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RED

Roads Economic Decision Model

Software User Guide
& Case Studies

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Africa Region
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The Roads Economic Decision Model (RED)

for the Economic Evaluation of Low Volume Roads

Software User Guide

&

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SOFTWARE USER GUIDE

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ABSTRACT

This manual presents the Roads Economic Decision Model (RED) developed to improve the decision-making process for the development and maintenance of low-volume rural roads. The model performs an economic evaluation of road investments options using the consumer surplus approach and is customized to the characteristics and needs of low-volume roads such as the high uncertainty of the assessment of the model inputs, particularly the traffic and condition of unpaved roads, the importance of vehicle speeds for model validation, the need for a comprehensive analysis of generated and induced traffic, and the need to clearly define all accrued benefits. RED computes benefits for normal, generated, induced, and diverted traffic, and takes into account changes in road length, condition, geometry, type, accidents, and days per year when the passage of vehicles is further disrupted by a highly deteriorated road condition (wet season). Users can add to the analysis other benefits, such as non-motorized traffic, social services and environmental impacts, if computed separately. The model is presented on a series of Excel 2000 workbooks that collect all user inputs, present the results on an efficient manner and performs sensitivity, switching values and risk analyses.

ACKNOWLEDGMENTS

DISCLAIMER

1.   INTRODUCTION

The decision-making process for the development and maintenance of low-volume rural roads suffers from the lack of an economic evaluation tool customized for this type of roads. The World Bank's Highway Design and Maintenance Standards Model [1] (HDM-III) and the Highway Development and Management Model (HDM-4) [2] present a very good framework for the economic analysis of road investments but are not particularly customized for unpaved roads, do not capture all the benefits associated with low-volume roads investments, and require inputs which are impractical to collect for vast networks with low traffic levels, such as surface layers material properties and refined traffic data. This manual presents an economic evaluation model customized for low-volume unpaved roads, with traffic volumes between around 50 and 300 vehicles per day, to fulfill the planning and programming needs of highways agencies in charge of low-volume roads presenting the results in a practical and effective manner. The appraisal of very low volume roads with traffic less than around 50 vehicles per day is best treated with a multi-criteria analysis or cost effectiveness analysis [6].

2.   THE MODEL

The Roads Economic Decision Model (RED) performs the economic evaluation of improvements and maintenance projects adopting the consumer surplus approach, which measures the benefits to road users and consumers of reduced transport costs. This approach was preferred to producer surplus [3] approach, which measures the 'value added' or generated benefits to productive users in the project zone of influence, e.g. agricultural producers, since the consumer surplus approach was judged to allow for a better judgment of the assumptions made and an improved assessment of the investment alternatives simulated. The HDM models also adopt the consumer surplus approach and can be used for the economic evaluation of low-volume roads but the author considers that they are not particularly customized for this purpose and are more demanding in terms of input requirements. RED simplifies the process and addresses the following additional concerns.

1.   Reduce the input requirements for low-volume roads.
2.   Take into account the higher uncertainty related to the input requirements.
3.   Clearly state the assumptions made, particularly on the road condition assessment and the economic development forecast (induced traffic).
4.   Compute internally the generated traffic due to decrease in transport costs based on a defined price elasticity of demand.

5.   Quantify the economic costs associated with the days per year when the passage of vehicles is further disrupted by a highly deteriorated road condition.
6.   Use alternative parameters to road roughness to define the level of service of low-volume roads (vehicle speeds and passability).
7.   Allow for the consideration in the analysis of road safety improvements.
8.   Include in the analysis other benefits (or costs) such as those related to non-motorized traffic, social service delivery and environmental impacts.
9.   Raise questions in non-traditional ways; for example, instead of asking what is the economic return of an investment, one could ask for the maximum economically justified investment for a proposed change in level of service, with additional investments being justified by other social impacts.
10. Present the results with sensitivity, switching values and stochastic risk analyses.
11. Have the evaluation model on a spreadsheet, such as Excel, in order to capitalize on built-in features and tools such as goal seek, scenarios, solver, data analysis, and additional analytical add-ins.

The main simplification of RED with relation to the HDM models is that it considers a constant level of service, during the analysis period, for the with and without project cases, while the HDM models include road deterioration equations. The road deterioration equations of the HDM models, which vary over time the roughness of a given road as function of condition, traffic, environment, and maintenance characteristics, are not implemented on RED. Rather, RED uses the concept of average levels of service, which is considered reasonable for low volume unpaved roads due to the following reasons.

1.   Difficulty in measuring or estimating the current roughness of unpaved roads.
2.   Seasonal changes in road condition and passability.
3.   Difficulty in determining the past and/or future grading frequencies.
4.   Cyclical nature of the road condition under a defined maintenance policy.
5.   Convenience in defining levels of service for low-volume roads with parameters other than average annual roughness and gravel thickness.

2.1   THE SOFTWARE

The RED software is composed of a series of Excel 2000 workbooks that contain a series of input worksheets, where all inputs are placed, output worksheets, where results are presented and support worksheets, where calculations are made. The main evaluation module workbook evaluates one road at a time and compares three project-alternatives against a without project case, yielding the economic indicators needed to select the more desirable option and to quantify its economic benefits. There is also a program evaluation module workbook that evaluates a network of roads. The main project benefits are the reduction of vehicle operating costs and time costs, which are computed from relationships relating vehicle operating costs and speeds to road roughness customized for a particular country. The model also performs a basic risk

analysis based on user defined triangular distributions for the main inputs. The table below lists the available Excel workbooks and Figure 1 presents the Excel workbooks with the corresponding worksheets.

Workbook Filename	RED Module	Purpose
RED - Main (version 3.2).XLS	Main Economic Evaluation Module	Perform the economic evaluation of one road
RED - HDM-III VOC (version 3.2).XLS	HDM-III Vehicle Operating Costs Module	Define the relationship between motorized vehicles operating costs and speeds to road roughness, for a particular country, using HDM-III relationships
RED - HDM-4 VOC (version 3.2).XLS	HDM-4 Vehicle Operating Costs Module	Define the relationship between motorized and non-motorized vehicles operating costs and speeds to road roughness, for a particular country, using HDM-4 relationships
RED - RISK (version 3.2).XLS	Risk Analysis Module	Perform risk analysis using triangular distributions for the main inputs
RED - Program (version 3.2).XLS	Program Evaluation Module	Perform the economic evaluation of a network of roads sections or road classes

The Main Economic Evaluation Module performs the economic evaluation of one road, where you define the road and the project-alternatives to be evaluated and RED present the corresponding results. The evaluation is done using defined relationships between vehicle operating costs and speeds to roughness. If you want to calibrate these relationships to a particular country, you have to first use the HDM-III Vehicle Operating Costs Module or the HDM-4 Vehicle Operating Costs Module. These relationships take the form of cubic polynomials and should be copied into the Main Economic Evaluation Module to overwrite existing relationships.

The HDM-III Vehicle Operating Costs Module is used to define the relationship between motorized vehicle operating costs and speeds to road roughness, for a particular country, using HDM-III equations [5]. The HDM-4 Vehicle Operating Costs Module is used to define the relationship between motorized and non-motorized vehicle operating costs and speeds to road roughness, for a particular country, using HDM-4 equations [2].

