
| Do Nothing | 0.486 | 0.229 | 0.194 | 0.090 | 0.027 | 0.22 | 0.05 |
| Flatten Slope | 0.983 | 0.013 | 0.004 | 0.000 | 0.00 | 0.00 | 0.00 |
| Install Barrier | 0.536 | 0.206 | 0.191 | 0.066 | 0.11 | 0.08 | 0.03 |
| Remove Objects | 0.486 | 0.217 | 0.200 | 0.096 | 0.30 | 0.25 | 0.05 |

The benefit-cost ratio economic evaluation, shown in Table 4.37, provides a clear indication that the best alternative for this particular roadside is to flatten the embankment slope. In this particular case, the amount of earthwork is relatively small, and the cost of the earthwork was entered at a low cost to emphasize the desired results. Any benefit-cost ratio value greater than 1.0 is considered an acceptable alternative. The third option of installing a barrier nearly reaches that value of 1.0, but because the value is less than 1.0, the net benefit is negative. Removing the object improvement alternative has a negative B/C ratio indicating that at this particular location, it acts as a barrier and stops some vehicles from rolling over, thus reducing the accident costs, and therefore it should be left in place.

Table 4.37 Flattening Slope: Benefit-Cost Analysis

| Improvement Alternative | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|
| Do Nothing | 71,479 | 11,258 | | | | |
| Flatten Slope | 296 | 18,602 | 71,184 | 7,344 | 9.69 | 63,839 |
| Install Barrier | 53,874 | 32,516 | 17,606 | 21,258 | 0.83 | -3,652 |
| Remove Objects | 75,648 | 51,258 | -4,169 | 40,000 | -0.10 | -44,169 |

The cost-effectiveness evaluation clearly indicates that slope flattening is the best alternative. The critical weighting values are similar to those used in the previous example. The results of the analysis are shown in Table 4.38 and Figure 4.7.

Table 4.38 Flattening Slope: Cost-Effectiveness Analysis

| Improvement Alternative | Mitigation Costs (PV$) | Severity |
|---|---|---|
| Do Nothing | 11,258 | 56283 |
| Flatten Slope | 18,602 | 124 |
| Install Barrier | 32,516 | 39348 |
| Remove Objects | 51,258 | 56584 |

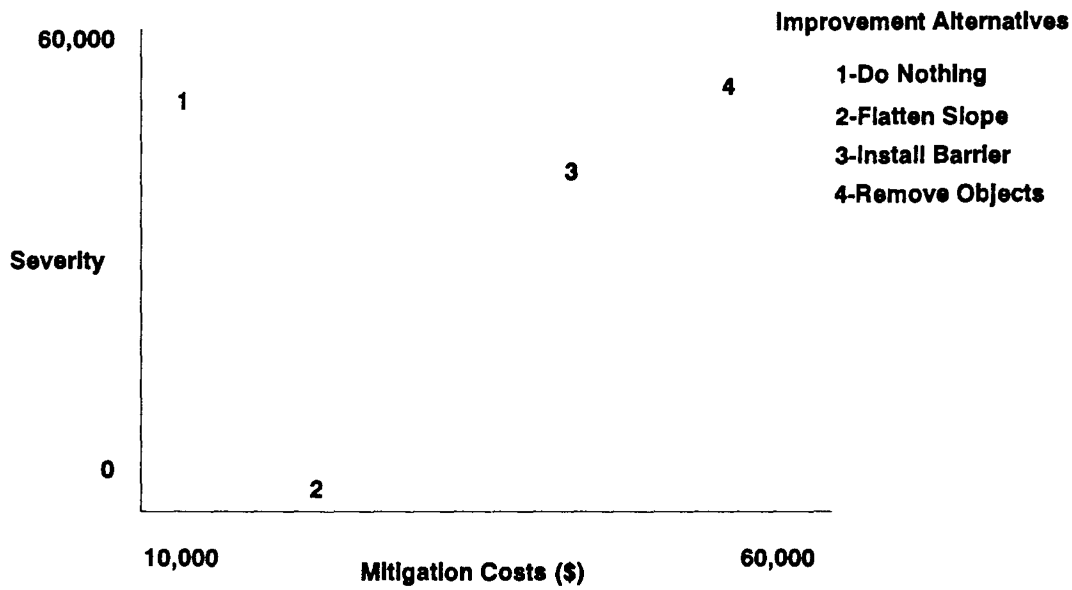



Figure 4.7 Cost-Effectiveness Graph: Flattening Embankment Slope Warranted

### 4.6.3 Roadside Barrier Warranted

The third typical situation to be modeled represents the case where the best alternative would be to install a roadside barrier. The hazardous roadside terrain is shown below in Figure 4.8, together with the relevant details of the roadside environment.

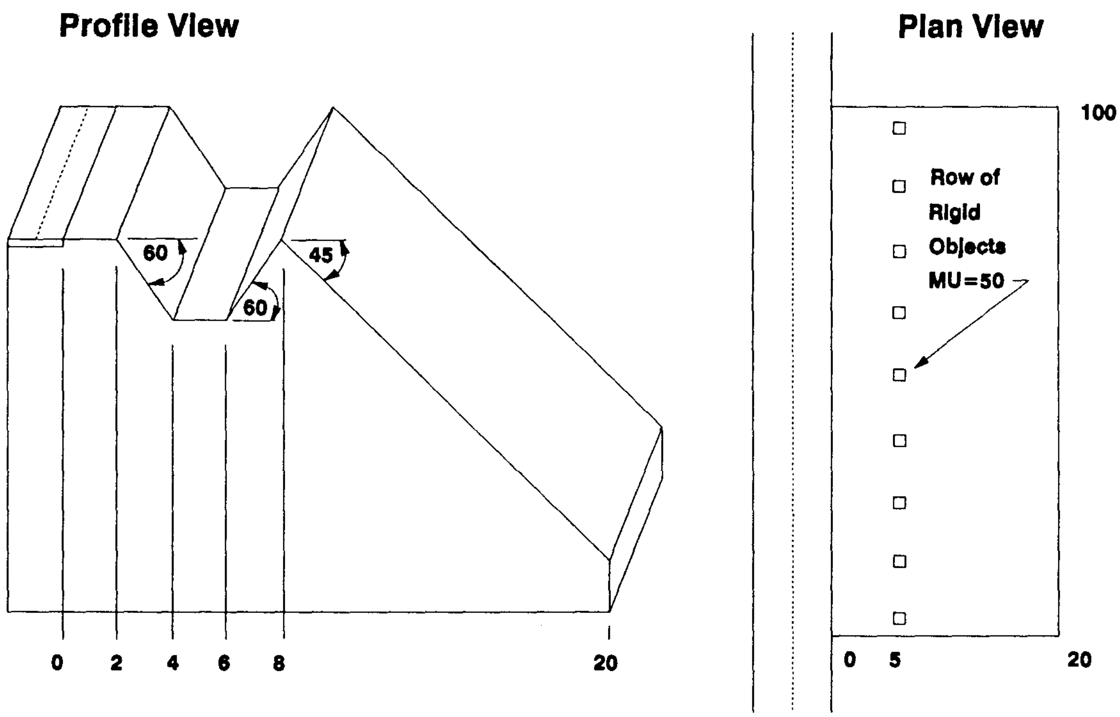



Figure 4.8 Hazardous Roadside Area: Roadside Barrier Warranted

The flattening of the slope improvement alternative simply simulates a 2:1 slope (-26.7 degrees) from the level shoulder, 2.0 meters from the edge of the roadway. Installing the barrier option simulates a deformable barrier,with a coefficient of friction (MU) of 50, 2.0 meters from the edge of the roadway. The removal of the objects alternative is self explanatory.

The accident severity consequence probability of the four alternatives indicates that the slope flattening alternative is the "safest", and the do-nothing and remove objects alternatives are the most "dangerous" alternative. The barrier installation improvement alternative has results between the safest and the most hazardous alternatives. The results produced by RHSM.V9 for the accident severity consequence probabilities are provided below in Table 4.39, together with the vehicle roll-over probabilities.

Table 4.39 Barrier Warranted: Accident Consequence Probabilities

| Improvement Alternatives | Accident Severity Consequence Probability | | | | Vehicle Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | Ter Chg |
| Do Nothing | 0.612 | 0.058 | 0.172 | 0.158 | 0.51 | 0.47 | 0.04 |
| Flatten Slope | 0.549 | 0.297 | 0.141 | 0.016 | 0.01 | 0.00 | 0.01 |
| Install Barrier | 0.609 | 0.106 | 0.186 | 0.099 | 0.26 | 0.26 | 0.00 |
| Remove Objects | 0.612 | 0.058 | 0.172 | 0.158 | 0.51 | 0.47 | 0.04 |

The results of the benefit-cost ratio economic evaluation indicates that both the flattening of the slope alternative and the barrier installation alternative are viable. However, the barrier installation has a higher B/C ratio and thus provides more return per dollar spent on mitigation purposes. However, the net benefit for the flattening of the slope alternative is greater. In this particular case, the decision to implement one of these two options is less clear and may depend on other factors such as budget constraints or political pressures. The result of the B/C ratio analysis is tabulated in Table 4.40. Notice that the alternative of removing the objects has no affect on the accident severity probability over the do-nothing alternative and therefore has a benefit-cost ratio of zero.

Table 4.40 Barrier Warranted: Benefit-Cost Analysis

| Improvement Alternative | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|
| Do Nothing | 119,674 | 11,258 | | | | |
| Flatten Slope | 16,390 | 42,340 | 103,284 | 31,083 | 3.32 | 72,201 |
| Install Barrier | 77,170 | 21,887 | 42,504 | 10,629 | 4.00 | 31,875 |
| Remove Objects | 119,674 | 51,258 | 0 | 40,000 | 0.00 | -40,000 |

The results of the cost-effectiveness evaluation are provided in Table 4.41 below and the results are graphed in Figure 4.9. The decision between options 2 and 3 must be made knowing that the reduction in severity of option 2 comes with a increase in mitigation cost.

Table 4.41 Barrier Warranted: Cost-Effectiveness Analysis

| Improvement Alternative | Mitigation Costs (PV$) | Severity |
|---|---|---|
| Do Nothing | 11,258 | 92963 |
| Flatten Slope | 43,340 | 9682 |
| Install Barrier | 21,887 | 58524 |
| Remove Objects | 51,258 | 92963 |

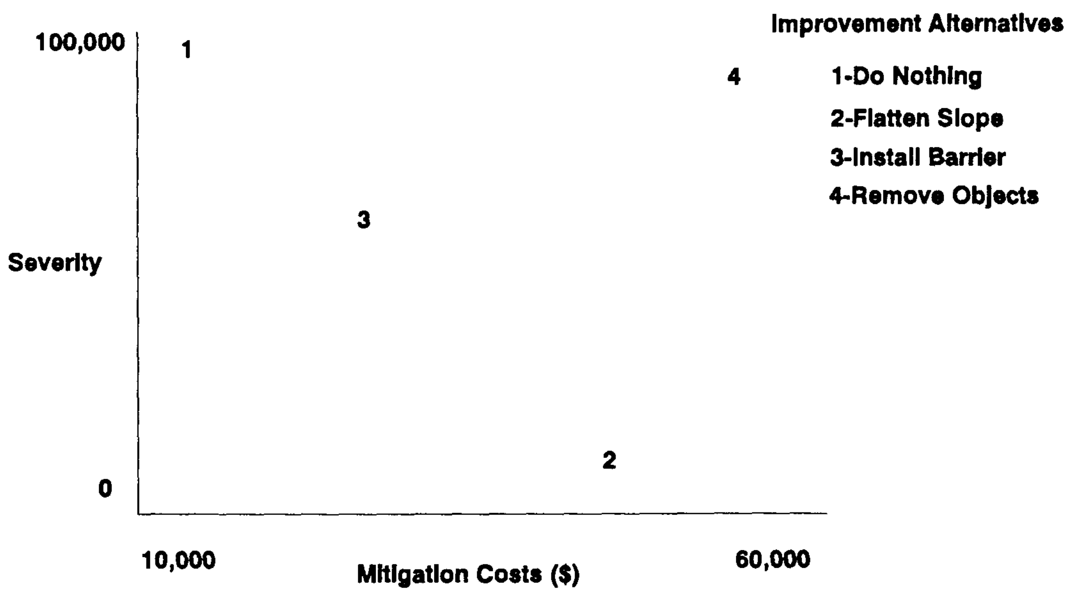



Figure 4.9 Cost-Effectiveness Graph: Roadside Barrier Warranted

**4.6.4 Hazardous Object Removal Warranted**

The final typical situation to be modelled represents the case where the best alternative would be to remove the hazardous objects in the roadside environment. The hazardous roadside terrain for this example is shown in Figure 4.10, together with the details.

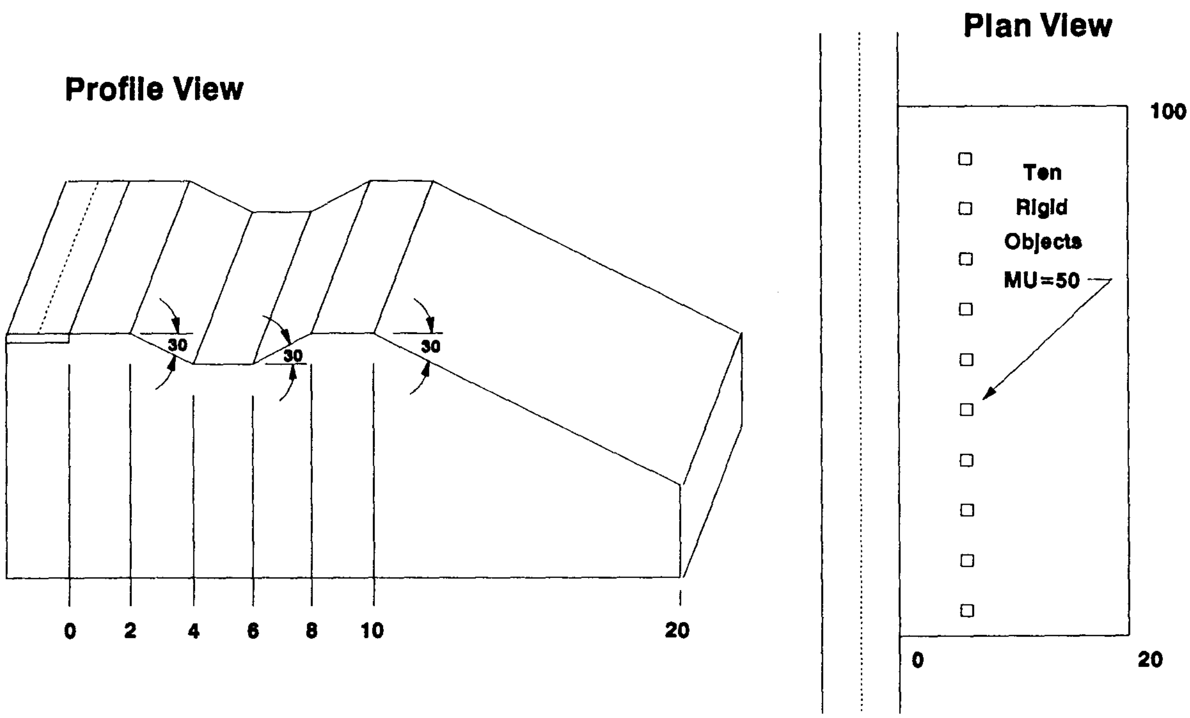



Figure 4.10 Hazardous Roadside Area: Roadside Object Removal Warranted

The description of the do-nothing alternative is presented above in the illustration. The slope flattening alternative flattens the slope to a 20 degree down-slope, starting at 2.0 meters from the edge of the roadway and continuing to the 20 meter maximum lateral displacement. The barrier installation option simulates a deformable barrier, with a coefficient of friction (MU) equal to 50, 2.0 meters from the roadway edge. The object removal alternative removes the ten rigid objects and leaves the terrain untouched.

The accident severity consequence probability determined by RHSM.V9 clearly indicates that removing the hazardous objects is the "safest" alternative. This is especially true for injury accidents or accidents at lower power-loss levels. The results of the accident severity consequence probability and vehicle roll-over probability are shown in Table 4.42.

Table 4.42 Object Removal: Accident Consequence Probability

| Improvement Alternatives | Accident Severity Consequence Probability | | | | Vehicle Roll-Over Probability | | |
|---|---|---|---|---|---|---|---|
| | ND | PDO | INJ | FAT | Total | on Slope | Ter Chg |
| Do Nothing | 0.611 | 0.225 | 0.142 | 0.012 | 0.04 | 0.00 | 0.04 |
| Flatten Slope | 0.599 | 0.247 | 0.139 | 0.015 | 0.00 | 0.00 | 0.00 |
| Install Barrier | 0.632 | 0.181 | 0.166 | 0.021 | 0.01 | 0.00 | 0.01 |
| Remove Objects | 0.828 | 0.139 | 0.019 | 0.014 | 0.08 | 0.00 | 0.08 |

The results of the benefit-cost ratio economic evaluation clearly indicate that the dollars required to flatten the slope or to install a barrier are not justified by the relatively small increase in the accident cost savings. In both cases, for approximately every 10.0 dollars spent for mitigation purposes, only 1.0 dollar is retrieved in accident savings. The option of removing the hazardous objects is the only alternative with a favourable benefit-cost ratio, with a value of 1.77. The results are provided below in Table 4.43.

Table 4.43 Object Removal: Benefit-Cost Analysis

| Improvement Alternative | TAC (PV$) | TMC (PV$) | RAC (PV$) | RMC (PV$) | B/C Ratio | Net Benefit |
|---|---|---|---|---|---|---|
| Do Nothing | 20,619 | 11,258 | | | | |
| Flatten Slope | 15,633 | 68,650 | 4,986 | 57,392 | 0.09 | -52,406 |
| Install Barrier | 19,798 | 21,887 | 821 | 10,629 | 0.08 | -9,808 |
| Remove Objects | 11,770 | 16,258 | 8,850 | 5,000 | 1.77 | 3,850 |

Finally, the cost-effectiveness evaluation is considered, and for this particular case, the results are very clear. The improvement alternatives simulated for flattening the slope and installing a roadside barrier both have higher severity and higher costs associated with them than option four (removing the hazardous objects). The do-nothing alternative has a slightly less mitigation cost than the object removal alternative, but the severity is significantly higher. Therefore it can be concluded that the "best" alternative would be to remove the hazardous objects. The results and the graphical illustration of the cost-effectiveness analysis are provided below in Table 4.44 and in Figure 4.11.

Table 4.44 Object Removal: Cost-Effectiveness Analysis

| Improvement Alternative | Mitigation Costs (PV$) | Severity |
|---|---|---|
| Do Nothing | 11,258 | 13377 |
| Flatten Slope | 68,650 | 9335 |
| Install Barrier | 21,887 | 12576 |
| Remove Objects | 16,258 | 8497 |

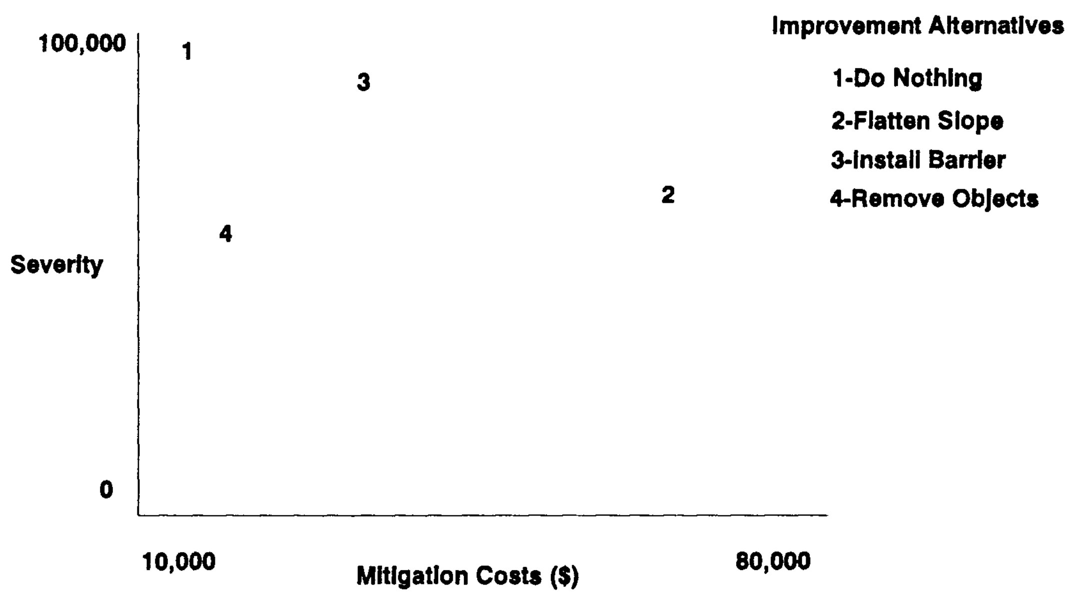



Figure 4.11 Cost-Effectiveness Graph: Roadside Object Removal Warranted

## 5.0 CONCLUSIONS and RECOMMENDATIONS

This chapter summarizes the results and conclusions gained from this research and makes recommendations based on these conclusions. The goal of this research project was to develop a user friendly computer program used by highway safety professionals to evaluate hazardous roadside locations, as well as evaluating improvement alternatives proposed to reduce the level of hazard. This goal has been achieved with the development of Version 9.0 of the Roadside-Hazard-Simulation-Model (RHSM.V9).

At the outset of this project, the focus dealt specifically with improving roadside barrier warrants. However, after reviewing the previous versions of RHSM and recognizing that the installation of a roadside barrier is only one solution for a hazardous roadside, the focus of the research was altered to include the evaluation of any improvement alternative. Consequently, the model will determine whether or not a roadside barrier is warranted, but it will also evaluate of any combination of improvement alternatives including embankment slope flattening, roadside barrier installation, or hazardous object removal.

Although some parts of the new version of RHSM are based on theory used in previous versions of the model, the entire model has been rewritten with an emphasis placed on model flexibility and user friendliness. Previous versions of the model tended to be somewhat difficult to use and unforgiving in nature, thus the new model was designed such that the user is confident working with the program. The menu-driven program provides numerous help screens and visual aids to facilitate this need for model friendliness.

After preliminary testing of RHSM.V9, the results produced by the model appear to be quite good. The model was subjected to four levels of testing including a results comparison with previous versions of the model, a results evaluation for hazardous embankment slopes and objects, a sensitivity analysis of the model's operational parameters and economic factors, and finally, a series of typical "real-life" applications of the model.

In comparing the results produced by RHSM.V9 with previous versions of the model, results appear to be sound. The criticism of two previous versions of the program (Version 6.2 and Version 7.0) was that they generated results far too severe, however, RHSM.V9 produced results significantly less severe for identical encroachment and roadside conditions. Version 5.0 of RHSM produced results that were good and fortunately, the results produced by Version 9.0 are quite similar, although slightly less severe.

The results evaluation for hazardous embankment slopes and hazardous roadside objects also produced favourable results. The analysis included varying the location of hazardous terrain, the severity of the embankment slope, the type of roadside terrain, the object type, the object rigidity, the object size, and the object location. In each case, the trend in the results are correct such that as the hazard becomes more severe, the corresponding accident consequence becomes more severe. The magnitude of the results are difficult to validate due to a lack of a large enough data base, however, the results appear to be intuitively realistic.

The sensitivity analysis of the model's operational and the economic factors also produce results which are quite good. The operational parameters tested include the encroachment speed, horizontal curve, time increments, number and location of encroachments, speed and angle increments, corrective parameters (braking, restraint, and steer-back), and vehicle model. The trends in the results for each parameter is correct as well as the relative importance of each operational parameter. The sensitivity of the economic factors used by RHSM.V9 include the encroachment rate, the accident costs, the mitigation costs, cost-effectiveness criteria importance, and the interest rate/time-period factors. The conclusion from this aspect of the evaluation of RHSM.V9 is that these economic factors are site specific in nature and require local knowledge to ensure values are correct for each factor in order to achieve confident over-all results.

The last level of testing included a series of typical applications of the model representing "real-life" situations, illustrating how the model is intended to be used. The user simulates the roadside and encroachment characteristics for the hazardous location (representing the "do-nothing" alternative), then a series of improvement alternatives can be devised and simulated for the hazardous location. The best solution was identified by the model for each "real-life" example tested, thus proving the effectiveness of the new model.

The general conclusion of this thesis is that RHSM.V9 can be used to improve the engineering analysis process in evaluating hazardous roadside locations. After preliminary testing of the model, the results, and the trends in the results, appear to be quite good. The program is meant to be used as a tool to assist the highway safety professional in making a decision regarding the implementation of roadside safety improvement alternatives, and should be used together with sound engineering judgement. Version 9.0 of RHSM has evolved significantly from the last version of RHSM, and although future research may be required to refine the results produced by the program, the model should form the foundation for evaluating hazardous roadsides and improvement alternatives on British Columbia's Highway network.

## 6.0 FUTURE RESEARCH

This final chapter of the research project recommends various areas of research which will further the development of the Roadside-Hazard-Simulation-Model. The model has been designed such that as new or better information becomes available, it can be immediately and easily incorporated into the new model.

Two components of the model which may require future research are the power-dissipation/probability of consequence table and the critical roll-over speed/probability of consequence table. These two tables are used to determine the over-all probability of consequence of an errant vehicle entering a hazardous roadside. Although the tables appear to produce valid results at the present time, further research to refine the tables could improve the over-all results. Once better information is available regarding these relationships, it can be entered directly into the calibration component of the model.

Other components of the model which may require future research includes the vehicle departure angle frequencies, the encroachment speed distribution, the encroachment rate factors, and the vehicle characteristics. Although significant changes in each of these components from is not expected, slight modifications based on new research may refine the results. More research is also required to determine the total costs of accidents, as well as the mitigation costs associated with each improvement alternative. Research is being done on the real cost of accidents at the present time, however, the mitigation cost research may have to be done on a site-specific basis due to the great variability in values.

Further research is also required to determine the relative rigidity or friction coefficient of various hazardous roadside objects. Research which quantifies these values is required, such as the Ministry of Transportation and Highways, Highway Safety Branch, sponsored research by Navin and Thomson [56] which should produce a relative rigidity value for concrete roadside barriers.

One final area of research which should be suggested in the future development of RHSM is the suitability of this type of program for an object oriented programming approach. At the outset of this project it was determined that an object oriented programming approach would be favourable, however due to time restrictions, it was decided to abandon this approach. If more time was available for the next revision of the program then this approach should be seriously considered.

**References**

[1] Transport Canada; Roadside Hazards: A Methodology and Technique for Determining Accident Potential, B.C. Research for Transport Canada, July 1978.

[2] Calcote, L.R.; Michie, L.D.; Location, Selection, and Maintenance of Highway Guardrails and Median Barriers, National Cooperative Highway Research Program (NCHRP) Report #54, p. 2, 1968.

[3] Bronstad, M.E.; Michie, L.D.; Location, Selection, and Maintenance of Highway Traffic Barriers, National Cooperative Highway Research Program (NCHRP) Report #118, pp. 8-9, 1971.

[4] Ministry of Transportation and Highways; Highway Engineering Branch Design Manual, Province of British Columbia, Canadian Cataloguing in Publication Data, p. B-4.1, 1992.

[5] TAC; Manual of Geometric Design Standards for Canadian Roads, 1986 Metric Edition, Roads and Transportation Association of Canada, Ottawa, Ontario, p. F-9 to F-37, 1986.

[6] Bronstad, M.E.; Michie, L.D.; Location, Selection, and Maintenance of Highway Traffic Barriers, National Cooperative Highway Research Program (NCHRP) Report #118, pp. 1-22, 1971.

[7] Ibid, pp. 1-22.

[8] Calcote, L.R.; Michie, L.D.; Location, Selection, and Maintenance of Highway Guardrails and Median Barriers, National Cooperative Highway Research Program (NCHRP) Report #54, p. 1-17, 1968.

[9] Bronstad, M.E.; Michie, L.D.; Location, Selection, and Maintenance of Highway Traffic Barriers, National Cooperative Highway Research Program (NCHRP) Report #118, pp. 1-22, 1971.

[10] AASHTO; Roadside Design Guide, American Association of State Highway and Transportation Officials, Washington, D.C., p. 5.1-5.39, 1989.

[11] Cooper, P.; Highway Safety Barriers, Transport Canada and B.C. Research, Vancouver, B.C., pp. 111-124, 1980.

[12] Perera, H.; Development of an Improved Highway-Vehicle-Object-Simulation-Model (HVOSM) for Multi-Faced Rigid Barriers, Texas Transportation Institute, Transportation Research Record #1233, pp. 104-116, 1989.

[13] McHenry, R.R.; DeLays, N.J.; Segal, D.J.; Determination of Physical Criteria for Roadside Energy Compression Systems, Calspan Corporation, Buffalo, New York, 1976.

[14] Cooper, P.; Highway Safety Barriers, Transport Canada and B.C. Research, Vancouver, B.C., pp. 94-95, 1980.

[15] Segal, D.J.; Highway-Vehicle-Object-Simulation-Model (HVOSM), Federal Highway Administration (FHWA-RD-75), Calspan Corporation, Buffalo, New York, 1976.

[16] Bligh, R.P.; Sicking, D.L.; Application of Barrier VII in Design of Flexible Barriers, Texas Transportation Institute, Transportation Research Record #1233, pp. 117-123, 1989.

[17] Powell, G.H.; A Computer Program for Evaluation of Automobile Barrier Systems, Federal Highway Administration (FHWA), U.S. Department of Transportation, 1973.

[18] Cooper, P.; Highway Safety Barriers, Transport Canada and B.C. Research, Vancouver, B.C., pp. 95-96, 1980.

[19] Bligh, R.P.; Sicking, D.L.; Application of Barrier VII in Design of Flexible Barriers, Texas Transportation Institute, Transportation Research Record #1233, pp. 117-123, 1989.

[20] Ibid, p. 119.

[21] Perera, H.S.; Ross, H.E.; Prediction of Roll-Overs Caused by Concrete Safety-Shaped Barriers, Texas Transportation Institute, Transportation Research Record #1233, 1989.

[22] Bruce, R.W.; Hann, E.E.; Iwankiw, N.R.; Guardrail/Vehicle Dynamic Interaction, Federal Highway Administration (FHWA), U.S. Department of Transportation, 1976.

[23] Cooper, P.; Highway Safety Barriers, Transport Canada and B.C. Research, Vancouver, B.C., p. 96, 1980.

[24] Ibid, p. 96.

[25] AASHTO; Roadside Design Guide, American Association of State Highway and Transportation Officials, Washington, D.C., p. A-2, 1989.

[26] Ibid, p. A-2.

[27] Roschke, P.N.; Advisory System for Design of Highway Safety Structures, Journal of Transportation Engineering, Vol. 117, Number 4, pp. 418-434, July-August 1991.

[28] Ibid, pp. 418-434.

[29] Zhou, H.; Layton, R.D.; Development of a Prototype Expert System for Roadside Safety, Journal of Transportation Engineer, Vol. 117, Number 4, pp. 435-443, 1991.

[31] Ray, M.H.; Logie, D.; An Object-Oriented Approach to Warranting Roadside Safety Hardware, Computing in Civil Engineering, American Society of Civil Engineers, New York, pp. 490-497, 1987.

[32] Ibid, pp. 490-497.

[33] Transport Canada; Roadside Hazards: A Methodology and Technique for Determining Accident Potential, B.C. Research for Transport Canada, July 1978.

[34] Transport Canada; Study of Single-Vehicle Off-Road Accidents, DeLeuw Cather Canada Ltd. and ADI Limited for Transport Canada, December 1978.

[35] Cooper, P.; Roadside Hazards: A Methodology and Technique for Determining Accident Potential, B.C. Research for Transport Canada, July 1978.

[36] Lenz, M.; Sanderson, R.W.; The Roadside Hazard Simulation Model (RHSM); A Methodology and Technique to Effectively Reduce the Single Vehicle Accident Potential (Version 6.2), Transport Canada, Ottawa, Ontario, 1984.

[37] Galway, M.C.; Sanderson, R.W.; Roadside Hazard Simulation Model, Version 7.0, Transport Canada, Ottawa, Ontario, 1986.

[38] Ministry of Transportation and Highways, Guardrail Warrants Memorandum, Province of British Columbia, Highway Safety Branch, Technical Memorandum, April 2, 1990.

[39] Transport Canada; Study of Single-Vehicle Off-Road Accidents, DeLeuw Cather Canada Ltd. and ADI Limited for Transport Canada, December 1978.

[40] Transport Canada; The Roadside Hazard Simulation Model (RHSM); A Methodology and Technique to Effectively Reduce the Single Vehicle Accident Potential (Version 6.2), Transport Canada, Ottawa, Ontario, p. 10, 1984.

[41] Koike, H.; Roadside Hazard Simulation Model: Its Development and Application, Proceedings of the Japan Society of Civil Engineers, p. 21, July 1985.

[42] Transport Canada; The Roadside Hazard Simulation Model (RHSM): A Methodology and Technique to Effectively Reduce the Single Vehicle Accident Potential (Version 6.2), Transport Canada, Ottawa, Ontario, p. 101, 1984.

[43] TAC; Manual of Geometric Design Standards for Canadian Roads, 1986 Metric Edition, Roads and Transportation Association of Canada, Ottawa, Ontario, p. F-9 to F-37, 1986.

[44] Ministry of Transportation and Highways; Highway Engineering Branch Design Manual, Province of British Columbia, Canadian Cataloguing in Publication Data, p. B-4.1, 1992.

[45] Transport Canada; Study of Single-Vehicle Off-Road Accidents, DeLeuw Cather Canada Ltd. and ADI Limited for Transport Canada, December 1978.

[46] Koike, H.; Roadside Hazard Simulation Model: Its Development and Application, Proceedings of the Japan Society of Civil Engineers, p. 22, July 1985.

[47] Transportation Centre; Study of the Relationship Between Vehicle Impact Speed and Various Sensitivity Parameters, University of Saskatchewan, Saskatoon, Saskatchewan, 1976.

[48] Campbell, K.L.; Energy Basis for Collision Severity, Society of Automotive Engineers (SAE) Paper Number 740565, 1974.

[49] Transport Canada; Study of Single-Vehicle Off-Road Accidents, DeLeuw Cather Canada Ltd. and ADI Limited for Transport Canada, December 1978.

[50] Transport Canada; The Roadside Hazard Simulation Model (RHSM): A Methodology and Technique to Effectively Reduce the Single Vehicle Accident Potential (Version 6.2), Transport Canada, Ottawa, Ontario, p. 23-35, 1984.

[51] TAC; Manual of Geometric Design Standards for Canadian Roads, 1986 Metric Edition, Roads and Transportation Association of Canada, Ottawa, Ontario, p. F-9 to F-37, 1986.

[52] TAC; Manual of Geometric Design Standards for Canadian Roads, 1986 Metric Edition, Roads and Transportation Association of Canada, Ottawa, Ontario, p. F-10, 1986.

[53] Ministry of Transportation and Highways; Roadside Guardrail Warrant Summary, Province of British Columbia, 1988.

[54] Navin, F.; Thomson, R.; M.o.T.H. Preliminary Report: Preliminary Tests of Concrete Roadside Barrier Impacts (Technical Memorandum R-6), Accident Investigation Team, University of British Columbia, Vancouver, B.C., Nov. 1991.

**Bibliography**


AASHTO; Roadside Design Guide, American Association of State Highway and Transportation Officials, Washington, D.C., p. 5.1-5.39, 1989.

Bligh, R.P.; Sicking, D.L.; Application of Barrier VII in Design of Flexible Barriers, Texas Transportation Institute, Transportation Research Record #1233, pp. 117-123, 1989.

Bronstad, M.E.; Michie, L.D.; Location, Selection, and Maintenance of Highway Traffic Barriers, National Cooperative Highway Research Program (NCHRP) Report #118, pp. 1-22, 1971.

Brown, G.; Benefit-Cost Analysis for Road Projects, The Cost Effective Procedure for Transportation Decisions, Civil Engineering 586 Class Notes, University of British Columbia, 1991.

Bruce, R.W.; Hann, E.E.; Iwankiw, N.R.; Guardrail/Vehicle Dynamic Interaction, Federal Highway Administration (FHWA), U.S. Department of Transportation, 1976.

Bryden, J.E.; Bruno, N.J.; Movable Concrete Median Barrier Risk Analysis, New York Department of Transportation, Transportation Research Record #1233, pp. 1-10, 1989.

Bryden, J.E.; Bruno, N.J.; Fortuniewicz, J.S.; Development of a Economic Model to Compare Median Barrier Costs, New York Department of Transportation, Transportation Research Record #1133, pp. 23-29, 1987.

Calcote, L.R.; Michie, L.D.; Location, Selection, and Maintenance of Highway Guardrails and Median Barriers, National Cooperative Highway Research Program (NCHRP) Report #54, p. 1-17, 1968.

Campbell, K.L.; Energy Basis for Collision Severity, Society of Automotive Engineers (SAE) Paper Number 740565, 1974.

Carney, J.F.; Ray, M.H.; Safety Performance Evaluation of 21st Century Appurtenances, American Society of Civil Engineers (ASCE), pp. 177-188, 1988.

Cooper, P.; Highway Safety Barriers, Transport Canada and B.C. Research, Vancouver, B.C., pp. 111-124, 1980.

German, A.; Roll-Over Collisions: A Continuing Problem for Occupant Mortality, Accident Research Team, The University of Western Ontario, pp. 1-17, 1989.

Koike, H.; Roadside Hazard Simulation Model: Its Development and Application, Proceedings of the Japan Society of Civil Engineers, p. 21, July 1985.

Lawson, S.D.; Some Approaches to Roadside Crash Protection In the U.S. and their Potential for Application in the U.K., Traffic Engineering and Control, Volume 29, Number 4, pp. 202-209, April 1988.

Michie, J.D.; Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances, National Cooperative Highway Research Program (NCHRP) Report #230, pp.1-41, March 1981.

Miller, H.W.; Evaluation of Roadside Safety Improvements, Institute of Transportation Engineers (ITE) Journal, pp. 31-41, November 1980.

Ministry of Transportation and Highways; Highway Engineering Branch Design Manual, Province of British Columbia, Canadian Cataloguing in Publication Data, p. B-4.1, 1992.

Ministry of Transportation and Highways; Roadside Guardrail Warrant Summary, Province of British Columbia, 1988.

Ministry of Transportation and Highways, Guardrail Warrants Memorandum, Province of British Columbia, Highway Safety Branch, Technical Memorandum, p. 3, April 2, 1990.

Mc Carthy, L.; Roadside Safety: A National Perspective, Public Roads, Volume 50, Number 4, pp. 124-128, March 1987.

McHenry, R.R.; DeLays, N.J.; Segal, D.J.; Determination of Physical Criteria for Roadside Energy Compression Systems, Calspan Corporation, Buffalo, New York, 1976.

Navin, F.; Thomson, R.; M.o.T.H. Preliminary Report: Preliminary Tests of Concrete Roadside Barrier Impacts (Technical Memorandum R-6), Accident Investigation Team, University of British Columbia, Vancouver, B.C., Nov. 1991.

Olivarez, D.R.; The 30-Foot Clear Zone Concept: A Guide not a Standard, Institute of Transportation Engineers (ITE) Journal, Volume 58, Number 9, pp. 45-46, September 1988.

Perera, H.; Development of an Improved Highway-Vehicle-Object-Simulation-Model (HVOSM) for Multi-Faced Rigid Barriers, Texas Transportation Institute, Transportation Research Record #1233, pp. 104-116, 1989.

Perera, H.S.; Ross, H.E.; Prediction of Roll-Overs Caused by Concrete Safety-Shaped Barriers, Texas Transportation Institute, Transportation Research Record #1233, 1989.

Pigman, J.G.; Agent, K.R.; Guidelines for the Installation of Guardrail, University of Kentucky, Transportation Research Record #1302, pp. 24-31, 1991.

Powell, G.H.; A Computer Program for Evaluation of Automobile Barrier Systems, Federal Highway Administration (FHWA), U.S. Department of Transportation, 1973.

Ramache, A.; Roadside Safety: A Knowledge-Based Approach, Transportation Operations Research, University of NewCastle upon Tyme, 1991.

Ray, M.H.; Logie, D.; An Object-Oriented Approach to Warranting Roadside Safety Hardware, Computing in Civil Engineering, American Society of Civil Engineers, New York, pp. 490-497, 1987.

Rollins, J.B.; McFarland, W.F.; Costs of Motor Vehicle Accidents and Injuries, Texas Transportation Institute, Transportation Research Record #1068, pp. 1-7, 1986.

Roschke, P.N.; Advisory System for Design of Highway Safety Structures, Journal of Transportation Engineering, Vol. 117, Number 4, pp. 418-434, July-August 1991.

Schultz, L.C.; Pennsylvania's Guide Rail Standard: A Cost-Effective Change, Pennsylvania Department of Transportation, Transportation Research Record #1065, pp. 12-18, 1986.

Segal, D.J.; Highway-Vehicle-Object-Simulation-Model (HVOSM), Federal Highway Administration (FHWA-RD-75), Calspan Corporation, Buffalo, New York, 1976.

Sicking, D.L.; Ross, H.E.; Benefit-Cost Analysis of Roadside Safety Alternatives, Texas Transportation Institute, Transportation Research Record #1065, pp. 98-105, 1986.

Sicking, D.L.; Guidelines for Positive Barrier Use in Construction Zones, Transportation Research Record #1035, pp. 85-93, 1987.

TAC; Manual of Geometric Design Standards for Canadian Roads, 1986 Metric Edition, Roads and Transportation Association of Canada, Ottawa, Ontario, p. F-9 to F-37, 1986.

Transport Canada; Roadside Hazards: A Methodology and Technique for Determining Accident Potential, B.C. Research for Transport Canada, July 1978.

Transport Canada; Study of Single-Vehicle Off-Road Accidents, DeLeuw Cather Canada Ltd. and ADI Limited for Transport Canada, December 1978.

Transport Canada; The Roadside Hazard Simulation Model (RHSM): A Methodology and Technique to Effectively Reduce the Single Vehicle Accident Potential (Version 6.2), Transport Canada, Ottawa, Ontario, p. 10, 1984.

Transportation Centre; Study of the Relationship Between Vehicle Impact Speed and Various Sensitivity Parameters, University of Saskatchewan, Saskatoon, Saskatchewan, 1976.

Turner, D.S.; Walters, J.V.; Hutt, J.N.; Patrick, J.E.; Survey of State Utility Manual Clear Zone Provisions, University of Alabama, Transportation Research Record #1233, pp. 164-177, 1989.

Turner, D.S.; Barnett, T.; Case Study: Poles in the Urban Clear Zone, University of Alabama, Transportation Research Record #1233, pp. 155-163, 1989.

Viner, J.G.; Tamanini, F.J.; Effective Highway Barriers, Accident Analysis and Prevention, Volume 5, pp. 203-214,1973.

Waterman, D.A.; A Guide to Expert Systems, Addison-Wesley Publishing co. Inc., Menlo Park, California, 1986.

Welch, R.E.; Concrete Safety-Shaped Simulations with Program GUARD, Federal Highway Administration (FHWA-RD-78-90), U.S. Department of Transportation, 1977.

Youngman, J.H.; Towards a Rational for Warrants with Application to Median Barriers, Accident Analysis and Prevention, Volume 5, pp. 223-230, 1973.

Zegeer, C.V.; Reinfurt, D.W.; Hunter, W.W.; Hummer, J.; Stewart, R.; Herf, L.; Accident Effects of Side-slope and Other Roadside Features on Two-Lane Roads, Transportation Research Record #1195, pp. 33-47, 1988.

Ziegler, A.J.; Risk of Vehicle-Tree Accidents and Management of Roadside Trees, Michigan Department of Transportation, Transportation Research Record #1127, pp. 37-43, 1987.

Zhou, H.; Layton, R.D.; Development of a Prototype Expert System for Roadside Safety, Journal of Transportation Engineering, Volume 117, Number 4, pp. 435-443, July-August 1991.

**APPENDIX INDEX** Page

**APPENDIX A: Glossary of Terms**

There are a number of terms used in this report which are commonly used in the discussion of roadside improvement alternatives. Although many of the terms may seem simple by definition, for reasons of clarity, the definitions as they relate to this research project are provided below.

*Improvement Alternative:*

refers to any proposed action which may improve a hazardous location in terms of the accident severity consequence level.

*Roadside Hazard:*

a roadside hazard includes any natural or man-made feature which could cause damage to an errant vehicle (or harm to its occupants) upon leaving the roadway and encountering the feature.

*Slope Reduction:*

included as an improvement alternative, refers to any action which will reduce the hazard produced by a steep embankment slope such as slope flattening or rounding of steep embankment slopes.

*Traffic Barriers:*

refers to any device which provides a relative degree of protection for a vehicle and its occupants from hazardous roadside features or from crossing a median. These are classified into two groups; longitudinal barriers and crash cushion barriers. Crash cushion barriers are used to decelerate vehicles, usually used for head-on impacts at bridge piers or off-ramp gore areas. These barriers are excluded in this report.

*Longitudinal Barriers:*

are traffic barriers placed parallel to the roadway in an attempt to redirect errant vehicles away from the off-road hazard. These include roadside barrier and median barriers.

*Roadside Barriers:*

are barriers, strategically placed to prevent an errant vehicle from having an off-road excursion either on a steep embankment slope, or at a roadside where hazardous obstacles (objects) exist.

*Encroachment Angle or Departure Angle:*

refers to the angle between the normal path that a vehicle travels on a roadway and the path that an errant vehicle takes during an off-road excursion.

*Probability of Consequence:*

based on the power loss experienced by an errant vehicle upon leaving the roadway, the probability of consequence defines the consequence level (fatal, injury, property damage only, no damage) in terms of an expected rate of occurrence or probability.

*Severity Index:*

The severity index is an index used to quantify the power loss, associated with a probability of consequence, into a realistic and meaningful value. As mentioned previously, the severity index includes four categories: no damage, property damage only, injury, and fatality, each representing a different level of power loss. A large power loss indicates a severe accident, and a negligible power loss indicates a minor accident.

**APPENDIX B: RHSM: Sample Output**

This appendix provides a sample of the output which can be obtained from the analysis using RHSM.V9. The first two pages (155 and 156) provide the input data for each of the four alternatives used in this example. The next two pages (157 and 158) contain the calibration data, including the Departure Angle Distributions, the Probability of Consequence Table, the Roll-Consequence Table, the Vehicle Characteristics, and the Economic Default Costs and Weights. The next two pages (159 and 160) provide the individual results for each alternative, including the Simulation Results, the Aggregated Consequence Probability, and the Economic Evaluation Factors. The last two pages (161 and 162) are the Summary of Results which compares the results of all the alternatives. The Title Page is also shown below. All output does not have to be printed; the user has the option to specify only the output required.

```
            ROADSIDE HAZARDS SIMULATION MODEL
              Transport Canada Road Safety

               RHSM Version 9 (June 1992)
                     developed by
                      Paul deLeur
                          for
          BC Ministry of Transportation and Highways
                 Highway Safety Branch
                          and
              University of British Columbia
             Department of Civil Engineering
                  Transportation Group

                   Date:  5/10/1992
                     Time: 11:48
```

INPUT DATA ****************************************************************

DO NOTHING........

Operational Data

| | | |
|---|---|---|
| Time Increment | * | 0.0500 s |
| Maximum Trajectory Time | * | 10.0000 s |
| Minimum Halt Speed | * | 1.0000 m/s |
| Number of Origin Points | * | 1 |
| Increment of Origin Shift | * | 0.0000 m |
| Mean Speed | * | 80.0000 kph |
| Standard Deviation of Speed | * | 10.0000 kph |
| Speed Increment in S.Dev. | * | 2.0000 s.d. |
| Angle Change Increment | * | 4.0000 deg. |
| Minimum Probability Considered | * | 0.0000 |
| Brake Application | * | 0.0000 % |
| Percentage Seatbelt Use | * | 50.0000 % |
| Steer Back Angle | Ç | 0.0000 deg. |
| Horizontal Curvature | * | Straight |
| Vehicle Model | Ç | 4 |

Terrain Data (Terrain Change Points)

| Lateral Offset (m) | Slope Angle (Deg) | Terrain Resistance | Rolling Resistance |
|---|---|---|---|
| 0.000 | 0.000 | 0.4000 | 0.0500 |
| 2.000 | -45.000 | 0.4000 | 0.0500 |
| 4.000 | 0.000 | 0.4000 | 0.0500 |
| 6.000 | 60.000 | 0.4000 | 0.0500 |
| 8.000 | 0.000 | 0.4000 | 0.0500 |

Object Data

| End Point 1 X (m) | Y (m) | End Point 2 X (m) | Y (m) | Object Width | Object Type | Friction Code |
|---|---|---|---|---|---|---|
| 50.0 | 6.0 | 60.0 | 2.0 | 2.0 | D | 50.0 |

FLATTEN SLOPE.....

Operational Data

| | | |
|---|---|---|
| Time Increment | * | 0.0500 s |
| Maximum Trajectory Time | * | 10.0000 s |
| Minimum Halt Speed | * | 1.0000 m/s |
| Number of Origin Points | * | 1 |
| Increment of Origin Shift | * | 0.0000 m |
| Mean Speed | * | 80.0000 kph |
| Standard Deviation of Speed | * | 10.0000 kph |
| Speed Increment in S.Dev. | * | 2.0000 s.d. |
| Angle Change Increment | * | 4.0000 deg. |
| Minimum Probability Considered | * | 0.0000 |
| Brake Application | * | 0.0000 % |
| Percentage Seatbelt Use | * | 50.0000 % |
| Steer Back Angle | ? | 0.0000 deg. |
| Horizontal Curvature | * | Straight |
| Vehicle Model | ? | 4 |

Terrain Data (Terrain Change Points)

| Lateral Offset (m) | Slope Angle (Deg) | Terrain Resistance | Rolling Resistance |
|---|---|---|---|
| 0.000 | 0.000 | 0.4000 | 0.0500 |
| 2.000 | -13.700 | 0.4000 | 0.0500 |
| 8.000 | 0.000 | 0.4000 | 0.0500 |

Object Data

| End Point 1 X (m) | Y (m) | End Point 2 X (m) | Y (m) | Object Width | Object Type | Friction Code |
|---|---|---|---|---|---|---|
| 50.0 | 6.0 | 60.0 | 2.0 | 2.0 | D | 50.0 |

INSTALL BARRIER...

Operational Data

| | | |
|---|---|---|
| Time Increment | * | 0.0500 s |
| Maximum Trajectory Time | * | 10.0000 s |
| Minimum Halt Speed | * | 1.0000 m/s |
| Number of Origin Points | * | 1 |
| Increment of Origin Shift | * | 0.0000 m |
| Mean Speed | * | 80.0000 kph |
| Standard Deviation of Speed | * | 10.0000 kph |
| Speed Increment in S.Dev. | * | 2.0000 s.d. |
| Angle Change Increment | * | 4.0000 deg. |
| Minimum Probability Considered | * | 0.0000 |
| Brake Application | * | 0.0000 % |
| Percentage Seatbelt Use | * | 50.0000 % |
| Steer Back Angle | | 0.0000 deg. |
| Horizontal Curvature | * | Straight |
| Vehicle Model | 3 | 4 |

Terrain Data (Terrain Change Points)

| Lateral Offset (m) | Slope Angle (Deg) | Terrain Resistance | Rolling Resistance |
|---|---|---|---|
| 0.000 | 0.000 | 0.4000 | 0.0500 |
| 2.000 | -45.000 | 0.4000 | 0.0500 |
| 4.000 | 0.000 | 0.4000 | 0.0500 |
| 6.000 | 60.000 | 0.4000 | 0.0500 |
| 8.000 | 0.000 | 0.4000 | 0.0500 |

Object Data

| End Point 1 X (m) | End Point 1 Y (m) | End Point 2 X (m) | End Point 2 Y (m) | Object Width | Object Type | Friction Code |
|---|---|---|---|---|---|---|
| 50.0 | 6.0 | 60.0 | 2.0 | 2.0 | D | 50.0 |
| 0.0 | 2.0 | 100.0 | 2.0 | 0.5 | D | 50.0 |

REMOVE OBJECTS....

Operational Data

| | | |
|---|---|---|
| Time Increment | * | 0.0500 s |
| Maximum Trajectory Time | * | 10.0000 s |
| Minimum Halt Speed | * | 1.0000 m/s |
| Number of Origin Points | * | 1 |
| Increment of Origin Shift | * | 0.0000 m |
| Mean Speed | * | 80.0000 kph |
| Standard Deviation of Speed | * | 10.0000 kph |
| Speed Increment in S.Dev. | * | 2.0000 s.d. |
| Angle Change Increment | * | 4.0000 deg. |
| Minimum Probability Considered | * | 0.0000 |
| Brake Application | * | 0.0000 % |
| Percentage Seatbelt Use | * | 50.0000 % |
| Steer Back Angle | | 0.0000 deg. |
| Horizontal Curvature | * | Straight |
| Vehicle Model | 3 | 4 |

Terrain Data (Terrain Change Points)

| Lateral Offset (m) | Slope Angle (Deg) | Terrain Resistance | Rolling Resistance |
|---|---|---|---|
| 0.000 | 0.000 | 0.4000 | 0.0500 |
| 2.000 | -45.000 | 0.4000 | 0.0500 |
| 4.000 | 0.000 | 0.4000 | 0.0500 |
| 6.000 | 60.000 | 0.4000 | 0.0500 |
| 8.000 | 0.000 | 0.4000 | 0.0500 |

Object Data

| End Point 1 X (m) | End Point 1 Y (m) | End Point 2 X (m) | End Point 2 Y (m) | Object Width | Object Type | Friction Code |
|---|---|---|---|---|---|---|

CALIBRATION DATA ********************************************************************

Departure Angle Frequency Distributions

Straight Section

| Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 44. | 4 | 218. | 6 | 472. | 8 | 760. | 10 | 908. |
| 12 | 943. | 14 | 943. | 16 | 895. | 18 | 786. | 20 | 672. |
| 22 | 572. | 24 | 480. | 26 | 410. | 28 | 341. | 30 | 284. |
| 32 | 245. | 34 | 205. | 36 | 166. | 38 | 140. | 40 | 118. |
| 42 | 96. | 44 | 79. | 46 | 57. | 48 | 48. | 50 | 39. |
| 52 | 26. | 54 | 17. | 56 | 13. | 58 | 9. | 60 | 4. |
| 62 | 4. | 64 | 3. | 66 | 2. | 68 | 1. | 70 | 0. |

Gentle Curve

| Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 30. | 4 | 150. | 6 | 320. | 8 | 570. | 10 | 770. |
| 12 | 870. | 14 | 890. | 16 | 890. | 18 | 850. | 20 | 780. |
| 22 | 670. | 24 | 560. | 26 | 460. | 28 | 375. | 30 | 320. |
| 32 | 275. | 34 | 235. | 36 | 200. | 38 | 165. | 40 | 140. |
| 42 | 120. | 44 | 95. | 46 | 75. | 48 | 55. | 50 | 45. |
| 52 | 35. | 54 | 25. | 56 | 20. | 58 | 15. | 60 | 10. |
| 62 | 8. | 64 | 6. | 66 | 4. | 68 | 2. | 70 | 0. |

Moderate Curve

| Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 20. | 4 | 100. | 6 | 210. | 8 | 340. | 10 | 540. |
| 12 | 700. | 14 | 780. | 16 | 815. | 18 | 825. | 20 | 820. |
| 22 | 790. | 24 | 715. | 26 | 590. | 28 | 485. | 30 | 385. |
| 32 | 325. | 34 | 275. | 36 | 235. | 38 | 200. | 40 | 170. |
| 42 | 140. | 44 | 115. | 46 | 90. | 48 | 70. | 50 | 60. |
| 52 | 50. | 54 | 40. | 56 | 30. | 58 | 20. | 60 | 15. |
| 62 | 12. | 64 | 9. | 66 | 6. | 68 | 3. | 70 | 0. |

Severe Curve

| Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. | Angle | Freq. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 10. | 4 | 60. | 6 | 150. | 8 | 275. | 10 | 400. |
| 12 | 530. | 14 | 620. | 16 | 675. | 18 | 715. | 20 | 725. |
| 22 | 730. | 24 | 725. | 26 | 690. | 28 | 630. | 30 | 535. |
| 32 | 455. | 34 | 380. | 36 | 315. | 38 | 260. | 40 | 215. |
| 42 | 175. | 44 | 145. | 46 | 120. | 48 | 100. | 50 | 80. |
| 52 | 65. | 54 | 55. | 56 | 45. | 58 | 35. | 60 | 25. |
| 62 | 20. | 64 | 16. | 66 | 12. | 68 | 8. | 70 | 4. |

Probability of Consequence Table

| | Power (W/kg) | No Damage | Unrestrained PDO | Unrestrained Fatal | Restrained PDO | Restrained Fatal |
|---|---|---|---|---|---|---|
| 1 | 0. | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 200. | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 300. | 0.50 | 0.50 | 0.00 | 0.50 | 0.00 |
| 4 | 432. | 0.01 | 0.98 | 0.00 | 0.99 | 0.00 |
| 5 | 1459. | 0.00 | 0.85 | 0.01 | 0.95 | 0.00 |
| 6 | 3092. | 0.00 | 0.60 | 0.03 | 0.70 | 0.00 |
| 7 | 5331. | 0.00 | 0.26 | 0.12 | 0.35 | 0.01 |
| 8 | 11628. | 0.00 | 0.00 | 0.45 | 0.02 | 0.05 |
| 9 | 15685. | 0.00 | 0.00 | 0.85 | 0.00 | 0.37 |

Roll Consequence Table

| Speed | Unrestrained PDO | Unrestrained Fatality | Restrained PDO | Restrained Fatality |
|---|---|---|---|---|
| 5.55 | 0.30000 | 0.11000 | 0.35000 | 0.06000 |
| 16.66 | 0.25000 | 0.29000 | 0.31000 | 0.20000 |
| 19.44 | 0.20000 | 0.36000 | 0.25000 | 0.25000 |
| 22.22 | 0.15000 | 0.40000 | 0.18000 | 0.29000 |
| 23.61 | 0.10000 | 0.45000 | 0.08000 | 0.34000 |
| 25.00 | 0.05000 | 0.52000 | 0.05000 | 0.40000 |
| 26.39 | 0.01000 | 0.61000 | 0.01000 | 0.55000 |
| 27.78 | 0.00000 | 0.70000 | 0.00000 | 0.66000 |
| 30.56 | 0.00000 | 0.79000 | 0.00000 | 0.69000 |
| 33.33 | 0.00000 | 0.85000 | 0.00000 | 0.75000 |
| 41.67 | 0.00000 | 1.00000 | 0.00000 | 1.00000 |

Vehicle Characteristics

| Vehicle Type | Wheel Base (m) | Track Width (m) | Weight (kg) | Centre of Gravity (m) |
|---|---|---|---|---|
| 1 | 2.40 | 1.30 | 922.00 | 0.51 |
| 2 | 2.52 | 1.42 | 979.00 | 0.53 |
| 3 | 2.59 | 1.42 | 1159.00 | 0.55 |
| 4 | 2.75 | 1.48 | 1404.00 | 0.58 |
| 5 | 2.95 | 1.55 | 1591.00 | 0.58 |
| 6 | 2.98 | 1.58 | 1859.00 | 0.58 |
| 7 | 2.24 | 1.30 | 636.00 | 0.51 |
| 8 | 2.75 | 1.48 | 1600.00 | 0.58 |

Economic Evaluation Default Costs and Weights

| Accident Costs (B/C Analysis) | | Accident Importance (C-E Analysis) | |
|---|---|---|---|
| ND = | 0.00 | ND = | 2 |
| PDO = | 4000.00 | PDO = | 20 |
| INJ = | 15000.00 | INJ = | 2000 |
| FAT = | 500001.01 | FAT = | 400000 |

RESULTS ************************************************************************

DO NOTHING........

Simulation Results

| | | |
|---|---|---|
| Total Number of Vehicle Trajectories | = | 144 |
| Total Number of Rolls | = | 39 |
| Probability of Vehicle Roll-Over | = | 0.27 |
| Number of Rolls at Terrain Change | = | 7 |
| Probability of Rolls at Terrain Change | = | 0.05 |
| Number of Rolls on Slope | = | 32 |
| Probability of Rolls on Slope | = | 0.22 |

Aggregated Probability of Overall Accident Consequence Classification

| | | |
|---|---|---|
| No Damage | = | 0.486 |
| Property Damage Only | = | 0.229 |
| Injury | = | 0.194 |
| Fatality | = | 0.090 |

Economic Evaluation Factors

| | | | | | |
|---|---|---|---|---|---|
| Encroachment Rate (/km/yr) | = | 1.4608 | | | |
| Total Accident Costs | = | 71480.44 | PV$/km | 6349.42 | $/km/year |
| Total Mitigation Costs | = | 11257.79 | PV$/km | 1000.00 | $/km/year |
| Total Severity (/km/year) | = | 53283. | | | |

FLATTEN SLOPE.....

Simulation Results

| | | |
|---|---|---|
| Total Number of Vehicle Trajectories | = | 144 |
| Total Number of Rolls | = | 0 |
| Number of Rolls at Terrain Change | = | 0 |
| Number of Rolls on Slope | = | 0 |

Aggregated Probability of Overall Accident Consequence Classification

| | | |
|---|---|---|
| No Damage | = | 0.905 |
| Property Damage Only | = | 0.087 |
| Injury | = | 0.007 |
| Fatality | = | 0.001 |

Economic Evaluation Factors

| | | | | | |
|---|---|---|---|---|---|
| Encroachment Rate (/km/yr) | = | 1.4608 | | | |
| Total Accident Costs | = | 1084.11 | PV$/km | 96.30 | $/km/year |
| Total Mitigation Costs | = | 48280.58 | PV$/km | 4288.64 | $/km/year |
| Total Severity (/km/year) | = | 362. | | | |

INSTALL BARRIER...

Simulation Results

```
Total Number of Vehicle Trajectories       =   144
Total Number of Rolls                      =    16
  Probability of Vehicle Roll-Over         =  0.11
Number of Rolls at Terrain Change          =     5
  Probability of Rolls at Terrain Change   =  0.03
Number of Rolls on Slope                   =    11
  Probability of Rolls on Slope            =  0.08
```

Aggregated Probability of Overall Accident Consequence Classification

```
No Damage            =   0.536
Property Damage Only =   0.206
Injury               =   0.191
Fatality             =   0.066
```

Economic Evaluation Factors

```
Encroachment Rate (/km/yr) =     1.4608
Total Accident Costs       =   53874.58 PV$/km        4785.54 $/km/year
Total Mitigation Costs     =   32515.57 PV$/km        2888.27 $/km/year
Total Severity (/km/year)  =     39348.
```

REMOVE OBJECTS....

Simulation Results

```
Total Number of Vehicle Trajectories       =   144
Total Number of Rolls                      =    43
  Probability of Vehicle Roll-Over         =  0.30
Number of Rolls at Terrain Change          =     7
  Probability of Rolls at Terrain Change   =  0.05
Number of Rolls on Slope                   =    36
  Probability of Rolls on Slope            =  0.25
```

Aggregated Probability of Overall Accident Consequence Classification

```
No Damage            =   0.487
Property Damage Only =   0.217
Injury               =   0.200
Fatality             =   0.096
```

Economic Evaluation Factors

```
Encroachment Rate (/km/yr) =     1.4608
Total Accident Costs       =   75649.85 PV$/km        6719.78 $/km/year
Total Mitigation Costs     =   51257.78 PV$/km        4553.10 $/km/year
Total Severity (/km/year)  =     56585.
```

SUMMARY OF RESULTS ***********************************************************

Summary of Accident Consequence Probabilities
(and differences from: DO NOTHING......)

| Alternatives | No Damage | P.D.O. | Injury | Fatality |
|---|---|---|---|---|
| DO NOTHING...... | 0.49 | 0.23 | 0.19 | 0.09 |
| FLATTEN SLOPE... | 0.91 ( 0.42) | 0.09 (-0.14) | 0.01 (-0.19) | 0.00 (-0.09) |
| INSTALL BARRIER. | 0.54 ( 0.05) | 0.21 (-0.02) | 0.19 ( 0.00) | 0.07 (-0.02) |
| REMOVE OBJECTS.. | 0.49 ( 0.00) | 0.22 (-0.01) | 0.20 ( 0.01) | 0.10 ( 0.01) |

Summary of Vehicle Roll-Over Probabilities

| Alternatives | Total Rolls Number | Total Rolls (Prob.) | Rolls on Slope Number | Rolls on Slope (Prob.) | Roll @ Terrain Ch Number | Roll @ Terrain Ch (Prob.) |
|---|---|---|---|---|---|---|
| DO NOTHING...... | 39 | ( 0.27) | 32 | ( 0.22) | 7 | ( 0.00) |
| FLATTEN SLOPE... | 0 | | 0 | | 0 | |
| INSTALL BARRIER. | 16 | ( 0.11) | 11 | ( 0.08) | 5 | ( 0.03) |
| REMOVE OBJECTS.. | 43 | ( 0.30) | 36 | ( 0.25) | 7 | ( 0.05) |

Benefit Cost Ratio Economic Evaluation
Relative Accident Savings and Relative Mitigatn Costs are
with respect to: DO NOTHING......

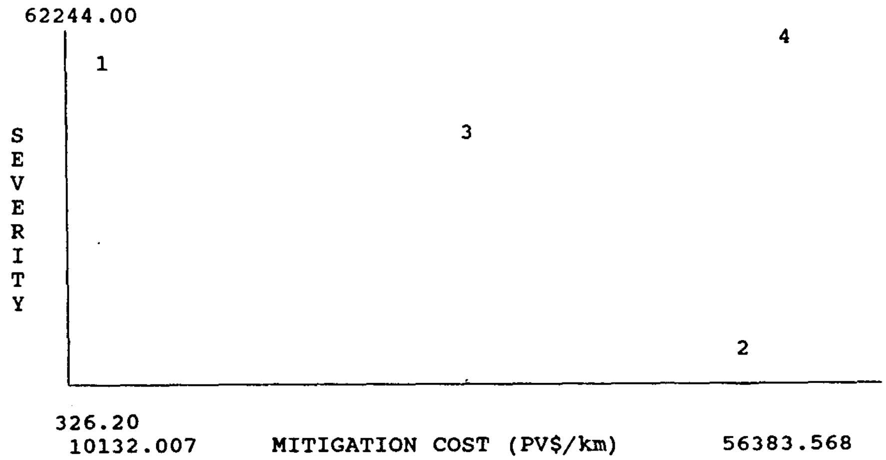
| Alternatives | Accident Costs (PV$) | Mitigatn Costs (PV$) | Relative Accident Savings (PV$) | Relative Mitigatn Costs (PV$) | B-C Ratio | Net Benefit (PV$) |
|---|---|---|---|---|---|---|
| DO NOTHING...... | 71480. | 11258. | | | | |
| FLATTEN SLOPE... | 1084. | 48281. | 70396. | 37023. | 1.90 | 33374. |
| INSTALL BARRIER. | 53875. | 32516. | 17606. | 21258. | 0.83 | -3652. |
| REMOVE OBJECTS.. | 75650. | 51258. | -4169. | 40000. | -0.10 | -44169. |

| Alternatives | Accident Costs ($/year) | Mitigatn Costs ($/year) | Relative Accident Savings ($/year) | Relative Mitigatn Costs ($/year) | B-C Ratio | Net Benefit ($/year) |
|---|---|---|---|---|---|---|
| DO NOTHING...... | 6349. | 1000. | | | | |
| FLATTEN SLOPE... | 96. | 4289. | 6253. | 3289. | 1.90 | 2964. |
| INSTALL BARRIER. | 4786. | 2888. | 1564. | 1888. | 0.83 | -324. |
| REMOVE OBJECTS.. | 6720. | 4553. | -370. | 3553. | -0.10 | -3923. |

Cost Effectiveness Economic Evaluation

| Alternatives | Mitigation Costs (PV$/km) | ($/km/year) | Severity (/km/year) |
|---|---|---|---|
| DO NOTHING...... | 11258. | 1000. | 53283. |
| FLATTEN SLOPE... | 48281. | 4289. | 362. |
| INSTALL BARRIER. | 32516. | 2888. | 39348. |
| REMOVE OBJECTS.. | 51258. | 4553. | 56585. |

COST EFFECTIVENESS EVALUATION




ALTERNATIVES

1 DO NOTHING......
2 FLATTEN SLOPE...
3 INSTALL BARRIER.
4 REMOVE OBJECTS..

Press <PGUP> or <PGDN> to page through results, <$> for an. costs & savings <CTRL><B> for benefit cost results, or <CTRL><X> or <ESC> to exit.

**APPENDIX C: RHSM: Structure**

1. Program RHSM:

   The purpose of this main program is to make the necessary calls to the subroutines at the appropriate time during the program operation.

2. Subroutine INPUT: (Called from RHSM)

   The purpose of this subroutine is to retrieve a previously stored input data file and load it into the program for analysis.

3. Subroutine EDIT: (Called from RHSM)

   The purpose of this subroutine is to initiate a new analysis or to edit a retrieved input data file for analysis.

4. Subroutine GRAPH2D (Called from EDIT)

   The purpose of this subroutine is to draw a cross-sectional view of the roadside terrain (perpendicular to the roadway) to provide a check for the user.

5. Subroutine ROADSIDE (Called from EDIT)

   The purpose of the subroutine is to draw a topographic map of the roadway, roadside area, and hazardous features to provide a visual check for the user.

6. Subroutine ECONOMIC (Called from RHSM)

   The purpose of this subroutine is to allow the user to edit most of the economic evaluation parameters associated with the encroachment rate, accident costs, and the present value-capital recovery factors.

7. Subroutine MITIGATION (Called from ECONOMIC)

   The purpose of this subroutine is to allow the user to edit the economic evaluation parameters associated with mitigation costs.

8. Subroutine TRAJECT (Called from RHSM)

   The purpose of this subroutine is to draw single trajectories of a user defined set of conditions (encroachment number, speed, and angle) to serve as a visual check.

9. Subroutine RUN (Called from RHSM)

   The purpose of this subroutine is to initiate the program analysis, keeping track of all the vehicle trajectories and results for each input set.

10. Subroutine SIMULATE (Called from TRAJECT and RUN)

    The purpose of this subroutine is to simulate a vehicle's motion as it traverses over a single trajectory in the roadside.

11. Subroutine OBJECT (Called from SIMULATE)

    The purpose of this subroutine is to check whether or not any objects are encountered during a single trajectory and calculate the induced decelerations.

12. Subroutine FLY (Called from SIMULATE)

    The purpose of this subroutine is to determine whether the vehicle becomes air-borne at each change in terrain slope.

13. Subroutine DYNROLL (Called from SIMULATE)

    The purpose of this subroutine is to monitor the air-borne vehicles and check for vehicle roll-over upon landing.

14. Subroutine STATROLL (Called from SIMULATE)

    The purpose of this subroutine is to determine whether a vehicle has rolled on the embankment slope.

15. Subroutine CONSEQ (Called from SIMULATE)

    The purpose of this subroutine is to determine the probability of accident consequence by utilizing the power loss and vehicle roll-over speeds.

16. Subroutine ECONRUN (Called from RUN)

    The purpose of this subroutine is to perform the economic analysis for each input set alternative.

17. Subroutine DISPLAY (Called from RHSM)

    The purpose of this subroutine is to display the results of the RHSM analysis onto the screen for the user to view.

18. Subroutine GRAPH3D (Called from DISPLAY)

    The purpose of this subroutine is to draw a three-dimensional graph of the results over the hazardous roadside area.

19. Subroutine PRINT (Called from RHSM)

    The purpose of this subroutine is to print the input data, calibration data, and/or the results either to a file or directly to the printer.

20. Subroutine SAVE (Called from RHSM)

The purpose of this subroutine is to save the input data sets to a file to be retrieved at a later time.

21. Subroutine CALIBRATE (Called from RHSM)

The purpose of this subroutine is to edit the calibration and operational parameters which are used for the default input data sets.

22. Subroutine GRAPH2D (Called from CALIBRATE)

The purpose of this subroutine is to draw a graph of the encroachment angle distributions and the probability of consequence distributions for both power loss and vehicle roll-over speeds.

23. Subroutine DEFAULTS (Called from RHSM)

The purpose of this subroutine is to load all the defaulted values into the program for each input data set.

# APPENDIX D: RHSM Source Code

Global Variable Include File

```
*    ----------------------------------------------
*
*    Global variable include file
*
*    ------------------------------------------------------------------
*
*    Variables:
*
*    ----------------------------------------------


*    Constants.

*      G        - gravitational acceleration constant.
*      PI       - pi.
*      RAD      - conversion multiplier from degrees to radians.


*    Operational variable defaults.

*      DEF      - array of default values for 15 operational
*                 variables listed below.
*      IDEF     - character array contains asterisks for each of
*                 the 15 operational variables of up to 10 input
*                 sets which have default values.


*    The following operational variables are dimensioned for up to
*    10 input sets:

*      AINCR    - angle increment to use in simulation.
*      BRAKE    - braking coefficient.
*      HCURVE   - horizontal curve type.
*                 = <blank>  for straight sections.
*                 = G        for gentle curves.
*                 = M        for moderate curves.
*                 = S        for severe curves.
*      MITER    - number of encroachment points.
*      MODEL    - model number of vehicle to use in simulation.
*      PMIN     - minimum probability to consider in simulation.
*      REST     - degree of occupant restraint.
*      STEER    - steerback angle.
*      TI       - time increment to use in simulation.
*      TITLE    - title of input set.
*      TMAX     - length of time to model each trajectory.
*      VINCR    - initial velocity increment to use in simulation
*                 (in standard deviations).
*      VMEAN    - mean initial velocity.
*      VMIN     - minimum initial velocity to consider in simulation.
*      VSD      - initial velocity standard deviation.
*      XINCR    - distance between successive encroachment points.
```

```
*    The following object variables are dimensioned for up to 10 input
*    sets:

*      NO        - number of objects.
*      THM        - array of object deceleration coefficients (mu) for
*                up to 50 deformable objects.
*      THTYP       - array of up to 50 object types.
*                 = R   for rigid objects.
*                 = D   for deformable objects.
*                 = S   for snappable objects.
*      THWID       - array of up to 50 object widths.
*      THX1       - array of up to 50 lower left corner x-coordinates.
*      THX2       - array of up to 50 lower right corner x-coordinates.
*      THX3       - array of up to 50 upper left corner x-coordinates.
*      THX4       - array of up to 50 upper right corner x-coordinates.
*      THY1       - array of up to 50 lower left corner y-coordinates.
*      THY2       - array of up to 50 lower right corner y-coordinates.
*      THY3       - array of up to 50 upper left corner y-coordinates.
*      THY4       - array of up to 50 upper right corner y-coordinates.


*    The following terrain variables are dimensioned for up to
*    10 input sets:

*      NT        - number of terrain strips.
*      TA        - array of slopes for up to 50 terrain strips.
*      TM         - array of terrain deceleration coefficients (mu)
*                for up to 50 terrain strips.
*      TR        - array of rolling deceleration coefficients (mu)
*                for up to 50 terrain strips.
*      TY        - array of up to 50 terrain strip offsets distances
*                from the road.


*    Encroachment angles.

*      NOBS       - array of the number of observations in the
*                encroachment probabilities table
*      PP        - array of encroachment angle probabilities for
*                4 different horizontal curvatures (Straight,
*                Gentle, Moderate, Severe) and 35 encroachment
*                angles between 2 and 70 degrees.


*    Probability of consequences variables.

*      NPLA       - number of entries in probability of consequences
*                table (up to 50).
*      PLA        - array containing the following data:
*                (1) - power level.
*                (2) - probability of no damage.
*                (3) - probability of property damage only for
*                     unrestrained occupants.
*                (4) - probability of fatalities for unrestrained
*                     occupants.
*                (5) - probability of property damage only for
*                     restrained occupants.
*                (6) - probability of fatalities for restrained
*                     occupants.
```

*     Roll consequences variables.

*       NVEL      - number of roll consequence entries (up to 50).
*       RP1       - array containing the following data:
*                 (1) - probability of property damage only for
*                       unrestrained occupants.
*                 (2) - probability of fatalities for unrestrained
*                       occupants.
*       RP2       - array containing the following data:
*                 (1) - probability of property damage only for
*                       restrained occupants.
*                 (2) - probability of fatalities for restrained
*                       occupants.
*       VEL       - array of velocities.

*     Variables used during simulation run.