Once you have used the Main Economic Evaluation Module to evaluate a given road, you can then use the Risk Analysis Module, which performs risk analysis using triangular distributions for the main inputs. The Risk Analysis Module interacts with the Main Economic Evaluation Module evaluating hundreds of what-if scenarios to yield the corresponding risk analysis results. The figure below presents the interaction between these RED modules.

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┌─────────────────────────────────────────────────────┐
│         ┌──────────────────────────────┐            │
│         │   Vehicle Operating Costs    │            │
│         │           Module             │            │
│         └──────────────────────────────┘            │
│                        │                            │
│   Transfer VOC and Speeds to Roughness Relationships│
│                        ▼                            │
│         ┌──────────────────────────────┐            │
│         │       Main Economic          │            │
│         │     Evaluation Module        │            │
│         └──────────────────────────────┘            │
│              │          Interact       ▲            │
│              ▼                         │            │
│         ┌──────────────────────────────┐            │
│         │       Risk Analysis          │            │
│         │           Module             │            │
│         └──────────────────────────────┘            │
└─────────────────────────────────────────────────────┘
```
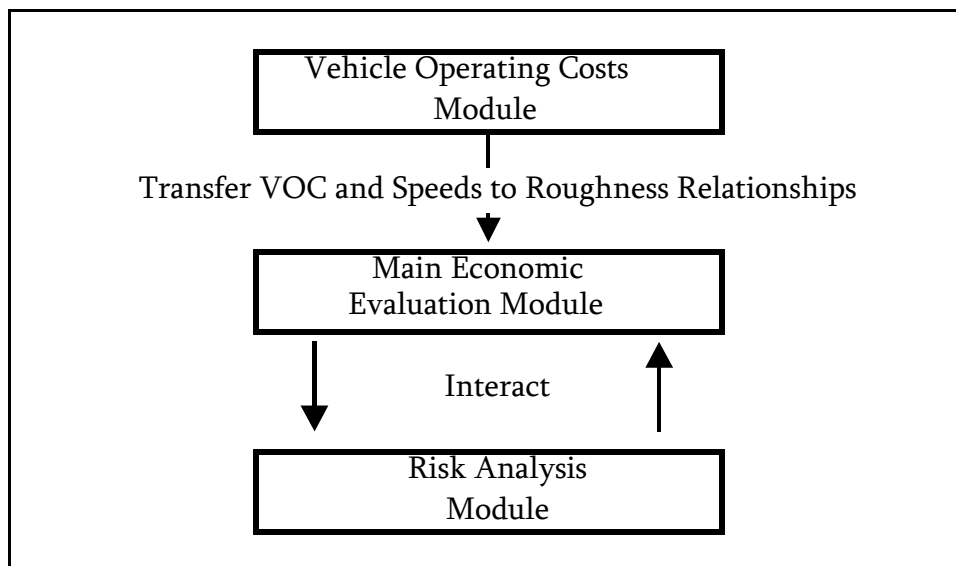
If you are evaluating many roads, you have two options: a) use the Main Economic Evaluation Module for evaluating each road one at a time, including risk analysis if necessary; or b) use the Program Evaluation Module to evaluate many roads at once and obtain the corresponding program results.

The RED workbooks can be located on any Windows folder and can be renamed if necessary. It is recommended that you make copies of the original workbooks and keep the originals in a safe place. You can then work on copies of the original workbooks, giving to them, if necessary, unique workbook names. To print any of the worksheets, use the print commands of Excel.

2.2   MAIN ECONOMIC EVALUATION MODULE

The Main Economic Evaluation Module is the main module and performs the economic evaluation of up to three project-alternatives for a given road. You define the current road characteristics and traffic and the features of four possible maintenance or improvement cases, one being the without project case and the other three being possible project-alternatives. The model evaluates the total transport costs of all four cases and computes the net benefits of the three project-alternatives compared with the without project case.

The names of the seven available input worksheets are given below. On these worksheets, you enter your inputs on all cells having a yellow background.

- Control and Setup
- Unit VOC and Speeds
- Time and Accidents
- Traffic
- Multi-Criteria Indicators
- Project-Alter. Main Features
- Project-Alter. Other Benefits

The names of the seventeen output worksheets are given below. The results are summarized on the "Project-Alter. Solution" worksheet and presented in detail, by project-alternative, on the remaining worksheets. On these worksheets, you define some parameters on cells having a yellow background and press buttons to perform the sensitivity and switching value analyses. The Net Present Value Graph compares, for all project alternatives, the Net Present Value and the Present Value of Agency Costs; and the Society Costs Graph compares the Present Value of Society Costs and the Present Value of Agency Costs.

- Project Alter. Solution
- Graph – Net Present Value
- Graph – Total Society Costs
- Alter. 1 Feasibility
- Alter. 1 User Impact
- Alter. 1 Benefits Distribution
- Alter. 1 Sensitivity
- Alter. 1 Switching Values
- Same for alternatives 2 and 3

Additionally, there are four support worksheets where calculations are made (Benefits 0, Costs Benefits 1, Costs Benefits 2, Costs Benefits 3, and Constants). RED uses these worksheets internally; therefore, you should not change any of their contents.

The input worksheets are described below.

Control and Setup

This worksheet defines the basic run control parameters and defines the names of vehicles, road terrain types, and road type types to be used in the evaluation. The Control Area collects the following main user inputs.

1.   Country name, project name, road identification code, road name, currency name, currency symbol, and evaluation date for reporting purposes.

2.   Duration of the wet season, in days, which can be set to zero if the dry and wet seasons have the same traffic and road condition characteristics.

3.   Road agency economic costs factor, which is the ratio of economic road agency costs (net of taxes and subsidies) divided by financial road agency costs (market values).

4.   Discount rate, in percent, used to compute present values.

5.   Evaluation periods, in years, which defines the number of years to be consider in the evaluation. Note that the evaluation period should be between 2 and 20 years.

6.   The initial calendar year, which is the calendar year of the first year of the evaluation period.

7.   Population served by the road.

The Setup Area prepares the model for a particular country. Here you define the names of up to nine vehicle types to be used in the analysis. The model comes with the following nine default vehicle types; you can change the vehicles names by entering new names with two words maximum.

1.   Cars and Utilities
2.   Light, Medium and Heavy Buses
3.   Light, Medium, Heavy and Articulated Trucks

For each vehicle type that you define on the setup area, RED needs the relationship between vehicle operating costs and speeds to road roughness. RED defines these relationships using cubic polynomials that can be computed using the other RED modules described on sections 2.3, 2.4 or 2.5 or by other means. The relation between vehicle operating costs and speeds to road roughness varies for different road terrain types and road types (surface type, width and other characteristics affecting desired speeds), therefore, RED allows you to define these relationships for up to nine combinations of terrain and road types. You should enter on the Setup Area the names of up to three possible terrain types and the names of up to three possible road types. The defaults terrain and road types are the given below and Figure 2 presents an illustration of these inputs. Note that each terrain type is labeled A, B or C and each road type is labeled X, Y or Z, which can't be changed.

1.   Flat, Rolling or Mountainous Terrain Type
2.   Earth, Gravel, or Paved Road Type

Note that on this worksheet you are just defining the names of the vehicles, road terrains, and road types. On the "Unit VOC and Speeds" worksheet, you will be defining the cubic polynomials for each of these options. Note also that if you will not be working with a particular vehicle type, you can erase the vehicle name and enter zero for the corresponding daily traffic.

The last input is your choice with reference to the parameter(s) to be used to define the road condition. You have the following three choices, which are illustrated on Figure 3.

1. Enter the road roughness, similar to the HDM-III and HDM-4 models; in this case, vehicles speeds and vehicle operating costs are estimated as a function of the inputted roughness.
2. Enter the speed of a motorized reference vehicle; in this case, RED estimates the road roughness based on the speed of the reference vehicle and then RED estimates the vehicle speeds and vehicle operating costs of all vehicles using the estimated roughness. RED offers the choice of entering the speed of a reference vehicle to characterize the condition of a given road because the road roughness of unpaved roads is difficult to measure or estimate due to its variability over seasons, path along the route and maintenance activities. Note that this option is appropriate only for level and rolling terrain, where vehicle speeds are essentially a function of roughness, but is not appropriate for a mountainous terrain or under other circumstances that limit vehicle speeds.
3. Enter both the roughness and the speeds of all vehicles directly; in this case, only vehicle operating costs are estimated as a function of the input roughness. This option is particularly appropriate for hilly and mountainous roads where vehicle speeds are less a function of roughness than of road geometry (vertical and horizontal alignments). If you use this option, is up to you to characterize the roughness and vehicle speeds of a given road.