*       ACCEL     - current vehicle acceleration.
*       ANGLE     - current vehicle horizontal angle with road.
*       ELEVATION - current vehicle elevation relative to road.
*       FLYING    - yes/no flag indicating whether a vehicle is
*                 currently airborne.
*       FLYTIME   - the amount of time elapsed since a vehicle
*                 became airborne.
*       GROUND    - elevation of ground at current vehicle location.
*       IENCR     - current encroachment number.
*       INCIANGLE - angle of incidence of vehicle when meeting the
*                 ground after being airborne.
*       INITANG   - current initial angle.
*       INITVEL   - current initial velocity.
*       KINENER   - rotational kinetic energy built up while a
*                 vehicle is airborne.
*       LASTPFAT  - cumulative fatality probability at last time
*                 increment.
*       LASTPINJ  - cumulative injury probability at last time
*                 increment.
*       LASTPND   - cumulative no damage probability at last time
*                 increment.
*       LASTPPDO  - cumulative property damage only probability at
*                 last time increment.
*       LASTXX    - x-coordinate of vehicle at last time increment.
*       LASTYY    - y-coordinate of vehicle at last time increment.
*       OTSTRIP   - the last terrain strip contacted.
*       PASTOBJ   - an array of flags indicating whether an object
*                 has been encountered along a trajectory.
*       PFAT      - current cumulative fatality probability.
*       PINJ      - current cumulative injury probability.
*       PND       - current cumulative no damage probability.
*       PPDO      - current cumulative property damage only probability.
*       PWR       - current power level.
*       TSTRIP    - terrain strip at current vehicle location.
*       VANGLE    - current vertical angle of vehicle.
*       VELOCITY  - current vehicle velocity.
*       VVERT     - initial vertical velocity when a vehicle.
*                 becomes airborne.
*       XX        - current x-coordinate of vehicle.
*       YY        - current y-coordinate of vehicle.

```
*   Simulation results.

*     DATA      - array of overall consequence probabilities for
*               each of 10 input sets.
*     NCALLS     - array of the number of encroachments simulated for
*               each of 10 input sets.
*     NIROL      - array of the number of dynamic rolls detected for
*               each of 10 input sets.
*     NJROL      - array of the number of static rolls detected for
*               each of 10 input sets.
*     NROLLS     - array of the total number of rolls detected for
*               each of 10 input sets.
*     SPRES      - array of overall consequence probabilities for
*               each of 10 input sets and each of 50 x 10
*               grid squares.


*   Variables used for the Economic Evaluation

*          ACCOST              - accident costs
*          AFCOST              - fill addition costs
*          BINSTALL            - barrier installation costs
*          BMAINT              - barrier maintenence costs
*          CUTCOST             - slope cutting costs
*          COSTROW             - right-of-way costs
*          CREMOVE             - object removal costs
*          FILLCOST            - additional fill costs
*          NREMOVE             - number of objects to be removed
*          WASTCOST            - slope cutting waste costs
*          BARRIER             - is barrier required
*          CFMAINT             - is maintenence required
*          OREMOVE             - is object removal required
*          ROW                 - is right-of-way required
*          SLOPE               - is slope reduction required
*          SEVERITY            - cost-effective severity criteria

*          BC                  - benefit-cost analysis
*          CE                  - cost-effectiveness analysis

*          CLIMATE             - climatic condition adjustment factor
*          DESSPD              - design speed adjustment factor
*          HORCURVE            - horizontal curve adjustment factor
*          LANEWID             - lane width adjustment factor
*          NUMLANE             - number of lanes adjustment factor
*          RDCLASS             - road class adjustment factor
*          SHLDWID             - shoulder width adjustment factor
*          SIGHT               - sight restrictions adjustment factor
*          TRAFFIC             - traffic composition adjustment factor
*          VERCURVE            - vertical curvature adjustment factor
*          ADT                 - average daily traffic volume
*          ENCRATE             - encroachment rate

*          TFAT                - total fatalities expected
*          TINJ                - total injuries expected
*          TND                 - total no damage expected
*          TPDO                          - total property damage only expected
*          INTEREST            - interest rate used
*          PERIOD              - time period used
```

```
*    The following vehicle variables are dimensioned for up to 8
*    vehicle models.

*      CG        - centre of gravity.
*      TRACK     - track width.
*      VMASS     - vehicle mass.
*      WBASE     - wheel base.


*    Default Variables

*              DEFACCST          - default value for  accident costs
*              DEFBINST          - default value for  barrier installation
*              DEFBMAIN          - default value for  barrier maintenence
*              DEFCUTCS          - default value for  slope cut costs
*              DEFFILCS          - default value for  slope fill costs
*              DEFWASCS          - default value for  cut waste costs
*              DEFADFCS          - default value for  fill addition costs
*              DEFCFMAI          - default value for  maintenence costs
*              DEFINTRT          - default value for  interest rate
*              DEFPERD           - default value for  time period
*              DEFSEVER          - default value for  cost-effective criteria severities
*              DSADJUST          - default value for  design speed adjustmnet factor
*              HCADJUST          - default value for  horizontal curve adjustment factor
*              LWADJUST          - default value for  lane width adjustment factor
*              NLADJUST          - default value for  number of lanes adjustment factor
*              RCADJUST          - default value for  road class adjustment factor
*              SADJUST           - default value for  sight restrictions adjustment factor
*              SWADJUST          - default value for  shoulder width adjustment factor
*              TADJUST           - default value for  traffic composition adjustment factor
*            VCADJUST            - default value for  vertical curvature adjustment factor
*              CADJUST           - default value for  climatic conditions adjuctment factor


*    Variables used for the Economic Results

*              CUT               - total slope cutting required
*              FILL              - total slope filling required
*              MITCOST           - total mitigation costs
*              TACCOST           - total accident cost

*    File and printer variables.

*     DONE       - yes/no flag indicating whether the analysis has
*                been completed since the current input sets
*                were last edited.  It is checked when trying to
*                display or print results.
*     INPUTF     - name of input data file.
*     OUTPUTF    - name of output data file.
*     OPTION     - yes/no flags for each of 8 print options.
*     OUTMODE    - mode of output.
*                  = D  for disk file.
*                  = P  for printer.
*     PAUSE      - yes/no flag indicating whether to pause printing
*                between pages for paper change.
*     SAVED      - yes/no flag indicating whether input data has
*                been saved.  It is checked when trying to exit
*                the program.
```

```
      INTEGER ADT, BARRIER(10), BC, CE, CLIMATE, DEFPERD, DEFSEVER(4),
     1 DESSPD, DONE, FLYING, HCURVE(10), HORCURVE, IENCR, LANEWID,
     2 MITER(10), MODEL(10), NCALLS(10), NIROL(10), NJROL(10), NO(10),
     3 NOBS(4), NPLA, NREMOVE(10,3), NROLLS(10), NT(10), NUMLANE, NVEL,
     4 OREMOVE(10), OTSTRIP, PASTOBJ(50), PERIOD, RDCLASS, ROW(10),
     5 SAVED, SEVERITY(4), SHLDWID, SIGHT, SLOPE(10), TRAFFIC, TSTRIP, VERCURVE

      REAL ACCEL, ACCOST(2,4), TACCOST(10), ADFCOST, AINCR(10),
     1 ANGLE, BINSTALL(10), BMAINT(10), BRAKE(10), CADJUST(6), CUT(10),
     2 CUTCOST, CFMAINT(10), CG(8), COSTROW(10), CREMOVE(10,3),
     3 DATA(10,4), DEF(15), DEFACCST(4), DEFADFCS, DEFBINST, DEFBMAIN,
     4 DEFCUTCS, DEFFILCS, DEFWASCS, DEFCFMAI, DEFINTRT, DISP,
     5 DSADJUST(5), ELEVATION, ENCRATE, FILL(10), FILLCOST, FLYTIME, G,
     6 GROUND, HCADJUST(6), INCIANGLE, INITANG, INITVEL, INTEREST,
     7 KINENER, LASTPFAT, LASTPINJ, LASTPND, LASTPPDO, LASTXX, LASTYY,
     8 LWADJUST(5), MAXZ, MINZ, MITCOST(10), NLADJUST(5), PFAT, PINJ,
     9 PND, PPDO, PI, PLA(50,6), PMIN(10), PP(4,35), PWR, RAD,
     1 RCADJUST(5), REST(10), RP1(50,2), RP2(50,2), SADJUST(6),
     2 SPRES(10,50,10,3), STEER(10), SWADJUST(5), TA(10,50),
     2 TADJUST(6), THM(10,50), THWID(10,50), THX1(10,50), THX2(10,50),
     3 THX3(10,50), THX4(10,50), THY1(10,50), THY2(10,50), THY3(10,50),
     4 THY4(10,50), TFAT, TINJ, TND, TPDO, TI(10), TM(10,50), TMAX(10),
     5 TR(10,50), TRACK(8), TY(10,50), VANGLE, VCADJUST(6), VEL(50),
     6 VELOCITY, VINCR(10), VMASS(8), VMEAN(10), VMIN(10), VSD(10),
     7 VVERT, WASTCOST, WBASE(8), XINCR(10), XX, YY

      CHARACTER*1 IDEF(10,15), OPTION(10), OUTMODE, PAUSE, THTYP(10,50)
      CHARACTER*36 INPUTF,OUTPUTF
      CHARACTER*50 TITLE(10)

      COMMON /ANGLE/  NOBS, PP
      COMMON /CONST/  G, PI, RAD
      COMMON /DEFLT/  CADJUST, DEF, DEFACCST, DEFBINST, DEFBMAIN,
     1          DEFCUTCS, DEFFILCS, DEFWASCS, DEFADFCS, DEFCFMAI,
     2          DEFINTRT, DEFPERD, DSADJUST, HCADJUST, IDEF,
     3          LWADJUST, NLADJUST, RCADJUST, DEFSEVER,
     3          SADJUST, SWADJUST, TADJUST, VCADJUST
      COMMON /ECON/   ACCOST, ADFCOST, ADT, BARRIER, BC, BINSTALL,
     1          BMAINT, CE, CUTCOST, CFMAINT, CLIMATE, COSTROW,
     2          CREMOVE, DESSPD, ENCRATE, FILLCOST, HORCURVE,
     3          INTEREST, LANEWID, NREMOVE, NUMLANE, OREMOVE,
     4          PERIOD, RDCLASS, ROW, SEVERITY, SHLDWID, SIGHT,
     5          SLOPE, TRAFFIC, TFAT, TINJ, TND, TPDO, VERCURVE, WASTCOST
      COMMON /ECRSLT/ TACCOST, CUT, FILL, MITCOST
      COMMON /IO/     DONE, INPUTF, OUTPUTF, OPTION, OUTMODE, PAUSE, SAVED
      COMMON /OBJCT/  NO, THM, THTYP, THWID, THX1, THX2, THX3, THX4,
     1          THY1, THY2, THY3, THY4
      COMMON /OPER/   AINCR, BRAKE, HCURVE, MITER,
     1          MODEL, PMIN, REST, STEER, TI, TITLE, TMAX,
     2          VINCR, VMEAN, VMIN, VSD, XINCR
      COMMON /PRCN/   NPLA, PLA
      COMMON /RESLT/  DATA, NCALLS, NIROL, NJROL, NROLLS
      COMMON /ROLC/   NVEL, RP1, RP2, VEL
      COMMON /RUNV/   ACCEL, ANGLE, DISP, ELEVATION, FLYING, FLYTIME,
     1          GROUND, IENCR, INCIANGLE, INITANG, INITVEL,
     2          KINENER, LASTPFAT, LASTPINJ, LASTPND, LASTPPDO,
     3          LASTXX, LASTYY, OTSTRIP, PASTOBJ, PFAT, PINJ, PND,
     4          PPDO, PWR, TSTRIP, VANGLE, VELOCITY, VVERT, XX, YY
      COMMON /SR/     SPRES
      COMMON /TERR/   NT, TA, TM, TR, TY
      COMMON /TRAJ/   MINZ, MAXZ
```

```
      COMMON /VHCST/  CG, TRACK, VMASS, WBASE

      PROGRAM RHSM
*
*     RHSM main menu
*
      INTEGER CHOICE
      INCLUDE 'RHSM.INS'
*
*     Set all inputs to default values
*
      CALL DEFAULTS
*
*     Set constants
*
      G = 9.8091
      PI = 3.14159
      RAD = 0.0174533
*
*     Load main menu
*
      CALL INITSCREEN
      WRITE (*,*) CHAR(255),CHAR(255),'SET LIBRARY TO RHSM.LIB/'
10    WRITE (*,*) CHAR(255), CHAR(255), 'MENU/'
      READ (*,*) CHOICE
*
*     Load input data from a file
*
      IF (CHOICE .EQ. 1) THEN
           CALL INPUT
*
*     Edit simulation data
*
      ELSEIF (CHOICE .EQ. 2) THEN
           CALL EDIT
           SAVED=0
*
*     Edit economic evaluation parameters
*
      ELSEIF (CHOICE.EQ.3) THEN
           CALL ECONOMIC
*
*     Plot trajectories
*
      ELSEIF (CHOICE.EQ.4) THEN
           CALL TRAJECT
*
*     Run analysis
*
      ELSEIF (CHOICE .EQ. 5) THEN
           CALL RUN
*
*     Display or graph results
*
      ELSEIF (CHOICE .EQ. 6.AND.DONE.EQ.1) THEN
           CALL DISPLAY
*
*     Print input data and results
*
      ELSEIF (CHOICE .EQ. 7.AND.DONE.EQ.1) THEN
           CALL PRINT
```

```
*
*     Save input data
*
      ELSEIF (CHOICE .EQ. 8) THEN
            CALL SAVE
            SAVED=1
*
*     Edit calibration and defaults data
*
      ELSEIF (CHOICE.EQ.9) THEN
            CALL CALIBRAT
*
*     Quit
*
      ELSEIF (CHOICE.EQ.10) THEN
            IF (SAVED.EQ.0) THEN
              WRITE (*,*) CHAR(255),CHAR(255),'SAVE/'
              CALL GETKEYBOARD(CH,II)
              IF (II.EQ.21) THEN
                CALL CLRSCR
                STOP
              ENDIF
            ELSE
              CALL CLRSCR
              STOP
            ENDIF
      ENDIF
      GOTO 10
      END
```

```
      SUBROUTINE INPUT
*
*     This subroutine loads input data from a file on disk
*
      INTEGER CODE, CF, POS
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
*
*     Enter name of file to input
*
      FIELD (1)=INPUTF
1     WRITE (*,*) CHAR(255), CHAR(255), 'IO/'
      FILNAM = 'IO'
      CODE = 0
      CF = 0
      POS = 1
      DO 5 I=1,36
           IF (ICHAR(INPUTF(I:I)).NE.32.AND.ICHAR(INPUTF(I:I)).NE.0) THEN
             POS=POS+1
           ELSE
             GOTO 6
           ENDIF
5     CONTINUE
6     CALL SCREENIO (FILNAM, CODE, CF, POS)
      IF (CODE.EQ.1) RETURN
      INPUTF = FIELD(1)
      DONE=0
      SAVED=1
*
*     Read data from file
*
      OPEN (10, FILE=INPUTF, STATUS='OLD',ERR=1000)
*
*     Read operating data for each input set
*
      DO 20 I=1,10
           READ (10,30,ERR=1000) TITLE(I)
30      FORMAT (A50)
           DO 50 J=1,16
             IDEF(I,J)=' '
50      CONTINUE
           READ (10,55,ERR=1000) TI(I),TMAX(I),VMIN(I),MITER(I),
     1  XINCR(I)
55      FORMAT (3F10.3,I4,F10.3)
           READ (10,57,ERR=1000) VMEAN(I), VSD(I), VINCR(I), AINCR(I),
     1  PMIN(I),BRAKE(I), REST(I)
57      FORMAT (7F10.3)
           READ (10,57,ERR=1000) STEER(I)
           READ (10,59,ERR=1000) HCURVE(I), MODEL(I)
59      FORMAT (2I3)
*
*     Check default values
*
           IF (TI(I).EQ.DEF(1)) IDEF(I,1)='*'
           IF (TMAX(I).EQ.DEF(2)) IDEF(I,2)='*'
           IF (VMIN(I).EQ.DEF(3)) IDEF(I,3)='*'
           IF (MITER(I).EQ.DEF(4)) IDEF(I,4)='*'
           IF (XINCR(I).EQ.DEF(5)) IDEF(I,5)='*'
           IF (VMEAN(I).EQ.DEF(6)) IDEF(I,6)='*'
```

```
          IF (VSD(I).EQ.DEF(7)) IDEF(I,7)='*'
          IF (VINCR(I).EQ.DEF(8)) IDEF(I,8)='*'
          IF (AINCR(I).EQ.DEF(9)) IDEF(I,9)='*'
          IF (PMIN(I).EQ.DEF(10)) IDEF(I,10)='*'
          IF (BRAKE(I).EQ.DEF(11)) IDEF(I,11)='*'
          IF (REST(I).EQ.DEF(12)) IDEF(I,12)='*'
          IF (STEER(I).EQ.DEF(13)) IDEF(I,13)='*'
          IF (HCURVE(I).EQ.INT(DEF(14))) IDEF(I,14)='*'
          IF (MODEL(I).EQ.INT(DEF(15))) IDEF(I,15)='*'
*
*     Read terrain data
*
          READ (10,61,ERR=1000) NT(I)
61      FORMAT (I3)
          DO 60 J=1,NT(I)
            READ (10,65,ERR=1000) TY(I,J), TA(I,J), TM(I,J), TR(I,J)
65        FORMAT (F6.3,F6.2,2F6.4)
60      CONTINUE
*
*     Read object data
*
          READ (10,61,ERR=1000) NO(I)
          DO 75 J=1,NO(I)
            READ (10,77,ERR=1000) THX1(I,J),THX2(I,J),THY1(I,J),
     1      THY2(I,J),THM(I,J),THWID(I,J),THTYP(I,J)
77        FORMAT (6F5.1,A1)
            THX3(I,J)=THX1(I,J)-THWID(I,J)*COS(3.1416/2-ATAN((THY2(I,J)-
     1      THY1(I,J))/(THX2(I,J)-THX1(I,J))))
            THY3(I,J)=THY1(I,J)+THWID(I,J)*SIN(3.1416/2-ATAN((THY2(I,J)-
     1      THY1(I,J))/(THX2(I,J)-THX1(I,J))))
            THX4(I,J)=THX2(I,J)-THWID(I,J)*COS(3.1416/2-ATAN((THY1(I,J)-
     1      THY2(I,J))/(THX1(I,J)-THX2(I,J))))
            THY4(I,J)=THY2(I,J)+THWID(I,J)*SIN(3.1416/2-ATAN((THY1(I,J)-
     1      THY2(I,J))/(THX1(I,J)-THX2(I,J))))
75      CONTINUE

20    CONTINUE
*
*     Roll consequence data
*
      READ (10,61,ERR=1000) NVEL
      DO 80 I=1,NVEL
          READ (10,90,ERR=1000) RP1(I,1),RP1(I,2)
          READ (10,90,ERR=1000) RP2(I,1),RP2(I,2)
          READ (10,90,ERR=1000) VEL(I)
90      FORMAT (2F10.3)
80    CONTINUE
*
*     Angle probability data
*
      DO 100 I=1,4
          NOBS(I)=0
          DO 100 J=1,35
            READ (10,110,ERR=1000) PP(I,J)
110       FORMAT (F10.3)
            NOBS(I)=NOBS(I)+PP(I,J)
100   CONTINUE
*
*     Vehicle characteristics
*
```

```
*
*     Vehicle characteristics
*
      DO 120 I=1,8
            READ (10,130,ERR=1000) CG(I)
            READ (10,130,ERR=1000) TRACK(I)
            READ (10,130,ERR=1000) VMASS(I)
            READ (10,130,ERR=1000) WBASE(I)
130      FORMAT (F10.3)
120   CONTINUE
*
*     Probability of consequence data
*
      READ (10,61,ERR=1000) NPLA
      DO 140 I=1,NPLA
            READ (10,150,ERR=1000) (PLA(I,J),J=1,6)
150      FORMAT (F7.1,5F7.5)
140   CONTINUE
*
*     Economic data
*
      DO 160 I=1,10
            READ (10,165) BARRIER(I),ROW(I),OREMOVE(I),NREMOVE(I,1),
     1   NREMOVE(I,2),NREMOVE(I,3)
165      FORMAT (6I4)
            READ (10,170) BINSTALL(I),BMAINT(I),CFMAINT(I),COSTROW(I),
     1   CREMOVE(I,1),CREMOVE(I,2),CREMOVE(I,3)
170      FORMAT (7F9.2)
160   CONTINUE
      READ (10,170) CUTCOST,FILLCOST,WASTCOST,ADFCOST
      READ (10,190) (ACCOST(1,I),I=1,4)
      READ (10,190) (ACCOST(2,I),I=1,4)
190   FORMAT (4F9.2)

      READ (10,200) CLIMATE, DESSPD, HORCURVE, LANEWID, NUMLANE,
     1 RDCLASS, SHLDWID, SIGHT, SLOPE, TRAFFIC, VERCURVE
200   FORMAT (11I1)
      READ (10,210) ADT,ENCRATE,INTEREST,PERIOD
210   FORMAT (I8,F8.4,F4.2,I4)

      READ (10,220) BC,CE
      IF (BC.EQ.1) THEN
            OPTION(9)='Y'
      ELSE
            OPTION(9)='N'
      ENDIF
      IF (CE.EQ.1) THEN
            OPTION(10)='Y'
      ELSE
            OPTION(10)='N'
      ENDIF
220   FORMAT (2I1)
      READ (10,230) SEVERITY(1),SEVERITY(2),SEVERITY(3),SEVERITY(4)
230   FORMAT (4I11)

      CLOSE (10)
      RETURN
*
*     Error reading file
*
```

```
*
*    Error reading file
*
*    Check if directory is to be displayed
*
1000 WRITE (*,*) CHAR(7),CHAR(7)
     CALL CURSOROFF
     WRITE (*,*) CHAR(255),CHAR(255),'FILERR/'
     CALL GETKEYBOARD(CH,II)
     CALL CURSORON
     GOTO 1
     END
```

```
      SUBROUTINE EDIT
*
*     This subroutine is used to edit simulation input data
*
      INTEGER CODE, CF, HC, ISET, NUMLIN, NUMPTS, POS
      REAL GX(100),GY(16,100),HOLD
      CHARACTER*1 CHOLD
      CHARACTER*12 FILNAM
      CHARACTER*18 XTITLE, YTITLE
      CHARACTER*76 FIELD(120)
      CHARACTER*80 TTLE
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
      COMMON / GRPH2D / NUMLIN,NUMPTS,GX,GY,XTITLE,YTITLE,TTLE

      ISET=1
*
*     Input Set Titles
*
1     WRITE (*,*) CHAR(255),CHAR(255),'TITLES/'
      DO 10 I=1,10
            FIELD(I)=TITLE(I)
10    CONTINUE
      CODE=0
      CF=ISET
      POS=0
      FILNAM='TITLES'
15    CALL SCREENIO (FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) RETURN
      DONE=0
      SAVED=0
      DO 20 I=1,10
            TITLE(I)=FIELD(I)
20    CONTINUE

      IF (CODE.EQ.18.AND.ICHAR(TITLE(CF)(1:1)).NE.0.AND.
     1 ICHAR(TITLE(CF)(1:1)).NE.32) THEN
            ISET=CF
25       WRITE (*,*) CHAR(255),CHAR(255),'EDIT/'
            READ (*,*) CHOICE
*
*     Operational Data
*
            IF (CHOICE.EQ.1) THEN
              WRITE (*,*) CHAR(255),CHAR(255),'OPERATE/'
              IF (HCURVE(ISET).EQ.1) FIELD(1)=' '
              IF (HCURVE(ISET).EQ.2) FIELD(1)='G'
              IF (HCURVE(ISET).EQ.3) FIELD(1)='M'
              IF (HCURVE(ISET).EQ.4) FIELD(1)='S'
              WRITE (FIELD(2),30) TI(ISET)
30          FORMAT (F10.3)
              WRITE (FIELD(3),30) TMAX(ISET)
              WRITE (FIELD(4),35) MITER(ISET)
35          FORMAT (I10)
              WRITE (FIELD(5),30) XINCR(ISET)
              WRITE (FIELD(6),30) VMEAN(ISET)
              WRITE (FIELD(7),30) VSD(ISET)
              WRITE (FIELD(8),30) VMIN(ISET)
              WRITE (FIELD(9),30) VINCR(ISET)
              WRITE (FIELD(10),30) AINCR(ISET)
              WRITE (FIELD(11),30) PMIN(ISET)
              WRITE (FIELD(12),30) STEER(ISET)
```

```
      WRITE (FIELD(13),30) BRAKE(ISET)
      WRITE (FIELD(14),30) REST(ISET)
      WRITE (FIELD(15),40) MODEL(ISET)
40    FORMAT (I1)
      FILNAM='OPERATE'
      CODE=0
      CF=0
      POS=0
50    CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) GOTO 25
      IF (CODE.NE.45) GOTO 50
      IF (ICHAR(FIELD(1)(1:1)).EQ.0.OR.ICHAR(FIELD(1)(1:1)).EQ.32) THEN
        HCURVE(ISET)=1
      ELSEIF (FIELD(1).EQ.'G') THEN
        HCURVE(ISET)=2
      ELSEIF (FIELD(1).EQ.'M') THEN
        HCURVE(ISET)=3
      ELSEIF (FIELD(1).EQ.'S') THEN
        HCURVE(ISET)=4
      ENDIF
      READ (FIELD(2),30) TI(ISET)
      READ (FIELD(3),30) TMAX(ISET)
      READ (FIELD(4),35) MITER(ISET)
      READ (FIELD(5),30) XINCR(ISET)
      READ (FIELD(6),30) VMEAN(ISET)
      READ (FIELD(7),30) VSD(ISET)
      READ (FIELD(8),30) VMIN(ISET)
      READ (FIELD(9),30) VINCR(ISET)
      READ (FIELD(10),30) AINCR(ISET)
      READ (FIELD(11),30) PMIN(ISET)
      READ (FIELD(12),30) STEER(ISET)
      READ (FIELD(13),30) BRAKE(ISET)
      READ (FIELD(14),30) REST(ISET)
      READ (FIELD(15),40) MODEL(ISET)
*
*     Check default values
*
      DO 55 J=1,16
        IDEF(ISET,J)=' '
55    CONTINUE
      IF (TI(ISET).EQ.DEF(1)) IDEF(ISET,1)='*'
      IF (TMAX(ISET).EQ.DEF(2)) IDEF(ISET,2)='*'
      IF (VMIN(ISET).EQ.DEF(3)) IDEF(ISET,3)='*'
      IF (MITER(ISET).EQ.DEF(4)) IDEF(ISET,4)='*'
      IF (XINCR(ISET).EQ.DEF(5)) IDEF(ISET,5)='*'
      IF (VMEAN(ISET).EQ.DEF(6)) IDEF(ISET,6)='*'
      IF (VSD(ISET).EQ.DEF(7)) IDEF(ISET,7)='*'
      IF (VINCR(ISET).EQ.DEF(8)) IDEF(ISET,8)='*'
      IF (AINCR(ISET).EQ.DEF(9)) IDEF(ISET,9)='*'
      IF (PMIN(ISET).EQ.DEF(10)) IDEF(ISET,10)='*'
      IF (BRAKE(ISET).EQ.DEF(11)) IDEF(ISET,11)='*'
      IF (REST(ISET).EQ.DEF(12)) IDEF(ISET,12)='*'
      IF (STEER(ISET).EQ.DEF(13)) IDEF(ISET,13)='*'
      IF (HCURVE(ISET).EQ.INT(DEF(14))) IDEF(ISET,14)='*'
      IF (MODEL(ISET).EQ.INT(DEF(15))) IDEF(ISET,15)='*'
*
*     Edit terrain data
*
```

```
*
*    Edit terrain data
*
          ELSEIF (CHOICE.EQ.2) THEN
65        WRITE (*,*) CHAR(255),CHAR(255),'TERRAIN/'
            DO 60 I=1,20
              WRITE (FIELD((I-1)*4+1),70) TY(ISET,I)
70          FORMAT (F6.3)
              WRITE (FIELD((I-1)*4+2),75) TA(ISET,I)
75          FORMAT (F6.2)
              WRITE (FIELD((I-1)*4+3),80) TM(ISET,I)
80          FORMAT (F6.4)
              WRITE (FIELD((I-1)*4+4),80) TR(ISET,I)
60        CONTINUE
            FILNAM='TERRAIN'
            CODE=0
            CF=0
            POS=0
90        CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 25
            IF (CODE.NE.45.AND.CODE.NE.34) GOTO 90
            NT(ISET)=0
            DO 95 I=1,20
              READ (FIELD((I-1)*4+1),70) TY(ISET,I)
              READ (FIELD((I-1)*4+2),75) TA(ISET,I)
              READ (FIELD((I-1)*4+3),80) TM(ISET,I)
              READ (FIELD((I-1)*4+4),80) TR(ISET,I)
              IF (I.EQ.1.OR.TY(ISET,I).NE.0) NT(ISET)=NT(ISET)+1
95        CONTINUE
*
*    Sort Terrain Data
*
            DO 96 I=1,19
              DO 96 J=I+1,20
                IF ((TY(ISET,I).GT.TY(ISET,J).AND.TY(ISET,J).NE.0)
     1          .OR.(I.NE.1.AND.TY(ISET,I).EQ.0)) THEN
                  HOLD=TY(ISET,I)
                  TY(ISET,I)=TY(ISET,J)
                  TY(ISET,J)=HOLD
                  HOLD=TA(ISET,I)
                  TA(ISET,I)=TA(ISET,J)
                  TA(ISET,J)=HOLD
                  HOLD=TM(ISET,I)
                  TM(ISET,I)=TM(ISET,J)
                  TM(ISET,J)=HOLD
                  HOLD=TR(ISET,I)
                  TR(ISET,I)=TR(ISET,J)
                  TR(ISET,J)=HOLD
                ENDIF
96        CONTINUE
*
*    Plot terrain profile
*
            IF (CODE.EQ.34) THEN
              NUMLIN=1
              NUMPTS=NT(ISET)+2
              GX(1)=0
              GY(1,1)=0
              DO 97 I=1,NT(ISET)
                GX(I+1)=TY(ISET,I)
                IF (I.EQ.1) THEN
                  GY(1,I+1)=0
```

```
              ELSE
                GY(1,I+1)=GY(1,I)+(GX(I+1)-GX(I))*TAN(TA(ISET,I-1)*RAD)
              ENDIF
97         CONTINUE
             GX(NT(ISET)+2)=20
             IF (NT(ISET).GT.0) THEN
               GY(1,NT(ISET)+2)=GY(1,NT(ISET)+1)+(GX(NT(ISET)+2)-
     1         GX(NT(ISET)+1))*TAN(TA(ISET,NT(ISET))*RAD)
             ELSE
               GY(1,NT(ISET)+2)=0
             ENDIF
             XTITLE='Distance from Road'
             YTITLE='    Elevation    '
             TTLE='Roadside Cross Section Profile'
             CALL GRAPH2D
             GOTO 65
           ENDIF
*
*    Clear Zone Object data
*
          ELSEIF (CHOICE.EQ.3) THEN
            IPAGE=1
105       WRITE (*,*) CHAR(255),CHAR(255),'OBJECT/'
            DO 100 I=1,10
              WRITE (FIELD(I),106) (IPAGE-1)*10+I
106         FORMAT (I2)
              WRITE (FIELD(10+I),110) THX1(ISET,(IPAGE-1)*10+I)
110         FORMAT (F5.1)
              WRITE (FIELD(20+I),110) THY1(ISET,(IPAGE-1)*10+I)
              WRITE (FIELD(30+I),110) THX2(ISET,(IPAGE-1)*10+I)
              WRITE (FIELD(40+I),110) THY2(ISET,(IPAGE-1)*10+I)
              WRITE (FIELD(50+I),110) THWID(ISET,(IPAGE-1)*10+I)
              FIELD(60+I)=THTYP(ISET,(IPAGE-1)*10+I)
              WRITE (FIELD(70+I),110) THM(ISET,(IPAGE-1)*10+I)
100       CONTINUE
            FILNAM='OBJECT'
            CODE=0
            CF=0
            POS=0
120       CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 25
            IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81) GOTO 120
            DO 130 I=1,10
              READ (FIELD(10+I),110) THX1(ISET,(IPAGE-1)*10+I)
              READ (FIELD(20+I),110) THY1(ISET,(IPAGE-1)*10+I)
              READ (FIELD(30+I),110) THX2(ISET,(IPAGE-1)*10+I)
              READ (FIELD(40+I),110) THY2(ISET,(IPAGE-1)*10+I)
              IF (THX1(ISET,(IPAGE-1)*10+I).GT.
     1        THX2(ISET,(IPAGE-1)*10+I)) THEN
                HOLD=THX1(ISET,(IPAGE-1)*10+I)
                THX1(ISET,(IPAGE-1)*10+I)=THX2(ISET,(IPAGE-1)*10+I)
                THX2(ISET,(IPAGE-1)*10+I)=HOLD
                HOLD=THY1(ISET,(IPAGE-1)*10+I)
                THY1(ISET,(IPAGE-1)*10+I)=THY2(ISET,(IPAGE-1)*10+I)
                THY2(ISET,(IPAGE-1)*10+I)=HOLD
              ENDIF
              READ (FIELD(50+I),110) THWID(ISET,(IPAGE-1)*10+I)
              THTYP(ISET,(IPAGE-1)*10+I)=FIELD(60+I)
              READ (FIELD(70+I),110) THM(ISET,(IPAGE-1)*10+I)
              IF (THWID(ISET,(IPAGE-1)*10+I).NE.0) THEN
```

```
      THX3(ISET,(IPAGE-1)*10+I)=THX1(ISET,(IPAGE-1)*10+I)-
     1 THWID(ISET,(IPAGE-1)*10+I)*COS(3.1416/2-
     2 ATAN((THY2(ISET,(IPAGE-1)*10+I)-THY1(ISET,(IPAGE-1)*
     3 10+I))/(THX2(ISET,(IPAGE-1)*10+I)-THX1(ISET,(IPAGE-1)*
     4 10+I))))
      THY3(ISET,(IPAGE-1)*10+I)=THY1(ISET,(IPAGE-1)*10+I)+
     1 THWID(ISET,(IPAGE-1)*10+I)*SIN(3.1416/2-
     2 ATAN((THY2(ISET,(IPAGE-1)*10+I)-THY1(ISET,(IPAGE-1)*
     3 10+I))/(THX2(ISET,(IPAGE-1)*10+I)-THX1(ISET,(IPAGE-1)*
     4 10+I))))
      THX4(ISET,(IPAGE-1)*10+I)=THX2(ISET,(IPAGE-1)*10+I)-
     1 THWID(ISET,(IPAGE-1)*10+I)*COS(3.1416/2-
     2 ATAN((THY1(ISET,(IPAGE-1)*10+I)-THY2(ISET,(IPAGE-1)*
     3 10+I))/(THX1(ISET,(IPAGE-1)*10+I)-THX2(ISET,(IPAGE-1)*
     4 10+I))))
      THY4(ISET,(IPAGE-1)*10+I)=THY2(ISET,(IPAGE-1)*10+I)+
     1 THWID(ISET,(IPAGE-1)*10+I)*SIN(3.1416/2-
     2 ATAN((THY1(ISET,(IPAGE-1)*10+I)-THY2(ISET,(IPAGE-1)*
     3 10+I))/(THX1(ISET,(IPAGE-1)*10+I)-THX2(ISET,(IPAGE-1)*
     4 10+I))))
      ENDIF
130   CONTINUE
      IF (CODE.EQ.81.OR.CODE.EQ.73) THEN
        IF (IPAGE.EQ.1) THEN
          IPAGE=2
        ELSE
          IPAGE=1
        ENDIF
        GOTO 105
      ENDIF
      NO(ISET)=0
      DO 128 I=1,20
        IF (THWID(ISET,I).GT.0) NO(ISET)=NO(ISET)+1
128   CONTINUE
      DO 135 I=1,19
        DO 135 J=I+1,20
          IF (THWID(ISET,I).LT.THWID(ISET,J)) THEN
            HOLD=THX1(ISET,I)
            THX1(ISET,I)=THX1(ISET,J)
            THX1(ISET,J)=HOLD
            HOLD=THY1(ISET,I)
            THY1(ISET,I)=THY1(ISET,J)
            THY1(ISET,J)=HOLD
            HOLD=THX2(ISET,I)
            THX2(ISET,I)=THX2(ISET,J)
            THX2(ISET,J)=HOLD
            HOLD=THY2(ISET,I)
            THY2(ISET,I)=THY2(ISET,J)
            THY2(ISET,J)=HOLD
            HOLD=THX3(ISET,I)
            THX3(ISET,I)=THX3(ISET,J)
            THX3(ISET,J)=HOLD
            HOLD=THY3(ISET,I)
            THY3(ISET,I)=THY3(ISET,J)
            THY3(ISET,J)=HOLD
            HOLD=THX4(ISET,I)
            THX4(ISET,I)=THX4(ISET,J)
            THX4(ISET,J)=HOLD
            HOLD=THY4(ISET,I)
            THY4(ISET,I)=THY4(ISET,J)
            THY4(ISET,J)=HOLD
            HOLD=THWID(ISET,I)
```

```
                THWID(ISET,I)=THWID(ISET,J)
                THWID(ISET,J)=HOLD
                CHOLD=THTYP(ISET,I)
                THTYP(ISET,I)=THTYP(ISET,J)
                THTYP(ISET,J)=CHOLD
                HOLD=THM(ISET,I)
                THM(ISET,I)=THM(ISET,J)
                THM(ISET,J)=HOLD
              ENDIF
135       CONTINUE
*
*    Map of Roadside
*
          ELSEIF (CHOICE.EQ.4) THEN
            CALL ROADSIDE(ISET)
          ELSE
            GOTO 1
          ENDIF
          GOTO 25
      ELSEIF (CODE.EQ.45) THEN
          RETURN
      ENDIF
      GOTO 1
      END
```

```
      SUBROUTINE GRAPH2D
*
*     This subroutine is used to plot a two dimensional graph
*
      INTEGER IX1,IX2,IY1,IY2,NUMLIN,NUMPTS
      REAL MAXX,MAXY,MINX,MINY,X(100),Y(16,100)
      CHARACTER*1 CH
      CHARACTER*18 XTITLE, YTITLE
      CHARACTER*80 TITLE
      COMMON / GRPH2D / NUMLIN,NUMPTS,X,Y,XTITLE,YTITLE,TITLE
*
*     Determine plot scales
*
      MAXX=X(1)
      MINX=X(1)
      MAXY=Y(1,1)
      MINY=Y(1,1)
      IF (MAXY.EQ.MINY) MAXY=MINY+1
      DO 10 I=1,NUMPTS
            IF (X(I).GT.MAXX) MAXX=X(I)
            IF (X(I).LT.MINX) MINX=X(I)
            DO 10 J=1,NUMLIN
              IF (Y(J,I).GT.MAXY) MAXY=Y(J,I)
              IF (Y(J,I).LT.MINY) MINY=Y(J,I)
10    CONTINUE
*
*     Draw axes
*
      CALL CLRSCR
      CALL SETSCREENMODE(16)
      CALL DRAW (40,40,40,310,7)
      CALL DRAW (40,310,640,310,7)
      DO 15 I=1,10
            CALL DRAW (40,40+(I-1)*270/10,43,40+(I-1)*270/10,7)
            CALL DRAW (40+I*600/10,310,40+I*600/10,307,7)
15    CONTINUE
      CALL GOTOXY (1,2)
      WRITE (*,20) MAXY
20    FORMAT (F10.3)
      CALL GOTOXY (1,4)
      DO 30 I=1,18
            WRITE (*,35) YTITLE(I:I)
35      FORMAT (1X,A1)
30    CONTINUE
      CALL GOTOXY (1,23)
      WRITE (*,20) MINY
      CALL GOTOXY (1,24)
      WRITE (*,40) MINX,XTITLE,MAXX
40    FORMAT (4X,F10.3,18X,A18,18X,F10.3)
*
*     Plot curve
*
      DO 50 I=1,NUMLIN
            IY2=310-(Y(I,1)-MINY)*270/(MAXY-MINY)
            IX2=40
            DO 50 J=2,NUMPTS
              IY1=310-(Y(I,J)-MINY)*270/(MAXY-MINY)
              IX1=40+(X(J)-MINX)*600/(MAXX-MINX)
              CALL DRAW (IX1,IY1,IX2,IY2,16-I)
              IY2=IY1
              IX2=IX1
50    CONTINUE
```

```
*
*    Write headings
*
     CALL GOTOXY(1,1)
     WRITE (*,60) TITLE
60    FORMAT (1X,A80)

     CALL GETKEYBOARD(CH,II)
     CALL SETSCREENMODE(3)
     RETURN
     END
```

```
      SUBROUTINE ROADSIDE(ISET)
*
*     This subroutine plots a map of the roadside
*
      INTEGER COLOUR,ISET,LASTY
      REAL DENOM,MEANANG,NUMER,RADIUS(4)
      INCLUDE 'RHSM.INS'
*
*     Titles
*
      CALL CLRSCR
      CALL SETSCREENMODE(16)
      CALL GOTOXY(1,1)
      WRITE (*,60)
60    FORMAT (1X,'Roadside Map')
*
*     Straight road section
*
      IF (HCURVE(ISET).EQ.1) THEN
          CALL GOTOXY (1,4)
          WRITE (*,65)
65        FORMAT (79X,'20')
          CALL GOTOXY (2,11)
          WRITE (*,70)
70        FORMAT (1X,'100',76X,'0')
*
*     Draw basic map
*
          CALL DRAW (30,50,30,166,7)
          CALL DRAW (30,50,610,50,7)
          CALL DRAW (30,166,610,166,7)
          CALL DRAW (610,50,610,166,7)
*
*     Draw road
*
          DO 10 I=30,610,30
            CALL DRAW (I,202,I+15,202,14)
10        CONTINUE
          CALL DRAW (30,238,610,238,7)
*
*     Draw terrain strips
*
          LASTY=166
          COLOUR=1
          DO 20 I=1,NT(ISET)
            NEXTY=166-TY(ISET,I)*(166-50)/20
            CALL DRAW (30,NEXTY,610,NEXTY,7)
            IF (ABS(NEXTY-LASTY).GE.3) CALL FILLSHAPE (320,(NEXTY+
     1      LASTY)/2,COLOUR,7)
            LASTY=NEXTY
            COLOUR=COLOUR+1
            IF (COLOUR.EQ.15) COLOUR=1
20        CONTINUE
          IF (ABS(50-LASTY).GE.3) CALL FILLSHAPE (320,(50+LASTY)/2,
     1    COLOUR,7)
*
*     Objects
*
```

```
*
*     Objects
*
          DO 30 I=1,NO(ISET)
            IX1=610-THX1(ISET,I)*(610-30)/100
            IY1=166-THY1(ISET,I)*(166-50)/20
            IX2=610-THX2(ISET,I)*(610-30)/100
            IY2=166-THY2(ISET,I)*(166-50)/20
            IX3=610-THX3(ISET,I)*(610-30)/100
            IY3=166-THY3(ISET,I)*(166-50)/20
            IX4=610-THX4(ISET,I)*(610-30)/100
            IY4=166-THY4(ISET,I)*(166-50)/20
            CALL DRAW (IX1,IY1,IX2,IY2,15)
            CALL DRAW (IX1,IY1,IX3,IY3,15)
            CALL DRAW (IX2,IY2,IX4,IY4,15)
            CALL DRAW (IX3,IY3,IX4,IY4,15)
30      CONTINUE
*
*     Draw the DeSotos
*
          NUMER=0
          DENOM=0
          DO 40 I=1,35
            NUMER=NUMER+I*2*PP(HCURVE(ISET),I)
            DENOM=DENOM+PP(HCURVE(ISET),I)
40      CONTINUE
          IF (DENOM.NE.0) THEN
            MEANANG=NUMER/DENOM
          ELSE
            MEANANG=35
          ENDIF
          MEANANG=MEANANG*RAD
          DO 50 I=1,MITER(ISET)
            OFFSET=XINCR(ISET)*(I-1)
            IX1=610-OFFSET*(610-30)/100+((WBASE(MODEL(ISET))*1.2*
     1      COS(MEANANG)+TRACK(MODEL(ISET))*COS(3.1416/2-MEANANG))/2-
     2      TRACK(MODEL(ISET))*COS(3.1416/2-MEANANG))*5.8
            IY1=166
            IX2=IX1-TRACK(MODEL(ISET))*5.8*COS(3.1416/2-MEANANG)
            IY2=IY1+TRACK(MODEL(ISET))*5.8*SIN(3.1416/2-MEANANG)
            IX3=IX1+WBASE(MODEL(ISET))*1.2*5.8*COS(MEANANG)
            IY3=IY1+WBASE(MODEL(ISET))*1.2*5.8*SIN(MEANANG)
            IX4=IX3-TRACK(MODEL(ISET))*5.8*COS(3.1416/2-MEANANG)
            IY4=IY3+TRACK(MODEL(ISET))*5.8*SIN(3.1416/2-MEANANG)
            CALL DRAW (IX1,IY1,IX2,IY2,15)
            CALL DRAW (IX1,IY1,IX3,IY3,15)
            CALL DRAW (IX2,IY2,IX4,IY4,15)
            CALL DRAW (IX3,IY3,IX4,IY4,15)
            IF (ABS(IY1-IY4).GE.3.AND.ABS(IX2-IX3).GE.3) CALL
     1      FILLSHAPE ((IX2+IX3)/2,(IY1+IY4)/2,MODEL(ISET),15)
            CALL DRAW (IX1-(IX1-IX3)/3,IY1+(IY3-IY1)/3,IX2-(IX2-IX4)/3,
     1      IY2+(IY4-IY2)/3,15)
            CALL DRAW (IX1-2*(IX1-IX3)/3,IY1+2*(IY3-IY1)/3,
     1      IX2-2*(IX2-IX4)/3,IY2+2*(IY4-IY2)/3,15)
50      CONTINUE
*
*     Curved sections
*
```

```
      ELSE
         RADIUS(2)=400
         RADIUS(3)=200
         RADIUS(4)=70
         IF (HCURVE(ISET).EQ.2) THEN
           CALL GOTOXY (1,5)
           WRITE (*,80)
80       FORMAT (78X,'20')
           CALL GOTOXY (1,12)
           WRITE (*,90)
90       FORMAT (2X,'100',73X,'0')
         ELSEIF (HCURVE(ISET).EQ.3) THEN
           CALL GOTOXY (1,6)
           WRITE (*,82)
82       FORMAT (76X,'20')
           CALL GOTOXY (1,12)
           WRITE (*,92)
92       FORMAT (4X,'100',66X,'0')
         ELSE
           CALL GOTOXY (1,10)
           WRITE (*,84)
84       FORMAT (73X,'20')
           CALL GOTOXY (1,14)
           WRITE (*,94)
94       FORMAT (11X,'100',53X,'0')
         ENDIF
*
*     Draw basic map
*
         SCALE=(238.-50.)/(RADIUS(HCURVE(ISET))+26-
     1  (RADIUS(HCURVE(ISET))-6)*COS(100./RADIUS(HCURVE(ISET))/2))
         XCEN=320
         YCEN=50+(RADIUS(HCURVE(ISET))+26)*SCALE
         DO 100 A=3.1416/2+100./RADIUS(HCURVE(ISET))/2,3.1416/2-
     1  100./RADIUS(HCURVE(ISET))/2,-100./RADIUS(HCURVE(ISET))/20
           IX1=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(A)*SCALE
           IY1=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(A)*SCALE
           IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           CALL DRAW (IX1,IY1,IX2,IY2,7)
           IX1=XCEN+(RADIUS(HCURVE(ISET))-6)*COS(A)*SCALE
           IY1=YCEN-(RADIUS(HCURVE(ISET))-6)*SIN(A)*SCALE
           IX2=XCEN+(RADIUS(HCURVE(ISET))-6)*COS(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           IY2=YCEN-(RADIUS(HCURVE(ISET))-6)*SIN(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           CALL DRAW (IX1,IY1,IX2,IY2,7)
           IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(A)*SCALE
           IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(A)*SCALE
           IX2=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           IY2=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           CALL DRAW (IX1,IY1,IX2,IY2,7)
           IX1=XCEN+(RADIUS(HCURVE(ISET)))*COS(A)*SCALE
           IY1=YCEN-(RADIUS(HCURVE(ISET)))*SIN(A)*SCALE
           IX2=XCEN+(RADIUS(HCURVE(ISET)))*COS(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
           IY2=YCEN-(RADIUS(HCURVE(ISET)))*SIN(A-100./
     1    RADIUS(HCURVE(ISET))/20)*SCALE
```

```
          CALL DRAW (IX1,IY1,IX1+(IX2-IX1)/2,IY1+(IY2-IY1)/2,14)
*
*   Draw terrain strips
*
          DO 110 I=1,NT(ISET)
            IX1=XCEN+(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*COS(A)*SCALE
            IY1=YCEN-(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*SIN(A)*SCALE
            IX2=XCEN+(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*COS(A-100./
     1      RADIUS(HCURVE(ISET))/20)*SCALE
            IY2=YCEN-(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*SIN(A-100./
     1      RADIUS(HCURVE(ISET))/20)*SCALE
            CALL DRAW (IX1,IY1,IX2,IY2,7)
110     CONTINUE
100   CONTINUE
*
*   Draw terrain ends
*
        IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(3.1416/2+100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(3.1416/2+100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(3.1416/2+100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(3.1416/2+100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        CALL DRAW (IX1,IY1,IX2,IY2,7)
        IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(3.1416/2-100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(3.1416/2-100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(3.1416/2-100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(3.1416/2-100./
     1  RADIUS(HCURVE(ISET))/2)*SCALE
        CALL DRAW (IX1,IY1,IX2,IY2,7)
*
*   Colour terrain strips
*
        LASTY=YCEN-(RADIUS(HCURVE(ISET))+6)*SCALE
        COLOUR=1
        DO 120 I=1,NT(ISET)
          NEXTY=YCEN-(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*SCALE
          IF (ABS(NEXTY-LASTY).GE.3) CALL FILLSHAPE (320,(NEXTY+
     1    LASTY)/2,COLOUR,7)
          LASTY=NEXTY
          COLOUR=COLOUR+1
          IF (COLOUR.EQ.15) COLOUR=1
120   CONTINUE
        IF (ABS(50-LASTY).GE.3) CALL FILLSHAPE (320,(50+LASTY)/2,
     1  COLOUR,7)
*
*   Objects
*
        DO 130 I=1,NO(ISET)
          DO 130 J=1,4
            IF (J.EQ.1) THEN
              XX1=100-THX1(ISET,I)
              YY1=THY1(ISET,I)
              XX2=100-THX2(ISET,I)
              YY2=THY2(ISET,I)
            ELSEIF (J.EQ.2) THEN
              XX1=100-THX1(ISET,I)
```

```
            YY1=THY1(ISET,I)
            XX2=100-THX3(ISET,I)
            YY2=THY3(ISET,I)
          ELSEIF (J.EQ.3) THEN
            XX1=100-THX2(ISET,I)
            YY1=THY2(ISET,I)
            XX2=100-THX4(ISET,I)
            YY2=THY4(ISET,I)
          ELSE
            XX1=100-THX3(ISET,I)
            YY1=THY3(ISET,I)
            XX2=100-THX4(ISET,I)
            YY2=THY4(ISET,I)
          ENDIF
          IF (ABS(XX1-XX2).GT.0.1) THEN
            YD1=YY1
            YD2=YY1+(YY2-YY1)/20
            DO 135 A=3.1416/2+100./RADIUS(HCURVE(ISET))/2-XX1/
     1      100.*100./RADIUS(HCURVE(ISET)),3.1416/2+100./
     2      RADIUS(HCURVE(ISET))/2-XX2/100.*100./
     3      RADIUS(HCURVE(ISET))-(XX1-XX2)/100.*100./
     4      RADIUS(HCURVE(ISET))/20,(XX1-XX2)/100.*
     5      100./RADIUS(HCURVE(ISET))/20
              YD1=YD1+(YY2-YY1)/20
              YD2=YD2+(YY2-YY1)/20
              IX1=XCEN+(RADIUS(HCURVE(ISET))+6+YD1)*COS(A)*SCALE
              IY1=YCEN-(RADIUS(HCURVE(ISET))+6+YD1)*SIN(A)*SCALE
              IX2=XCEN+(RADIUS(HCURVE(ISET))+6+YD2)*
     1       COS(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2       SCALE
              IY2=YCEN-(RADIUS(HCURVE(ISET))+6+YD2)*
     1       SIN(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2       SCALE
              CALL DRAW (IX1,IY1,IX2,IY2,15)
135         CONTINUE
          ELSE
            IX1=XCEN+(RADIUS(HCURVE(ISET))+6+YY1)*COS(3.1416/2+
     1      100./RADIUS(HCURVE(ISET))/2-XX1/100.*100./
     2      RADIUS(HCURVE(ISET)))*SCALE
            IY1=YCEN-(RADIUS(HCURVE(ISET))+6+YY1)*SIN(3.1416/2+
     1      100./RADIUS(HCURVE(ISET))/2-XX1/100.*100./
     2      RADIUS(HCURVE(ISET)))*SCALE
            IY2=YCEN-(RADIUS(HCURVE(ISET))+6+YY2)*SIN(3.1416/2+
     1      100./RADIUS(HCURVE(ISET))/2-XX2/100.*100./
     2      RADIUS(HCURVE(ISET)))*SCALE
            CALL DRAW (IX1,IY1,IX1,IY2,15)
          ENDIF
130   CONTINUE
*
*   Draw the DeSotos
*
      NUMER=0
      DENOM=0
      DO 140 I=1,35
        NUMER=NUMER+I*2*PP(HCURVE(ISET),I)
        DENOM=DENOM+PP(HCURVE(ISET),I)
140   CONTINUE
      IF (DENOM.NE.0) THEN
        MEANANG=NUMER/DENOM
      ELSE
        MEANANG=35
      ENDIF
```

```
          MEANANG=MEANANG*RAD
          DO 150 I=1,MITER(ISET)
            OFFSET=XINCR(ISET)*(I-1)
            IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(3.1416/2-
     1   100./RADIUS(HCURVE(ISET))/2+OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET)))*SCALE
            IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(3.1416/2-
     1   100./RADIUS(HCURVE(ISET))/2+OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET)))*SCALE
            IX2=IX1-TRACK(MODEL(ISET))*SCALE*COS(3.1416/2-MEANANG-
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            IY2=IY1+TRACK(MODEL(ISET))*SCALE*SIN(3.1416/2-MEANANG-
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            IX3=IX1+WBASE(MODEL(ISET))*1.2*SCALE*COS(MEANANG+
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            IY3=IY1+WBASE(MODEL(ISET))*1.2*SCALE*SIN(MEANANG+
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            IX4=IX3-TRACK(MODEL(ISET))*SCALE*COS(3.1416/2-MEANANG-
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            IY4=IY3+TRACK(MODEL(ISET))*SCALE*SIN(3.1416/2-MEANANG-
     1   (3.1416/2-100./RADIUS(HCURVE(ISET))/2-OFFSET/100.*100./
     2   RADIUS(HCURVE(ISET))))
            CALL DRAW (IX1,IY1,IX2,IY2,15)
            CALL DRAW (IX1,IY1,IX3,IY3,15)
            CALL DRAW (IX2,IY2,IX4,IY4,15)
            CALL DRAW (IX3,IY3,IX4,IY4,15)
            IF (ABS(IY1-IY4).GE.3.AND.ABS(IX2-IX3).GE.3) CALL
     1   FILLSHAPE ((IX2+IX3)/2,(IY1+IY4)/2,MODEL(ISET),15)
            CALL DRAW (IX1-(IX1-IX3)/3,IY1+(IY3-IY1)/3,IX2-(IX2-IX4)/3,
     1   IY2+(IY4-IY2)/3,15)
            CALL DRAW (IX1-2*(IX1-IX3)/3,IY1+2*(IY3-IY1)/3,
     1   IX2-2*(IX2-IX4)/3,IY2+2*(IY4-IY2)/3,15)
150     CONTINUE
        ENDIF
*
*   Draw messages
*
        CALL GOTOXY (1,18)
        WRITE (*,390)
390   FORMAT (3X,'Terrain changes are represented by coloured strips',
     1 ' parallel to the road')
        WRITE (*,400)
400   FORMAT (3X,'Roadside objects are represented by white rectangles')
        WRITE (*,410)
410   FORMAT (3X,'Encroachment points and mean departure angles')
        WRITE (*,420)
420   FORMAT (4X,'are shown using cars leaving the road')
        WRITE (*,*)
        WRITE (*,430)
430   FORMAT (3X,'Press any key to return to edit menu')
        CALL GETKEYBOARD(CH,II)
        CALL SETSCREENMODE(3)
        RETURN
        END
```

```
      SUBROUTINE ECONOMIC
*
*     This subroutine is used to edit economic evaluation parameters
*
      INTEGER CF,CHOICE,CODE,COLUMN,IPAGE,MENU,NSET,POS,ROWW
      CHARACTER*1 CH
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
*
*     Load evaluation type menu
*
1     WRITE (*,*) CHAR(255),CHAR(255),'EDIT-EV/'
      IF (BC.EQ.1) FIELD(1)='Y'
      IF (BC.EQ.0) FIELD(1)='N'
      IF (CE.EQ.1) FIELD(2)='Y'
      IF (CE.EQ.0) FIELD(2)='N'
      CODE=0
      POS=0
      CF=0
      FILNAM='EDIT-EV'
5     CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) RETURN
      IF (CODE.NE.48.AND.CODE.NE.46.AND.CODE.NE.45) GOTO 5
      IF (FIELD(1).EQ.'Y') BC=1
      IF (FIELD(1).EQ.'N') BC=0
      IF (FIELD(2).EQ.'Y') CE=1
      IF (FIELD(2).EQ.'N') CE=0
      OPTION(9)=FIELD(1)
      OPTION(10)=FIELD(2)
*
*     Benefit Cost analysis
*
      IF (CODE.EQ.48.AND.BC.EQ.1) THEN
15      WRITE (*,*) CHAR(255),CHAR(255),'EDIT-BC/'
          READ (*,10) CHOICE
10      FORMAT (I3)
*
*     Encroachment Rate
*
          IF (CHOICE.EQ.1) THEN
*
*     Enter encroachment rate or choose to calculate it
*
17          WRITE (*,*) CHAR(255),CHAR(255),'ENCROACH/'
              WRITE (FIELD(1),20) ENCRATE
20          FORMAT (F8.4)
              CODE=0
              CF=0
              POS=0
              FILNAM='ENCRCH1'
              CALL SCREENIO(FILNAM,CODE,CF,POS)
              IF (CODE.EQ.1) GOTO 15
              READ (FIELD(1),20) ENCRATE
*
*     Enter parameters to calculate encroachment rate
*
              IF (ENCRATE.EQ.0) THEN
                IPAGE=1
```

```
*
*    Page 1
*
33        IF (IPAGE.EQ.1) THEN
            MENU=1
            WRITE (*,*) CHAR(255),CHAR(255),'ENCROACH/'
            WRITE (*,*) CHAR(255),CHAR(255),'ENCRSUB/'
            CALL GOTOXY(19,15+RDCLASS)
            CALL PUTCHATTR(CHAR(17),1,2,1)
            CALL GOTOXY(35,15+DESSPD)
            CALL PUTCHATTR(CHAR(17),1,2,1)
            CALL GOTOXY(47,15+LANEWID)
            CALL PUTCHATTR(CHAR(17),1,2,1)
            CALL GOTOXY(64,15+NUMLANE)
            CALL PUTCHATTR(CHAR(17),1,2,1)
            CALL GOTOXY(76,15+SHLDWID)
            CALL PUTCHATTR(CHAR(17),1,2,1)
30         WRITE (FIELD(1),25) ADT
25         FORMAT (I8)
            CODE=0
            CF=0
            POS=0
            FILNAM='ENCRSUB'
            CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 17
            READ (FIELD(1),25) ADT
            IF (CODE.EQ.73.OR.CODE.EQ.81) THEN
              IPAGE=2
              GOTO 33
            ELSEIF (CODE.EQ.45) THEN
              GOTO 15
            ENDIF
            CALL CURSOROFF
35         IF (MENU.EQ.1) THEN
              CHOICE=RDCLASS
              COLUMN=19
            ELSEIF (MENU.EQ.2) THEN
              CHOICE=DESSPD
              COLUMN=35
            ELSEIF (MENU.EQ.3) THEN
              CHOICE=LANEWID
              COLUMN=47
            ELSEIF (MENU.EQ.4) THEN
              CHOICE=NUMLANE
              COLUMN=64
            ELSE
              CHOICE=SHLDWID
              COLUMN=76
            ENDIF
40         CALL GOTOXY(COLUMN,15+CHOICE)
            CALL PUTCHATTR(CHAR(17),1,10,1)
            CALL GETKEYBOARD(CH,CODE)
            IF (CODE.EQ.1) GOTO 17
            IF (CODE.EQ.72) THEN
              CALL PUTCHATTR(' ',1,10,1)
              CHOICE=CHOICE-1
              IF (CHOICE.EQ.0) CHOICE=5
            ELSEIF (CODE.EQ.80) THEN
              CALL PUTCHATTR(' ',1,10,1)
              CHOICE=CHOICE+1
              IF (CHOICE.EQ.6) CHOICE=1
```

```
      ELSEIF (CODE.EQ.75.OR.CODE.EQ.77.OR.CODE.EQ.73.OR.
     1    CODE.EQ.81.OR.CODE.EQ.45) THEN
        CALL PUTCHATTR(CHAR(17),1,2,1)
        IF (MENU.EQ.1) THEN
          RDCLASS=CHOICE
        ELSEIF (MENU.EQ.2) THEN
          DESSPD=CHOICE
        ELSEIF (MENU.EQ.3) THEN
          LANEWID=CHOICE
        ELSEIF (MENU.EQ.4) THEN
          NUMLANE=CHOICE
        ELSE
          SHLDWID=CHOICE
        ENDIF
        IF (CODE.EQ.75) THEN
          IF (MENU.EQ.1) GOTO 30
          MENU=MENU-1
          GOTO 35
        ELSEIF (CODE.EQ.77) THEN
          IF (MENU.EQ.5) GOTO 30
          MENU=MENU+1
          GOTO 35
        ELSEIF (CODE.EQ.45) THEN
          GOTO 15
        ELSE
          IPAGE=2
          GOTO 33
        ENDIF
      ENDIF
      GOTO 40
*
*  Page 2
*
     ELSE
      WRITE (*,*) CHAR(255),CHAR(255),'ENCRCH2/'
      MENU=1
      CALL GOTOXY(27,10+HORCURVE)
      CALL PUTCHATTR(CHAR(17),1,2,1)
      CALL GOTOXY(45,10+VERCURVE)
      CALL PUTCHATTR(CHAR(17),1,2,1)
      CALL GOTOXY(79,10+CLIMATE)
      CALL PUTCHATTR(CHAR(17),1,2,1)
      CALL GOTOXY(27,18+TRAFFIC)
      CALL PUTCHATTR(CHAR(17),1,2,1)
      CALL GOTOXY(55,18+SIGHT)
      CALL PUTCHATTR(CHAR(17),1,2,1)
      CALL CURSOROFF
50    IF (MENU.EQ.1) THEN
        CHOICE=HORCURVE
        COLUMN=27
        ROWW=10
      ELSEIF (MENU.EQ.2) THEN
        CHOICE=VERCURVE
        COLUMN=45
        ROWW=10
      ELSEIF (MENU.EQ.3) THEN
        CHOICE=CLIMATE
        COLUMN=79
        ROWW=10
```

```
            ELSEIF (MENU.EQ.4) THEN
              CHOICE=TRAFFIC
              COLUMN=27
              ROWW=18
            ELSE
              CHOICE=SIGHT
              COLUMN=55
              ROWW=18
            ENDIF
60          CALL GOTOXY(COLUMN,ROWW+CHOICE)
            CALL PUTCHATTR(CHAR(17),1,10,1)
            CALL GETKEYBOARD(CH,CODE)
            IF (CODE.EQ.1) GOTO 17
            IF (CODE.EQ.72) THEN
              CALL PUTCHATTR(' ',1,10,1)
              CHOICE=CHOICE-1
              IF (CHOICE.EQ.0) CHOICE=6
            ELSEIF (CODE.EQ.80) THEN
              CALL PUTCHATTR(' ',1,10,1)
              CHOICE=CHOICE+1
              IF (CHOICE.EQ.7) CHOICE=1
            ELSEIF (CODE.EQ.75.OR.CODE.EQ.77.OR.CODE.EQ.73.OR.
     1      CODE.EQ.81.OR.CODE.EQ.45) THEN
              CALL PUTCHATTR(CHAR(17),1,2,1)
              IF (MENU.EQ.1) THEN
                HORCURVE=CHOICE
              ELSEIF (MENU.EQ.2) THEN
                VERCURVE=CHOICE
              ELSEIF (MENU.EQ.3) THEN
                CLIMATE=CHOICE
              ELSEIF (MENU.EQ.4) THEN
                TRAFFIC=CHOICE
              ELSE
                SIGHT=CHOICE
              ENDIF
              IF (CODE.EQ.75) THEN
                MENU=MENU-1
                IF (MENU.EQ.0) MENU=5
                GOTO 50
              ELSEIF (CODE.EQ.77) THEN
                MENU=MENU+1
                IF (MENU.EQ.6) MENU=1
                GOTO 50
              ELSEIF (CODE.EQ.45) THEN
                GOTO 15
              ELSE
                IPAGE=1
                GOTO 33
              ENDIF
            ENDIF
            GOTO 60
          ENDIF
        ELSE
          GOTO 15
        ENDIF
*
*     Accident costs
*
```

```
*
*     Accident costs
*
            ELSEIF (CHOICE.EQ.2) THEN
              WRITE (*,*) CHAR(255),CHAR(255),'ACC-COST/'
              DO 70 I=1,2
                DO 70 J=1,4
                  WRITE (FIELD((J-1)*3+I),80) ACCOST(I,J)
80             FORMAT (F10.2)
                  WRITE (FIELD(J*3),80) ACCOST(1,J)+ACCOST(2,J)
70          CONTINUE
              CODE=0
              CF=0
              POS=0
              FILNAM='ACC-COST'
85          CALL SCREENIO(FILNAM,CODE,CF,POS)
              IF (CODE.EQ.1) GOTO 15
              IF (CODE.NE.20.AND.CODE.NE.45) GOTO 85
              DO 90 I=1,2
                DO 90 J=1,4
                  READ (FIELD((J-1)*3+I),80) ACCOST(I,J)
90          CONTINUE
              IF (CODE.EQ.20) THEN
                DO 100 I=1,4
                  WRITE (FIELD(I*3),80) ACCOST(1,I)+ACCOST(2,I)
100           CONTINUE
              ELSEIF (CODE.EQ.45) THEN
                GOTO 15
              ENDIF
              GOTO 85
*
*     Mitigation costs
*
            ELSEIF (CHOICE.EQ.3) THEN
              CALL MITIGATION
              GOTO 15
*
*     Present Value and Capital Recovery Data
*
            ELSEIF (CHOICE.EQ.4) THEN
              WRITE (*,*) CHAR(255),CHAR(255),'PV-CREEN/'
              WRITE (FIELD(1),170) INTEREST
170         FORMAT (F5.2)
              WRITE (FIELD(2),180) PERIOD
180         FORMAT (I4)
              CODE=0
              CF=0
              POS=0
              FILNAM='PV-CR'
190         CALL SCREENIO(FILNAM,CODE,CF,POS)
              IF (CODE.EQ.1) GOTO 15
              IF (CODE.NE.45) GOTO 190
              READ (FIELD(1),170) INTEREST
              READ (FIELD(2),180) PERIOD
              GOTO 15
            ELSE
              GOTO 1
            ENDIF
*
*     Cost Effectiveness Analysis
*
```

```
*
*    Cost Effectiveness Analysis
*
     ELSEIF (CODE.EQ.46.AND.CE.EQ.1) THEN
201    WRITE (*,*) CHAR(255),CHAR(255),'EDIT-CE/'
         READ (*,10) CHOICE
*
*    Cost Effectiveness Weightings
*
         IF (CHOICE.EQ.1) THEN
           WRITE (*,*) CHAR(255),CHAR(255),'COSTEFF/'
           DO 200 I=1,4
             WRITE (FIELD(I),210) SEVERITY(I)
210         FORMAT (I11)
200       CONTINUE
           CODE=0
           CF=0
           POS=0
           FILNAM='COSTEFF'
205       CALL SCREENIO(FILNAM,CODE,CF,POS)
           IF (CODE.EQ.1) GOTO 201
           IF (CODE.NE.45) GOTO 205
           DO 220 I=1,4
             READ (FIELD(I),210) SEVERITY(I)
220       CONTINUE
*
*    Mitigation costs
*
         ELSEIF (CHOICE.EQ.2) THEN
           CALL MITIGATION
         ELSE
           GOTO 1
         ENDIF
         GOTO 201
     ELSEIF (CODE.EQ.45) THEN
         RETURN
     ENDIF
     GOTO 1
     END
```

```
      SUBROUTINE MITIGATION
*
*     This subroutine edits mitigation cost data
*
      INTEGER CF,CODE,ISET,POS
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD

      ISET=0
114   ISET=ISET+1
      IF (ISET.EQ.11) RETURN
      IF (ICHAR(TITLE(ISET)(1:1)).EQ.32.OR.ICHAR(TITLE(ISET)(1:1)).EQ.
     1 0) GOTO 114
115   WRITE (*,*) CHAR(255),CHAR(255),'MIT-COST/'
      WRITE (FIELD(1),10) ISET
10    FORMAT (I3)
      FIELD(2)=TITLE(ISET)
      IF (BARRIER(ISET).EQ.0) FIELD(3)='N'
      IF (BARRIER(ISET).EQ.1) FIELD(3)='Y'
      WRITE (FIELD(4),120) BINSTALL(ISET)
120   FORMAT (F9.2)
      WRITE (FIELD(5),120) BMAINT(ISET)
      IF (SLOPE(ISET).EQ.0) FIELD(6)='N'
      IF (SLOPE(ISET).EQ.1) FIELD(6)='Y'
      WRITE (FIELD(7),120) CUTCOST
      WRITE (FIELD(8),120) FILLCOST
      WRITE (FIELD(9),120) WASTCOST
      WRITE (FIELD(10),120) ADFCOST
      WRITE (FIELD(11),120) CFMAINT(ISET)
      IF (OREMOVE(ISET).EQ.0) FIELD(12)='N'
      IF (OREMOVE(ISET).EQ.1) FIELD(12)='Y'
      DO 130 I=1,3
            WRITE (FIELD(13+(I-1)*2),10) NREMOVE(ISET,I)
            WRITE (FIELD(14+(I-1)*2),120) CREMOVE(ISET,I)
130   CONTINUE
      IF (ROW(ISET).EQ.0) FIELD(19)='N'
      IF (ROW(ISET).EQ.1) FIELD(19)='Y'
      WRITE (FIELD(20),120) COSTROW(ISET)
      CODE=0
      CF=0
      POS=0
      FILNAM='MIT-COST'
135   CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) RETURN
      IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81) GOTO 135
      IF (FIELD(3).EQ.'N') BARRIER(ISET)=0
      IF (FIELD(3).EQ.'Y') BARRIER(ISET)=1
      READ (FIELD(4),120) BINSTALL(ISET)
      READ (FIELD(5),120) BMAINT(ISET)
      IF (FIELD(6).EQ.'N') SLOPE(ISET)=0
      IF (FIELD(6).EQ.'Y') SLOPE(ISET)=1
      READ (FIELD(7),120) CUTCOST
      READ (FIELD(8),120) FILLCOST
      READ (FIELD(9),120) WASTCOST
      READ (FIELD(10),120) ADFCOST
      READ (FIELD(11),120) CFMAINT(ISET)
      IF (FIELD(12).EQ.'N') OREMOVE(ISET)=0
      IF (FIELD(12).EQ.'Y') OREMOVE(ISET)=1
```

```
      DO 140 I=1,3
            READ (FIELD(13+(I-1)*2),10) NREMOVE(ISET,I)
            READ (FIELD(14+(I-1)*2),120) CREMOVE(ISET,I)
140   CONTINUE
      IF (FIELD(19).EQ.'N') ROW(ISET)=0
      IF (FIELD(19).EQ.'Y') ROW(ISET)=1
      READ (FIELD(20),120) COSTROW(ISET)

      IF (CODE.EQ.73) THEN
150      ISET=ISET-1
            IF (ISET.EQ.0) ISET=10
            IF (ICHAR(TITLE(ISET)(1:1)).EQ.32.OR.ICHAR(TITLE(ISET)(1:1)).
     1  EQ.0) GOTO 150
      ELSEIF (CODE.EQ.81) THEN
160      ISET=ISET+1
            IF (ISET.EQ.11) ISET=1
            IF (ICHAR(TITLE(ISET)(1:1)).EQ.32.OR.ICHAR(TITLE(ISET)(1:1)).
     1  EQ.0) GOTO 160
      ELSE
            RETURN
      ENDIF
      GOTO 115
      END
```

```
      SUBROUTINE TRAJECT
*
*     This subroutine plots single trajectories given a set of initial
*     conditions
*
      INTEGER CODE, CF, ISET, POS, RUNTYPE
      REAL LASTY,RADIUS(4)
      CHARACTER*1 CH
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
*
*     Reset trajectory variables
*
      IENCR=0
      INITVEL=0
      INITANG=0
*
*     Choose input set
*
12    WRITE (*,*) CHAR(255),CHAR(255),'TRAJECT1/'
      DO 22 I=1,10
            DO 22 J=1,50
              CALL GOTOXY (21+J,7+I)
              CALL PUTCHAR(TITLE(I)(J:J),1)
22    CONTINUE
32    WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY4/'
      READ (*,42) ISET
42    FORMAT (I3)
      IF (ISET.EQ.11) RETURN
      IF (ICHAR(TITLE(ISET)(1:1)).EQ.0.OR.ICHAR(TITLE(ISET)(1:1)).
     1 EQ.32) GOTO 32
*
*     Enter initial variables
*
43      WRITE (*,*) CHAR(255),CHAR(255),'TRAJECT/'
          FIELD(1)=TITLE(ISET)
          WRITE (FIELD(2),52) IENCR
52      FORMAT (I8)
          WRITE (FIELD(3),52) MITER(ISET)
          WRITE (FIELD(4),62) XINCR(ISET)
62      FORMAT (F8.2)
          WRITE (FIELD(5),62) INITVEL
          WRITE (FIELD(6),62) VMEAN(ISET)
          WRITE (FIELD(7),62) VSD(ISET)
          WRITE (FIELD(8),62) VMIN(ISET)
          WRITE (FIELD(9),62) INITANG
*
*     Read trajectory parameters
*
          CODE=0
          POS=0
          CF=0
          FILNAM='TRAJECT'
          CALL SCREENIO(FILNAM,CODE,CF,POS)
          IF (CODE.EQ.1) GOTO 12
          READ (FIELD(2),52) IENCR
          READ (FIELD(5),62) INITVEL
          READ (FIELD(9),62) INITANG
```

```
*
*    Draw map on screen
*
     CALL CLRSCR
     CALL SETSCREENMODE(16)
     CALL GOTOXY(1,1)
     WRITE (*,61) ISET,IENCR,INITANG,INITVEL
61   FORMAT (1X,'Trajectory Plot: ISET = ',I2,' EN = ',I8,' IA = ',
    1 F8.2,' IV = ',F8.2)
*
*    Straight road section
*
     IF (HCURVE(ISET).EQ.1) THEN
          CALL GOTOXY (1,4)
          WRITE (*,65)
65      FORMAT (79X,'20')
          CALL GOTOXY (2,11)
          WRITE (*,70)
70      FORMAT (1X,'100',76X,'0')
*
*    Draw basic map
*
          CALL DRAW (30,50,30,166,7)
          CALL DRAW (30,50,610,50,7)
          CALL DRAW (30,166,610,166,7)
          CALL DRAW (610,50,610,166,7)
*
*    Draw terrain strips
*
          LASTY=166
          DO 20 I=1,NT(ISET)
            NEXTY=166-TY(ISET,I)*(166-50)/20
            CALL DRAW (30,NEXTY,610,NEXTY,7)
            LASTY=NEXTY
20      CONTINUE
*
*    Objects
*
          DO 30 I=1,NO(ISET)
            IX1=610-THX1(ISET,I)*(610-30)/100
            IY1=166-THY1(ISET,I)*(166-50)/20
            IX2=610-THX2(ISET,I)*(610-30)/100
            IY2=166-THY2(ISET,I)*(166-50)/20
            IX3=610-THX3(ISET,I)*(610-30)/100
            IY3=166-THY3(ISET,I)*(166-50)/20
            IX4=610-THX4(ISET,I)*(610-30)/100
            IY4=166-THY4(ISET,I)*(166-50)/20
            CALL DRAW (IX1,IY1,IX2,IY2,15)
            CALL DRAW (IX1,IY1,IX3,IY3,15)
            CALL DRAW (IX2,IY2,IX4,IY4,15)
            CALL DRAW (IX3,IY3,IX4,IY4,15)
30      CONTINUE
*
*    Curved sections
*
     ELSE
          RADIUS(2)=400
          RADIUS(3)=200
          RADIUS(4)=70
```

```
      IF (HCURVE(ISET).EQ.2) THEN
        CALL GOTOXY (1,5)
        WRITE (*,80)
80    FORMAT (78X,'20')
        CALL GOTOXY (1,12)
        WRITE (*,90)
90    FORMAT (2X,'100',73X,'0')
      ELSEIF (HCURVE(ISET).EQ.3) THEN
        CALL GOTOXY (1,6)
        WRITE (*,82)
82    FORMAT (76X,'20')
        CALL GOTOXY (1,12)
        WRITE (*,92)
92    FORMAT (4X,'100',66X,'0')
      ELSE
        CALL GOTOXY (1,10)
        WRITE (*,84)
84    FORMAT (73X,'20')
        CALL GOTOXY (1,14)
        WRITE (*,94)
94    FORMAT (11X,'100',53X,'0')
      ENDIF
*
*  Draw basic map
*
      SCALE=(238.-50.)/(RADIUS(HCURVE(ISET))+26-
   1 (RADIUS(HCURVE(ISET))-6)*COS(100./RADIUS(HCURVE(ISET))/2))
      XCEN=320
      YCEN=50+(RADIUS(HCURVE(ISET))+26)*SCALE
      DO 100 A=3.1416/2+100./RADIUS(HCURVE(ISET))/2,3.1416/2-
   1 100./RADIUS(HCURVE(ISET))/2,-100./RADIUS(HCURVE(ISET))/20
        IX1=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(A)*SCALE
        IY1=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(A)*SCALE
        IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(A-100./
   1    RADIUS(HCURVE(ISET))/20)*SCALE
        IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(A-100./
   1    RADIUS(HCURVE(ISET))/20)*SCALE
        CALL DRAW (IX1,IY1,IX2,IY2,7)
        IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(A)*SCALE
        IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(A)*SCALE
        IX2=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(A-100./
   1    RADIUS(HCURVE(ISET))/20)*SCALE
        IY2=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(A-100./
   1    RADIUS(HCURVE(ISET))/20)*SCALE
        CALL DRAW (IX1,IY1,IX2,IY2,7)
*
*  Draw terrain strips
*
        DO 110 I=1,NT(ISET)
          IX1=XCEN+(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*COS(A)*SCALE
          IY1=YCEN-(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*SIN(A)*SCALE
          IX2=XCEN+(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*COS(A-100./
   1      RADIUS(HCURVE(ISET))/20)*SCALE
          IY2=YCEN-(RADIUS(HCURVE(ISET))+6+TY(ISET,I))*SIN(A-100./
   1      RADIUS(HCURVE(ISET))/20)*SCALE
          CALL DRAW (IX1,IY1,IX2,IY2,7)
110     CONTINUE
100   CONTINUE
```

```
*
*    Draw terrain ends
*
         IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(3.1416/2+100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(3.1416/2+100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(3.1416/2+100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(3.1416/2+100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         CALL DRAW (IX1,IY1,IX2,IY2,7)
         IX1=XCEN+(RADIUS(HCURVE(ISET))+6)*COS(3.1416/2-100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IY1=YCEN-(RADIUS(HCURVE(ISET))+6)*SIN(3.1416/2-100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IX2=XCEN+(RADIUS(HCURVE(ISET))+26)*COS(3.1416/2-100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         IY2=YCEN-(RADIUS(HCURVE(ISET))+26)*SIN(3.1416/2-100./
     1   RADIUS(HCURVE(ISET))/2)*SCALE
         CALL DRAW (IX1,IY1,IX2,IY2,7)
*
*    Objects
*
         DO 130 I=1,NO(ISET)
           DO 130 J=1,4
             IF (J.EQ.1) THEN
               XX1=100-THX1(ISET,I)
               YY1=THY1(ISET,I)
               XX2=100-THX2(ISET,I)
               YY2=THY2(ISET,I)
             ELSEIF (J.EQ.2) THEN
               XX1=100-THX1(ISET,I)
               YY1=THY1(ISET,I)
               XX2=100-THX3(ISET,I)
               YY2=THY3(ISET,I)
             ELSEIF (J.EQ.3) THEN
               XX1=100-THX2(ISET,I)
               YY1=THY2(ISET,I)
               XX2=100-THX4(ISET,I)
               YY2=THY4(ISET,I)
             ELSE
               XX1=100-THX3(ISET,I)
               YY1=THY3(ISET,I)
               XX2=100-THX4(ISET,I)
               YY2=THY4(ISET,I)
             ENDIF
             YD1=YY1
             YD2=YY1+(YY2-YY1)/20
             DO 130 A=3.1416/2+100./RADIUS(HCURVE(ISET))/2-XX1/
     1       100.*100./RADIUS(HCURVE(ISET)),3.1416/2+100./
     2       RADIUS(HCURVE(ISET))/2-XX2/100.*100./
     3       RADIUS(HCURVE(ISET))-(XX1-XX2)/100.*100./
     4       RADIUS(HCURVE(ISET))/20,(XX1-XX2)/100.*
     5       100./RADIUS(HCURVE(ISET))/20
               YD1=YD1+(YY2-YY1)/20
               YD2=YD2+(YY2-YY1)/20
               IX1=XCEN+(RADIUS(HCURVE(ISET))+6+YD1)*COS(A)*SCALE
               IY1=YCEN-(RADIUS(HCURVE(ISET))+6+YD1)*SIN(A)*SCALE
               IX2=XCEN+(RADIUS(HCURVE(ISET))+6+YD2)*
     1         COS(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2         SCALE
```

```
              IY2=YCEN-(RADIUS(HCURVE(ISET))+6+YD2)*
     1        SIN(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2        SCALE
              CALL DRAW (IX1,IY1,IX2,IY2,15)
130     CONTINUE
      ENDIF
*
*     Draw cross section
*
      CALL DRAW (40,213,40,313,7)
      CALL DRAW (40,313,600,313,7)
      IF (NT(ISET).EQ.0) THEN
           CALL DRAW (40,225,600,225,2)
      ELSE
           MINZ=0
           MAXZ=0
           Z=0
           DO 160 I=1,NT(ISET)
             IF (I.LT.NT(ISET)) THEN
               Z=Z+(TY(ISET,I+1)-TY(ISET,I))*TAN(TA(ISET,I)*RAD)
             ELSE
               Z=Z+(20.0-TY(ISET,I))*TAN(TA(ISET,I)*RAD)
             ENDIF
             IF (Z.GT.MAXZ) MAXZ=Z
             IF (Z.LT.MINZ) MINZ=Z
160     CONTINUE
           IF (MAXZ.EQ.MINZ) MAXZ=MINZ+1
           IX1=40
           IY1=313-(0.0-MINZ)/(MAXZ-MINZ)*(313-213)
           Z=0
           DO 170 I=1,NT(ISET)
             IX2=40+TY(ISET,I)/20.0*560
             IY2=313-(Z-MINZ)/(MAXZ-MINZ)*(313-213)
             CALL DRAW (IX1,IY1,IX2,IY2,2)
             IF (I.LT.NT(ISET)) THEN
               Z=Z+(TY(ISET,I+1)-TY(ISET,I))*TAN(TA(ISET,I)*RAD)
             ELSE
               Z=Z+(20.0-TY(ISET,I))*TAN(TA(ISET,I)*RAD)
             ENDIF
             IX1=IX2
             IY1=IY2
170     CONTINUE
           IX2=600
           IY2=313-(Z-MINZ)/(MAXZ-MINZ)*(313-213)
           CALL DRAW (IX1,IY1,IX2,IY2,2)
      ENDIF
      CALL GOTOXY(1,15)
      WRITE (*,172) MAXZ
172   FORMAT (1X,F4.0)
      CALL GOTOXY(1,21)
      WRITE (*,172) MINZ
      CALL GOTOXY (1,23)
      WRITE (*,173)
173   FORMAT (5X,'0',67X,'20')
*
*     Put input data into proper units
*
      INITVEL = INITVEL / 3.6
      REST(ISET) = REST(ISET) / 100.
      STEER(ISET) = STEER(ISET) * RAD
      DO 140 J=1,NT(ISET)
           TA(ISET,J) = TA(ISET,J) * RAD
```

```
140  CONTINUE
     ANGLE=INITANG*RAD
*
*    Plot trajectory
*
     RUNTYPE=2
     CALL SIMULATE(ISET,RUNTYPE)
*
*    Reset input data units
*
     INITVEL = 3.6 * INITVEL
     REST(ISET) = 100. * REST(ISET)
     STEER(ISET) = STEER(ISET) / RAD
     DO 150 J=1,NT(ISET)
           TA(ISET,J) = TA(ISET,J) / RAD
150  CONTINUE
     CALL GETKEYBOARD(CH,II)
     CALL SETSCREENMODE(3)
     CALL CLRSCR
     GOTO 43
     END
```

```
      SUBROUTINE RUN
*
*     This subroutine runs the RHSM analysis
*
      INTEGER ISET,NITER,RUNTYPE
      LOGICAL KYP

      INCLUDE 'RHSM.INS'
*
*     For every input set
*
      DO 10 ISET=1,10
         IF (ICHAR(TITLE(ISET)(1:1)).NE.0.AND.ICHAR(TITLE(ISET)(1:1)).
     1   NE.32) THEN
*
*     Put input data into proper units
*
            VMEAN(ISET) = VMEAN(ISET) / 3.6
            VSD(ISET) = VSD(ISET) / 3.6
            VMIN(ISET) = VMIN(ISET) / 3.6
            BRAKE(ISET) = BRAKE(ISET) / 100.
            REST(ISET) = REST(ISET) / 100.
            STEER(ISET) = STEER(ISET) * RAD
            DO 15 J=1,NT(ISET)
              TA(ISET,J) = TA(ISET,J) * RAD
15          CONTINUE
*
*     Reset results variables
*
            DATA(ISET,1)=0
            DATA(ISET,2)=0
            DATA(ISET,3)=0
            DATA(ISET,4)=0
            NCALLS(ISET)=0
            NROLLS(ISET)=0
            NIROL(ISET)=0
            NJROL(ISET)=0
*
*     Percent complete message
*
            CALL CLRSCR
            CALL CURSOROFF
            WRITE (*,18) ISET
18          FORMAT (1X,'Input Set ',I2,' (Press <ESC> to abort)')
            WRITE (*,*) ' Percent Complete'
            WRITE (*,*)
            NITER=MITER(ISET)*68.0/AINCR(ISET)
*
*     For every encroachment point
*
            DO 20 IENCR=1,MITER(ISET)
*
*     For every encroachment angle
*
              DO 20 INITANG=2.0,70.0,AINCR(ISET)
*
*     Update percent complete message
*
                CALL GOTOXY(1,4)
                WRITE (*,*) INT(((INITANG-2.0)/AINCR(ISET)+(IENCR-1)*
     1          68.0/AINCR(ISET))*100/NITER)
```

```
*
*     For every encroachment velocity
*
                  DO 20 INITVEL=VMIN(ISET),150.0/3.6,(VINCR(ISET)*
     1            VSD(ISET))
*
*     Check if user pressed escape
*
                    CALL KEYPRESSED(KYP)
                    IF (KYP) THEN
                      CALL GETKEYBOARD(CH,II)
                      IF (II.EQ.1) THEN
                        DONE=0
                        VMEAN(ISET) = 3.6 * VMEAN(ISET)
                        VSD(ISET) = 3.6 * VSD(ISET)
                        VMIN(ISET) = 3.6 * VMIN(ISET)
                        BRAKE(ISET) = 100. * BRAKE(ISET)
                        REST(ISET) = 100. * REST(ISET)
                        STEER(ISET) = STEER(ISET) / RAD
                        DO 21 J=1,NT(ISET)
                          TA(ISET,J) = TA(ISET,J) / RAD
21                     CONTINUE
                        RETURN
                      ENDIF
                    ENDIF
                    ANGLE=INITANG*RAD
                    NCALLS(ISET)=NCALLS(ISET)+1
*
*     Simulate vehicle on trajectory and update results
*     Note: RUNTYPE distinguishes this analysis from a trajectory plot
*
                    RUNTYPE=1
                    CALL SIMULATE(ISET,RUNTYPE)
20          CONTINUE
*
*     Perform economic analysis
*
              CALL ECONRUN(ISET)
*
*     Reset input data units
*
              VMEAN(ISET) = 3.6 * VMEAN(ISET)
              VSD(ISET) = 3.6 * VSD(ISET)
              VMIN(ISET) = 3.6 * VMIN(ISET)
              BRAKE(ISET) = 100. * BRAKE(ISET)
              REST(ISET) = 100. * REST(ISET)
              STEER(ISET) = STEER(ISET) / RAD
              DO 26 J=1,NT(ISET)
                TA(ISET,J) = TA(ISET,J) / RAD
26          CONTINUE
             ENDIF
10     CONTINUE
       CALL CURSORON
       DONE=1
       RETURN
       END
```

```
      SUBROUTINE SIMULATE(ISET,RUNTYPE)
*
*     This subroutine simulates a vehicle driving over a single
*     trajectory
*
      INTEGER DIVEIN,ISET,ROLL,RUNTYPE
      REAL LASTELEV,PANG,PVEL,RADIUS(4),TIME
      INCLUDE 'RHSM.INS'
*
*     Velocity and angle probability for RHSM analysis
*
      IF (RUNTYPE.EQ.1) THEN
           PVEL=(1/(VSD(ISET)*SQRT(2*PI))*EXP(-0.5*((INITVEL-
     1 VINCR(ISET)*VSD(ISET)/2-VMEAN(ISET))/VSD(ISET))**2)+
     2 1/(VSD(ISET)*SQRT(2*PI))*EXP(-0.5*((INITVEL+
     3 VINCR(ISET)*VSD(ISET)/2-VMEAN(ISET))/VSD(ISET))**2))/
     4 2*VINCR(ISET)*VSD(ISET)
           PANG=(PP(HCURVE(ISET),INT(INITANG/2))+(INITANG-
     1 2*INT(INITANG/2))/2.0*(PP(HCURVE(ISET),INT(INITANG/2)+1)-
     2 PP(HCURVE(ISET),INT(INITANG/2))))/NOBS(HCURVE(ISET))
      ENDIF
*
*     Determine initial location, velocity and acceleration
*
      XX=(IENCR-1)*XINCR(ISET)
      YY=0
      LASTXX=XX
      LASTYY=YY
      VELOCITY=INITVEL
      ACCEL=0
      TSTRIP=0
      ELEVATION=0
      LASTELEV=0
      GROUND=0
      FLYING=0
      VANGLE=0
*
*     Reset passing of object flags
*
      DO 22 K=1,NO(ISET)
           PASTOBJ(K)=0
22    CONTINUE
*
*     First terrain strip
*
      OTSTRIP=TSTRIP
23    IF (TSTRIP.LT.NT(ISET)) THEN
           IF (YY.GE.TY(ISET,TSTRIP+1)) THEN
             TSTRIP=TSTRIP+1
             GOTO 23
           ENDIF
      ENDIF
*
*     Increment time through trajectory
*
      DO 21 TIME=0.0,TMAX(ISET),TI(ISET)
*
*     Current location, ground elevation and vehicle elevation
*
```

```
*
*   Current location, ground elevation and vehicle elevation
*
          ROLL=0
          DIVEIN=0
          IF (TSTRIP.GE.1) THEN
            LASTXX=XX
            XX=XX+VELOCITY*TI(ISET)*COS(ANGLE)*COS(VANGLE)
            LASTYY=YY
            YY=YY+VELOCITY*TI(ISET)*SIN(ANGLE)*COS(VANGLE)
*
*   Terrain changes
*
            OTSTRIP=TSTRIP
50        IF (TSTRIP.LT.NT(ISET)) THEN
              IF (YY.GE.TY(ISET,TSTRIP+1)) THEN
                TSTRIP=TSTRIP+1
                GOTO 50
              ENDIF
            ENDIF
            GROUND=GROUND+VELOCITY*TI(ISET)*TAN(TA(ISET,TSTRIP))*
   1    SIN(ANGLE)*COS(VANGLE)
*
*   Vehicle in contact with the ground
*
*   Vehicle stability on slope
*
            IF (FLYING.EQ.0) THEN
              CALL STATROLL(ISET,ROLL)
              IF (ROLL.EQ.1) GOTO 80
*
*   Check if vehicle flys at terrain changes
*
              IF (OTSTRIP.NE.TSTRIP) CALL FLY(ISET)
*
*   Airborne vehicle
*
            ELSE
              CALL DYNROLL(ISET,ROLL,DIVEIN)
              IF (ROLL.EQ.1.OR.DIVEIN.EQ.1) GOTO 80
            ENDIF
            IF (FLYING.EQ.0) THEN
              LASTELEV=ELEVATION
              ELEVATION=GROUND
              VANGLE=-ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE))
*
*   Adjust horizontal angle for steerback
*
              IF (STEER(ISET).NE.0) THEN
                IF (VELOCITY**2*STEER(ISET)/WBASE(MODEL(ISET))*
   1        COS(ANGLE+3.1416/2)*COS(ATAN(TAN(TA(ISET,TSTRIP))*
   2        SIN(ANGLE+3.1416/2)))*TI(ISET)+VELOCITY*COS(ANGLE)*
   3        COS(VANGLE).NE.0) THEN
                  ANGLE=ATAN((VELOCITY**2*STEER(ISET)/
   1          WBASE(MODEL(ISET))*SIN(ANGLE+3.1416/2)*
   2          COS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE+
   3          3.1416/2)))*TI(ISET)+VELOCITY*SIN(ANGLE)*
   4          COS(VANGLE))/(VELOCITY**2*STEER(ISET)/
   5          WBASE(MODEL(ISET))*COS(ANGLE+3.1416/2)*
   6          COS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE+
   7          3.1416/2)))*TI(ISET)+VELOCITY*COS(ANGLE)*
   8          COS(VANGLE)))
```

```
          ELSEIF (VELOCITY**2*STEER(ISET)/WBASE(MODEL(ISET))*
     1          SIN(ANGLE+3.1416/2)*COS(ATAN(TAN(TA(ISET,TSTRIP))*
     2          SIN(ANGLE+3.1416/2)))*TI(ISET)+VELOCITY*SIN(ANGLE)*
     3          COS(VANGLE).GT.0) THEN
              ANGLE=3.1416/2
            ELSE
              ANGLE=-3.1416/2
            ENDIF
          ENDIF
        ELSE
          LASTELEV=ELEVATION
          VVERT=VELOCITY*SIN(VANGLE)
          ELEVATION=ELEVATION-0.5*G*TI(ISET)**2-VVERT*TI(ISET)
          VANGLE=ATAN((VVERT+G*FLYTIME)/(VELOCITY*COS(VANGLE)))
        ENDIF
      ELSE
        LASTXX=XX
        XX=XX+VELOCITY*TI(ISET)*COS(ANGLE)
        LASTYY=YY
        YY=YY+VELOCITY*TI(ISET)*SIN(ANGLE)
      ENDIF
      IF (XX.GT.100.OR.XX.LT.0) RETURN
      IF (YY.GT.20.OR.YY.LT.0) RETURN
*
*   Terrain changes
*
51    IF (TSTRIP.LT.NT(ISET)) THEN
        IF (YY.GE.TY(ISET,TSTRIP+1)) THEN
          TSTRIP=TSTRIP+1
          GOTO 51
        ENDIF
      ENDIF
*
*   Acceleration change because of terrain
*
      ACCEL=G*SIN(VANGLE)
      IF (FLYING.EQ.0) THEN
        IF (TSTRIP.GT.0) ACCEL=ACCEL-(TR(ISET,TSTRIP)+
     1  TM(ISET,TSTRIP))*G
      ENDIF
*
*   Acceleration change because of objects
*
      CALL OBJECT(ISET)
*
*   Acceleration change because of braking
*
      IF (FLYING.EQ.0) ACCEL=ACCEL-BRAKE(ISET)*G
*
*   Calculate velocity and power
*
      VELOCITY=VELOCITY+ACCEL*TI(ISET)/2
      PWR=ABS(VELOCITY*ACCEL)
      VELOCITY=VELOCITY+ACCEL*TI(ISET)/2

*
*   Plot trajectory
*
```

```
*
*    Plot trajectory
*
80     IF (RUNTYPE.EQ.2) THEN
         IF (HCURVE(ISET).EQ.1) THEN
           IX1=610-LASTXX*(610-30)/100
           IY1=166-LASTYY*(166-50)/20
           IX2=610-XX*(610-30)/100
           IY2=166-YY*(166-50)/20
           CALL DRAW (IX1,IY1,IX2,IY2,15)
         ELSE
           RADIUS(2)=400
           RADIUS(3)=200
           RADIUS(4)=70
           SCALE=(238.-50.)/(RADIUS(HCURVE(ISET))+26-
     1   (RADIUS(HCURVE(ISET))-6)*COS(100./RADIUS(HCURVE(ISET))/
     2   2))
           XCEN=320
           YCEN=50+(RADIUS(HCURVE(ISET))+26)*SCALE
           XX1=100-LASTXX
           YY1=LASTYY
           XX2=100-XX
           YY2=YY
           YD1=YY1
           YD2=YY1+(YY2-YY1)/20
           DO 130 A=3.1416/2+100./RADIUS(HCURVE(ISET))/2-XX1/
     1   100.*100./RADIUS(HCURVE(ISET)),3.1416/2+100./
     2   RADIUS(HCURVE(ISET))/2-XX2/100.*100./
     3   RADIUS(HCURVE(ISET))-(XX1-XX2)/100.*100./
     4   RADIUS(HCURVE(ISET))/20,(XX1-XX2)/100.*
     5   100./RADIUS(HCURVE(ISET))/20
             YD1=YD1+(YY2-YY1)/20
             YD2=YD2+(YY2-YY1)/20
             IX1=XCEN+(RADIUS(HCURVE(ISET))+6+YD1)*COS(A)*SCALE
             IY1=YCEN-(RADIUS(HCURVE(ISET))+6+YD1)*SIN(A)*SCALE
             IX2=XCEN+(RADIUS(HCURVE(ISET))+6+YD2)*
     1     COS(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2     SCALE
             IY2=YCEN-(RADIUS(HCURVE(ISET))+6+YD2)*
     1     SIN(A+(XX1-XX2)/100.*100./RADIUS(HCURVE(ISET))/20)*
     2     SCALE
             CALL DRAW (IX1,IY1,IX2,IY2,15)
130        CONTINUE
         ENDIF
         IX1=40+LASTYY/20.0*560
         IY1=313-(LASTELEV-MINZ)/(MAXZ-MINZ)*(313-213)
         IX2=40+YY/20.0*560
         IY2=313-(ELEVATION-MINZ)/(MAXZ-MINZ)*(313-213)
         CALL DRAW (IX1,IY1,IX2,IY2,15)
         IF (ROLL.EQ.1) THEN
           CALL DRAW (IX2,IY2,IX2+6,IY2-5,15)
           CALL DRAW (IX2+6,IY2-5,IX2+11,IY2-10,15)
           CALL DRAW (IX2+11,IY2-10,IX2+11,IY2-15,15)
           CALL DRAW (IX2+11,IY2-15,IX2+8,IY2-20,15)
           CALL DRAW (IX2+8,IY2-20,IX2+3,IY2-23,15)
           CALL DRAW (IX2+3,IY2-23,IX2-2,IY2-20,15)
           CALL DRAW (IX2-2,IY2-20,IX2-4,IY2-15,15)
           CALL DRAW (IX2-4,IY2-15,IX2-2,IY2-10,15)
         ENDIF
       ENDIF
```

```
*
*     Calculate outcome probabilities using probability of
*     consequences or rolling consequences table
*
          CALL CONSEQ(ISET,ROLL)
*
*     Update overall probabilities for RHSM analysis
*
          IF (RUNTYPE.EQ.1) THEN
            LASTPND=DATA(ISET,1)
            LASTPPDO=DATA(ISET,2)
            LASTPINJ=DATA(ISET,3)
            LASTPFAT=DATA(ISET,4)
            DATA(ISET,4)=LASTPFAT+PFAT*PANG*PVEL*(1-LASTPFAT)
            DATA(ISET,3)=LASTPINJ*(1-PFAT*PANG*PVEL)+PINJ*PANG*PVEL*
     1   (1-LASTPFAT-LASTPINJ)
            DATA(ISET,2)=LASTPPDO*(1-(PFAT+PINJ)*PANG*PVEL)+
     1   PPDO*PANG*PVEL*LASTPND
            DATA(ISET,1)=1-DATA(ISET,2)-DATA(ISET,3)-DATA(ISET,4)
*
*     Update spacial probabilities
*
            IX=INT(XX/2)+1
            IY=INT(YY/2)+1
            SPRES(ISET,IX,IY,3)=SPRES(ISET,IX,IY,3)+PFAT*PANG*PVEL*
     1   (1-LASTPFAT)
            SPRES(ISET,IX,IY,2)=SPRES(ISET,IX,IY,2)+PINJ*PANG*PVEL*
     1   (1-LASTPFAT-LASTPINJ)
            SPRES(ISET,IX,IY,1)=SPRES(ISET,IX,IY,1)+PPDO*PANG*PVEL*
     1   LASTPND
          ENDIF
          IF (VELOCITY.LE.0) RETURN
21   CONTINUE
     RETURN
     END
```

```
      SUBROUTINE OBJECT (ISET)
*
*     This subroutine checks if objects are encountered and calculates
*     the induced decelerations
*
      INTEGER ISET
      REAL A,COORD(5,2),B,C,LX(2),LY(2),NX(2),NY(2),OBJANGLE(2),
     1 OBJDIST(2),XCROSS,XX1,XX2,YCROSS,YY1,YY2
      INCLUDE 'RHSM.INS'
*
*     For each object
*
      DO 25 K=1,NO(ISET)
*
*     Do a quick check to see if object is in vicinity
*
          IF ((((XX.GE.THX1(ISET,K).OR.XX.GE.THX3(ISET,K)).AND.
     1 (XX.LE.THX2(ISET,K).OR.XX.LE.THX4(ISET,K)).AND.
     2 (YY.GE.THY1(ISET,K).OR.YY.GE.THY2(ISET,K)).AND.
     3 (YY.LE.THY3(ISET,K).OR.YY.LE.THY4(ISET,K))).OR.
     4 SQRT((XX-THX1(ISET,K))**2+(YY-THY1(ISET,K))**2).LE.5).AND.
     5 PASTOBJ(K).EQ.0) THEN
*
*     Determine crossing points of object lines and vehicle side
*     trajectories to see if object lies on vehicle path
*
            NX(1)=XX-TRACK(MODEL(ISET))/2*SIN(ANGLE)*COS(VANGLE*COS(ANGLE))
            NY(1)=YY+TRACK(MODEL(ISET))/2*COS(ANGLE)*COS(VANGLE*COS(ANGLE))
            LX(1)=LASTXX-TRACK(MODEL(ISET))/2*SIN(ANGLE)*COS(VANGLE*COS(ANGLE))
            LY(1)=LASTYY+TRACK(MODEL(ISET))/2*COS(ANGLE)*COS(VANGLE*COS(ANGLE))
            NX(2)=XX+TRACK(MODEL(ISET))/2*SIN(ANGLE)*COS(VANGLE*COS(ANGLE))
            NY(2)=YY-TRACK(MODEL(ISET))/2*COS(ANGLE)*COS(VANGLE*COS(ANGLE))
            LX(2)=LASTXX+TRACK(MODEL(ISET))/2*SIN(ANGLE)*COS(VANGLE*COS(ANGLE))
            LY(2)=LASTYY-TRACK(MODEL(ISET))/2*COS(ANGLE)*COS(VANGLE*COS(ANGLE))
            DO 26 M=1,2
              OBJDIST(M)=-1
*
*     For each object, determine corners making up four sides
*
              DO 27 L=1,4
                IF (L.EQ.1) THEN
                  XX1=THX1(ISET,K)
                  YY1=THY1(ISET,K)
                  XX2=THX2(ISET,K)
                  YY2=THY2(ISET,K)
                ELSEIF (L.EQ.2) THEN
                  XX1=THX1(ISET,K)
                  YY1=THY1(ISET,K)
                  XX2=THX3(ISET,K)
                  YY2=THY3(ISET,K)
                ELSEIF (L.EQ.3) THEN
                  XX1=THX2(ISET,K)
                  YY1=THY2(ISET,K)
                  XX2=THX4(ISET,K)
                  YY2=THY4(ISET,K)
                ELSE
                  XX1=THX3(ISET,K)
                  YY1=THY3(ISET,K)
                  XX2=THX4(ISET,K)
                  YY2=THY4(ISET,K)
                ENDIF
```

```
*
*    If neither trajectory nor object line are vertical
*
              IF (ABS(XX1-XX2).GT.0.1) THEN
                IF (ABS(NX(M)-LX(M)).GT.0.1) THEN
*
*    If lines are not parallel
*
                  IF (ABS((YY1-YY2)/(XX1-XX2)-(NY(M)-LY(M))/
     1            (NX(M)-LX(M))).GT.0.01) THEN
                    XCROSS=(NY(M)-YY2+(YY1-YY2)/(XX1-XX2)*XX2-
     1              (LY(M)-NY(M))/(LX(M)-NX(M))*NX(M))/
     2              ((YY1-YY2)/(XX1-XX2)-(LY(M)-NY(M))/
     3              (LX(M)-NX(M)))
                    YCROSS=LY(M)+(NY(M)-LY(M))/(NX(M)-LX(M))*
     1              (XCROSS-LX(M))
                    IF (((XCROSS.GT.XX1.AND.XCROSS.LT.XX2).OR.
     1              (XCROSS.LT.XX1.AND.XCROSS.GT.XX2)).AND.
     2              ((XCROSS.GT.LX(M).AND.XCROSS.LT.NX(M)).OR.
     3              (XCROSS.LT.LX(M).AND.XCROSS.GT.NX(M)))) THEN
                      IF ((OBJDIST(M).EQ.-1).OR.(OBJDIST(M).GT.
     1                SQRT((XCROSS-LX(M))**2+(YCROSS-
     2                LY(M))**2))) THEN
                        OBJDIST(M)=SQRT((XCROSS-LX(M))**2+
     1                  (YCROSS-LY(M))**2)
                        C=SQRT((YY2-LY(M))**2+(XX2-LX(M))**2)
                        B=SQRT((YY2-YCROSS)**2+(XX2-XCROSS)**2)
                        A=SQRT((YCROSS-LY(M))**2+(XCROSS-
     1                  LX(M))**2)
                        OBJANGLE(M)=ACOS((A**2+B**2-C**2)/
     1                  (2*A*B))
                        IF (OBJANGLE(M).GT.3.1416/2)
     1                  OBJANGLE(M)=3.1416-OBJANGLE(M)
                      ENDIF
                    ENDIF
                  ENDIF
*
*    If only trajectory is vertical
*
                ELSE
                  XCROSS=NX(M)
                  YCROSS=YY1+(YY2-YY1)/(XX2-XX1)*(XCROSS-XX1)
                  IF (((XCROSS.GT.XX1.AND.XCROSS.LT.XX2).OR.
     1            (XCROSS.LT.XX1.AND.XCROSS.GT.XX2)).AND.
     2            ((YCROSS.GT.LY(M).AND.YCROSS.LT.NY(M)).OR.
     3            (YCROSS.LT.LY(M).AND.YCROSS.GT.NY(M)))) THEN
                    IF ((OBJDIST(M).EQ.-1).OR.(OBJDIST(M).GT.
     1              SQRT((XCROSS-LX(M))**2+(YCROSS-
     2              LY(M))**2))) THEN
                      OBJDIST(M)=SQRT((XCROSS-LX(M))**2+
     1                (YCROSS-LY(M))**2)
                      C=SQRT((YY2-LY(M))**2+(XX2-LX(M))**2)
                      B=SQRT((YY2-YCROSS)**2+(XX2-XCROSS)**2)
                      A=SQRT((YCROSS-LY(M))**2+(XCROSS-
     1                LX(M))**2)
                      OBJANGLE(M)=ACOS((A**2+B**2-C**2)/(2*A*B))
                      IF (OBJANGLE(M).GT.3.1416/2) OBJANGLE(M)=
     1                3.1416-OBJANGLE(M)
                    ENDIF
                  ENDIF
                ENDIF
```

```
*
*     If only object line is vertical
*
                  ELSE
                    IF (ABS(NX(M)-LX(M)).GT.0.1) THEN
                      XCROSS=XX1
                      YCROSS=LY(M)+(NY(M)-LY(M))/(NX(M)-LX(M))*
     1              (XCROSS-LX(M))
                      IF (((YCROSS.GT.YY1.AND.YCROSS.LT.YY2).OR.
     1              (YCROSS.LT.YY1.AND.YCROSS.GT.YY2)).AND.
     2              ((XCROSS.GT.LX(M).AND.XCROSS.LT.NX(M)).OR.
     3              (XCROSS.LT.LX(M).AND.XCROSS.GT.NX(M)))) THEN
                        IF ((OBJDIST(M).EQ.-1).OR.(OBJDIST(M).GT.
     1                SQRT((XCROSS-LX(M))**2+(YCROSS-
     2                LY(M))**2))) THEN
                          OBJDIST(M)=SQRT((XCROSS-LX(M))**2+
     1                  (YCROSS-LY(M))**2)
                          C=SQRT((YY2-LY(M))**2+(XX2-LX(M))**2)
                          B=SQRT((YY2-YCROSS)**2+(XX2-XCROSS)**2)
                          A=SQRT((YCROSS-LY(M))**2+(XCROSS-
     1                  LX(M))**2)
                          OBJANGLE(M)=ACOS((A**2+B**2-C**2)/(2*A*B))
                          IF (OBJANGLE(M).GT.3.1416/2) OBJANGLE(M)=
     1                  3.1416-OBJANGLE(M)
                        ENDIF
                      ENDIF
                    ENDIF
                  ENDIF
27            CONTINUE
26          CONTINUE
*
*     Calculates the accelerations induced by meeting objects
*
            OBJD=0
            IF (OBJDIST(1).NE.-1.AND.OBJDIST(2).NE.-1) THEN
              IF (OBJANGLE(1).EQ.OBJANGLE(2)) THEN
                OBJD=1
                OBJA=OBJANGLE(1)
              ELSE
                OBJD=1
                OBJA=3.1416/2
              ENDIF
            ELSEIF (OBJDIST(1).NE.-1) THEN
              OBJD=1
              OBJA=3.1416/2
            ELSEIF (OBJDIST(2).NE.-1) THEN
              OBJD=1
              OBJA=3.1416/2
            ENDIF
*
*     Check if object lies entirely in vehicle's path
*
            IF (OBJD.EQ.0) THEN
              COORD(1,1)=NX(1)
              COORD(1,2)=NY(1)
              COORD(2,1)=NX(2)
              COORD(2,2)=NY(2)
              COORD(3,1)=LX(2)
              COORD(3,2)=LY(2)
              COORD(4,1)=LX(1)
              COORD(4,2)=LY(1)
              COORD(5,1)=NX(1)
```

```
            COORD(5,2)=NY(1)
            CONTROL=0
            DO 30 I=1,4
              CONTROL=CONTROL+COORD(I,1)*COORD(I+1,2)
              CONTROL=CONTROL-COORD(I+1,1)*COORD(I,2)
30         CONTINUE
            CONTROL=ABS(CONTROL)
            DO 40 I=1,4
              TESTAREA=0
              DO 50 J=1,4
                IF (I.EQ.J) THEN
                  TESTAREA=TESTAREA+COORD(J,1)*YY1
                  TESTAREA=TESTAREA+XX1*COORD(J+1,2)
                  TESTAREA=TESTAREA-XX1*COORD(J,2)
                  TESTAREA=TESTAREA-COORD(J+1,1)*YY1
                ELSE
                  TESTAREA=TESTAREA+COORD(I,1)*COORD(I+1,2)
                  TESTAREA=TESTAREA-COORD(I+1,1)*COORD(I,2)
                ENDIF
50           CONTINUE
              TESTAREA=ABS(TESTAREA)
              IF (TESTAREA.GT.CONTROL) GOTO 45
40         CONTINUE
            OBJD=1
            OBJA=3.1416/2
          ENDIF
*
*   Rigid objects
*
45       IF (OBJD.EQ.1) THEN
            IF (THTYP(ISET,K).EQ.'R') THEN
              IF (VMASS(MODEL(ISET)).GT.1500) THEN
                ACCEL=ACCEL-(1.325*VELOCITY*SIN(OBJA)-
     1        1.325*VELOCITY*COS(OBJA)*SIN(OBJA))*G
              ELSE
                ACCEL=ACCEL-(1.325*VELOCITY*SIN(OBJA)+
     1        1.325*VELOCITY*COS(OBJA)*SIN(OBJA))*
     2        (270.0*EXP(-3.5*VELOCITY**0.10))*G
              ENDIF
*
*   Deformable objects
*
            ELSEIF (THTYP(ISET,K).EQ.'D') THEN
              IF (VMASS(MODEL(ISET)).GT.1500) THEN
                ACCEL=ACCEL-(1.325*VELOCITY*THM(ISET,K)/100*
     1        SIN(OBJA)-1.325*VELOCITY*THM(ISET,K)/100*
     2        COS(OBJA)*SIN(OBJA))*G
              ELSE
                ACCEL=ACCEL-(1.325*VELOCITY*THM(ISET,K)/100*
     1        SIN(OBJA)+1.325*VELOCITY*THM(ISET,K)/100*
     2        COS(OBJA)*SIN(OBJA))*
     3        (640.0*EXP(-3.6*VELOCITY**0.12))*G
              ENDIF

*
*   Passable objects
*
```

```
*
*     Passable objects
*
                ELSE
                  IF (VMASS(MODEL(ISET)).GT.1500) THEN
                    ACCEL=ACCEL-(3.6*EXP(1.46*(VELOCITY*
     1          SIN(OBJA))**0.34)/(9.8*VELOCITY*
     2          SIN(OBJA))-3.6*EXP(1.46*(VELOCITY*
     3          COS(OBJA))**0.34)/(9.8*VELOCITY*
     4          COS(OBJA)*SIN(OBJA)))*G
                  ELSE
                    ACCEL=ACCEL-(3.6*EXP(1.46*(VELOCITY*
     1          SIN(OBJA))**0.34)/(9.8*VELOCITY*
     2          SIN(OBJA))+3.6*EXP(1.46*(VELOCITY*
     3          COS(OBJA))**0.34)/(9.8*VELOCITY*
     4          COS(OBJA)*SIN(OBJA)))*
     5          640.0*EXP(-3.6*VELOCITY**0.12)*G
                  ENDIF
                ENDIF
                PASTOBJ(K)=1
              ENDIF
            ENDIF
25    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FLY(ISET)
*
*     This subroutine initiates flying at terrain changes
*
      INTEGER ISET
      INCLUDE 'RHSM.INS'
*
*     If flying off shoulder
*
      IF (TSTRIP.EQ.1) THEN
         IF (TA(ISET,TSTRIP).LT.0) THEN
           VVERT=VELOCITY*SIN(VANGLE)
           FLYING=1
           KINENER=0
           FLYTIME=0
           IF (ANGLE.LE.ATAN(TRACK(MODEL(ISET))/WBASE(MODEL(ISET))))
     1     THEN
              DISP=TRACK(MODEL(ISET))/4-WBASE(MODEL(ISET))**2/(12*
     1        TRACK(MODEL(ISET)))*(TAN(ANGLE))**2
           ELSE
              DISP=WBASE(MODEL(ISET))**2/(6*WBASE(MODEL(ISET))*
     1        TAN(ANGLE))
           ENDIF
         ENDIF
*
*     If flying off one terrain strip over another
*
      ELSE
         IF (TA(ISET,TSTRIP).LT.TA(ISET,OTSTRIP)) THEN
           VVERT=VELOCITY*SIN(VANGLE)
           FLYING=1
           KINENER=0
           FLYTIME=0
           IF (ANGLE.LE.ATAN(TRACK(MODEL(ISET))/WBASE(MODEL(ISET))))
     1     THEN
              DISP=TRACK(MODEL(ISET))/4-WBASE(MODEL(ISET))**2/(12*
     1        TRACK(MODEL(ISET)))*(TAN(ANGLE))**2
           ELSE
              DISP=WBASE(MODEL(ISET))**2/(6*WBASE(MODEL(ISET))*
     1        TAN(ANGLE))
           ENDIF
         ENDIF
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE DYNROLL(ISET,ROLL,DIVEIN)
*
*     This subroutine monitors airborne vehicles and checks for
*     rolling upon landing
*
      INTEGER DIVEIN,ISET,ROLL
      REAL POTENER,VINCIDENCE
      INCLUDE 'RHSM.INS'
*
*     If vehicle has not yet landed
*
      ROLL=0
      DIVEIN=0
      IF (ELEVATION.GT.GROUND) THEN
            KINENER=KINENER+0.5*(6*G*DISP)/(WBASE(MODEL(ISET))**2+
     1   TRACK(MODEL(ISET))**2)*TI(ISET)
            FLYTIME=FLYTIME+TI(ISET)
*
*     If vehicle has landed
*
      ELSE
*
*     Check for rolling
*
            FLYING=0
            INCIANGLE=3.1416-VANGLE-ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE))
            IF (INCIANGLE.GT.3.1416/2) INCIANGLE=3.1416-INCIANGLE
            IF (FLYTIME.GT.0) THEN
              POTENER=VMASS(MODEL(ISET))*(CG(MODEL(ISET))**2+
     1      TRACK(MODEL(ISET))**2/4)**0.5*(1-SIN(INCIANGLE+
     2      ATAN(2*CG(MODEL(ISET))/TRACK(MODEL(ISET)))))
              IF (KINENER.GT.POTENER) THEN
*
*     Vehicle rolls
*
                NROLLS(ISET)=NROLLS(ISET)+1
                NIROL(ISET)=NIROL(ISET)+1
                ROLL=1
*
*     Vehicle does not roll
*
              ELSE
                VINCIDENCE=-VELOCITY*SIN(INCIANGLE)
                IF (TA(ISET,TSTRIP).LT.0) THEN
                  ACCEL=ACCEL-(0.8662-0.1852*VINCIDENCE*TAN(INCIANGLE)+
     1          0.256*(VINCIDENCE*TAN(INCIANGLE))**2-1)*G*
     2          TM(ISET,TSTRIP)
                ELSE
                  ACCEL=ACCEL-(0.8637+0.4961*VINCIDENCE*TAN(INCIANGLE)+
     1          0.07288*(VINCIDENCE*TAN(INCIANGLE))**2-1)*G*
     2          TM(ISET,TSTRIP)
                ENDIF
                VELOCITY=VELOCITY+ACCEL*TI(ISET)/2
                PWR=ABS(VELOCITY*ACCEL)
                VELOCITY=VELOCITY+ACCEL*TI(ISET)/2
                DIVEIN=1
              ENDIF
            ENDIF
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE STATROLL(ISET,ROLL)
*
*     This subroutine checks for rolling on slopes
*
      INTEGER ISET,ROLL
      REAL VCRIT
      INCLUDE 'RHSM.INS'
*
*     Outwards roll (if back steering)
      ROLL=0
      IF ((STEER(ISET).GT.0.AND.ATAN(TAN(TA(ISET,TSTRIP))*
     1 SIN(ANGLE+3.1416/2)).GE.0).OR.(STEER(ISET).LT.0.AND.
     2 ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE-3.1416/2)).GE.0)) THEN
            IF (ABS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE-3.1416/2))).GT.
     1   ATAN(TRACK(MODEL(ISET))/(2*CG(MODEL(ISET))))) THEN
               VCRIT=0
            ELSE
               VCRIT=SQRT((VMASS(MODEL(ISET))*G*
     1      (COS(ABS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE+3.1416/2))))*
     2      TRACK(MODEL(ISET))/2-SIN(ABS(ATAN(TAN(TA(ISET,TSTRIP))*
     3      SIN(ANGLE+3.1416/2))))*CG(MODEL(ISET)))/CG(MODEL(ISET)))*
     4      WBASE(MODEL(ISET))/(VMASS(MODEL(ISET))*ABS(STEER(ISET))))
            ENDIF
*
*     Static roll (back steering)
            IF (VELOCITY.GT.VCRIT) THEN
               NROLLS(ISET)=NROLLS(ISET)+1
               NJROL(ISET)=NJROL(ISET)+1
               ROLL=1
            ENDIF
*
*     Inwards roll (back steering)
*
      ELSEIF ((STEER(ISET).GT.0.AND.ATAN(TAN(TA(ISET,TSTRIP))*
     1 SIN(ANGLE+3.1416/2)).LT.0).OR.(STEER(ISET).LT.0.AND.