Unit VOC and Speeds

This worksheet defines the relationships between vehicle operating costs and speeds to roughness for nine possible combinations of terrain and road types for nine possible vehicle types. Here you also define the relationship between roughness to the speed of a reference vehicle for the nine possible combinations of terrain and road types. All these relationships take the form of cubic polynomials. For Example:

VOC ($/veh-km) as a function of roughness (IRI):

$$VOC = a0 + a1*IRI + a2*IRI^2 + a3*IRI^3$$

for a car, flat terrain and two-lane road for a given country

a0 = 0.115347
a1 = -0.000428
a2 = 0.000928
a3 = -0.000018

You have to provide the corresponding coefficients (a0, a1, a2, and a3) for the cubic polynomials, which are the foundation of RED and can be easily computed, for a particular country, using the RED modules, which adopt the HDM-III or the HDM-4 vehicle operating costs and speeds equations. These coefficients can also be obtained by other means or by other models,

thus, the RED Main Economic Evaluation Module can be used in conjunction with any vehicle operating costs and speeds prediction model.

Time and Accidents

This worksheet defines time and accidents costs. The model computes benefits due to a reduction in passenger's time, cargo holding time, and accidents costs. To compute time related benefits, you enter the number of passengers per vehicle type and the value of a passenger time and the cargo holding time. To compute safety benefits, you enter the average cost per accident broken down, if data is available, in accidents with fatalities, accidents with injuries and accidents with damage only.

Traffic

RED evaluates benefits accruing to the following traffic types.

1.   Normal traffic, i.e. traffic passing along the road in the absence of any new investment.
2.   Generated traffic due to decrease in transport costs, i.e., traffic associated with existing users of the project road driving more frequently or driving further than before.
3.   Induced traffic due to local economic development, i.e., traffic attracted to the project road from other roads, changing its origin or destination, due to increased development activity in the road's zone of influence brought about by the project.
4.   Diverted traffic, i.e., traffic that diverts to the project road from an alternative road with the same origin and destination as the project.

For the dry season and the wet season separately, you enter, for each vehicle type, the normal traffic (AADT) present at the first year of the evaluation period and the traffic growth rate for the normal, generated, and diverted traffic, which is considered to be the same for all these traffic types. The traffic growth rate is entered for up to four five-year periods and defines the increase in traffic that occurs due to an overall increase in economic activity, which affects equally these traffic types and all project-alternatives. The induced traffic and growth for the dry and wet seasons is defined separately.

You define the generated traffic due to decrease in transport costs either by defining it as a percentage of the normal traffic, similar to the HDM models, or by inputting a price elasticity of demand [4]; i.e. the percent increase in traffic per percent decrease in transport costs. The price elasticity of demand is then used to calculate the generated traffic based on the estimated decrease in road user costs. In this case, the price elasticity of demand should be estimated for the users of the road under consideration, not for all users with same origin and destination.

You define the induced traffic due to local economic development by entering for each project-alternative, vehicle type, and year the corresponding traffic. This gives you total flexibility to define the year when the traffic will appear, the amount of traffic, and different traffic growth

rates over the evaluation period. Note that the diverted traffic is defined on the "Project-Alternatives Main Features" worksheet for each project-alternative.

Figure 4 presents an illustration of the benefits calculation for normal traffic, generated traffic, and induced traffic. For generated and induced traffic, RED approximates the benefits by calculating one-half the reduction of transport costs for each unit of generated or induced traffic. The benefits accruing to diverted traffic are estimated on the basis of the difference in transport costs using the alternative road and using the project road.

Multi-Criteria Indicators

This worksheet stores up to 8 multi-criteria indicators for future reference. You can change the definition of the multi-criteria indicators and input the corresponding indicators. Note that these multi-criteria indicators are not being used on the economic analysis done by RED; they are collected here for future reference and analysis.

Project-Alter. Main Features

This worksheet defines the features of the four project-alternatives to be evaluated. The first project-alternative is the without project case that represents a do minimum road agency policy and costs (base case). The other three project-alternatives are the ones being compared against the without project case. For all project-alternatives, you enter first the following.

1.   Description of the project-alternative.
2.   Terrain type code (A, B or C), and road type code (X, Y or Z).
3.   Road condition during the period with good passability (dry season) and, if applicable, during the period of disrupted passability (wet season). The road condition is expressed in terms of road length and a) roughness or b) speed of a reference vehicle or c) roughness and speeds of all vehicles. The definition of how to characterize the road condition is done at the "Control and Setup" worksheet.

RED assumes, for each project-alternative, an average level of service over the analysis period that is represented by an average road roughness and average vehicle speeds. Figure 5 shows an illustration of the average level of service and compares it with the road deterioration predictions of the HDM models.

The average yearly level of service is defined for the following two possible seasonal periods during a year.

1.   Period with good passability (dry season)
2.   Period when the passability is disrupted by a highly deteriorated road condition (wet season); in this case, as illustrated on Figure 6, vehicles will find alternatives routes or use alternative paths along the existing road that facilitate the passage, resulting in

higher transport costs due to a change in travel distance, road roughness, and speeds. Note that RED does not compute the economic costs of days when the passage of vehicle is totally interrupted.

You then enter the following.

1. Investment duration in years (0 to 3) and percent of investment costs in each year, in percent.
2. Financial investment costs per kilometer, in thousands of currency per km.
3. Fixed financial maintenance costs per kilometer-year, in thousands of currency per km-year.
4. Variable financial maintenance costs per kilometer-year-traffic, in thousands of currency per km-year-ADT, which is an optional annual maintenance costs that is traffic dependent.

The investment refers to an initial investment (paving, regravelling, rehabilitation, etc.) starting on the first year of the evaluation period with the specified duration. If for a project-alternative, there will not be an initial investment; you should enter 0 as the investment duration and the investment cost. The maintenance costs are annualized maintenance costs needed to maintain the specified level of service. There is a fixed component (independent of traffic) and an optionally variable component function of traffic. Note that you enter financial costs (market values) and RED computes internally the economic costs based on the multiplier you defined on the "Control and Setup" worksheet.

Finally, you optionally enter the following.

1. Accidents rate, in number of accidents per 100 million vehicle-km, and optionally percent of accidents with fatalities, injuries and damage only, in percent. Note that if you have entered only the average costs per accident on the "Time and Accidents" worksheet, you need to enter only the overall accidents rate, disregarding the percents with fatality, injury, and damaged only.
2. Diverted traffic from an alternative road and characteristics of the alternative road, which are the road length, terrain type road type and roughness.

Project-Alter. Other Benefits

This worksheet collects other net benefits for each project-alternative that should be computed separately. You can enter, for each project-alternative and year, other net benefits such as social services and environmental impacts. Note that the net benefits can be positive (additional benefits in relation to the without project case) or negative (additional costs in relation to the without project case).

The output worksheets are described below.

Project-Alter. Solution

This worksheet presents a results summary (see Figure 7). For each project-alternative, RED presents the following economic indicators.

1.   Net present value at the given discount rate, in millions of U.S dollar.
2.   Internal rate of return, in percent.
3.   Equivalent annual net benefits, in U.S dollar per km. This represents an equivalent annual stream of net benefits over the evaluation period with a present value, at the giving discount rate, equal to the net present value divided by the road length.
4.   Modified rate of return considering the reinvestment rate and the financing rate assumed to be the given discount rate, in percent.
5.   Net present value per financial investment costs ratio.
6.   Net present value per present value of economic agency costs ratio.
7   First-year benefits per economic investment cost ratio.
8.   Financial investment cost, in millions of U.S dollar.
9.   Present value of economic agency costs, in millions of U.S dollar.
10. Present value of economic normal traffic user costs, in millions of U.S dollar.
11. Present value of economic generated traffic user costs, in millions of U.S dollar.
12. Present value of economic society costs, in millions of U.S dollar.
13. Number of fatalities per km-year after investment.
14. Investment per population served, in U.S dollar/person.

Graph – Net Present Value

This worksheet presents a graph comparing the net present value and the present value of economic agency costs for all project-alternatives.

Graph – Total Society Costs

This worksheet presents a graph comparing the present value of total society costs and the present value of economic agency costs for all project-alternatives.

Alter. 1 Feasibility

This worksheet presents the economic evaluation details for option 1. At the top of the table you have all the main input assumptions and below you have the computed vehicle speeds, travel times, traffic and streams of net benefits (see Figure 8). At the bottom of the table you have the economic indicators. This worksheet also performs a basic sensitivity analysis on the road agency and user net benefits streams. You can change the sensitivity multipliers on cells "N28" and "O28". Note that there is a similar worksheet for options 2 and 3.

Option 1. User Impacts

This worksheet presents the user impacts of the proposed investments. It shows, for each vehicle type, the economic annual road user costs reduction with relation to the without project-alternative, in percent. It also presents, for the project-alternative and the without project option, for each vehicle type, the financial unit trip costs and the financial annual trip costs the year after the investment is done (see Figure 9). Note that there is a similar worksheet for options 2 and 3.

Option 1. Benefits Distribution

This worksheet presents the distribution of the total net society benefits among road agency benefits and road users benefits. It also shows the distribution of the road user net benefits among vehicle types and source of benefits (see Figure 10). Note that there is a similar worksheet for options 2 and 3.

Option 1. Sensitivity

This worksheet presents a sensitivity analysis for all main inputs. You enter two possible multipliers for each main input parameter, on columns "G" and "L", and, after you press the button named "Update Sensitivity" located at the top of the worksheet, the model presents the corresponding economic indicators (see Figure 11). Note that there is a similar worksheet for options 2 and 3.

Option 1 Switching Values

This worksheet presents switching values analysis for all main inputs. After you press the button named "Update Switching Values" located at the top of the worksheet, the model presents the corresponding switching values for each main input parameter (see Figure 12). For each input parameter being evaluated, the switching value is the value of the input parameter that would yield a net present value equal to zero or an internal rate of return equal to the discount rate. The switching value is used to access the impact of an input parameter on the benefits of a project. Note that there is a similar worksheet for options 2 and 3.

Benefits 1, Benefits 2, Benefits 3, Benefits 4

These worksheets perform the project-alternatives benefits calculations done by RED. There are no user inputs on these worksheets and the worksheets are not formatted to be printed.

Constants

This worksheet stores sensitivity and risk multipliers. Some observations: a) the multipliers multiply each input on all RED formulas; b) all these multipliers should be set to 1 to obtain the original base scenario; c) you can not move this range, otherwise, the risk analysis module will not work properly; d) these risk multipliers can be used to perform a risk analysis with any commercial risk analysis program; and e) the Investment Economic Cost Multipliers are not used on the risk, sensitivity and switching values analyses, but can be used to evaluate cases when different project-alternatives have different economic to financial costs ratios.

2.3   HDM-III VEHICLE OPERATING COSTS MODULE

The HDM-III Vehicle Operating Costs Module computes, for a particular country, vehicle operating costs and speeds as a function of road roughness for nine terrain and road types and the following nine motorized vehicle types.

- Car
- Pickup
- Small Bus
- Medium Bus
- Large Bus
- Light Truck
- Medium Truck
- Heavy Truck
- Articulated Truck

It implements the HDM-III vehicle operating costs equations [5] and requires the same inputs as HDM-III. The three input worksheets, where you enter your inputs on all cells having a yellow background, are the following.

- Basic Input Data
- Calibration Data
- Compute Results

The output worksheets are the following.

- Coefficients
- Speeds
- VOC
- HDM-III & Equations Comparison
- Typical VOC and Speeds

Basic Input Data

This worksheet collects the main country specific input parameters (see Figure 13a). You enter three terrain types characteristics (rise plus fall and curvature), three road types characteristics (desired speeds) and the following vehicle characteristics for nine motorized vehicle types.

1.   Economic vehicle, tire, fuel, lubricants, maintenance and crew costs and interest rate.
2.   Vehicle utilization in kilometers and hours driven per year.
3.   Vehicle service life and gross vehicle weight.

Note that if some vehicle types are not available in your country, you can place zero as the daily traffic of a vehicle type on the Main Evaluation Module, but you cannot leave blank the input data for a vehicle type on the HDM-III Vehicle Operating Costs Module. You should fill all the input data for all vehicle types, even if you just copy the contents of an available vehicle type into the column of a vehicle type that is not available.

The country, year, currency and exchange inputs are entered for future reference only. On this worksheet you also select the vehicle type to be used as the reference vehicle to estimate roughness as a function of speed of the reference vehicle.

Calibration Data

This worksheet further calibrates the HDM-III equations to local conditions. You enter all HDM-III calibrations parameters, on the cells with yellow background, if needed and if data is available, such as vehicle physical characteristics and other fuel, tires, maintenance and utilization model parameters.

Compute Results

This worksheet has a button, named "Compute Results", that executes an Excel macro that computes the results. Once the calculations are done, you can view the results on the following worksheets or press the other button, named "Copy and Paste Results into Main Module", to automatically copy all the resulting coefficients relating vehicle operating costs and speeds to roughness into the Main Economic Evaluation Module, for all vehicles. In this case, you have to supply the workbook name of the Main Economic Evaluation Module that should be located on the same folder as the HDM-III Vehicle Operating Costs Module.

Coefficients

This worksheet presents the cubic polynomials coefficients relating vehicle operating costs and speeds to roughness. Note that this worksheet has the same format as the "Unit VOC and Speeds" worksheet of the Main Economic Evaluation Module and that these coefficients (in light blue) are the ones copied into the Main Economic Evaluation Module.