     2 ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE-3.1416/2)).LT.0)) THEN
            IF (ABS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE-3.1416/2))).GT.
     1   ATAN(TRACK(MODEL(ISET))/(2*CG(MODEL(ISET))))) THEN
               VCRIT=SQRT((VMASS(MODEL(ISET))*G*
     1      (-COS(ABS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE+3.1416/2))))*
     2      TRACK(MODEL(ISET))/2+SIN(ABS(ATAN(TAN(TA(ISET,TSTRIP))*
     3      SIN(ANGLE+3.1416/2))))*CG(MODEL(ISET)))/CG(MODEL(ISET)))*
     4      WBASE(MODEL(ISET))/(VMASS(MODEL(ISET))*ABS(STEER(ISET))))
            ENDIF
*
*     Static roll
            IF (VELOCITY.LT.VCRIT) THEN
               NROLLS(ISET)=NROLLS(ISET)+1
               NJROL(ISET)=NJROL(ISET)+1
               ROLL=1
            ENDIF
*
*     If not back steering
*
      ELSEIF (ABS(ATAN(TAN(TA(ISET,TSTRIP))*SIN(ANGLE-3.1416/2))).GT.
     1 ATAN(TRACK(MODEL(ISET))/(2*CG(MODEL(ISET))))) THEN
            NROLLS(ISET)=NROLLS(ISET)+1
            NJROL(ISET)=NJROL(ISET)+1
            ROLL=1
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE CONSEQ(ISET,ROLL)
*
*     This subroutine determines the consequences of power values
*     and rolling
*
      INCLUDE 'RHSM.INS'
*
*     Calculate outcome probabilities using probability of
*     consequences table
*
      IF (ROLL.EQ.0) THEN
         IF (PWR.LT.PLA(1,1)) THEN
           PPDO=(PLA(1,3)*(1-REST(ISET))+PLA(1,5)*REST(ISET))*PWR/
     1     PLA(1,1)
           PFAT=(PLA(1,4)*(1-REST(ISET))+PLA(1,6)*REST(ISET))*PWR/
     1     PLA(1,1)
           PND=1-(1-PLA(1,2))*PWR/PLA(1,1)
           PINJ=1-PPDO-PFAT-PND
         ELSE
           DO 70 K=2,NPLA
             IF (PWR.LT.PLA(K,1)) THEN
               PPDO=PLA(K-1,3)*(1-REST(ISET))+PLA(K-1,5)*REST(ISET)+
     1         (PWR-PLA(K-1,1))*(PLA(K,3)*(1-REST(ISET))+PLA(K,5)*
     2         REST(ISET)-PLA(K-1,3)*(1-REST(ISET))-PLA(K-1,5)*
     3         REST(ISET))/(PLA(K,1)-PLA(K-1,1))
               PFAT=PLA(K-1,4)*(1-REST(ISET))+PLA(K-1,6)*REST(ISET)+
     1         (PWR-PLA(K-1,1))*(PLA(K,4)*(1-REST(ISET))+PLA(K,6)*
     2         REST(ISET)-PLA(K-1,4)*(1-REST(ISET))-PLA(K-1,6)*
     3         REST(ISET))/(PLA(K,1)-PLA(K-1,1))
               PND=PLA(K-1,2)+(PWR-PLA(K-1,1))*(PLA(K,2)-PLA(K-1,2))/
     1         (PLA(K,1)-PLA(K-1,1))
               PINJ=1-PPDO-PFAT-PND
               RETURN
             ENDIF
70         CONTINUE
         ENDIF
*
*     Vehicle rolls
*
      ELSE
         IF (VELOCITY.LT.VEL(1)) THEN
           PPDO=(RP1(1,1)*(1-REST(ISET))+RP2(1,1)*REST(ISET))*
     1     VELOCITY/VEL(1)
           PFAT=(RP1(1,2)*(1-REST(ISET))+RP2(1,2)*REST(ISET))*
     1     VELOCITY/VEL(1)
           PND=0
           PINJ=1-PPDO-PFAT-PND
           VELOCITY=0
           ACCEL=0
         ELSE
           DO 55 K=2,NVEL
             IF (VELOCITY.LT.VEL(K)) THEN
               PPDO=RP1(K-1,1)*(1-REST(ISET))+RP2(K-1,1)*REST(ISET)+
     1         (VELOCITY-VEL(K-1))*(RP1(K,1)*(1-REST(ISET))+RP2(K,1)*
     2         REST(ISET)-RP1(K-1,1)*(1-REST(ISET))-RP2(K-1,1)*
     3         REST(ISET))/(VEL(K)-VEL(K-1))
               PFAT=RP1(K-1,2)*(1-REST(ISET))+RP2(K-1,2)*REST(ISET)+
     1         (VELOCITY-VEL(K-1))*(RP1(K,2)*(1-REST(ISET))+RP2(K,2)*
     2         REST(ISET)-RP1(K-1,2)*(1-REST(ISET))-RP2(K-1,2)*
     3         REST(ISET))/(VEL(K)-VEL(K-1))
```

```
            PND=0
            PINJ=1-PPDO-PFAT-PND
            VELOCITY=0
            ACCEL=0
            RETURN
          ENDIF
55      CONTINUE
        ENDIF
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE ECONRUN(ISET)
*
*     This subroutine performs economic analyses for specific input sets
*
      INTEGER ISET,STRIP1,STRIP2
      REAL BASE(5),ELEV1,ELEV2
      INCLUDE 'RHSM.INS'
      DATA BASE /0.25, 0.25, 0.2, 0.35, 0.4/
*
*     Calculate encroachment rate (if neccesary)
*
      IF (ENCRATE.LE.0) ENCRATE = ADT/1000*BASE(RDCLASS)*
     1 RCADJUST(RDCLASS)*DSADJUST(DESSPD)*LWADJUST(LANEWID)*
     2 NLADJUST(NUMLANE)*SWADJUST(SHLDWID)*HCADJUST(HORCURVE)*
     3 VCADJUST(VERCURVE)*CADJUST(CLIMATE)*TADJUST(TRAFFIC)*
     4 SADJUST(SIGHT)
*
*     Calculate total accident costs
*
      TACCOST(ISET)=0
      DO 10 I=1,4
         TACCOST(ISET)=TACCOST(ISET)+ENCRATE*DATA(ISET,I)*(ACCOST(1,I)+
     1   ACCOST(2,I))
10    CONTINUE
*
*     Calculate mitigation costs
*
      MITCOST(ISET)=0
*
*     Barriers
*
      IF (ISET.GT.1) THEN
         IF (BARRIER(ISET).EQ.1) THEN
           MITCOST(ISET)=MITCOST(ISET)+BINSTALL(ISET)+BMAINT(ISET)*
     1    ((1+INTEREST/100)**PERIOD-1)/(INTEREST/100*
     2    (1+INTEREST/100)**PERIOD)
         ENDIF
*
*     Slope changes
*
         IF (SLOPE(ISET).EQ.1) THEN
           STRIP1=0
           STRIP2=0
           ELEV1=0
           ELEV2=0
           CUT(ISET)=0
           FILL(ISET)=0
           DO 20 A=1,20,1
30          IF (A.GT.TY(1,STRIP1+1).AND.(TY(1,STRIP1+1).NE.0.OR.
     1      STRIP1.EQ.0)) THEN
               STRIP1=STRIP1+1
               GOTO 30
             ENDIF
40          IF (A.GT.TY(ISET,STRIP2+1).AND.(TY(ISET,STRIP2+1).NE.0.
     1      OR.STRIP2.EQ.0)) THEN
               STRIP2=STRIP2+1
               GOTO 40
             ENDIF
             OLDELEV1=ELEV1
             OLDELEV2=ELEV2
             IF (STRIP1.GT.0) ELEV1=ELEV1+1*TAN(TA(1,STRIP1)*RAD)
             IF (STRIP2.GT.0) ELEV2=ELEV2+1*TAN(TA(ISET,STRIP2))
```

```
          IF (ELEV1.GT.ELEV2) CUT(ISET)=CUT(ISET)+
     1      ((ELEV1+OLDELEV1)/2-(ELEV2+OLDELEV2)/2)*1*100
          IF (ELEV2.GT.ELEV1) FILL(ISET)=FILL(ISET)+
     1      ((ELEV2+OLDELEV2)/2-(ELEV1+OLDELEV1)/2)*
     1      1*100
20      CONTINUE

        MITCOST(ISET)=MITCOST(ISET)+CUT(ISET)*CUTCOST+FILL(ISET)*
     1  FILLCOST
        IF (CUT(ISET).GT.FILL(ISET)) MITCOST(ISET)=MITCOST(ISET)+
     1  (CUT(ISET)-FILL(ISET))*WASTCOST
        IF (FILL(ISET).GT.CUT(ISET)) MITCOST(ISET)=MITCOST(ISET)+
     1  (FILL(ISET)-CUT(ISET))*ADFCOST
       ENDIF
*
*   Object removal costs
*
       IF (OREMOVE(ISET).EQ.1) THEN
        DO 50 I=1,3
          MITCOST(ISET)=MITCOST(ISET)+NREMOVE(ISET,I)*
     1    CREMOVE(ISET,I)
50      CONTINUE
       ENDIF
*
*   Right of way acquisition
*
       IF (ROW(ISET).EQ.1) MITCOST(ISET)=MITCOST(ISET)+COSTROW(ISET)
      ENDIF
*
*   Maintenance costs
*
      MITCOST(ISET)=MITCOST(ISET)+CFMAINT(ISET)*
     1 ((1+INTEREST/100)**PERIOD-1)/(INTEREST/100*
     2 (1+INTEREST/100)**PERIOD)
      RETURN
      END
```

```
      SUBROUTINE DISPLAY
*
*     This subroutine displays results of RHSM on the screen
*
      INTEGER CHOICE,CONSQ,ECONTYPE,DOLLAR,ISET,NUMPTS(2),VANTAGE
      REAL MAXX,MAXY,MINX,MINY,X(100),Y(100),Z(100,100)
      CHARACTER*1 CH
      CHARACTER*9 ZTITLE
      CHARACTER*17 XTITLE,YTITLE
      CHARACTER*80 TTLE
      INCLUDE 'RHSM.INS'
      COMMON / GRPH3D / NUMPTS,X,Y,Z,XTITLE,YTITLE,ZTITLE,TTLE
*
*     Menu screens
*
      DOLLAR=0
      IF (BC.EQ.1) THEN
           ECONTYPE=0
      ELSEIF (CE.EQ.1) THEN
           ECONTYPE=1
      ELSE
           ECONTYPE=-1
      ENDIF

      WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY1/'
      READ (*,10) CHOICE
10    FORMAT (I3)
*
*     Load first display screen
*
      IF (CHOICE.EQ.1) THEN
           CALL CURSOROFF
           IPAGE=1
1       IF (ICHAR(TITLE(IPAGE)(1:1)).NE.0.AND.ICHAR(TITLE(IPAGE)(1:1)).
     1  NE.32) THEN
             CALL CLRSCR
             WRITE (*,20) TITLE(IPAGE)
20         FORMAT (1X,A50)

             WRITE (*,*)
             WRITE (*,80)
80         FORMAT (2X,'Simulation Results')
             WRITE (*,90) NCALLS(IPAGE)
90         FORMAT (7X,'Total Number of Trajectories          = ',I5)
             WRITE (*,100) NROLLS(IPAGE)
100        FORMAT (7X,'Total Number of Rolls                 = ',I5)
             IF (NROLLS(IPAGE).GT.0) WRITE (*,105) REAL(NROLLS(IPAGE))/
     1     REAL(NCALLS(IPAGE))
105        FORMAT (9X,'Probability of Vehicle Roll-Over     = ',F5.2)
             WRITE (*,110) NIROL(IPAGE)
110        FORMAT (7X,'Number of Rolls at Terrain Change      = ',I5)
             IF (NROLLS(IPAGE).GT.0) WRITE (*,120) REAL(NIROL(IPAGE))/
     1     REAL(NCALLS(IPAGE))
120        FORMAT (9X,'Probability of Rolls @ Terrain Change = ',F5.2)
             WRITE (*,130) NJROL(IPAGE)
130        FORMAT (7X,'Number of Rolls on Slope              = ',I5)
             IF (NROLLS(IPAGE).GT.0) WRITE (*,140) REAL(NJROL(IPAGE))/
     1     REAL(NCALLS(IPAGE))
140        FORMAT (9X,'Probability of Roll-Over on Slope    = ',F5.2)
             WRITE (*,*)
             WRITE (*,150)
```

```
150     FORMAT (2X,'Aggregated Probability of Overall Accident ',
  1    'Consequence Classification')
         WRITE (*,160) DATA(IPAGE,1)
160     FORMAT (7X,'No Damage            = ',F7.3)
         WRITE (*,170) DATA(IPAGE,2)
170     FORMAT (7X,'Property Damage Only = ',F7.3)
         WRITE (*,180) DATA(IPAGE,3)
180     FORMAT (7X,'Injury               = ',F7.3)
         WRITE (*,190) DATA(IPAGE,4)
190     FORMAT (7X,'Fatality             = ',F7.3)
         WRITE (*,*)
         WRITE (*,201)
201     FORMAT (2X,'Economic Evaluation Factors')
         IF (ECONTYPE.EQ.0) THEN
           WRITE (*,203) ENCRATE
203       FORMAT (7X,'Encroachment Rate (events/km/y) = ',F10.2)
         ENDIF
         IF (DOLLAR.EQ.0) THEN
           IF (ECONTYPE.EQ.0) THEN
             WRITE (*,205) TACCOST(IPAGE)
205         FORMAT (7X,'Total Accident Costs (PV$/km)   = ',F10.2)
           ELSEIF (ECONTYPE.EQ.1) THEN
             WRITE (*,207) (SEVERITY(1)*DATA(IPAGE,1)+SEVERITY(2)*
  1         DATA(IPAGE,2)+SEVERITY(3)*DATA(IPAGE,3)+SEVERITY(4)*
  2         DATA(IPAGE,4))*ENCRATE
207         FORMAT (7X,'Total Severity (/km/year)       = ',F12.0)
           ENDIF
           IF (ECONTYPE.EQ.0.OR.ECONTYPE.EQ.1) THEN
             WRITE (*,210) MITCOST(IPAGE)
210         FORMAT (7X,'Total Mitigation Costs (PV$/km) = ',F10.2)
             CALL GOTOXY (1,23)
             WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
  1         ' results, <$> for annual costs'
           ELSE
             CALL GOTOXY (1,23)
             WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
  1         ' results'
           ENDIF
         ELSE
           IF (ECONTYPE.EQ.0) THEN
             WRITE (*,206) TACCOST(IPAGE)*INTEREST/100*
  1         (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1)
206         FORMAT (7X,'Total Accident Costs ($/km/yr)   = ',F10.2)
           ELSEIF (ECONTYPE.EQ.1) THEN
             WRITE (*,207) (SEVERITY(1)*DATA(IPAGE,1)+SEVERITY(2)*
  1         DATA(IPAGE,2)+SEVERITY(3)*DATA(IPAGE,3)+SEVERITY(4)*
  2         DATA(IPAGE,4))*ENCRATE
           ENDIF
           IF (ECONTYPE.EQ.0.OR.ECONTYPE.EQ.1) THEN
             WRITE (*,211) MITCOST(IPAGE)*INTEREST/100*
  1         (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1)
211         FORMAT (7X,'Total Mitigation Costs ($/km/yr) = ',
  1         F10.2)
             CALL GOTOXY (1,23)
             WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
  1         ' results, <$> for present value costs'
           ELSE
             CALL GOTOXY (1,23)
             WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
  1         ' results'
           ENDIF
         ENDIF
```

```
      IF (ECONTYPE.EQ.0.AND.CE.EQ.1) THEN
        WRITE (*,*) '  <CTRL><C> for cost effect. results,'//
1      ' or <CTRL><X> or <ESC> to exit.'
      ELSEIF (ECONTYPE.EQ.1.AND.BC.EQ.1) THEN
        WRITE (*,*) '  <CTRL><B> for benefit cost results,'//
1      ' or <CTRL><X> or <ESC> to exit.'
      ELSE
        WRITE (*,*) ' or <CTRL><X> or <ESC> to exit'
      ENDIF
195   CALL GETKEYBOARD(CH,II)
      IF (II.EQ.73) THEN
        IPAGE=IPAGE-1
        IF (IPAGE.EQ.0) THEN
          IF (ECONTYPE.EQ.0.OR.ECONTYPE.EQ.1) THEN
            GOTO 496
          ELSE
            GOTO 396
          ENDIF
        ENDIF
        GOTO 1
      ELSEIF (II.EQ.81) THEN
        IPAGE=IPAGE+1
        IF (IPAGE.EQ.11) GOTO 196
        GOTO 1
      ELSEIF (II.EQ.1.OR.II.EQ.45) THEN
        CALL CURSORON
        RETURN
      ELSEIF (ICHAR(CH).EQ.36) THEN
        IF (DOLLAR.EQ.0) THEN
          DOLLAR=1
        ELSE
          DOLLAR=0
        ENDIF
        GOTO 1
      ELSEIF (II.EQ.48.AND.ECONTYPE.EQ.1.AND.BC.EQ.1) THEN
        ECONTYPE=0
        GOTO 1
      ELSEIF (II.EQ.46.AND.ECONTYPE.EQ.0.AND.CE.EQ.1) THEN
        ECONTYPE=1
        GOTO 1
      ELSE
        GOTO 195
      ENDIF
    ELSEIF (II.EQ.73) THEN
      IPAGE=IPAGE-1
      GOTO 1
    ELSEIF (IPAGE.LE.10.AND.II.EQ.81) THEN
      IPAGE=IPAGE+1
      GOTO 1
    ENDIF

196 CALL CLRSCR
      WRITE (*,230) 1
230 FORMAT (1X,'Summary of Results (Page ',I1,' of 3)')
      WRITE (*,*)
      WRITE (*,233)
233 FORMAT (2x,'Summary of Accident Consequence Probabilities')
      WRITE (*,240) TITLE(1)
240 FORMAT (3X,'(and differences from ',A16,')')
      WRITE (*,*)
      WRITE (*,250)
```

```
250     FORMAT (6X,'Alternatives',7X,'No Damage',7X,'P.D.O.',8X,
   1  'Injury',7X,'Fatality')
          WRITE (*,255)
255     FORMAT (6X,72('_'))
          WRITE (*,*)
          WRITE (*,260) TITLE(1),DATA(1,1),DATA(1,2),DATA(1,3),DATA(1,4)
260     FORMAT (6X,A16,2X,F4.2,10X,F4.2,10X,F4.2,10X,F4.2)
          DO 270 I=2,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).NE.
   1     32) THEN
              WRITE (*,280) TITLE(I),DATA(I,1),DATA(I,1)-DATA(1,1),
   1        DATA(I,2),DATA(I,2)-DATA(1,2),DATA(I,3),DATA(I,3)-
   2        DATA(1,3),DATA(I,4),DATA(I,4)-DATA(1,4)
280         FORMAT (6X,A16,4(2X,F4.2,1X,'(',F5.2,')'))
            ENDIF
270     CONTINUE
          CALL GOTOXY (1,23)
          WRITE (*,*) 'Press <PGUP> or <PGDN> to page through results'
          WRITE (*,*) '  or <CTRL><X> or <ESC> to exit.'
320     CALL GETKEYBOARD(CH,II)
          IF (II.EQ.73) THEN
            IPAGE=10
            GOTO 1
          ELSEIF (II.EQ.81) THEN
            GOTO 396
          ELSEIF (II.EQ.1.OR.II.EQ.45) THEN
            CALL CURSORON
            RETURN
          ELSE
            GOTO 320
          ENDIF

396     CALL CLRSCR
          WRITE (*,230) 2
          WRITE (*,*)
          WRITE (*,282)
282     FORMAT (2X,'Summary of Vehicle Roll-Over Probabilities')
          WRITE (*,*)
          WRITE (*,290)
290     FORMAT (25X,'Total Roll-Overs',3X,'Rolls on Slope',4X,
   1  'Roll @ Terrain Chg')
          WRITE (*,300)
300     FORMAT (6X,'Alternatives',7X,'Number',2X,'(Prob.)',4X,
   1  'Number',2X,'(Prob.)',4X,'Number',2X,'(Prob.)')
          WRITE (*,305)
305     FORMAT (6X,74('_'))
          WRITE (*,*)
          IF (NROLLS(1).GT.0) THEN
            WRITE (*,301) TITLE(1),NROLLS(1),REAL(NROLLS(1))/
   1     REAL(NCALLS(1)),NJROL(1),REAL(NJROL(1))/REAL(NCALLS(1)),
   2     NIROL(1),REAL(NIROL(1))/REAL(NCALLS(1))
301       FORMAT (6X,A16,3X,I5,3X,'(',F5.2,')',2(4X,I5,3X,'(',F5.2,
   1     ')'))
          ELSE
            WRITE (*,306) TITLE(1)
306       FORMAT (6X,A16,3X,'    0',14X,'    0',14X,'    0')
          ENDIF
```

```
          DO 310 I=2,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
     1    NE.32) THEN
              IF (NROLLS(I).GT.0) THEN
                IF (NROLLS(1).GT.0) THEN
                  WRITE (*,308) TITLE(I),NROLLS(I),REAL(NROLLS(I))/
     1        REAL(NCALLS(I)),NJROL(I),REAL(NJROL(I))/
     2        REAL(NCALLS(I)),NIROL(I),REAL(NIROL(I))/
     3        REAL(NCALLS(I))
308            FORMAT (6X,A16,3X,I5,3X,'(',F5.2,')',2(4X,I5,3X,
     1        '(',F5.2,')'))
                ELSE
                  WRITE (*,308) TITLE(I),NROLLS(I),REAL(NROLLS(I))/
     1        REAL(NCALLS(I)),NJROL(I),REAL(NJROL(I))/
     2        REAL(NCALLS(I)),NIROL(I),REAL(NIROL(I))/
     3        REAL(NCALLS(I))
                ENDIF
              ELSE
                WRITE (*,306) TITLE(I)
              ENDIF
            ENDIF
310     CONTINUE
          CALL GOTOXY (1,23)
          WRITE (*,*) 'Press <PGUP> or <PGDN> to page through results'
          WRITE (*,*) ' or <CTRL><X> or <ESC> to exit.'
420     CALL GETKEYBOARD(CH,II)
          IF (II.EQ.73) THEN
            GOTO 196
          ELSEIF (II.EQ.81) THEN
            IPAGE=1
            IF (ECONTYPE.EQ.0.OR.ECONTYPE.EQ.1) THEN
              GOTO 496
            ELSE
              GOTO 1
            ENDIF
          ELSEIF (II.EQ.1.OR.II.EQ.45) THEN
            CALL CURSORON
            RETURN
          ELSE
            GOTO 420
          ENDIF

496     IF (ECONTYPE.EQ.0) THEN
            CALL CLRSCR
            WRITE (*,230) 3
            WRITE (*,*)
            WRITE (*,500)
500       FORMAT(2X,'Economic Evaluation of Improvement Alternatives')
            WRITE (*,502) TITLE(1)
502       FORMAT (4X,'Relative Accident Savings & Relative Mitigatn',
     1    ' costs are wrt: ',A16)
            WRITE (*,510)
510       FORMAT (42X,'Relative',2X,'Relative')
            WRITE (*,515)
515       FORMAT (22X,'Accident',2X,'Mitigatn',2X,'Accident',2X,
     1    'Mitigatn',4X,'B-C',5X,'Net')
            WRITE (*,517)
517       FORMAT (24X,'Costs',5X,'Costs',4X,'Savings',4X,'Costs',4X,
     1    'Ratio',2X,'Benefit')
            IF (DOLLAR.EQ.0) THEN
              WRITE (*,520)
```

```
520         FORMAT (6X,'Alternatives',6X,3('(PV$)',5X),'(PV$)',12X,
    1      '(PV$)')
            ELSE
              WRITE (*,525)
525         FORMAT (6X,'Alternatives',4X,4('($/year)',2X),8X,
    1      '($/year)')
            ENDIF
            WRITE (*,530)
530        FORMAT (6X,72('_'))
            WRITE (*,*)
            IF (DOLLAR.EQ.0) THEN
              WRITE (*,540) TITLE(1),TACCOST(1),MITCOST(1)
540         FORMAT (6X,A16,2(F9.0,1X))
            ELSE
              WRITE (*,540) TITLE(1),TACCOST(1)*INTEREST/100*
    1      (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1),
    2      MITCOST(1)*INTEREST/100*(1+INTEREST/100)**PERIOD/
    3      ((1+INTEREST/100)**PERIOD-1)
            ENDIF
            DO 550 I=2,10
              IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
    1      NE.32) THEN
                IF (DOLLAR.EQ.0) THEN
                  IF (MITCOST(I).NE.MITCOST(1)) THEN
                    WRITE (*,543) TITLE(I),TACCOST(I),MITCOST(I),
    1          TACCOST(1)-TACCOST(I),MITCOST(I)-MITCOST(1),
    2          (TACCOST(1)-TACCOST(I))/(MITCOST(I)-MITCOST(1)),
    3          (TACCOST(1)-TACCOST(I))-(MITCOST(I)-MITCOST(1))
543              FORMAT (6X,A16,4(F9.0,1X),1X,F5.2,1X,F9.0)
                  ELSE
                    WRITE (*,545) TITLE(I),TACCOST(I),MITCOST(I),
    1          TACCOST(1)-TACCOST(I),MITCOST(I)-MITCOST(1),
    2          (TACCOST(1)-TACCOST(I))-(MITCOST(I)-MITCOST(1))
545              FORMAT (6X,A16,4(F9.0,1X),1X,'----',1X,F9.0)
                  ENDIF
                ELSE
                  IF (MITCOST(I).NE.MITCOST(1)) THEN
                    WRITE (*,543) TITLE(I),TACCOST(I)*INTEREST/100*
    1          (1+INTEREST/100)**PERIOD/
    2          ((1+INTEREST/100)**PERIOD-1),MITCOST(I)*
    3          INTEREST/100*(1+INTEREST/100)**PERIOD/
    4          ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
    5          TACCOST(I))*INTEREST/100*
    6          (1+INTEREST/100)**PERIOD/
    7          ((1+INTEREST/100)**PERIOD-1),(MITCOST(I)-
    8          MITCOST(1))*INTEREST/100*
    9          (1+INTEREST/100)**PERIOD/
    1          ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
    2          TACCOST(I))/(MITCOST(I)-MITCOST(1)),
    3          ((TACCOST(1)-TACCOST(I))-(MITCOST(I)-
    4          MITCOST(1)))*INTEREST/100*
    5          (1+INTEREST/100)**PERIOD/
    3          ((1+INTEREST/100)**PERIOD-1)
                  ELSE
                    WRITE (*,545) TITLE(I),TACCOST(I)*INTEREST/100*
    1          (1+INTEREST/100)**PERIOD/
    2          ((1+INTEREST/100)**PERIOD-1),MITCOST(I)*
    3          INTEREST/100*(1+INTEREST/100)**PERIOD/
    4          ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
    5          TACCOST(I))*INTEREST/100*
    6          (1+INTEREST/100)**PERIOD/
    7          ((1+INTEREST/100)**PERIOD-1),(MITCOST(I)-
```

```
     8          MITCOST(1))*INTEREST/100*
     9          (1+INTEREST/100)**PERIOD/
     1          ((1+INTEREST/100)**PERIOD-1),((TACCOST(1)-
     2          TACCOST(I))-(MITCOST(I)-MITCOST(1)))*
     3          INTEREST/100*(1+INTEREST/100)**PERIOD/
     4          ((1+INTEREST/100)**PERIOD-1)
                  ENDIF
                ENDIF
              ENDIF
550     CONTINUE
*
*  Display cost effectiveness summary
*
         ELSEIF (ECONTYPE.EQ.1) THEN
           CALL SETSCREENMODE(16)
*
*  Determine graph scales
*
           MAXY=(SEVERITY(1)*DATA(1,1)+SEVERITY(2)*DATA(1,2)+
     1     SEVERITY(3)*DATA(1,3)+SEVERITY(4)*DATA(1,4))*ENCRATE
           MINY=(SEVERITY(1)*DATA(1,1)+SEVERITY(2)*DATA(1,2)+
     1     SEVERITY(3)*DATA(1,3)+SEVERITY(4)*DATA(1,4))*ENCRATE
           MAXX=MITCOST(1)
           MAXISET=1
           MINX=MITCOST(1)
           MINISET=1
           DO 600 I=1,10
             IF (ICHAR(TITLE(I)).NE.0.AND.ICHAR(TITLE(I)).NE.32) THEN
               IF ((SEVERITY(1)*DATA(I,1)+SEVERITY(2)*
     1         DATA(I,2)+SEVERITY(3)*DATA(I,3)+SEVERITY(4)*
     2         DATA(I,4))*ENCRATE.GT.MAXY) MAXY=(SEVERITY(1)*
     3         DATA(I,1)+SEVERITY(2)*DATA(I,2)+SEVERITY(3)*
     4         DATA(I,3)+SEVERITY(4)*DATA(I,4))*ENCRATE
               IF ((SEVERITY(1)*DATA(I,1)+SEVERITY(2)*
     1         DATA(I,2)+SEVERITY(3)*DATA(I,3)+SEVERITY(4)*
     2         DATA(I,4))*ENCRATE.LT.MINY) MINY=(SEVERITY(1)*
     3         DATA(I,1)+SEVERITY(2)*DATA(I,2)+SEVERITY(3)*
     4         DATA(I,3)+SEVERITY(4)*DATA(I,4))*ENCRATE
               IF (MITCOST(I).GT.MAXX) THEN
                 MAXX=MITCOST(I)
                 MAXISET=I
               ENDIF
               IF (MITCOST(I).LT.MINX) THEN
                 MINX=MITCOST(I)
                 MINISET=I
               ENDIF
               CALL GOTOXY (1,2+I)
               WRITE (*,605) I,TITLE(I)
605            FORMAT (61X,I2,1X,A16)
             ENDIF
600        CONTINUE
           MAXY=MAXY*1.1
           MINY=MINY*0.9
           MAXX=MAXX*1.1
           MINX=MINX*0.9
           IF (MAXX.EQ.MINX) MAXX=MINX+1
           IF (MAXY.EQ.MINY) MAXY=MINY+1
```

```
*
*    Draw graph outline and axes
*
           CALL DRAW (40,40,40,250,7)
           CALL DRAW (40,250,480,250,7)
           CALL GOTOXY (1,2)
           WRITE (*,620) MAXY
620       FORMAT (F10.2)
           CALL GOTOXY (1,7)
           WRITE (*,635) 'S'
635       FORMAT (1X,A1)
           WRITE (*,635) 'E'
           WRITE (*,635) 'V'
           WRITE (*,635) 'E'
           WRITE (*,635) 'R'
           WRITE (*,635) 'I'
           WRITE (*,635) 'T'
           WRITE (*,635) 'Y'
           CALL GOTOXY (1,19)
           WRITE (*,620) MINY
           CALL GOTOXY (1,20)
           IF (DOLLAR.EQ.0) THEN
             WRITE (*,640) MINX,MAXX
640         FORMAT (4X,F10.3,5X,'MITIGATION COST (PV$/km)',6X,F10.3)
           ELSE
             WRITE (*,645) MINX*INTEREST/100*(1+INTEREST/100)**PERIOD/
  1        ((1+INTEREST/100)**PERIOD-1),MAXX*INTEREST/100*
  2        (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1)
645         FORMAT (4X,F10.3,4X,'MITIGATION COST ($/km/yr)',4X,F10.3)
           ENDIF
           CALL GOTOXY (1,1)
           WRITE (*,650)
650       FORMAT (1X,'COST EFFECTIVENESS EVALUATION',36X,
  1       'ALTERNATIVES')
*
*    Plot points on graph
*
           ICOLOUR=9
           DO 660 I=1,10
             IF (ICHAR(TITLE(I)).NE.0.AND.ICHAR(TITLE(I)).NE.32) THEN
               IX=40+(MITCOST(I)-MINX)/(MAXX-MINX)*440
               IY=250-((SEVERITY(1)*DATA(I,1)+SEVERITY(2)*
  1           DATA(I,2)+SEVERITY(3)*DATA(I,3)+SEVERITY(4)*
  2           DATA(I,4))*ENCRATE-MINY)/(MAXY-MINY)*210
               CALL CIRCLE (IX,IY,2,ICOLOUR)
               IX=IX*80/640+1
               IY=IY*25/350
               CALL GOTOXY(IX,IY)
               WRITE (CH,670) I
670           FORMAT (I1)
               CALL PUTCHATTR(CH,0,ICOLOUR,1)
               ICOLOUR=ICOLOUR+1
               IF (ICOLOUR.EQ.16) ICOLOUR=9
             ENDIF
660       CONTINUE
         ENDIF

         CALL GOTOXY (1,23)
         IF (DOLLAR.EQ.0) THEN
           WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
  1      ' results, <$> for an. costs & savings'
```

```
          ELSE
            WRITE (*,*) 'Press <PGUP> or <PGDN> to page through'//
     1      ' results, <$> for PV costs & savings'
          ENDIF
          IF (ECONTYPE.EQ.0.AND.CE.EQ.1) THEN
            WRITE (*,*) '  <CTRL><C> for cost effect. results,'//
     1      ' or <CTRL><X> or <ESC> to exit.'
          ELSEIF (BC.EQ.1) THEN
            WRITE (*,*) '  <CTRL><B> for benefit cost results,'//
     1      ' or <CTRL><X> or <ESC> to exit.'
          ENDIF
560     CALL GETKEYBOARD(CH,II)
          CALL SETSCREENMODE(3)
          IF (II.EQ.73) THEN
            GOTO 396
          ELSEIF (II.EQ.81) THEN
            IPAGE=1
            GOTO 1
          ELSEIF (II.EQ.1.OR.II.EQ.45) THEN
            CALL CURSORON
            RETURN
          ELSEIF (ICHAR(CH).EQ.36) THEN
            IF (DOLLAR.EQ.1) THEN
              DOLLAR=0
            ELSE
              DOLLAR=1
            ENDIF
            GOTO 496
          ELSEIF (II.EQ.48.AND.ECONTYPE.EQ.1.AND.BC.EQ.1) THEN
            ECONTYPE=0
            GOTO 496
          ELSEIF (II.EQ.46.AND.ECONTYPE.EQ.0.AND.CE.EQ.1) THEN
            ECONTYPE=1
            GOTO 496
          ELSE
            GOTO 560
          ENDIF
          GOTO 496
*
*     Graph results
*
      ELSEIF (CHOICE.EQ.2) THEN
*
*     Choose input set
*
435     WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY2/'
          DO 430 I=1,10
            DO 430 J=1,50
              CALL GOTOXY (21+J,7+I)
              CALL PUTCHAR(TITLE(I)(J:J),1)
430     CONTINUE
440     WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY4/'
          READ (*,10) ISET
          IF (ISET.EQ.11) RETURN
          IF (ICHAR(TITLE(ISET)(1:1)).EQ.0.OR.ICHAR(TITLE(ISET)(1:1)).
     1  EQ.32) GOTO 440
*
*     Choose consequence category
*
          WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY3/'
          READ (*,10) CONSQ
          IF (CONSQ.EQ.4) GOTO 435
```

```
*
*     Choose vantage point
*
            WRITE (*,*) CHAR(255),CHAR(255),'DISPLAY5/'
            READ (*,10) VANTAGE
            IF (VANTAGE.EQ.5) GOTO 435
*
*     Set graph variables
*
            IF (VANTAGE.EQ.1) THEN
              XTITLE=' DIST. FROM ROAD'
              YTITLE='DIST. ALONG ROAD'
              NUMPTS(1)=10
              NUMPTS(2)=50
              DO 460 I=1,10
                X(I)=19-(I-1)*2
                DO 460 J=1,50
                  Y(J)=99-(J-1)*2
                  Z(I,J)=SPRES(ISET,50-J+1,10-I+1,CONSQ)*100
460         CONTINUE
              IF (CONSQ.EQ.1) WRITE (TTLE,450) ISET,'Top Left',
     1      'Property Damage Only'
450         FORMAT (1X,'Input Set ',I2,2X,A9,' Vantage Point',2X,A22)
              IF (CONSQ.EQ.2) WRITE (TTLE,450) ISET,'Top Left','Injuries'
              IF (CONSQ.EQ.3) WRITE (TTLE,450) ISET,'Top Left',
     1      'Fatalities'
            ELSEIF (VANTAGE.EQ.2) THEN
              XTITLE='DIST. ALONG ROAD'
              YTITLE=' DIST. FROM ROAD'
              NUMPTS(1)=50
              NUMPTS(2)=10
              DO 470 I=1,50
                X(I)=99-(I-1)*2
                DO 470 J=1,10
                  Y(J)=J*2-1
                  Z(I,J)=SPRES(ISET,50-I+1,J,CONSQ)*100
470         CONTINUE
              IF (CONSQ.EQ.1) WRITE (TTLE,450) ISET,'Bot Left',
     1      'Property Damage Only'
              IF (CONSQ.EQ.2) WRITE (TTLE,450) ISET,'Bot Left','Injuries'
              IF (CONSQ.EQ.3) WRITE (TTLE,450) ISET,'Bot Left',
     1      'Fatalities'
            ELSEIF (VANTAGE.EQ.3) THEN
              XTITLE='DIST. ALONG ROAD'
              YTITLE=' DIST. FROM ROAD'
              NUMPTS(1)=50
              NUMPTS(2)=10
              DO 480 I=1,50
                X(I)=I*2-1
                DO 480 J=1,10
                  Y(J)=19-(J-1)*2
                  Z(I,J)=SPRES(ISET,I,10-J+1,CONSQ)*100
480         CONTINUE
              IF (CONSQ.EQ.1) WRITE (TTLE,450) ISET,'Top Right',
     1      'Property Damage Only'
              IF (CONSQ.EQ.2) WRITE (TTLE,450) ISET,'Top Right','Injuries'
              IF (CONSQ.EQ.3) WRITE (TTLE,450) ISET,'Top Right',
     1      'Fatalities'
```

```
          ELSE
            XTITLE=' DIST. FROM ROAD'
            YTITLE='DIST. ALONG ROAD'
            NUMPTS(1)=10
            NUMPTS(2)=50
            DO 490 I=1,10
              X(I)=I*2-1
              DO 490 J=1,50
                Y(J)=J*2-1
                Z(I,J)=SPRES(ISET,J,I,CONSQ)*100
490       CONTINUE
            IF (CONSQ.EQ.1) WRITE (TTLE,450) ISET,'Bot Right',
     1    'Property Damage Only'
            IF (CONSQ.EQ.2) WRITE (TTLE,450) ISET,'Bot Right','Injuries'
            IF (CONSQ.EQ.3) WRITE (TTLE,450) ISET,'Bot Right',
     1    'Fatalities'
          ENDIF
          ZTITLE='PROB.(%)'
*
*    Plot graph
*
          CALL GRAPH3D
          GOTO 435
      ELSE
          RETURN
      ENDIF
      END
```

```
      SUBROUTINE GRAPH3D
*
*     This subroutine is used to plot a three dimensional graph
*
      INTEGER COLOUR,COUNTX,COUNTY,IX1,IX2,IX3,IX4,IY1,IY2,IY3,IY4,
     1 NUMPTS(2)
      REAL GVAL1(20),GVAL2(20),MAXX,MAXY,MAXZ,MINX,MINY,MINZ,
     1 UT(20,20),X(100),XCR,Y(100),YCR,Z(100,100)
      CHARACTER*1 CH
      CHARACTER*9 ZTITLE
      CHARACTER*17 XTITLE,YTITLE
      CHARACTER*80 TITLE
      LOGICAL KYP

      COMMON / GRPH3D / NUMPTS,X,Y,Z,XTITLE,YTITLE,ZTITLE,TITLE
*
*     Determine plot scales
*
      MAXX=X(NUMPTS(1))
      MINX=X(1)
      MAXY=Y(NUMPTS(2))
      MINY=Y(1)
      MAXZ=Z(1,1)
      MINZ=Z(1,1)
      DO 10 I=1,NUMPTS(1)
            DO 10 J=1,NUMPTS(2)
              IF (Z(I,J).GT.MAXZ) MAXZ=Z(I,J)
              IF (Z(I,J).LT.MINZ) MINZ=Z(I,J)
10    CONTINUE
*
*     Calculate plotted points
*
      DO 25 I=1,20
            GVAL1(I)=MINX+(I-1)*(MAXX-MINX)/19
            DO 25 J=1,20
              GVAL2(J)=MINY+(J-1)*(MAXY-MINY)/19
25    CONTINUE
      CALL CLRSCR
      CALL CURSOROFF
      CALL GOTOXY (1,1)
      WRITE (*,*) 'Creating graph ...'
      WRITE (*,*) ' Percentage complete'
      WRITE (*,*)

      COUNTX=1
      DO 27 I=2,NUMPTS(1)
26      COUNTY=1
          IF ((GVAL1(COUNTX).GE.X(I-1).AND.GVAL1(COUNTX).LE.X(I)).OR.
     1  (GVAL1(COUNTX).LE.X(I-1).AND.GVAL1(COUNTX).GE.X(I))) THEN
            DO 28 J=2,NUMPTS(2)
29          IF ((GVAL2(COUNTY).GE.Y(J-1).AND.GVAL2(COUNTY).LE.Y(J)).
     1      OR.(GVAL2(COUNTY).LE.Y(J-1).AND.GVAL2(COUNTY).GE.Y(J)))
     2      THEN
                UT(COUNTX,COUNTY)=Z(I,J)*(GVAL1(COUNTX)-X(I-1))/
     1        (X(I)-X(I-1))*(GVAL2(COUNTY)-Y(J-1))/(Y(J)-Y(J-1))+
     2        Z(I-1,J)*(X(I)-GVAL1(COUNTX))/(X(I)-X(I-1))*
     3        (GVAL2(COUNTY)-Y(J-1))/(Y(J)-Y(J-1))+Z(I,J-1)*
     4        (GVAL1(COUNTX)-X(I-1))/(X(I)-X(I-1))*
     5        (Y(J)-GVAL2(COUNTY))/(Y(J)-Y(J-1))+Z(I-1,J-1)*
     6        (X(I)-GVAL1(COUNTX))/(X(I)-X(I-1))*(Y(J)-
     7        GVAL2(COUNTY))/(Y(J)-Y(J-1))