Speeds

This worksheet presents the resulting vehicle speeds as a function of roughness for all nine terrain and road types and nine vehicle types.

VOC

This worksheet presents the resulting unit vehicle operating costs as a function of roughness for all nine terrain and road types and nine vehicle types. Note that the HDM-III Module creates a text file delimited with commas on the current directory, titled "compo.csv", which contains the vehicle operating costs composition (fuel consumption, depreciation, labor, etc.) for each road and vehicle type. If needed, you can open that file in Excel to study the vehicle operating costs composition.

HDM-III & Equations Comparison

This worksheet compares the results of the HDM-III model equations and the cubic polynomials derived by the HDM-III Vehicle Operating Costs Module. You enter the geometry type, road type, and vehicle number and the worksheet presents the corresponding vehicle operating costs and speeds comparison.

Typical VOC and Speeds

This worksheet presents typical vehicle operating costs and speeds, for all nine terrain and road types and nine vehicle types, for five possible road condition classes (Very Good, Good, Fair, Poor, Very Poor). You define the representative roughness of each road condition class, enter a typical traffic composition for the calculation of average vehicle fleet VOC and speeds, and press the "Update Results" button. Note that the worksheet also computes the cubic polynomials relating the fleet vehicle operating costs and speeds to roughness, which are given starting on cell Q12.

2.4   HDM-4 VEHICLE OPERATING COSTS MODULE

The HDM-4 Vehicle Operating Costs Module computes, for a particular country, vehicle operating costs and speeds as a function of road roughness for nine terrain and road types and nine motorized or non-motorized vehicle types, which are selected among the following possible vehicle types.

- Motorcycle
- Car Small
- Car Medium

- Car Large
- Delivery Vehicle
- Goods Vehicle
- Four-Wheel Drive
- Truck Light
- Truck Medium
- Truck Heavy
- Truck Articulated
- Bus Mini
- Bus Light
- Bus Medium
- Bus Heavy
- Coach
- Bicycle
- Rickshaw
- Animal Cart
- Pedestrian

It implements the HDM-4 vehicle operating costs equations [2] and requires the same inputs as HDM-4. The three input worksheets, where you enter your inputs on all cells having a yellow background, are the following.

- Basic Input Data
- Calibration Data
- Compute Results

The output worksheets are the following.

- Coefficients
- Typical VOC and Speeds
- Speeds
- VOC
- VOC Components
- HDM-4 & Equations Comparison
- Typical VOC and Speed

Basic Input Data

This worksheet collects the main country specific input parameters (see Figure 13b). You enter basic road characteristics, such as altitude, percent of time driven on snow, percent of time driven on water, and paved roads texture depth. You enter three terrain types characteristics (rise plus fall, curvature, number of rise and falls and super-elevation), three road types characteristics (surface type, road width, speed limit, speed limit enforcement factor, roadside friction

and non-motorized traffic friction). You select up to nine motorized or non-motorized vehicle types, by using the pull-down menu on each vehicle type description, and enter the following vehicle characteristics for the up to nine vehicle types.

1.   Economic vehicle, tire, fuel, lubricants, maintenance and crew costs and interest rate.
2.   Vehicle utilization in kilometers and hours driven per year.
3.   Vehicle service life, percent of time for private use, and gross vehicle weight.

Note that you are not required to select and use nine vehicles. If your vehicle fleet has less than nine vehicle types, you can disable a vehicle type by selecting "Not Used" as the vehicle type description. You should fill all the input data for all valid vehicle types.

Note that the HDM-4 equations are not very sensitive to the following inputs: altitude, percent of time driven on snow, percent of time driven on water, paved roads texture depth, number of rise and falls, super-elevation, speed limit enforcement and roadside and NMT factors (in italics); therefore, you can use the supplied values if you don't have country specific values.

The country, year, currency and exchange inputs are entered for future reference only. On this worksheet you also select the vehicle type to be used as the reference vehicle to estimate roughness as a function of speed of the reference vehicle.

Calibration Data

This worksheet further calibrates the HDM-4 equations to local conditions. You can enter, on the cells with yellow background, all HDM-4 calibrations parameters, if needed and if data is available, such as vehicle physical characteristics and other fuel, tires, maintenance and utilization model parameters.

Compute Results

This worksheet has a button, named "Compute Results", that executes an Excel macro that computes the results. Once the calculations are done, you can view the results on the following worksheets or press the other button, named "Copy and Paste Results into Main Module", to automatically copy all the resulting coefficients relating vehicle operating costs and speeds to roughness into the Main Economic Evaluation Module, for all vehicles. In this case, you have to supply the workbook name of the Main Economic Evaluation Module that should be located on the same folder as the HDM-4 Vehicle Operating Costs Module.

Coefficients

This worksheet presents the cubic polynomials coefficients relating vehicle operating costs and speeds to roughness. Note that this worksheet has the same format as the "Unit VOC and

Speeds" worksheet of the Main Economic Evaluation Module and that these coefficients (in light blue) are the ones copied into the Main Economic Evaluation Module.

Speeds

This worksheet presents the resulting vehicle speeds as a function of roughness for all nine terrain and road types and nine vehicle types.

VOC

This worksheet presents the resulting unit vehicle operating costs as a function of roughness for all nine terrain and road types and nine vehicle types.

VOC Components

This worksheet presents the resulting unit vehicle operating costs components (fuel consumption, tire consumption, etc.) as a function of roughness for all nine terrain and road types and nine vehicle types.

HDM-4 & Equations Comparison

This worksheet compares the results of the HDM-4 model equations and the cubic polynomials derived by the HDM-4 Vehicle Operating Costs Module. You enter the geometry type, road type, and vehicle number and the worksheet presents the corresponding vehicle operating costs and speeds comparison.

Typical VOC and Speeds

This worksheet presents typical vehicle operating costs and speeds, for all nine terrain and road types and nine vehicle types, for five possible road condition classes (Very Good, Good, Fair, Poor, Very Poor). You define the representative roughness of each road condition class, enter a typical traffic composition for the calculation of average vehicle fleet VOC and speeds, and press the "Update Results" button. Note that the worksheet also computes the cubic polynomials relating the fleet vehicle operating costs and speeds to roughness, which are given starting on cell Q12.

2.5   RISK ANALYSIS MODULE

The Risk Analysis Module performs a risk analysis based on triangular probability distributions for the main twenty input parameters. With the risk analysis module, you can explicitly include the uncertainty present in the estimates of the input parameters to generate results that

show all possible outcomes. You define the estimate of an input variable and some measure of the likelihood of occurrence for that estimate taking the forms of a triangular probability distribution. The risk analysis module then uses this information to analyze every possible outcome, executing hundreds of what-if scenarios. In each scenario, random inputs following the defined input probability distribution are generated, and the resulting frequency distributions presented in graphical form. The two input worksheets are the following.

- Basic Input Data
- Compute Results

The output worksheets are the following.

- Risk Analysis Solution
- Option 1 Net Present Value
- Option 2 Net Present Value
- Option 3 Net Present Value
- Option 1 Rate of Return
- Option 2 Rate of Return
- Option 3 Rate of Return
- Inputs Distribution

Before using the Risk Analysis Module, you should use the Vehicle Operating Costs Module and the Main Economic Evaluation Module to compare, without risk analysis, the project-alternatives of the road you are evaluating. On the Main Economic Evaluation Module, you should enter the most likely value for all inputs. Once you have entered all the most likely values on the Main Economic Evaluation Module, you are ready to add the risk analysis to the evaluation.

Basic Input Data

This worksheet collects the main risk parameters (see Figure 14). You have entered estimates of the most likely value for each of the main input parameters on the Main Economic Evaluation Module and on this "Basic Input Data" worksheet you enter, for each of the main input parameters, two multipliers to the estimates entered into the Main Economic Evaluation Module to define triangular distributions. The first multiplier defines the minimum possible value of the input parameter (there is zero possibility that the actual value will be lower than the minimum value). For example, if the multiplier is set to 0.7, this means that the minimum possible value for that parameter is 70 percent of the estimated most likely value entered into the Main Economic Evaluation Module. The second multiplier defines the maximum possible value of the input parameter (there is zero possibility that the actual value will be higher than the maximum value). For example, if the multiplier is set to 1.2, this means that the maximum possible value for that parameter is 120 percent of the estimated most likely value entered into the Main Economic Evaluation Module. For this example, we then have the following.

Minimum possible value		-> 70% of most likely value
Most likely value		-> Value entered on main module
Maximum possible value	-	-> 120% of most likely value

This implies, for this example, that there is a 60 percent probability (30/(30+20)) that the actual value is less than the estimated most likely value and 40 percent probability (20/(30+20)) that the actual value is more than the estimated most likely value. Note that if you do not want to vary a particular main input parameter, you should place 1.0 as the minimum and maximum values multipliers for that parameter.

Compute Results

This worksheet executes an Excel macro that computes the risk analysis. First you have to enter the number of scenarios to evaluate (less than 1,000) and the workbook name of the Main Economic Evaluation Module, which should be located on the same folder as the Risk Analysis Module.

One you have entered the number of scenarios to evaluate and the main module workbook name, you should press the button named "Compute Risk Analysis". The Risk Analysis Module evaluates all the scenarios and presents the results on the following worksheets.

Risk Analysis Solution

This worksheet presents a summary of the risk analysis results (See Figure 15). Here you will find for, the net present value and rate of return, the following indicators:

1. The point estimate, which is the value computed by the Main Economic Evaluation Module based on the estimated most likely values for all inputs.
2. Average of the results of all scenarios evaluated by the risks analysis.
3. Standard deviation of the results of all scenarios evaluated by the risks analysis.
4. Minimum of the results of all scenarios evaluated by the risks analysis.
5. Maximum of the results of all scenarios evaluated by the risks analysis.
6. Median of the results of all scenarios evaluated by the risks analysis.
7. Probability that the net present value is less than zero or that the internal rate of return is less than 12%.

Option 1 – Net Present Value

This worksheet presents the resulting probability distribution for the net present value of project-alternatives 1 (see Figure 16). Note that there is a similar worksheet for options 2 and 3. You will find the following results.

1. Net present value point estimate, minimum, maximum, average, standard deviation and median.
2. Net present value percentile for three percentile options that could represent the worst, most likely and best scenarios.
3. Probability that the net present value is less than or greater than 0.
4. Frequency distribution graph.
5. Cumulative distribution graph.

Option 1 – Rate of Return

This worksheet presents the resulting probability distribution for the internal rate of return of project-alternatives 1. Note that there is a similar worksheet for options 2 and 3. You will find the following results.

1. Internal rate of return point estimate, minimum, maximum, average, standard deviation and median.
2. Internal rate of return percentile for three percentile options that could represent the worst, most likely and best scenarios.
3. Probability that the internal rate of return is less than or greater than 12 %.
4. Frequency distribution graph.
5. Cumulative distribution graph.

Inputs Distribution

This worksheet presents the resulting probability distributions for the main input parameters. You select one input parameter at the top of the worksheet and the model displays the following results.

1. Input parameter multiplier minimum, maximum, average, standard deviation and median.
2. Input parameter multiplier percentile for three percentile options.
3. Probability that input parameter multiplier is less than or greater than 1.
4. Frequency distribution graph.
5. Cumulative distribution graph.

2.6 PROGRAM EVALUATION MODULE

The Program Evaluation Module evaluates of a series of roads at once and allows you to obtain the corresponding program results. With the Main Economic Evaluation Module, you evaluate one road at a time and obtain the economic comparison of project-alternatives for a particular road. With the Program Evaluation Module, you evaluate many roads at once and obtain the corresponding results for each road as well as the overall program economic indicators, without

or with budget constraints. The budget constraint optimization is done with the EBM-32 model, which optimization algorithm works with up to 400 roads, therefore, the maximum number of roads that can be evaluated at once with the Program Evaluation Module is 400 roads.

The Program Evaluation Module allows you to perform two "RED Main Economic Evaluation Module runs" per road, thus, evaluating up to seven project-alternatives per road. The first run evaluates project-alternatives 0, 1, 2 and 3 and the second run evaluates project-alternatives 4, 5 and 6. The base alternative (project-alternative 0) should be common to both RED runs.

The input worksheet is the following.

- RED Inputs

The output worksheets are the following.

- RED Outputs
- Road Section Net Present Value
- Unconstrained Budget
- Budget Constraint A
- Budget Constraint B
- Budget Constraint C
- Budget Constraint D
- Budget Constraint E
- Recommended Program
- Network Net Present Value
- Multi-Criteria

RED Inputs

This worksheet collects all the necessary inputs related to the road program. Each line represent one road and the columns represent the same inputs as the one presented on the input worksheets of the Main Economic Evaluation Module. For each road, you define the analysis control and the traffic, as well as the characteristics of the seven project-alternatives to be evaluated (road characteristics and condition, investment and maintenance costs, and accident rates). You should enter the information of the first road on row 11 and enter the information of as many roads as needed on the following rows, up to a maximum of 400 roads, remembering that each row represents a road and that you can not leave blank rows in your roads database.

To import the data stored on a Main Economic Evaluation Module, place the cursor on a desired target row and press Ctrl-R. You will be asked the name of the Main Economic Evaluation Module, which contains the data you want to import, and the run number to place the data. If you select run number 1, you will import the road characteristics and the data of project-

alternatives 0, 1, 2 and 3 from the corresponding project-alternatives on the Main Economic Evaluation Module. If you select run number 2, you will import data of project-alternatives 4, 5 and 6 from the project-alternatives 1, 2 and 3 on the Main Economic Evaluation Module.

To export data to a Main Economic Evaluation Module, place the cursor on a desired source row and press Ctrl-L. You will be asked the name of the Main Economic Evaluation Module, which will contain the data you want to export, and the run number to collect the data. If you select run number 1, you will export the road characteristics and the data of project-alternatives 0, 1, 2 and 3 into the corresponding project-alternatives on the Main Economic Evaluation Module. If you select run number 2, you will export data from project-alternatives 0, 4, 5 and 6 into the project-alternatives 0,1, 2 and 3 on the Main Economic Evaluation Module.