```

```
            IF (COUNTY.LT.20) THEN
              COUNTY=COUNTY+1
              CALL GOTOXY(1,4)
              WRITE (*,*) ((COUNTX-1)*20+COUNTY)*100/400
              CALL KEYPRESSED(KYP)
              IF (KYP) THEN
                CALL GETKEYBOARD(CH,II)
                IF (II.EQ.1) RETURN
              ENDIF
              GOTO 29
            ENDIF
          ENDIF
28      CONTINUE
          IF (COUNTX.LT.20) THEN
            COUNTX=COUNTX+1
            GOTO 26
          ENDIF
        ENDIF
27    CONTINUE
      CALL CURSORON
*
*     Draw axes
*
      CALL CLRSCR
      CALL SETSCREENMODE(16)
      CALL GOTOXY (1,7)
      WRITE (*,30) MAXZ
30    FORMAT (F10.3)
      CALL GOTOXY (1,9)
      DO 40 I=1,9
        WRITE (*,50) ZTITLE(I:I)
50      FORMAT (1X,A1)
40    CONTINUE
      CALL GOTOXY (1,18)
      WRITE (*,30) MINZ
      CALL GOTOXY (1,24)
      WRITE (*,60) MINY,MINX
60    FORMAT (30X,F10.3,4X,F10.3)
      CALL GOTOXY (1,22)
      WRITE (*,70) YTITLE,XTITLE
70    FORMAT (13X,A17,27X,A17)
      CALL GOTOXY (1,20)
      WRITE (*,80) MAXY,MAXX
80    FORMAT (F10.3,57X,F10.3)
      CALL DRAW (40,108,40,242,7)
      CALL DRAW (40,242,340,310,7)
      CALL DRAW (340,310,640,242,7)
*
*     Plot curves
*
      DO 90 I=20,2,-1
        IY2=310-(GVAL1(I)-MINX)*68/(MAXX-MINX)-68-
     1  (UT(I,20)-MINZ)/(MAXZ-MINZ)*135
        IX2=340+(GVAL1(I)-MINX)*300/(MAXX-MINX)-300
        IY4=310-(GVAL1(I-1)-MINX)*68/(MAXX-MINX)-68-
     1  (UT(I-1,20)-MINZ)/(MAXZ-MINZ)*135
        IX4=340+(GVAL1(I-1)-MINX)*300/(MAXX-MINX)-300
        CALL DRAW (IX2,IY2,IX4,IY4,5)
        DO 90 J=19,1,-1
          CALL KEYPRESSED(KYP)
          IF (KYP) THEN
```

```
          CALL GETKEYBOARD(CH,II)
          IF (II.EQ.1) THEN
            CALL SETSCREENMODE(3)
            RETURN
          ENDIF
        ENDIF
        IY1=310-(GVAL1(I)-MINX)*68/(MAXX-MINX)-
     1  (GVAL2(J)-MINY)*68/(MAXY-MINY)-(UT(I,J)-MINZ)/(MAXZ-MINZ)*
     2  135
        IX1=340+(GVAL1(I)-MINX)*300/(MAXX-MINX)-
     1  (GVAL2(J)-MINY)*300/(MAXY-MINY)
        IY3=310-(GVAL1(I-1)-MINX)*68/(MAXX-MINX)-
     1  (GVAL2(J)-MINY)*68/(MAXY-MINY)-(UT(I-1,J)-MINZ)/(MAXZ-MINZ)*
     2  135
        IX3=340+(GVAL1(I-1)-MINX)*300/(MAXX-MINX)-
     1  (GVAL2(J)-MINY)*300/(MAXY-MINY)
        CALL DRAW (IX1,IY1,IX2,IY2,5)
        CALL DRAW (IX3,IY3,IX4,IY4,5)
        CALL DRAW (IX1,IY1,IX3,IY3,5)
        CALL DRAW (IX2,IY2,IX4,IY4,5)
*
*   Colour squares
*
        IF (IY2.GT.IY3) THEN
          COLOUR=1
        ELSE
          COLOUR=15
        ENDIF
        XCR=0
        YCR=0
        IF (IX1-IX2.NE.0.AND.IX3-IX4.NE.0) THEN
          IF ((IY1-IY2)/(IX1-IX2)-(IY3-IY4)/(IX3-IX4).NE.0) THEN
            XCR=(IY3-IY1+(IY1-IY2)/(IX1-IX2)*IX1-(IY3-IY4)/
     1      (IX3-IX4)*IX3)/((IY1-IY2)/(IX1-IX2)-(IY3-IY4)/
     2      (IX3-IX4))
            YCR=IY1+(IY1-IY2)/(IX1-IX2)*(XCR-IX1)
          ENDIF
        ELSEIF (IX1-IX2.NE.0) THEN
          XCR=IX3
          YCR=IY1+(IY1-IY2)/(IX1-IX2)*(XCR-IX1)
        ELSEIF (IX3-IX4.NE.0) THEN
          XCR=IX1
          YCR=IY3+(IY3-IY4)/(IX3-IX4)*(XCR-IX3)
        ENDIF

        IF (((XCR.GT.IX1.AND.XCR.LT.IX2).OR.(XCR.GT.IX2.AND.
     1  XCR.LT.IX1)).AND.((XCR.GT.IX3.AND.XCR.LT.IX4).OR.
     2  (XCR.GT.IX4.AND.XCR.LT.IX3)).AND.((YCR.GT.IY1.AND.YCR.
     3  LT.IY2).OR.(YCR.GT.IY2.AND.YCR.LT.IY1)).AND.((YCR.GT.
     4  IY3.AND.YCR.LT.IY4).OR.(YCR.GT.IY4.AND.YCR.LT.IY3)))
     5  THEN
          IF (ABS(IX1*IY3+IX3*YCR+XCR*IY1-IX3*IY1-XCR*IY3-
     1    IX1*YCR).GT.50) THEN
            IF ((SQRT(REAL(IX1-IX3)**2+REAL(IY1-IY3)**2)+
     1      SQRT(REAL(IX3-XCR)**2+REAL(IY3-YCR)**2)+
     2      SQRT(REAL(IX1-XCR)**2+REAL(IY1-YCR)**2))/
     3      ABS(IX1*IY3+IX3*YCR+XCR*IY1-IX3*IY1-XCR*IY3-
     4      IX1*YCR).LT.1) THEN
              CALL FILLSHAPE((IX1+IX3+XCR)/3,
     1        (IY1+IY3+YCR)/3,3,5)
              CALL FILLSHAPE((IX1+IX3+XCR)/3,
     1        (IY1+IY3+YCR)/3,COLOUR,5)
```

```
            ENDIF
          ENDIF
          IF (ABS(IX4*IY2+IX2*YCR+XCR*IY4-IX2*IY4-XCR*IY2-
     1    IX4*YCR).GT.50) THEN
            IF ((SQRT(REAL(IX4-IX2)**2+REAL(IY4-IY2)**2)+
     1      SQRT(REAL(IX2-XCR)**2+REAL(IY2-YCR)**2)+
     2      SQRT(REAL(IX4-XCR)**2+REAL(IY4-YCR)**2))/
     3      ABS(IX4*IY2+IX2*YCR+XCR*IY4-IX2*IY4-XCR*IY2-
     4      IX4*YCR).LT.1) THEN
              CALL FILLSHAPE((IX2+IX4+XCR)/3,
     1        (IY2+IY4+YCR)/3,3,5)
              CALL FILLSHAPE((IX2+IX4+XCR)/3,
     1        (IY2+IY4+YCR)/3,COLOUR,5)
            ENDIF
          ENDIF
        ELSE
          XCR=0
          YCR=0
          IF (IX1-IX3.NE.0.AND.IX2-IX4.NE.0) THEN
            IF ((IY1-IY3)/(IX1-IX3)-(IY2-IY4)/(IX2-IX4).
     1      NE.0) THEN
              XCR=(IY2-IY1+(IY1-IY3)/(IX1-IX3)*IX1-
     1        (IY2-IY4)/(IX2-IX4)*IX2)/((IY1-IY3)/
     2        (IX1-IX3)-(IY2-IY4)/(IX2-IX4))
              YCR=IY1+(IY1-IY3)/(IX1-IX3)*(XCR-IX1)
            ENDIF
          ELSEIF (IX1-IX3.NE.0) THEN
            XCR=IX2
            YCR=IY1+(IY1-IY3)/(IX1-IX3)*(XCR-IX1)
          ELSEIF (IX2-IX4.NE.0) THEN
            XCR=IX1
            YCR=IY2+(IY2-IY4)/(IX2-IX4)*(XCR-IX2)
          ENDIF
          IF (((XCR.GT.IX1.AND.XCR.LT.IX3).OR.(XCR.GT.IX3.
     1    AND.XCR.LT.IX1)).AND.((XCR.GT.IX2.AND.XCR.LT.
     2    IX4).OR.(XCR.GT.IX4.AND.XCR.LT.IX2)).AND.((YCR.
     3    GT.IY1.AND.YCR.LT.IY3).OR.(YCR.GT.IY3.AND.YCR.
     4    LT.IY1)).AND.((YCR.GT.IY2.AND.YCR.LT.IY4).OR.
     5    (YCR.GT.IY4.AND.YCR.LT.IY2))) THEN
            IF (ABS(IX1*IY2+IX2*YCR+XCR*IY1-IX2*IY1-XCR*IY2-
     1      IX1*YCR).GT.50) THEN
              IF ((SQRT(REAL(IX1-IX2)**2+REAL(IY1-IY2)**2)+
     1        SQRT(REAL(IX2-XCR)**2+REAL(IY2-YCR)**2)+
     2        SQRT(REAL(IX1-XCR)**2+REAL(IY1-YCR)**2))/
     3        ABS(IX1*IY2+IX2*YCR+XCR*IY1-IX2*IY1-XCR*IY2-
     4        IX1*YCR).LT.1) THEN
                CALL FILLSHAPE((IX1+IX2+XCR)/3,
     1          (IY1+IY2+YCR)/3,3,5)
                CALL FILLSHAPE((IX1+IX2+XCR)/3,
     1          (IY1+IY2+YCR)/3,COLOUR,5)
              ENDIF
            ENDIF
            IF (ABS(IX4*IY3+IX3*YCR+XCR*IY4-IX3*IY4-XCR*IY3-
     1      IX4*YCR).GT.50) THEN
              IF ((SQRT(REAL(IX4-IX3)**2+REAL(IY4-IY3)**2)+
     1        SQRT(REAL(IX3-XCR)**2+REAL(IY3-YCR)**2)+
     2        SQRT(REAL(IX4-XCR)**2+REAL(IY4-YCR)**2))/
     3        ABS(IX4*IY3+IX3*YCR+XCR*IY4-IX3*IY4-XCR*IY3-
     4        IX4*YCR).LT.1) THEN
                CALL FILLSHAPE((IX3+IX4+XCR)/3,
     1          (IY3+IY4+YCR)/3,3,5)
                CALL FILLSHAPE((IX3+IX4+XCR)/3,
```

```
     1              (IY3+IY4+YCR)/3,COLOUR,5)
                  ENDIF
                ENDIF
              ELSEIF (ABS(IX1*IY2+IX2*IY4+IX4*IY3+IX3*IY1-
     1       IY1*IX2-IY2*IX4-IY4*IX3-IY3*IX1).EQ.
     2       ABS(IX1*IY4+IX4*IY3+IX3*IY1-IY1*IX4-IY4*IX3-
     3       IY3*IX1)+ABS(IX1*IY2+IX2*IY4+IX4*IY1-IY1*IX2-
     4       IY2*IX4-IY4*IX1)) THEN
                IF (ABS(IX1*IY4+IX4*IY3+IX3*IY1-IY1*IX4-IY4*IX3-
     1         IY3*IX1).GT.50.AND.ABS(IX1*IY2+IX2*IY4+IX4*IY1-
     2         IY1*IX2-IY2*IX4-IY4*IX1).GT.50) THEN
                  IF ((SQRT(REAL(IX4-IX3)**2+
     1           REAL(IY4-IY3)**2)+SQRT(REAL(IX3-IX1)**2+
     2           REAL(IY3-IY1)**2)+SQRT(REAL(IX4-IX1)**2+
     3           REAL(IY4-IY1)**2))/ABS(IX1*IY4+IX4*IY3+
     4           IX3*IY1-IY1*IX4-IY4*IX3-IY3*IX1).LT.1.AND.
     5           (SQRT(REAL(IX4-IX2)**2+REAL(IY4-IY2)**2)+
     6           SQRT(REAL(IX2-IX1)**2+REAL(IY2-IY1)**2)+
     7           SQRT(REAL(IX4-IX1)**2+REAL(IY4-IY1)**2))/
     8           ABS(IX1*IY2+IX2*IY4+IX4*IY1-IY1*IX2-IY2*IX4-
     9           IY4*IX1).LT.1) THEN
                    CALL FILLSHAPE((IX1+IX4)/2,
     1             (IY1+IY4)/2,3,5)
                    CALL FILLSHAPE((IX1+IX4)/2,
     1             (IY1+IY4)/2,COLOUR,5)
                    GOTO 130
                  ENDIF
                ENDIF
              ENDIF
              IF (ABS(IX2*IY3+IX3*IY1+IX1*IY2-IY2*IX3-IY3*IX1-
     1       IY1*IX2).GT.50.AND.ABS(IX2*IY4+IX4*IY3+IX3*IY2-
     2       IY2*IX4-IY4*IX3-IY3*IX2).GT.50) THEN
                IF ((SQRT(REAL(IX3-IX1)**2+REAL(IY3-IY1)**2)+
     1         SQRT(REAL(IX1-IX2)**2+REAL(IY1-IY2)**2)+
     2         SQRT(REAL(IX3-IX2)**2+REAL(IY3-IY2)**2))/
     3         ABS(IX2*IY3+IX3*IY1+IX1*IY2-IY2*IX3-IY3*IX1-
     4         IY1*IX2).LT.1.AND.(SQRT(REAL(IX3-IX4)**2+
     5         REAL(IY3-IY4)**2)+SQRT(REAL(IX4-IX2)**2+
     6         REAL(IY4-IY2)**2)+SQRT(REAL(IX3-IX2)**2+
     7         REAL(IY3-IY2)**2))/ABS(IX2*IY4+IX4*IY3+IX3*IY2-
     8         IY2*IX4-IY4*IX3-IY3*IX2).LT.1) THEN
                  CALL FILLSHAPE((IX2+IX3)/2,(IY2+IY3)/2,3,5)
                  CALL FILLSHAPE((IX2+IX3)/2,(IY2+IY3)/2,
     1           COLOUR,5)
                ENDIF
              ENDIF
            ENDIF
130       CALL DRAW (IX1,IY1,IX2,IY2,10)
            CALL DRAW (IX3,IY3,IX4,IY4,10)
            CALL DRAW (IX1,IY1,IX3,IY3,10)
            CALL DRAW (IX2,IY2,IX4,IY4,10)
            IY2=IY1
            IX2=IX1
            IY4=IY3
            IX4=IX3
90    CONTINUE
*
*     Write headings
*
```

```
*
*    Write headings
*
      CALL GOTOXY(1,1)
      WRITE (*,160) TITLE
160   FORMAT (1X,A80)
      CALL GETKEYBOARD(CH,II)
      CALL SETSCREENMODE(3)
      RETURN
      END
```

```
      SUBROUTINE PRINT
*
*     This subroutine prints input(s) and results to a file or to the
*     printer
*
      INTEGER CODE,CF,DAY,HOUR,LINENO,MINUTE,MONTH,POS,YEAR
      CHARACTER*1 CH
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
*
*     Output options screen
*
1     WRITE (*,*) CHAR(255),CHAR(255),'PRINT/'
      FIELD(1)=OUTMODE
      FIELD(2)=PAUSE
      FIELD(3)=OUTPUTF
      DO 10 I=1,10
            FIELD(I+3)=OPTION(I)
10    CONTINUE
      FILNAM='PRINT'
      CODE=0
      CF=0
      POS=0
15    CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.NE.1.AND.CODE.NE.31) GOTO 15
      OUTMODE=FIELD(1)
      PAUSE=FIELD(2)
      OUTPUTF=FIELD(3)
      DO 20 I=1,10
            OPTION(I)=FIELD(I+3)
20    CONTINUE
      IF (CODE.EQ.1) RETURN

      IF (OUTMODE.EQ.'P') THEN
            OPEN (10,FILE='LPT1',ERR=1000)
      ELSE
            OPEN (10,FILE=OUTPUTF,ERR=1500)
      ENDIF
*
*     Title on page 1
*
      IF (OUTMODE.EQ.'P') THEN
            CALL CLRSCR
            DO 25 I=1,15
              WRITE (10,*)
25          CONTINUE
      ENDIF
      WRITE (10,29)
29    FORMAT (20X,42('_'))
      WRITE (10,*)
      WRITE (10,30)
30    FORMAT (24X,'ROADSIDE HAZARDS SIMULATION MODEL')
      WRITE (10,40)
40    FORMAT (24X,' Transport Canada Road Safety')
      WRITE (10,*)
      WRITE (10,45)
45    FORMAT (20X,42('_'))
      WRITE (10,*)
      WRITE (10,50)
50    FORMAT (24X,'   RHSM Version 9 (June 1992)')
```

```
      WRITE (10,56)
56    FORMAT (24X,'        developed by')
      WRITE (10,51)
51    FORMAT (20X,'BC Ministry of Transportation and Highways')
      WRITE (10,52)
52    FORMAT (24X,'    Highway Safety Branch')
      WRITE (10,53)
53    FORMAT (24X,'             and')
      WRITE (10,54)
54    FORMAT (24X,' University of British Columbia')
      WRITE (10,55)
55    FORMAT (24X,'    Transportation Studies')
      WRITE (10,*)
      WRITE (10,57)
57    FORMAT (20X,42('_'))
      WRITE (10,*)
      CALL DATE(YEAR,MONTH,DAY)
      CALL TIME(HOUR,MINUTE,II,IJ)
      WRITE (10,60) DAY,MONTH,YEAR
60    FORMAT (33X,'Date: ',I2,'/',I2,'/',I4)
      IF (MINUTE.GE.10) THEN
            WRITE (10,70) HOUR,MINUTE
70       FORMAT (35X,'Time: ',I2,':',I2)
      ELSE
            WRITE (10,80) HOUR,MINUTE
80       FORMAT (35X,'Time: ',I2,':0',I1)
      ENDIF
      WRITE (10,*)
      WRITE (10,83)
83    FORMAT (20X,42('_'))
      IF (OUTMODE.EQ.'P') THEN
            WRITE (10,85)
85       FORMAT ('1')
            IF (PAUSE.EQ.'Y') THEN
              WRITE (*,*) ' Press any key to continue printing ...'
              CALL GETKEYBOARD(CH,II)
            ENDIF
      ENDIF
      LINENO=0
      WRITE (10,90)
90    FORMAT (6X,'INPUT DATA ',60('*'))
      WRITE (10,*)
      LINENO=LINENO+2
*
*     Output operating data
*
      DO 110 I=1,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
     1  NE.32) THEN
              WRITE (10,120) TITLE(I)
120         FORMAT (7X,A50)
              WRITE (10,*)
              IF (OPTION(1).EQ.'Y') THEN
                WRITE (10,100)
100           FORMAT (8X,'Operational Data')
                WRITE (10,*)
                WRITE (10,130) 'Time Increment                ',
     1          IDEF(I,1),TI(I),'s          '
130           FORMAT (12X,A30,10X,A1,4X,F9.4,1X,A11)
                WRITE (10,130) 'Maximum Trajectory Time       ',
     1          IDEF(I,2),TMAX(I),'s          '
```

```
          WRITE (10,130) 'Minimum Halt Speed          ',
     1    IDEF(I,3),VMIN(I),'m/s      '
          WRITE (10,135) 'Number of Origin Points     ',
     1    IDEF(I,4),MITER(I)
135       FORMAT (12X,A30,10X,A1,4X,I4)
          WRITE (10,130) 'Increment of Origin Shift   ',
     1    IDEF(I,5),XINCR(I),'m        '
          WRITE (10,130) 'Mean Speed                  ',
     1    IDEF(I,7),VMEAN(I),'kph      '
          WRITE (10,130) 'Standard Deviation of Speed ',
     1    IDEF(I,8),VSD(I),'kph      '
          WRITE (10,130) 'Speed Increment in S.Dev.   ',
     1    IDEF(I,9),VINCR(I),'s.d.     '
          WRITE (10,130) 'Angle Change Increment      ',
     1    IDEF(I,10),AINCR(I),'deg.     '
          WRITE (10,130) 'Minimum Probability Considered',
     1    IDEF(I,11),PMIN(I),' '
          WRITE (10,130) 'Brake Application           ',
     1    IDEF(I,12),BRAKE(I),'%        '
          WRITE (10,130) 'Percentage Seatbelt Use     ',
     1    IDEF(I,13),REST(I),'%        '
          WRITE (10,130) 'Steer Back Angle            ',
     1    IDEF(I,17),STEER(I),'deg.     '
          IF (HCURVE(I).EQ.1) WRITE (10,150) '*','Straight'
          IF (HCURVE(I).EQ.2) WRITE (10,150) ' ',' Gentle'
          IF (HCURVE(I).EQ.3) WRITE (10,150) ' ','Moderate'
          IF (HCURVE(I).EQ.4) WRITE (10,150) ' ',' Severe'
150       FORMAT (12X,'Horizontal Curvature',20X,A1,5X,A8)
          WRITE (10,135) 'Vehicle Model               ',
     1    IDEF(I,19),MODEL(I)
          WRITE (10,*)
          LINENO=LINENO+18
        ENDIF
*
*    Output terrain data
*
        IF (OPTION(2).EQ.'Y') THEN
          IF (LINENO+7+NT(I).GT.60) THEN
            IF (OUTMODE.EQ.'P') THEN
              WRITE (10,85)
              IF (PAUSE.EQ.'Y') THEN
                WRITE (*,*) ' Press any key to continue ',
     1          'printing ...'
                CALL GETKEYBOARD(CH,II)
              ENDIF
            ENDIF
            LINENO=0
          ENDIF
          WRITE (10,155)
155       FORMAT (8X,'Terrain Data   (Terrain Change Points)')
          WRITE (10,*)
          WRITE (10,170)
170       FORMAT (12X,'Lateral',10X,'Slope',10X,'Terrain',9X,
     1    'Rolling')
          WRITE (10,180)
180       FORMAT (12X,'Offset (m)',7X,'Angle (Deg)',4X,
     1    'Resistance',6X,'Resistance')
          WRITE (10,190)
190       FORMAT (12X,58('_'))
          WRITE (10,*)
```

```
            DO 200 J=1,NT(I)
              WRITE (10,210) TY(I,J),TA(I,J),TM(I,J),TR(I,J)
210          FORMAT (12X,F6.3,10X,F7.3,2(10X,F6.4))
200         CONTINUE
            WRITE (10,*)
            LINENO=LINENO+7+NT(I)
          ENDIF
*
*    Output object data
*
          IF (OPTION(3).EQ.'Y') THEN
            IF (LINENO+7+NO(I).GT.60) THEN
              IF (OUTMODE.EQ.'P') THEN
                WRITE (10,85)
                IF (PAUSE.EQ.'Y') THEN
                  WRITE (*,*) ' Press any key to continue ',
     1            'printing ...'
                  CALL GETKEYBOARD(CH,II)
                ENDIF
              ENDIF
              LINENO=0
            ENDIF
            WRITE (10,220)
220         FORMAT (8X,'Object Data')
            WRITE (10,*)
            WRITE (10,230)
230         FORMAT (12X,' End Point 1',6X,' End Point 2',5X,
     1      'Object',4X,'Object',4X,'Friction')
            WRITE (10,240)
240         FORMAT (12X,2('X (m)',3X,'Y (m)',5X),'Width',4X,
     1      ' Type ',4X,'  Code  ')
            WRITE (10,245)
245         FORMAT (12X,63('_'))
            WRITE (10,*)
            DO 250 J=1,NO(I)
              WRITE (10,260) THX1(I,J),THY1(I,J),THX2(I,J),
     1        THY2(I,J),THWID(I,J),THTYP(I,J),THM(I,J)
260           FORMAT (12X,F5.1,3X,F5.1,5X,F5.1,3X,F5.1,5X,
     1        F5.1,7X,A1,8X,F5.1)
250         CONTINUE
            WRITE (10,*)
            LINENO=LINENO+7+NO(I)
          ENDIF

          IF (OUTMODE.EQ.'P') THEN
            WRITE (10,85)
            IF (PAUSE.EQ.'Y') THEN
              WRITE (*,*) ' Press any key to continue ',
     1        'printing ...'
              CALL GETKEYBOARD(CH,II)
            ENDIF
          ENDIF
          LINENO=0
        ENDIF
110   CONTINUE
*
*    Output departure angles
*
      IF (OPTION(4).EQ.'Y') THEN
        WRITE (10,269)
269     FORMAT (2X,'CALIBRATION DATA ',77('*'))
        WRITE (10,*)
```

```
        WRITE (10,270)
270   FORMAT (3X,'Departure Angle Frequency Distributions')
        WRITE (10,*)
        WRITE (10,*)
        DO 275 I=1,4
          IF (I.EQ.1) WRITE (10,276) 'Straight Section'
276     FORMAT (5X,A16)
          IF (I.EQ.2) WRITE (10,276) 'Gentle Curve    '
          IF (I.EQ.3) WRITE (10,276) 'Moderate Curve  '
          IF (I.EQ.4) WRITE (10,276) 'Severe Curve    '
          WRITE (10,*)
          WRITE (10,280)
280     FORMAT (6X,4('Angle',2X,'Freq.',3X),'Angle',2X,'Freq.')
          WRITE (10,283)
283     FORMAT (6X,72('_'))
          DO 290 J=1,7
            WRITE (10,300) 2*((J-1)*5+1),PP(I,(J-1)*5+1),
   1      2*((J-1)*5+2),PP(I,(J-1)*5+2),2*((J-1)*5+3),
   2      PP(I,(J-1)*5+3),2*((J-1)*5+4),PP(I,(J-1)*5+4),
   3      2*((J-1)*5+5),PP(I,(J-1)*5+5)
300       FORMAT (8X,4(I2,3X,F5.0,5X),I2,3X,F5.0)
290     CONTINUE
          WRITE (10,*)
          WRITE (10,*)
          IF (OUTMODE.EQ.'P'.AND.(I.EQ.4)) THEN
            WRITE (10,85)
            IF (PAUSE.EQ.'Y') THEN
              WRITE (*,*) ' Press any key to continue printing ...'
              CALL GETKEYBOARD(CH,II)
            ENDIF
          ENDIF
275   CONTINUE
    ENDIF
*
*   Output Probability Consequence Distribution
*
    IF (OPTION(5).EQ.'Y') THEN
        WRITE (10,310)
310   FORMAT (7X,'Probability of Consequence Table')
        WRITE (10,*)
        WRITE (10,320)
320   FORMAT (21X,'Power',7X,'No',8X,'Unrestrained',8X,'Restrained')
        WRITE (10,330)
330   FORMAT (21X,'(W/kg)',4X,'Damage',6X,'PDO',5X,'Fatal',
   1  7X,'PDO',5X,'Fatal')
        WRITE (10,333)
333   FORMAT (12X,64('_'))
        WRITE (10,*)
        DO 340 I = 1, NPLA
          WRITE (10,350) I, (PLA(I,J), J = 1, 6)
350     FORMAT (12X,I4,F10.0,5(5X,F5.2))
340   CONTINUE
        WRITE (10,*)
        LINENO=LINENO+7+NPLA
    ENDIF
*
*   Output Probability of Roll Table
*
    IF (OPTION(6).EQ.'Y') THEN
        IF (LINENO+7+NVEL.GT.60) THEN
          IF (OUTMODE.EQ.'P') THEN
```

```
                WRITE (10,85)
                IF (PAUSE.EQ.'Y') THEN
                  WRITE (*,*) ' Press any key to continue ',
     1          'printing ...'
                  CALL GETKEYBOARD(CH,II)
                ENDIF
              ENDIF
              LINENO=0
            ENDIF
            WRITE (10,360)
 360      FORMAT (7X,'Roll Consequence Table')
            WRITE (10,*)
            WRITE (10,370)
 370      FORMAT (31X,'Unrestrained',15X,'Restrained')
            WRITE (10,380)
 380      FORMAT (14X,'Speed',2(10X,'PDO',5X,'Fatality'))
            WRITE (10,383)
 383      FORMAT (12X,59('_'))
            WRITE (10,*)
            DO 390 I=1,NVEL
              WRITE (10,400) VEL(I),RP1(I,1),RP1(I,2),RP2(I,1),RP2(I,2)
 400        FORMAT (12X,F7.2,4(6X,F7.5))
 390      CONTINUE
            WRITE (10,*)
            LINENO=LINENO+7+NVEL
      ENDIF
*
*     Output Vehicle Characteristics
*
      IF (OPTION(7).EQ.'Y') THEN
            IF (LINENO+15.GT.60) THEN
              IF (OUTMODE.EQ.'P') THEN
                WRITE (10,85)
                IF (PAUSE.EQ.'Y') THEN
                  WRITE (*,*) ' Press any key to continue ',
     1          'printing ...'
                  CALL GETKEYBOARD(CH,II)
                ENDIF
              ENDIF
              LINENO=0
            ENDIF
            WRITE (10,410)
 410      FORMAT (7X,'Vehicle Characteristics')
            WRITE (10,*)
            WRITE (10,420)
 420      FORMAT (12X,'Vehicle',6X,'Wheel',8X,'Track',8X,' Weight',6X,
     1    'Centre of')
            WRITE (10,430)
 430      FORMAT (12X,'Type',9X,'Base (m)',5X,'Width (m)',4X,
     1    ' (kg)',7X,'Gravity (m)')
            WRITE (10,433)
 433      FORMAT (12X,63('_'))
            WRITE (10,*)
            DO 440 I=1,8
              WRITE (10,450) I,WBASE(I),TRACK(I),VMASS(I),CG(I)
 450        FORMAT (14X,I1,10X,F5.2,8X,F5.2,8X,F8.2,6X,F5.2)
 440      CONTINUE
            WRITE (10,*)
            LINENO=LINENO+15
            WRITE (10,451)
 451      FORMAT (7X,'Economic Evaluation Default Costs and Weights')
            WRITE (10,*)
```

```
      WRITE (10,452)
452   FORMAT (10X,'Accident Costs (B/C Analysis)',4X,'Accident ',
     1 'Importance (C-E Analysis)')
      WRITE (10,453)
453   FORMAT (10X,29('_'),4X,34('_'))
      WRITE (10,*)
      TND=0
      TPDO=0
      TINJ=0
      TFAT=0
      TND=TND+ACCOST(1,1)+ACCOST(2,1)
      TPDO=TPDO+ACCOST(1,2)+ACCOST(2,2)
      TINJ=TINJ+ACCOST(1,3)+ACCOST(2,3)
      TFAT=TFAT+ACCOST(1,4)+ACCOST(2,4)
      WRITE (10,454) TND,SEVERITY(1)
454   FORMAT (15X,'ND  = ',F10.2,13X,'ND  = ',I10)
      WRITE (10,455) TPDO,SEVERITY(2)
455   FORMAT (15X,'PDO = ',F10.2,13X,'PDO = ',I10)
      WRITE (10,456) TINJ,SEVERITY(3)
456   FORMAT (15X,'INJ = ',F10.2,13X,'INJ = ',I10)
      WRITE (10,457) TFAT,SEVERITY(4)
457   FORMAT (15X,'FAT = ',F10.2,13X,'FAT = ',I10)
      ENDIF
*
*     Output Results
*
      IF (OPTION(8).EQ.'Y'.OR.OPTION(9).EQ.'Y'.OR.OPTION(10).EQ.'Y')
     1 THEN
        IF (LINENO.GT.0) THEN
          WRITE (10,85)
          LINENO=0
        ENDIF
        WRITE (10,465)
465     FORMAT (6X,'RESULTS ',66('*'))
        WRITE (10,*)
      ENDIF
      DO 460 I=1,10
        IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
     1  NE.32) THEN
          WRITE (10,470) TITLE(I)
470       FORMAT (6X,A50)
          WRITE (10,*)
          IF (OPTION(8).EQ.'Y') THEN
            WRITE (10,480)
480         FORMAT (7X,'Simulation Results')
            WRITE (10,*)
            WRITE (10,490) NCALLS(I)
490         FORMAT (8X,'Total Number of Vehicle Trajectories     = ',
     1      I5)
            WRITE (10,500) NROLLS(I)
500         FORMAT (8X,'Total Number of Rolls                    = ',
     1      I5)
            IF (NROLLS(I).GT.0) WRITE (10,505) REAL(NROLLS(I))/
     1      REAL(NCALLS(I))
505         FORMAT (10X,'Probability of Vehicle Roll-Over      = ',
     1      F5.2)
            WRITE (10,510) NIROL(I)
510         FORMAT (8X,'Number of Rolls at Terrain Change        = ',
     1      I5)
            IF (NROLLS(I).GT.0) WRITE (10,520) REAL(NIROL(I))/
     1      REAL(NCALLS(I))
```

```
520        FORMAT (10X,'Probability of Rolls at Terrain Change = ',
   1       F5.2)
              WRITE (10,530) NJROL(I)
530        FORMAT (8X,'Number of Rolls on Slope               = ',
   1       I5)
              IF (NROLLS(I).GT.0) WRITE (10,540) REAL(NJROL(I))/
   1       REAL(NCALLS(I))
540        FORMAT (10X,'Probability of Rolls on Slope         = ',
   1       F5.2)
              WRITE (10,*)
              WRITE (10,550)
550        FORMAT (7X,'Aggregated Probability of Overall Accident ',
   1       'Consequence Classification')
              WRITE (10,*)
              WRITE (10,560) DATA(I,1)
560        FORMAT (8X,'No Damage            = ',F7.3)
              WRITE (10,570) DATA(I,2)
570        FORMAT (8X,'Property Damage Only = ',F7.3)
              WRITE (10,580) DATA(I,3)
580        FORMAT (8X,'Injury               = ',F7.3)
              WRITE (10,590) DATA(I,4)
590        FORMAT (8X,'Fatality             = ',F7.3)
              WRITE (10,*)
            ENDIF
            WRITE (10,802)
802        FORMAT (7X,'Economic Evaluation Factors')
            WRITE (10,*)
            IF (OPTION(9).EQ.'Y'.AND.BC.EQ.1) THEN
              WRITE (10,800) ENCRATE
800        FORMAT (8X,'Encroachment Rate (/km/yr) = ',F10.4)
              WRITE (10,810) TACCOST(I),TACCOST(I)*INTEREST/100*
   1       (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1)
810        FORMAT (8X,'Total Accident Costs       = ',F10.2,
   1       ' PV$/km',5X,F10.2,' $/km/year')
            ENDIF
            IF (OPTION(9).EQ.'Y'.OR.OPTION(10).EQ.'Y') THEN
              WRITE (10,815) MITCOST(I),MITCOST(I)*INTEREST/100*
   1       (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1)
815        FORMAT (8X,'Total Mitigation Costs     = ',F10.2,
   1       ' PV$/km',5X,F10.2,' $/km/year')
            ENDIF
            IF (OPTION(10).EQ.'Y') THEN
              WRITE (10,820) (SEVERITY(1)*DATA(I,1)+SEVERITY(2)*
   1       DATA(I,2)+SEVERITY(3)*DATA(I,3)+SEVERITY(4)*
   2       DATA(I,4))*ENCRATE
820        FORMAT (8X,'Total Severity (/km/year)  = ',F10.0)
            ENDIF
            IF (OUTMODE.EQ.'P') THEN
              WRITE (10,85)
              IF (PAUSE.EQ.'Y') THEN
                WRITE (*,*) ' Press any key to continue ',
   1         'printing ...'
                CALL GETKEYBOARD(CH,II)
              ENDIF
            ENDIF
          ENDIF
460   CONTINUE

      IF (OPTION(8).EQ.'Y'.OR.OPTION(9).EQ.'Y'.OR.OPTION(10).EQ.'Y')
     1 THEN
```

```
          IF (LINENO.GT.0) THEN
            WRITE (10,85)
            LINENO=0
          ENDIF
          WRITE (10,629)
629     FORMAT (3X,'SUMMARY OF RESULTS ',62('*'))
          WRITE (10,*)
      ENDIF
      IF (OPTION(8).EQ.'Y') THEN
          WRITE (10,630)
630     FORMAT (4X,'Summary of Accident Consequence Probabilities')
          WRITE (10,640) TITLE(1)
640     FORMAT (5X,'(and differences from:  ',A16,')')
          WRITE (10,*)
          WRITE (10,650)
650     FORMAT (8X,'Alternatives',7X,'No Damage',7X,'P.D.O.',8X,
     1  'Injury',7X,'Fatality')
          WRITE (10,653)
653     FORMAT (8X,72('_'))
          WRITE (10,*)
          WRITE (10,660) TITLE(1),DATA(1,1),DATA(1,2),DATA(1,3),DATA(1,4)
660     FORMAT (8X,A16,2X,F4.2,10X,F4.2,10X,F4.2,10X,F4.2)
          DO 670 I=2,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
     1      NE.32) THEN
              WRITE (10,680) TITLE(I),DATA(I,1),DATA(I,1)-DATA(1,1),
     1        DATA(I,2),DATA(I,2)-DATA(1,2),DATA(I,3),DATA(I,3)-
     2        DATA(1,3),DATA(I,4),DATA(I,4)-DATA(1,4)
680           FORMAT (8X,A16,4(2X,F4.2,1X,'(',F5.2,')'))
            ENDIF
            LINENO=LINENO+1
670     CONTINUE
          WRITE (10,*)
          WRITE (10,*)
          WRITE (10,689)
689     FORMAT (4X,'Summary of Vehicle Roll-Over Probabilities')
          WRITE (10,*)
          WRITE (10,690)
690     FORMAT (27X,'Total Rolls',8X,'Rolls on Slope',4X,
     1  'Roll @ Terrain Chg')
          WRITE (10,700)
700     FORMAT (8X,'Alternatives',7X,'Number',2X,'(Prob.)',4X,
     1  'Number',2X,'(Prob.)',4X,'Number',2X,'(Prob.)')
          WRITE (10,705)
705     FORMAT (8X,74('_'))
          WRITE (10,*)
          IF (NROLLS(1).GT.0) THEN
            WRITE (10,707) TITLE(1),NROLLS(1),REAL(NROLLS(1))/
     1      REAL(NCALLS(1)),NJROL(1),REAL(NJROL(1))/REAL(NCALLS(1)),
     1      NIROL(1),REAL(NIROL(1)/NCALLS(1))
707         FORMAT (8X,A16,3X,I5,3X,'(',F5.2,')',2(4X,I5,3X,
     1      '(',F5.2,')'))
          ELSE
            WRITE (10,706) TITLE(1)
706         FORMAT (8X,A16,3X,'    0',14X,'    0',14X,'    0')
          ENDIF
          DO 710 I=2,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
     1      NE.32) THEN
              IF (NROLLS(I).GT.0) THEN
                IF (NROLLS(1).GT.0) THEN
```

```
          WRITE (10,708) TITLE(I),NROLLS(I),REAL(NROLLS(I))/
   1      REAL(NCALLS(I)),NJROL(I),REAL(NJROL(I))/
   2      REAL(NCALLS(I)),NIROL(I),REAL(NIROL(I))/
   3      REAL(NCALLS(I))
708        FORMAT (8X,A16,3X,I5,3X,'(',F5.2,')',2(4X,I5,3X,
   1      '(',F5.2,')'))
         ELSE
          WRITE (10,708) TITLE(I),NROLLS(I),REAL(NROLLS(I))/
   1      REAL(NCALLS(I)),NJROL(I),REAL(NJROL(I))/
   2      REAL(NCALLS(I)),NIROL(I),REAL(NIROL(I))/
   3      REAL(NCALLS(I))

C           WRITE (10,680) TITLE(I),REAL(NIROL(I)*100/
C   1       NROLLS(I)),REAL(NIROL(I)*100/NROLLS(I)-NIROL(1)*
C   2       100/NROLLS(1)),REAL(NJROL(I)*100/NROLLS(I)),
C   3       REAL(NJROL(I)*100/NROLLS(I)-NJROL(1)*100/NROLLS(1))
C         ELSE
C           WRITE (10,660) TITLE(I),REAL(NIROL(I)*100/
C   1       NROLLS(I)),REAL(NJROL(I)*100/NROLLS(I))
            ENDIF
          ELSE
            WRITE (10,706) TITLE(I)
          ENDIF
          LINENO=LINENO+1
        ENDIF
710   CONTINUE
      WRITE (10,*)
      WRITE (10,*)
      LINENO=LINENO+12
    ENDIF
*
*   Output benefit cost analysis summary
*
    IF (OPTION(9).EQ.'Y') THEN
      IF (LINENO+18+NT(I).GT.60) THEN
        IF (OUTMODE.EQ.'P') THEN
          WRITE (10,85)
          IF (PAUSE.EQ.'Y') THEN
            WRITE (*,*) ' Press any key to continue ',
   1        'printing ...'
            CALL GETKEYBOARD(CH,II)
          ENDIF
        ENDIF
        LINENO=0
      ENDIF
      WRITE (10,900)
900   FORMAT (4X,'Benefit Cost Ratio Economic Evaluation')
      WRITE (10,901)
901   FORMAT (5X,'Relative Accident Savings and Relative Mitigatn',
   1  ' Costs are')
      WRITE (10,902) TITLE(1)
902   FORMAT (5X,'with respect to:  ',A16)
      WRITE (10,*)
      DO 905 J=1,2
C     WRITE (10,910)
C910   FORMAT (38X,'Accident',3X,'Mitigation')
        WRITE (10,915)
915    FORMAT (44X,'Relative',2X,'Relative')
        WRITE (10,917)
917    FORMAT (24X,'Accident',2X,'Mitigatn',2X,'Accident',2X,
   1   'Mitigatn',4X,'B-C',5X,'Net')
```

```
          WRITE (10,918)
918      FORMAT (26X,'Costs',5X,'Costs',4X,'Savings',4X,'Costs',4X,
    1    'Ratio',2X,'Benefit')
          IF (J.EQ.1) THEN
            WRITE (10,920)
920        FORMAT (8X,'Alternatives',6X,3('(PV$)',5X),'(PV$)',12X,
    1    '(PV$)')
          ELSE
            WRITE (10,925)
925        FORMAT (8X,'Alternatives',4X,4('($/year)',2X),8X,
    1      '($/year)')
          ENDIF
          WRITE (10,930)
930      FORMAT (8X,72('_'))
          WRITE (10,*)
          IF (J.EQ.1) THEN
            WRITE (10,940) TITLE(1),TACCOST(1),MITCOST(1)
940        FORMAT (8X,A16,2(F9.0,1X))
          ELSE
            WRITE (10,940) TITLE(1),TACCOST(1)*INTEREST/100*
    1      (1+INTEREST/100)**PERIOD/((1+INTEREST/100)**PERIOD-1),
    2      MITCOST(1)*INTEREST/100*(1+INTEREST/100)**PERIOD/
    3      ((1+INTEREST/100)**PERIOD-1)
          ENDIF
          DO 950 I=2,10
            IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).
    1      NE.32) THEN
              IF (J.EQ.1) THEN
                IF (MITCOST(I).NE.MITCOST(1)) THEN
                  WRITE (10,943) TITLE(I),TACCOST(I),MITCOST(I),