You have to enter the data related to vehicle operating costs, passenger and cargo time, and accident costs in a "master" Main Economic Evaluation Module that will be used to evaluate the different roads. The Program Evaluation Module will copy the contents of a road, stored on the RED Inputs worksheet, into the "master" Main Economic Evaluation Module, which will compute the results in the background. After the results are computed, the Program Evaluation Module will copy the results and place them on the different output worksheets of the Program Evaluation Module. To obtain the network results, you need first need to specify, on cell B3, the name of the "master" Main Economic Evaluation Module, which should be located on the same folder as the Program Evaluation Module, and then press the "Execute RED Model" button located at the top of the worksheet.

RED Outputs

This worksheet stores the results obtained from the program evaluation. Here you will find, for each road, all the resulting economic indicators for the seven project-alternatives being evaluated.

Road Section Net Present Value

This worksheet presents the results for each road individually. You select a road and the worksheet presents the corresponding results, including a graph of the NPV and Investment Costs (see Figure 17). The graph also shows an uncertainty margin line that is at a, user specified, percentage of the highest NPV. This line represents that all alternatives above the line are within the uncertainty margin, therefore, could be selected instead of the alternative with highest NPV.

Unconstrained Budget

This worksheet presents the resulting program for an unconstrained budget scenario, in which the selected alternative per road is the one with highest NPV. The worksheet presents the following indicators for each road and for the entire program.

- Road length
- Road characteristics (name, terrain and road type, traffic and roughness)
- Selected alternative
- NPV, in million
- IRR, in %
- Equivalent annual benefits, in US$/km-year
- Modified IRR, in %
- PV of economic agency costs, in millions US$
- Financial investment cost, in millions US$
- NPV per PV of agency costs ratio
- NPV per investment ratio
- Recurrent maintenance costs, in millions US$ per year
- Population served, in number of persons
- Investment per population, in US$ per person
- Population per investment, in persons per 1,000 US$

Budget Constraint A

This worksheet presents the resulting program for a given budget scenario, in which the selected alternative per road is the one obtained from an EBM-32 optimization. To characterize the budget constraint scenario, you should enter the capital resources available for the program on cell E7, in millions USD, and then press the button "Perform Budget Optimization". Once the optimization is done, you should press the button "Collect Optimization Results" to update the worksheet with the optimization results. The indicators presented on the worksheet are the same ones as the ones presented on the Unconstrained Budget worksheet. Note that you will know that the optimization is done when then optimization popup windows closes after a few seconds or minutes. Note also that in order to perform the optimization, the file EBM-32.EXE should be placed on the same folder as the Program Evaluation Module and the Main Economic Evaluation Module.

Budget Constraint B to E

These worksheets have the same structure as Budget Constraint A worksheet. For each budget constraint scenario (A, B, C, D and E), you enter the available budget on cell E7, perform the optimization, and collect the optimization results.

Recommended Program

This worksheet allows you to manually select a project-alternative per road and obtain the corresponding program results. You should enter you selection of project-alternatives starting on cell I41 and then press the button "Update Recommended Program". The resulting indicators presented are the same ones as the ones presented on the Unconstrained Budget worksheet.

Program Net Present Value

This worksheet presents the results for each budget scenario and the recommended program scenario, including a graph of the Net Present Value and Program Investment Costs. The graph also shows an uncertainty margin line that is at a, user specified, percentage of the highest NPV. This line represents that all budget scenarios above the line are within the uncertainty margin, therefore, could be selected instead of the budget scenario with highest NPV.

Multi-Criteria

This worksheet presents the results of the multi-criteria analysis for the recommended program. You should enter the relative weights for each of the indicators and press the Update Multi-Criteria Analysis button to collect the recommended work program and the corresponding multi-criteria indicators. The worksheet presents the following indicators for each road.

- Road length
- Road characteristics (name, terrain and road type, traffic and roughness)
- Selected alternative
- Financial investment cost, in millions USD
- NPV, in millions
- IRR, in %
- NPV per investment ratio
- Population served, in number of persons
- Investment per population served
- Population per investment, in persons per 1,000 USD
- Up to eight multi-criteria indicators (-10-low, 0-medium and 10-high priority)
- Overall multi-criteria indicator
- NPV per investment importance rank, (1-highest priority, 2-second priority, 3-third priority, 4-fourth priority, etc.)
- Population per investment importance rank (1-highest priority, 2-second priority, 3-third priority, 4-fourth priority, etc.)
- Multi-criteria importance rank (1-highest priority, 2-second priority, 3-third priority, 4-fourth priority, etc.)
- NPV per investment importance class, (-10-low, 0-medium and 10-high priority)
- Population per investment importance class (10-low, 0-medium and 10-high priority)
- Multi-criteria importance class (-10-low, 0-medium and 10-high priority)

3.   MODEL APPLICATIONS

Two typical RED applications are presented which consist of the economic justification of paving an unpaved road and justifying maintenance expenditures needed to maintain a certain level of service.

APPLICATION 1 - PAVING A GRAVEL ROAD

The project road is a 10 kilometer two lane gravel road with 200 vehicles per day, 60 percent trucks and buses with 3 percent growth rate, on a rolling terrain. The road receives very good maintenance that consists of grading every 60 days (approximately at the passage of 12,000 vehicles with the current traffic) and regravelling every 5 years. This maintenance policy yields a road with good passability all year and the estimated average roughness over the evaluation period is equal to 10.0 IRI. RED evaluates the following project-alternatives.

1.   Improve even further the maintenance policy increasing the grading frequency to one grading every 45 days and keeping the regravelling interval of 5 years. In this case, the estimated average roughness is 7.0 IRI.
2.   Upgrade the road to surface treatment standard. In this case, the estimated average roughness is 3.5 IRI.
3.   Upgrade the road to asphalt concrete standard. In this case, the estimated average roughness is 2.7 IRI.

In this case study, the level of service of each project-alternative is defined by an estimated average roughness over the evaluation period. The roughness estimates are done outside RED. Note that the duration of the wet season (period with disrupted passability) is zero for all project-alternatives.

The basic inputs are given on the table below.

	Without Project	Project-Option 1	Project-Option 2	Project-Option 3
Description	Grading 60 Days	Grading 45 Days	ST Road Standard	AC Road Standard
Terrain	Rolling	Rolling	Rolling	Rolling
Type	Gravel	Gravel	Paved	Paved
Average Roughness	10.0	7.0	3.0	2.0
Duration of the Wet Season (days)	0	0	0	0
Investment duration (years)	0	1	1	1
Investment ($/km)	0	21,000	100,000	150,000
Maintenance costs:				
Fixed ($/km/year)	5,000	5,000	5,200	1,500
Variable ($/km/year/ADT)	3	4	0	0
Accidents (#/100m veh-km)	200	200	100	100
Normal traffic (AADT)	200	200	200	200
Generated traffic due to reduction in transport costs (price elasticity of demand for all vehicles)	1	1	1	1
Induced traffic due to economic development	0	0	0	0
Diverted traffic from Alternative route	0	0	0	0

Option 1 investment cost is for an initial rehabilitation and options 2 and 3 investment costs for are paving costs. Future annualized maintenance costs needed to maintain the proposed levels of service are the following: (a) for the without project case and option 1, the costs of routine maintenance and regravelling every 5 years (fixed) and the costs of gradings (variable), (b) for options 2, the costs of routine maintenance, patching and a future overlay and (c) for option 3, only the costs of routine maintenance and patching, because a future overlay will not be needed during the analysis period. The estimates for the investment costs and the annualized maintenance costs required for each project-alternative are done outside RED based on local units costs and estimates of work requirements and timing.