    1            TACCOST(1)-TACCOST(I),MITCOST(I)-MITCOST(1),
    2            (TACCOST(1)-TACCOST(I))/(MITCOST(I)-MITCOST(1)),
    3            (TACCOST(1)-TACCOST(I))-(MITCOST(I)-MITCOST(1))
943              FORMAT (8X,A16,4(F9.0,1X),1X,F5.2,1X,F9.0)
                ELSE
                  WRITE (10,945) TITLE(I),TACCOST(I),MITCOST(I),
    1            TACCOST(1)-TACCOST(I),MITCOST(I)-MITCOST(1),
    2            (TACCOST(1)-TACCOST(I))-(MITCOST(I)-MITCOST(1))
945              FORMAT (8X,A16,4(F9.0,1X),1X,'----',1X,F9.0)
                ENDIF
              ELSE
                IF (MITCOST(I).NE.MITCOST(1)) THEN
                  WRITE (10,943) TITLE(I),TACCOST(I)*INTEREST/100*
    1            (1+INTEREST/100)**PERIOD/
    2            ((1+INTEREST/100)**PERIOD-1),MITCOST(I)*
    3            INTEREST/100*(1+INTEREST/100)**PERIOD/
    4            ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
    5            TACCOST(I))*INTEREST/100*
    6            (1+INTEREST/100)**PERIOD/
    7            ((1+INTEREST/100)**PERIOD-1),(MITCOST(I)-
    8            MITCOST(1))*INTEREST/100*
    9            (1+INTEREST/100)**PERIOD/
    1            ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
    2            TACCOST(I))/(MITCOST(I)-MITCOST(1)),
    3            ((TACCOST(1)-TACCOST(I))-(MITCOST(I)-
    4            MITCOST(1)))*INTEREST/100*
    5            (1+INTEREST/100)**PERIOD/
    3            ((1+INTEREST/100)**PERIOD-1)
```

```
                ELSE
                  WRITE (10,945) TITLE(I),TACCOST(I)*INTEREST/100*
     1            (1+INTEREST/100)**PERIOD/
     2            ((1+INTEREST/100)**PERIOD-1),MITCOST(I)*
     3            INTEREST/100*(1+INTEREST/100)**PERIOD/
     4            ((1+INTEREST/100)**PERIOD-1),(TACCOST(1)-
     5            TACCOST(I))*INTEREST/100*
     6            (1+INTEREST/100)**PERIOD/
     7            ((1+INTEREST/100)**PERIOD-1),(MITCOST(I)-
     8            MITCOST(1))*INTEREST/100*
     9            (1+INTEREST/100)**PERIOD/
     1            ((1+INTEREST/100)**PERIOD-1),((TACCOST(1)-
     2            TACCOST(I))-(MITCOST(I)-MITCOST(1)))*
     3            INTEREST/100*(1+INTEREST/100)**PERIOD/
     4            ((1+INTEREST/100)**PERIOD-1)
                ENDIF
              ENDIF
              LINENO=LINENO+1
            ENDIF
950     CONTINUE
          WRITE (10,*)
          WRITE (10,*)
905     CONTINUE
        LINENO=LINENO+20
      ENDIF
*
*     Output cost effectiveness analysis summary
*
      IF (OPTION(10).EQ.'Y') THEN
        IF (LINENO+8+NT(I).GT.60) THEN
          IF (OUTMODE.EQ.'P') THEN
            WRITE (10,85)
            IF (PAUSE.EQ.'Y') THEN
              WRITE (*,*) ' Press any key to continue ',
     1        'printing ...'
              CALL GETKEYBOARD(CH,II)
            ENDIF
          ENDIF
          LINENO=0
        ENDIF
        WRITE (10,1001)
1001    FORMAT(4X,'Cost Effectiveness Economic Evaluation')
        WRITE (10,*)
        WRITE (10,1010)
1010    FORMAT (29X,'Mitigation Costs',7X,'Severity')
        WRITE (10,1015)
1015    FORMAT (8X,'Alternatives',6X,'(PV$/km)',3X,'($/km/year)',
     1  3X,'(/km/year)' )
        WRITE (10,1030)
1030    FORMAT (8X,53('_'))
        WRITE (10,*)
        DO 1050 I=1,10
          IF (ICHAR(TITLE(I)(1:1)).NE.0.AND.ICHAR(TITLE(I)(1:1)).NE.32) THEN
            WRITE (10,1040) TITLE(I),MITCOST(I),MITCOST(I)*
     1      INTEREST/100*(1+INTEREST/100)**PERIOD/
     2      ((1+INTEREST/100)**PERIOD-1),(SEVERITY(1)*DATA(I,1)+
     3      SEVERITY(2)*DATA(I,2)+SEVERITY(3)*DATA(I,3)+SEVERITY(4)*
     4      DATA(I,4))*ENCRATE
1040        FORMAT (8X,A16,2X,F9.0,3X,F9.0,3X,F12.0)
          ENDIF
1050    CONTINUE
      ENDIF
```

```
      CLOSE (10)
      RETURN
*
*     Error writing to printer
*
1000  WRITE (*,*) CHAR(7),CHAR(7)
      WRITE (*,*) CHAR(255),CHAR(255),'PRNTERR/'
      CALL GETKEYBOARD(CH,II)
      GOTO 1
*
*     Error opening file
*
1500  WRITE (*,*) CHAR(7),CHAR(7)
      WRITE (*,*) CHAR(255),CHAR(255),'FILERR/'
      CALL GETKEYBOARD(CH,II)
      GOTO 1
      END
```

```
      SUBROUTINE SAVE
*
*     This subroutine saves input data to a file
*
      INTEGER CODE, CF, POS
      CHARACTER*12 FILNAM
      CHARACTER*76 FIELD(120)
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
*
*     Enter name of file to save
*
1     WRITE (*,*) CHAR(255), CHAR(255), 'IO/'
      FIELD(1)=INPUTF
      FILNAM = 'IO'
      CODE = 0
      CF = 0
      POS = 1
      DO 5 I=1,36
          IF (ICHAR(INPUTF(I:I)).NE.32.AND.ICHAR(INPUTF(I:I)).NE.0) THEN
            POS=POS+1
          ELSE
            GOTO 6
          ENDIF
5     CONTINUE
6     CALL SCREENIO (FILNAM, CODE, CF, POS)
      IF (CODE .EQ. 1) RETURN
      SAVE=1
      INPUTF = FIELD(1)
*
*     Save data to file
*
      OPEN (10, FILE=INPUTF,ERR=1000)
*
*     Save operating data
*
      DO 20 I=1,10
          WRITE (10,30) TITLE(I)
30      FORMAT (A50)
          DO 50 J=1,16
            IDEF(I,J)=' '
50      CONTINUE
          WRITE (10,55) TI(I),TMAX(I),VMIN(I),MITER(I),XINCR(I)
55      FORMAT (3F10.3,I4,F10.3)
          WRITE (10,57) VMEAN(I), VSD(I), VINCR(I), AINCR(I), PMIN(I),
     1  BRAKE(I), REST(I)
57      FORMAT (7F10.3)
          WRITE (10,57) STEER(I)
          WRITE (10,59) HCURVE(I), MODEL(I)
59      FORMAT (2I3)
*
*     Save terrain data
*
          WRITE (10,61) NT(I)
61      FORMAT (I3)
          DO 60 J=1,NT(I)
            WRITE (10,65) TY(I,J), TA(I,J), TM(I,J), TR(I,J)
65        FORMAT (F6.3,F6.2,2F6.4)
60      CONTINUE
```

```
*
*     Save object data
*
          WRITE (10,61) NO(I)
          DO 75 J=1,NO(I)
            WRITE (10,77) THX1(I,J),THX2(I,J),THY1(I,J),THY2(I,J),
     1    THM(I,J),THWID(I,J),THTYP(I,J)
77        FORMAT (6F5.1,A1)
75      CONTINUE

20    CONTINUE
*
*     Roll consequence data
*
      WRITE (10,61) NVEL
      DO 80 I=1,NVEL
          WRITE (10,90) RP1(I,1),RP1(I,2)
          WRITE (10,90) RP2(I,1),RP2(I,2)
          WRITE (10,90) VEL(I)
90      FORMAT (2F10.3)
80    CONTINUE
*
*     Angle probability data
*
      DO 100 I=1,4
          DO 100 J=1,35
            WRITE (10,110) PP(I,J)
110       FORMAT (F10.3)
100   CONTINUE
*
*     Vehicle characteristics
*
      DO 120 I=1,8
          WRITE (10,130) CG(I)
          WRITE (10,130) TRACK(I)
          WRITE (10,130) VMASS(I)
          WRITE (10,130) WBASE(I)
130     FORMAT (F10.3)
120   CONTINUE
*
*     Probability of consequence data
*
      WRITE (10,61) NPLA
      DO 140 I=1,NPLA
          WRITE (10,150) (PLA(I,J),J=1,6)
150     FORMAT (F7.1,5F7.5)
140   CONTINUE

*     Economic data

      DO 160 I=1,10
          WRITE (10,165) BARRIER(I),ROW(I),OREMOVE(I),NREMOVE(I,1),
     1  NREMOVE(I,2),NREMOVE(I,3)
165     FORMAT (6I4)
          WRITE (10,170) BINSTALL(I),BMAINT(I),CFMAINT(I),COSTROW(I),
     1  CREMOVE(I,1),CREMOVE(I,2),CREMOVE(I,3)
170     FORMAT (7F9.2)
160   CONTINUE
      WRITE (10,170) CUTCOST,FILLCOST,WASTCOST,ADFCOST
      WRITE (10,190) (ACCOST(1,I),I=1,4)
      WRITE (10,190) (ACCOST(2,I),I=1,4)
190   FORMAT (4F9.2)
```

```
      WRITE (10,200) CLIMATE, DESSPD, HORCURVE, LANEWID, NUMLANE,
     1 RDCLASS, SHLDWID, SIGHT, SLOPE, TRAFFIC, VERCURVE
200   FORMAT (11I1)
      WRITE (10,210) ADT,ENCRATE,INTEREST,PERIOD
210   FORMAT (I8,F8.4,F4.2,I4)

      WRITE (10,220) BC,CE
220   FORMAT (2I1)
      WRITE (10,230) SEVERITY(1),SEVERITY(2),SEVERITY(3),SEVERITY(4)
230   FORMAT (4I11)

      CLOSE (10)
      RETURN
*
*     Error opening file
*
1000  WRITE (*,*) CHAR(7),CHAR(7)
      CALL CURSOROFF
      WRITE (*,*) CHAR(255),CHAR(255),'FILERR/'
      CALL GETKEYBOARD(CH,II)
      CALL CURSORON
      GOTO 1
      END
```

```
      SUBROUTINE CALIBRAT
*
*     This subroutine is used to edit calibration and operational
*     default input data
*
      INTEGER CHOICE, CODE, COLUMN, CF, HC, MENU, NUMLIN, NUMPTS, POS,
     1 ROWW
      REAL GX(100),GY(16,100),HOLD
      CHARACTER*12 FILNAM
      CHARACTER*18 XTITLE, YTITLE
      CHARACTER*36 PATH
      CHARACTER*76 FIELD(120)
      CHARACTER*80 TTLE
      INCLUDE 'RHSM.INS'
      COMMON /SCRN/ FIELD
      COMMON / GRPH2D / NUMLIN,NUMPTS,GX,GY,XTITLE,YTITLE,TTLE
*
*     Load menu
*
25    WRITE (*,*) CHAR(255),CHAR(255),'CALIBRAT/'
      READ (*,10) CHOICE
10    FORMAT (I3)
*
*     Edit default operational data
*
      IF (CHOICE.EQ.1) THEN
          WRITE (*,*) CHAR(255),CHAR(255),'OPERATE/'
          IF (DEF(14).EQ.1) FIELD(1)=' '
          IF (DEF(14).EQ.2) FIELD(1)='G'
          IF (DEF(14).EQ.3) FIELD(1)='M'
          IF (DEF(14).EQ.4) FIELD(1)='S'
          WRITE (FIELD(2),30) DEF(1)
30      FORMAT (F10.3)
          WRITE (FIELD(3),30) DEF(2)
          IREAD=DEF(4)
          WRITE (FIELD(4),35) IREAD
35      FORMAT (I10)
          WRITE (FIELD(5),30) DEF(5)
          WRITE (FIELD(6),30) DEF(6)
          WRITE (FIELD(7),30) DEF(7)
          WRITE (FIELD(8),30) DEF(3)
          WRITE (FIELD(9),30) DEF(8)
          WRITE (FIELD(10),30) DEF(9)
          WRITE (FIELD(11),30) DEF(10)
          WRITE (FIELD(12),30) DEF(13)
          WRITE (FIELD(13),30) DEF(11)
          WRITE (FIELD(14),30) DEF(12)
          IREAD=DEF(15)
          WRITE (FIELD(15),40) IREAD
40      FORMAT (I1)
          FILNAM='OPERATE'
          CODE=0
          CF=0
          POS=0
50      CALL SCREENIO(FILNAM,CODE,CF,POS)
          IF (CODE.EQ.1) GOTO 25
          IF (CODE.NE.45) GOTO 50
          IF (ICHAR(FIELD(1)(1:1)).EQ.0.OR.ICHAR(FIELD(1)(1:1)).EQ.32)
     1    THEN
            DEF(14)=1
          ELSEIF (FIELD(1).EQ.'G') THEN
            DEF(14)=2
```

```
            ELSEIF (FIELD(1).EQ.'M') THEN
              DEF(14)=3
            ELSEIF (FIELD(1).EQ.'S') THEN
              DEF(14)=4
            ENDIF
            READ (FIELD(2),30) DEF(1)
            READ (FIELD(3),30) DEF(2)
            READ (FIELD(4),35) IREAD
            DEF(4)=IREAD
            READ (FIELD(5),30) DEF(5)
            READ (FIELD(6),30) DEF(6)
            READ (FIELD(7),30) DEF(7)
            READ (FIELD(8),30) DEF(3)
            READ (FIELD(9),30) DEF(8)
            READ (FIELD(10),30) DEF(9)
            READ (FIELD(11),30) DEF(10)
            READ (FIELD(12),30) DEF(13)
            READ (FIELD(13),30) DEF(11)
            READ (FIELD(14),30) DEF(12)
            READ (FIELD(15),40) IREAD
            DEF(15)=IREAD

*     Departure Angle Data

      ELSEIF (CHOICE.EQ.2) THEN
            HC=1
129     WRITE (*,*) CHAR(255),CHAR(255),'DEP-ANG/'
            IF (HC.EQ.1) FIELD(1)='Straight'
            IF (HC.EQ.2) FIELD(1)='Gentle Curve'
            IF (HC.EQ.3) FIELD(1)='Moderate Curve'
            IF (HC.EQ.4) FIELD(1)='Severe Curve'
            DO 131 I=1,35
              WRITE (FIELD(I+1),132) PP(HC,I)
132       FORMAT (F6.0)
131     CONTINUE
            FILNAM='DEP-ANG'
            CODE=0
            CF=0
            POS=0
133     CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 25
            IF (CODE.NE.45.AND.CODE.NE.34.AND.CODE.NE.73.AND.CODE.NE.81)
     1  GOTO 133
            NOBS(HC)=0
            DO 134 I=1,35
              READ (FIELD(I+1),132) PP(HC,I)
              NOBS(HC)=NOBS(HC)+PP(HC,I)
134     CONTINUE

            IF (CODE.EQ.34) THEN
              NUMLIN=4
              NUMPTS=35
              DO 136 I=1,35
                GX(I)=I*2
                DO 136 J=1,4
                  GY(J,I)=PP(J,I)
136       CONTINUE
              XTITLE=' Departure Angle'
              YTITLE='  Frequency   '
              TTLE='Departure Angle Freq. (Straight - W, Gentle Cv'//
     1      ' - Y, Moderate - M, Severe - R)'
```

```
          CALL GRAPH2D
          GOTO 129
        ELSEIF (CODE.EQ.73) THEN
          HC=HC-1
          IF (HC.EQ.0) HC=4
          GOTO 129
        ELSEIF (CODE.EQ.81) THEN
          HC=HC+1
          IF (HC.EQ.5) HC=1
          GOTO 129
        ENDIF

*     Probability of Consequence Data

      ELSEIF (CHOICE.EQ.3) THEN
        IPAGE=1
145     WRITE (*,*) CHAR(255),CHAR(255),'PROCON/'
        DO 140 I=1,10
          WRITE (FIELD((I-1)*7+1),147) I+10*(IPAGE-1)
147       FORMAT (I2)
          WRITE (FIELD((I-1)*7+2),150) PLA(I+10*(IPAGE-1),1)
150       FORMAT (F7.1)
          DO 140 J=2,6
            WRITE (FIELD((I-1)*7+J+1),160) PLA(I+10*(IPAGE-1),J)
160         FORMAT (F7.5)
140     CONTINUE
        FILNAM='PROCON'
        CODE=0
        CF=0
        POS=0
170     CALL SCREENIO(FILNAM,CODE,CF,POS)
        IF (CODE.EQ.1) GOTO 25
        IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81.AND.
     1  CODE.NE.34) GOTO 170
        DO 180 I=1,10
          READ (FIELD((I-1)*7+2),150) PLA(I+10*(IPAGE-1),1)
          DO 180 J=2,6
            READ (FIELD((I-1)*7+J+1),160) PLA(I+10*(IPAGE-1),J)
180     CONTINUE

        IF (CODE.EQ.73) THEN
          IPAGE=IPAGE-1
          IF (IPAGE.EQ.0) IPAGE=5
          GOTO 145
        ELSEIF (CODE.EQ.81) THEN
          IPAGE=IPAGE+1
          IF (IPAGE.EQ.6) IPAGE=1
          GOTO 145
        ENDIF

*     Sort Probability of Consequence Data

        DO 182 I=1,49
          DO 182 J=I+1,50
            IF ((PLA(I,1).GT.PLA(J,1).AND.PLA(J,1).NE.0)
     1      .OR.(I.NE.1.AND.PLA(I,1).EQ.0)) THEN
              DO 183 K=1,6
                HOLD=PLA(I,K)
                PLA(I,K)=PLA(J,K)
                PLA(J,K)=HOLD
183           CONTINUE
            ENDIF
```

```
182    CONTINUE
         NPLA=0
         DO 184 I=1,50
           IF (PLA(I,1).NE.0) NPLA=NPLA+1
184    CONTINUE

         IF (CODE.EQ.34) THEN
           NUMLIN=3
           NUMPTS=NPLA
           XTITLE='  Power Level  '
           YTITLE=' Prob of Conseq.'
           DO 186 I=1,NPLA
             GX(I)=PLA(I,1)
             DO 186 J=1,3
               GY(J,I)=PLA(I,J+1)
186      CONTINUE
           TTLE='Prob of Conseq. - Unrestrained (No Dmge - Wht,'//
   1     ' PDO - Yel, Fatality - Mag)'
           CALL GRAPH2D
           DO 187 I=1,NPLA
             GX(I)=PLA(I,1)
             GY(1,I)=PLA(I,2)
             GY(2,I)=PLA(I,4)
             GY(3,I)=PLA(I,5)
187      CONTINUE
           TTLE='Prob of Conseq. - Restrained (No Dmge - Wht,'//
   1     ' PDO - Yel, Fatality - Mag)'
           CALL GRAPH2D
           GOTO 145
         ENDIF

*     Roll Consequences

      ELSEIF (CHOICE.EQ.4) THEN
         IPAGE=1
188    WRITE (*,*) CHAR(255),CHAR(255),'ROLCON/'
         DO 190 I=1,10
           WRITE (FIELD((I-1)*6+1),147) I+10*(IPAGE-1)
           WRITE (FIELD((I-1)*6+2),200) VEL(I+10*(IPAGE-1))
200      FORMAT (F7.2)
           WRITE (FIELD((I-1)*6+3),160) RP1(I+10*(IPAGE-1),1)
           WRITE (FIELD((I-1)*6+4),160) RP1(I+10*(IPAGE-1),2)
           WRITE (FIELD((I-1)*6+5),160) RP2(I+10*(IPAGE-1),1)
           WRITE (FIELD((I-1)*6+6),160) RP2(I+10*(IPAGE-1),2)
190    CONTINUE
         FILNAM='ROLCON'
         CODE=0
         CF=0
         POS=0
210    CALL SCREENIO(FILNAM,CODE,CF,POS)
         IF (CODE.EQ.1) GOTO 25
         IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81.AND.CODE.NE.
   1  34) GOTO 210
         DO 220 I=1,10
           READ (FIELD((I-1)*6+2),200) VEL(I+10*(IPAGE-1))
           READ (FIELD((I-1)*6+3),160) RP1(I+10*(IPAGE-1),1)
           READ (FIELD((I-1)*6+4),160) RP1(I+10*(IPAGE-1),2)
           READ (FIELD((I-1)*6+5),160) RP2(I+10*(IPAGE-1),1)
           READ (FIELD((I-1)*6+6),160) RP2(I+10*(IPAGE-1),2)
220    CONTINUE
```

```
      IF (CODE.EQ.73) THEN
        IPAGE=IPAGE-1
        IF (IPAGE.EQ.0) IPAGE=5
        GOTO 188
      ELSEIF (CODE.EQ.81) THEN
        IPAGE=IPAGE+1
        IF (IPAGE.EQ.6) IPAGE=1
        GOTO 188
      ENDIF

*   Sort Roll Consequences data

      DO 222 I=1,49
        DO 222 J=I+1,50
          IF ((VEL(I).GT.VEL(J).AND.VEL(J).NE.0)
    1     .OR.(I.NE.1.AND.VEL(I).EQ.0)) THEN
            HOLD=VEL(I)
            VEL(I)=VEL(J)
            VEL(J)=HOLD
            DO 223 K=1,2
              HOLD=RP1(I,K)
              RP1(I,K)=RP1(J,K)
              RP1(J,K)=HOLD
223         CONTINUE
            DO 224 K=1,2
              HOLD=RP1(I,K)
              RP1(I,K)=RP1(J,K)
              RP1(J,K)=HOLD
224         CONTINUE
          ENDIF
222   CONTINUE
      NVEL=0
      DO 225 I=1,50
        IF (VEL(I).NE.0) NVEL=NVEL+1
225   CONTINUE

      IF (CODE.EQ.34) THEN
        NUMLIN=2
        NUMPTS=NVEL
        XTITLE=' Vehicle Speed'
        YTITLE='  Roll Conseq.'
        DO 226 I=1,NVEL
          GX(I)=VEL(I)
          DO 226 J=1,2
            GY(J,I)=RP1(I,J)
226     CONTINUE
        TTLE='Roll Consequences - Unrestrained (PDO - Wht,'//
    1   ' Fatality - Yel)'
        CALL GRAPH2D
        DO 227 I=1,NVEL
          GX(I)=VEL(I)
          DO 227 J=1,2
            GY(J,I)=RP2(I,J)
227     CONTINUE
        TTLE='Roll Consequences - Restrained (PDO - Wht,'//
    1   ' Fatality - Yel)'
        CALL GRAPH2D
        GOTO 188
      ENDIF
```

```
*     Vehicle Characteristics

      ELSEIF (CHOICE.EQ.5) THEN
            WRITE (*,*) CHAR(255),CHAR(255),'VEH-CHAR/'
            DO 230 I=1,8
              WRITE (FIELD((I-1)*4+1),240) CG(I)
240         FORMAT (F8.2)
              WRITE (FIELD((I-1)*4+2),240) TRACK(I)
              WRITE (FIELD((I-1)*4+3),240) VMASS(I)
              WRITE (FIELD((I-1)*4+4),240) WBASE(I)
230       CONTINUE
            FILNAM='VEH-CHAR'
            CODE=0
            CF=0
            POS=0
250       CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 25
            IF (CODE.NE.45) GOTO 250
            DO 260 I=1,8
              READ (FIELD((I-1)*4+1),240) CG(I)
              READ (FIELD((I-1)*4+2),240) TRACK(I)
              READ (FIELD((I-1)*4+3),240) VMASS(I)
              READ (FIELD((I-1)*4+4),240) WBASE(I)
260       CONTINUE

*     Encroachment Rate Calibration

      ELSEIF (CHOICE.EQ.6) THEN
399       WRITE (*,*) CHAR(255),CHAR(255),'ENCRCAL1/'
            DO 410 I=1,5
              WRITE (FIELD(I),400) RCADJUST(I)
400         FORMAT (F4.2)
              WRITE (FIELD(5+I),400) DSADJUST(I)
              WRITE (FIELD(10+I),400) LWADJUST(I)
              WRITE (FIELD(15+I),400) NLADJUST(I)
              WRITE (FIELD(20+I),400) SWADJUST(I)
410       CONTINUE
            CODE=0
            CF=0
            POS=0
            FILNAM='ENCRCAL1'
420       CALL SCREENIO(FILNAM,CODE,CF,POS)
            IF (CODE.EQ.1) GOTO 25
            IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81) GOTO 420
            DO 430 I=1,5
              READ (FIELD(I),400) RCADJUST(I)
              READ (FIELD(5+I),400) DSADJUST(I)
              READ (FIELD(10+I),400) LWADJUST(I)
              READ (FIELD(15+I),400) NLADJUST(I)
              READ (FIELD(20+I),400) SWADJUST(I)
430       CONTINUE
            IF (CODE.EQ.73.OR.CODE.EQ.81) THEN
              WRITE (*,*) CHAR(255),CHAR(255),'ENCRCAL2/'
              DO 440 I=1,6
                WRITE (FIELD(I),400) HCADJUST(I)
                WRITE (FIELD(6+I),400) VCADJUST(I)
                WRITE (FIELD(12+I),400) CADJUST(I)
                WRITE (FIELD(18+I),400) TADJUST(I)
                WRITE (FIELD(24+I),400) SADJUST(I)
```

```
440    CONTINUE
         CODE=0
         CF=0
         POS=0
         FILNAM='ENCRCAL2'
450    CALL SCREENIO(FILNAM,CODE,CF,POS)
         IF (CODE.EQ.1) GOTO 25
         IF (CODE.NE.45.AND.CODE.NE.73.AND.CODE.NE.81) GOTO 450
         DO 460 I=1,6
           READ (FIELD(I),400) HCADJUST(I)
           READ (FIELD(6+I),400) VCADJUST(I)
           READ (FIELD(12+I),400) CADJUST(I)
           READ (FIELD(18+I),400) TADJUST(I)
           READ (FIELD(24+I),400) SADJUST(I)
460    CONTINUE
         IF (CODE.EQ.73.OR.CODE.EQ.81) THEN
           GOTO 399
         ENDIF
       ENDIF

*    Encroachment Rate Defaults

     ELSEIF (CHOICE.EQ.7) THEN
633    MENU=1
       WRITE (*,*) CHAR(255),CHAR(255),'ENCRCAL3/'
       CALL GOTOXY(19,10+RDCLASS)
       CALL PUTCHATTR(CHAR(17),1,2,1)
       CALL GOTOXY(35,10+DESSPD)
       CALL PUTCHATTR(CHAR(17),1,2,1)
       CALL GOTOXY(47,10+LANEWID)
       CALL PUTCHATTR(CHAR(17),1,2,1)
       CALL GOTOXY(64,10+NUMLANE)
       CALL PUTCHATTR(CHAR(17),1,2,1)
       CALL GOTOXY(76,10+SHLDWID)
       CALL PUTCHATTR(CHAR(17),1,2,1)
       CALL CURSOROFF
635    IF (MENU.EQ.1) THEN
         CHOICE=RDCLASS
         COLUMN=19
       ELSEIF (MENU.EQ.2) THEN
         CHOICE=DESSPD
         COLUMN=35
       ELSEIF (MENU.EQ.3) THEN
         CHOICE=LANEWID
         COLUMN=47
       ELSEIF (MENU.EQ.4) THEN
         CHOICE=NUMLANE
         COLUMN=64
       ELSE
         CHOICE=SHLDWID
         COLUMN=76
       ENDIF
640    CALL GOTOXY(COLUMN,10+CHOICE)
       CALL PUTCHATTR(CHAR(17),1,10,1)
       CALL GETKEYBOARD(CH,CODE)
       IF (CODE.EQ.1) GOTO 25
       IF (CODE.EQ.72) THEN
         CALL PUTCHATTR(' ',1,10,1)
         CHOICE=CHOICE-1
         IF (CHOICE.EQ.0) CHOICE=5
```

```
      ELSEIF (CODE.EQ.80) THEN
        CALL PUTCHATTR(' ',1,10,1)
        CHOICE=CHOICE+1
        IF (CHOICE.EQ.6) CHOICE=1
      ELSEIF (CODE.EQ.75.OR.CODE.EQ.77.OR.CODE.EQ.73.OR.CODE.EQ.81.
     1 OR.CODE.EQ.45) THEN
        CALL PUTCHATTR(CHAR(17),1,2,1)
        IF (MENU.EQ.1) THEN
          RDCLASS=CHOICE
        ELSEIF (MENU.EQ.2) THEN
          DESSPD=CHOICE
        ELSEIF (MENU.EQ.3) THEN
          LANEWID=CHOICE
        ELSEIF (MENU.EQ.4) THEN
          NUMLANE=CHOICE
        ELSE
          SHLDWID=CHOICE
        ENDIF
        IF (CODE.EQ.75) THEN
          MENU=MENU-1
          IF (MENU.EQ.0) MENU=5
          GOTO 635
        ELSEIF (CODE.EQ.77) THEN
          MENU=MENU+1
          IF (MENU.EQ.6) MENU=1
          GOTO 635
        ELSEIF (CODE.EQ.45) THEN
          GOTO 25
        ELSE
*
*   Page 2
*
          WRITE (*,*) CHAR(255),CHAR(255),'ENCRCH2/'
          MENU=1
          CALL GOTOXY(27,10+HORCURVE)
          CALL PUTCHATTR(CHAR(17),1,2,1)
          CALL GOTOXY(45,10+VERCURVE)
          CALL PUTCHATTR(CHAR(17),1,2,1)
          CALL GOTOXY(79,10+CLIMATE)
          CALL PUTCHATTR(CHAR(17),1,2,1)
          CALL GOTOXY(27,18+TRAFFIC)
          CALL PUTCHATTR(CHAR(17),1,2,1)
          CALL GOTOXY(55,18+SIGHT)
          CALL PUTCHATTR(CHAR(17),1,2,1)
          CALL CURSOROFF
650       IF (MENU.EQ.1) THEN
            CHOICE=HORCURVE
            COLUMN=27
            ROWW=10
          ELSEIF (MENU.EQ.2) THEN
            CHOICE=VERCURVE
            COLUMN=45
            ROWW=10
          ELSEIF (MENU.EQ.3) THEN
            CHOICE=CLIMATE
            COLUMN=79
            ROWW=10
          ELSEIF (MENU.EQ.4) THEN
            CHOICE=TRAFFIC
            COLUMN=27
            ROWW=18
```

```
          ELSE
            CHOICE=SIGHT
            COLUMN=55
            ROWW=18
          ENDIF
660     CALL GOTOXY(COLUMN,ROWW+CHOICE)
          CALL PUTCHATTR(CHAR(17),1,10,1)
          CALL GETKEYBOARD(CH,CODE)
          IF (CODE.EQ.1) GOTO 25
          IF (CODE.EQ.72) THEN
            CALL PUTCHATTR(' ',1,10,1)
            CHOICE=CHOICE-1
            IF (CHOICE.EQ.0) CHOICE=6
            GOTO 660
          ELSEIF (CODE.EQ.80) THEN
            CALL PUTCHATTR(' ',1,10,1)
            CHOICE=CHOICE+1
            IF (CHOICE.EQ.7) CHOICE=1
            GOTO 660
          ELSEIF (CODE.EQ.75.OR.CODE.EQ.77.OR.CODE.EQ.73.OR.
     1      CODE.EQ.81.OR.CODE.EQ.45) THEN
            CALL PUTCHATTR(CHAR(17),1,2,1)
            IF (MENU.EQ.1) THEN
              HORCURVE=CHOICE
            ELSEIF (MENU.EQ.2) THEN
              VERCURVE=CHOICE
            ELSEIF (MENU.EQ.3) THEN
              CLIMATE=CHOICE
            ELSEIF (MENU.EQ.4) THEN
              TRAFFIC=CHOICE
            ELSE
              SIGHT=CHOICE
            ENDIF
            IF (CODE.EQ.75) THEN
              MENU=MENU-1
              IF (MENU.EQ.0) MENU=5
              GOTO 650
            ELSEIF (CODE.EQ.77) THEN
              MENU=MENU+1
              IF (MENU.EQ.6) MENU=1
              GOTO 650
            ELSEIF (CODE.EQ.45) THEN
              GOTO 25
            ELSE
              GOTO 633
            ENDIF
          ENDIF
          GOTO 650
        ENDIF
      ENDIF
      GOTO 640

*     Unit costs

      ELSEIF (CHOICE.EQ.8) THEN
        WRITE (*,*) CHAR(255),CHAR(255),'UNITCOST/'
        WRITE (FIELD(1),470) DEFBINST
470     FORMAT (F9.2)
        WRITE (FIELD(2),470) DEFBMAIN
        WRITE (FIELD(3),470) DEFCUTCS
        WRITE (FIELD(4),470) DEFFILCS
        WRITE (FIELD(5),470) DEFWASCS
```

```
      WRITE (FIELD(6),470) DEFADFCS
      WRITE (FIELD(7),470) DEFCFMAI
      DO 480 I=1,3
        WRITE (FIELD(7+I),470) DEFACCST(I)
480   CONTINUE
      WRITE (FIELD(11),485) DEFACCST(4)
485   FORMAT (F10.2)
      WRITE (FIELD(12),490) DEFINTRT
490   FORMAT (F5.2)
      WRITE (FIELD(13),500) DEFPERD
500   FORMAT (I4)
      CODE=0
      CF=0
      POS=0
      FILNAM='UNITCOST'
510   CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) GOTO 25
      IF (CODE.NE.45) GOTO 510
      READ (FIELD(1),470) DEFBINST
      READ (FIELD(2),470) DEFBMAIN
      READ (FIELD(3),470) DEFCUTCS
      READ (FIELD(4),470) DEFFILCS
      READ (FIELD(5),470) DEFWASCS
      READ (FIELD(6),470) DEFADFCS
      READ (FIELD(7),470) DEFCFMAI
      DO 520 I=1,3
        READ (FIELD(7+I),470) DEFACCST(I)
520   CONTINUE
      READ (FIELD(11),485) DEFACCST(I)
      READ (FIELD(12),490) DEFINTRT
      READ (FIELD(13),500) DEFPERD

*     Cost Effectiveness Severity Weightings

    ELSEIF (CHOICE.EQ.9) THEN
      WRITE (*,*) CHAR(255),CHAR(255),'COSTEFF/'
      DO 705 I=1,4
        WRITE (FIELD(I),710) DEFSEVER(I)
710     FORMAT (I11)
705   CONTINUE
      CODE=0
      CF=0
      POS=0
      FILNAM='COSTEFF'
706   CALL SCREENIO(FILNAM,CODE,CF,POS)
      IF (CODE.EQ.1) GOTO 25
      IF (CODE.NE.45) GOTO 706
      DO 720 I=1,4
        READ (FIELD(I),710) DEFSEVER(I)
720   CONTINUE

*     Save New Defaults

    ELSEIF (CHOICE.EQ.10) THEN
      WRITE (*,*) CHAR(255),CHAR(255),'NEWDEF/'
      CALL GETKEYBOARD(CH,II)
      IF (II.EQ.21) THEN
        OPEN (10,FILE='DEFAULTS')
        PATH=' '
        ILEN=0
        DO 276 I=1,36
          IF (INPUTF(I:I).EQ.'\') ILEN=I
```

```
276     CONTINUE
          PATH=INPUTF(:ILEN)
          WRITE (10,275) PATH
275     FORMAT (A36)

          DO 280 I=1,15
            WRITE (10,290) DEF(I)
290       FORMAT (F10.3)
280     CONTINUE

          WRITE (10,295) NVEL
295     FORMAT (I3)
          DO 300 I=1,NVEL
            WRITE (10,310) RP1(I,1),RP1(I,2)
            WRITE (10,310) RP2(I,1),RP2(I,2)
            WRITE (10,310) VEL(I)
310       FORMAT (2F10.3)
300     CONTINUE

          DO 320 I=1,4
            DO 320 J=1,35
              WRITE (10,330) PP(I,J)
330         FORMAT (F10.3)
320     CONTINUE

          DO 340 I=1,8
            WRITE (10,350) CG(I)
            WRITE (10,350) TRACK(I)
            WRITE (10,350) VMASS(I)
            WRITE (10,350) WBASE(I)
350       FORMAT (F10.3)
340     CONTINUE

          WRITE (10,295) NPLA
          DO 370 I=1,NPLA
            WRITE (10,380) (PLA(I,J),J=1,6)
380       FORMAT (F7.1,5F7.5)
370     CONTINUE

          DO 530 I=1,5
            WRITE (10,540) RCADJUST(I),DSADJUST(I),LWADJUST(I),
     1      NLADJUST(I),SWADJUST(I)
540       FORMAT (5F4.2)
530     CONTINUE
          DO 550 I=1,6
            WRITE (10,540) HCADJUST(I),VCADJUST(I),CADJUST(I),
     1      TADJUST(I),SADJUST(I)
550     CONTINUE

          WRITE (10,560) DEFBINST,DEFBMAIN,DEFCUTCS,DEFFILCS,DEFWASCS,
     1    DEFADFCS,DEFCFMAI
560     FORMAT (7F10.2)
          WRITE (10,560) (DEFACCST(I),I=1,4)
          WRITE (10,570) DEFINTRT,DEFPERD
570     FORMAT (F4.2,I4)

          WRITE (10,700) CLIMATE, DESSPD, HORCURVE, LANEWID,
     1    NUMLANE, RDCLASS, SHLDWID, SIGHT, SLOPE, TRAFFIC, VERCURVE
700     FORMAT (11I1)
```

```
          WRITE (10,701) DEFSEVER(1),DEFSEVER(2),DEFSEVER(3),
     1    DEFSEVER(4)
701       FORMAT (4I11)

          CLOSE (10)
        ENDIF
      ELSE
        RETURN
      ENDIF
      GOTO 25
      END
```

```
      SUBROUTINE DEFAULTS

      LOGICAL EXISTS
      INCLUDE 'RHSM.INS'

      INQUIRE (FILE='DEFAULTS',EXIST=EXISTS)
      IF (EXISTS) THEN
          OPEN (10,FILE='DEFAULTS', STATUS='OLD')

          READ (10,275) INPUTF
275     FORMAT (A36)

*     Operational data

          DO 10 I=1,15
            READ (10,20) DEF(I)
20        FORMAT (F10.3)
10      CONTINUE

          DO 25 I=1,10
            TI(I)=DEF(1)
            TMAX(I)=DEF(2)
            VMIN(I)=DEF(3)
            MITER(I)=DEF(4)
            XINCR(I)=DEF(5)
            VMEAN(I)=DEF(6)
            VSD(I)=DEF(7)
            VINCR(I)=DEF(8)
            AINCR(I)=DEF(9)
            PMIN(I)=DEF(10)
            BRAKE(I)=DEF(11)
            REST(I)=DEF(12)
            STEER(I)=DEF(13)
            HCURVE(I)=DEF(14)
            MODEL(I)=DEF(15)
25      CONTINUE

*     Roll consequence data

          READ (10,26) NVEL
26      FORMAT (I3)
          DO 30 I=1,NVEL
            READ (10,40) RP1(I,1),RP1(I,2)
            READ (10,40) RP2(I,1),RP2(I,2)
            READ (10,40) VEL(I)
40        FORMAT (2F10.3)
30      CONTINUE

*     Angle probability data

          DO 50 I=1,4
            NOBS(I)=0
            DO 50 J=1,35
              READ (10,60) PP(I,J)
              NOBS(I)=NOBS(I)+PP(I,J)
60          FORMAT (F10.3)
50      CONTINUE
```

```
*     Vehicle characteristics

           DO 70 I=1,8
             READ (10,80) CG(I)
             READ (10,80) TRACK(I)
             READ (10,80) VMASS(I)
             READ (10,80) WBASE(I)
80          FORMAT (F10.3)
70        CONTINUE

*     Probability of consequence data

           READ (10,26) NPLA
           DO 90 I=1,NPLA
             READ (10,100) (PLA(I,J),J=1,6)
100         FORMAT (F7.1,5F7.5)
90        CONTINUE

*     Economic data

           DO 530 I=1,5
             READ (10,540) RCADJUST(I),DSADJUST(I),LWADJUST(I),
     1      NLADJUST(I),SWADJUST(I)
540         FORMAT (5F4.2)
530       CONTINUE
           DO 550 I=1,6
             READ (10,540) HCADJUST(I),VCADJUST(I),CADJUST(I),
     1      TADJUST(I),SADJUST(I)
550       CONTINUE

           READ (10,560) DEFBINST,DEFBMAIN,DEFCUTCS,DEFFILCS,DEFWASCS,
     1    DEFADFCS,DEFCFMAI
560       FORMAT (7F10.2)
           READ (10,560) (DEFACCST(I),I=1,4)
           READ (10,570) DEFINTRT,DEFPERD
570       FORMAT (F4.2,I4)
*
*     Set input sets to default values
*
           DO 575 I=1,10
             BINSTALL(I)=DEFBINST
             BMAINT(I)=DEFBMAIN
             CFMAINT(I)=DEFCFMAI
575       CONTINUE
           CUTCOST=DEFCUTCS
           FILLCOST=DEFFILCS
           WASTCOST=DEFWASCS
           ADFCOST=DEFADFCS
           DO 576 I=1,4
             ACCOST(1,I)=DEFACCST(I)
576       CONTINUE
           INTEREST=DEFINTRT
           PERIOD=DEFPERD

           READ (10,700) CLIMATE, DESSPD, HORCURVE, LANEWID,
     1    NUMLANE, RDCLASS, SHLDWID, SIGHT, SLOPE, TRAFFIC, VERCURVE
700       FORMAT (11I1)

           READ (10,701) DEFSEVER(1),DEFSEVER(2),DEFSEVER(3),
     1    DEFSEVER(4)
701       FORMAT (4I11)
```

```
      DO 702 I=1,4
        SEVERITY(I)=DEFSEVER(I)
702   CONTINUE

      CLOSE (10)
    ENDIF
    OUTMODE='D'
    PAUSE='N'
    OPTION(1)='Y'
    OPTION(2)='Y'
    OPTION(3)='Y'
    OPTION(4)='N'
    OPTION(5)='N'
    OPTION(6)='N'
    OPTION(7)='N'
    OPTION(8)='Y'
    DONE=0
    SAVED=1
    RETURN
    END
```