The analysis assumes accident rates will reduce in half when paving occurs due to an improved road geometry and road width. There are no induced traffic due to economic development or diverted traffic from an alternative road. The price elasticity of demand for transport is set to 1.0, for all vehicles, meaning that a one percent decrease in transport costs yields a one percent increase in generated traffic due to reduction in transport costs. This means that RED will compute internally the generated traffic as a function of the reduction of road user costs in relation to the without project case road user costs.

Time saving are based on value of time of 1.0 USD per hour for cars passengers and 0.5 USD per hour for bus passengers. Cars have an occupancy of 3 persons and buses ranging from 10 to 40

persons. The evaluation period is 20 years, discount rate is 12 percent and economic to financial costs multiplier is 0.85. Note that the average roughness and annualized maintenance needs over the evaluation period should be consistent with the duration of the evaluation period. If a heavy rehabilitation or investment will be needed in a future year, the corresponding costs and resulting level of service should be included in the estimates or the evaluation period should be reduced in order to not include this future activity in the evaluation.

The following results show that options 1 and 2 yield a net present value greater than zero while option 3 has a negative net present value, therefore, option 3 is not economically justified at the given discount rate of 12 percent.

	Without Project	Project- Option 1	Project- Option 2	Project- Option 3
Net present value (millions $)	0	0.151	0.097	-0.014
Internal rate of return (%)	NA	23%	14%	12%
Internal rate of return Sensitivity				
- Normal traffic X 0.75	NA	17%	9%	9%
- Roughness X 1.25	NA	8%	13%	11%
- Investment costs X 1.25	NA	19%	10%	9%
- Maintenance costs X 1.25	NA	17%	12%	12%
- Price elasticity = 0	NA	22%	12%	10%

The net present value is used to compare project-alternatives. Option 1 has the highest net present value, therefore, this indicates that this is economically the best option among the four options considered. What is not evident is if this improved maintenance policy could be realistically implemented during the next twenty years because it entails gradings every 45 days and is highly probable that the road agency will not have the capacity to perform these frequent gradings under increased traffic. For option 1, the sensitivity analysis shows that if proper maintenance is not done and roughness becomes 25 percent higher than the estimate (7.0*1.25=8.75 IRI), the rate of return drops from 23 to 8 percent, while for the paving options the drop is much less under a 25 percent higher roughness scenario, 14 to 9 percent and 12 to 9 percent respectively. The sensitivity analysis also shows the high sensitivity of option 1 to future maintenance costs. For option 1, if future maintenance costs are increased by 25 percent, the rate of return reduces from 23 to 19 percent, while for options 2 and 3 the reduction is only from 14 to 10 percent and from 12 to 9 percent respectively, indicating that the paving option economic justification relies less on future maintenance costs. This indicates that option 1 should be a recommended option only if there are assurances that future maintenance could be properly implemented and that a major increase in maintenance costs will not occur. If that is not the case, one could recommend the surface treatment paving option.

The surface treatment paving option yields net present value of 0.097 million USD and a rate of return of 14 percent and under the sensitivity scenarios the rate of return is reduced to a range from 9 to 13 percent indicating that this option is marginally economically justified. The analysis shows that the reduction in road user costs is on average 28 percent for all vehicles, therefore, the generated traffic is around 28 percent of the normal traffic due to adopted price elasticity of 1.0. Note that if one does not include generated traffic in the analysis (price elasticity equal to zero), the rate of return reduces to 12 percent for the surface treatment paving option. Induced traffic due to local economic development was not considered in the analysis, but if, for example, one considers that induced traffic representing 20 percent of normal traffic will materialize after paving, the rate of return of the surface treatment paving option increases to 15 percent indicating the importance of assessing the induced traffic for projects that have a potential to induce economic development in the project area of influence.

To assess the assumptions made regarding the road condition with and without the project, one can examine the following resulting speeds and travel times.

	Without Project	Project– Option 2
Car speeds (km/hour)	62	94
Medium bus speeds (km/hour)	57	79
Heavy truck speeds (km/hour)	57	81
Car travel time (hours)	0:09	0:06
Medium bus travel time (hours)	0:10	0:07
Heavy truck travel time (hours)	0:10	0:07

If the resulting speeds and travel times are not realistic, one has the option of entering as inputs to the model the speed of a reference vehicle to characterize road condition. For example, if one considers that on this road the average car speeds for the without project case is not realistic and in reality cars are traveling on average at 60 km/hour, after changing the road condition inputs from roughness to speeds of a reference vehicle (car) and entering 60 km/hour as the car speed for the without project case, one obtains an estimated road roughness without the project of 12 IRI and a rate of return of 19 percent for the surface treatment paving option. This indicates that for a proper calibration of the mode, care should be taken on the estimates of road roughness or speeds.

A risk analysis for the surface treatment paving option (2) was done based on the following assumptions.

1. The minimum possible normal traffic is 70 percent of the estimated most likely value (200 ADT) and the maximum value is 130 percent.
2. The minimum possible generated traffic is 25 percent of the estimated most likely value and the maximum value is 175 percent.

3.   The minimum possible roughness without project is 70 percent of the estimated most likely value (8.5 IRI) and the maximum value is 130 percent.
4.   The minimum possible roughness after paving is 90 percent of the estimated most likely value (3.5 IRI) and the maximum value is 110 percent.
5.   The minimum possible paving cost is 85 percent of the estimated most likely value (100,000 $/km) and the maximum value 135 percent.

This means that there is a very high uncertainty regarding the generated traffic, high uncertainty regarding the normal traffic and the roughness of the unpaved road, and some uncertainty regarding the roughness after paving. In these cases, no bias on the estimates of the most likely values was considered. On the other hand, the paving cost vary from 85 to 135 percent of the estimated most likely value indicating that there is 70 percent probability (35/(15+35)) that the paving cost will be higher than the estimated most likely value, implying a bias on the estimate of the most likely value.

For this case study, it was decided to evaluate 600 scenarios with the Risk Analysis Module considering this number of scenarios adequate to obtain smooth output probability distributions. After executing the 600 what-if scenarios, the Risk Analysis Module presents the resulting frequency distribution of the 600 net present values and 600 internal rates of return obtained from the analysis. The figure below presents the resulting internal rate of return frequency distribution graph for the surface treatment paving option.

The results of the risk analysis can be summarized by the following statistics obtained analyzing the resulting frequency distribution.

1.   The mean rate of return is 12 percent.
2.   The standard deviation rate of return is 4 percent.
3.   The probability that the rate of return is less than 12 percent is 44 percent.

One can compute the most likely rate of return, which is the 50 percent percentile, which means that 50 percent of the computed what-if scenarios have a rate of return lower than the most likely rate of return. In this case study, the most likely rate of return is 12 percent.

Taux de rentabilité interne
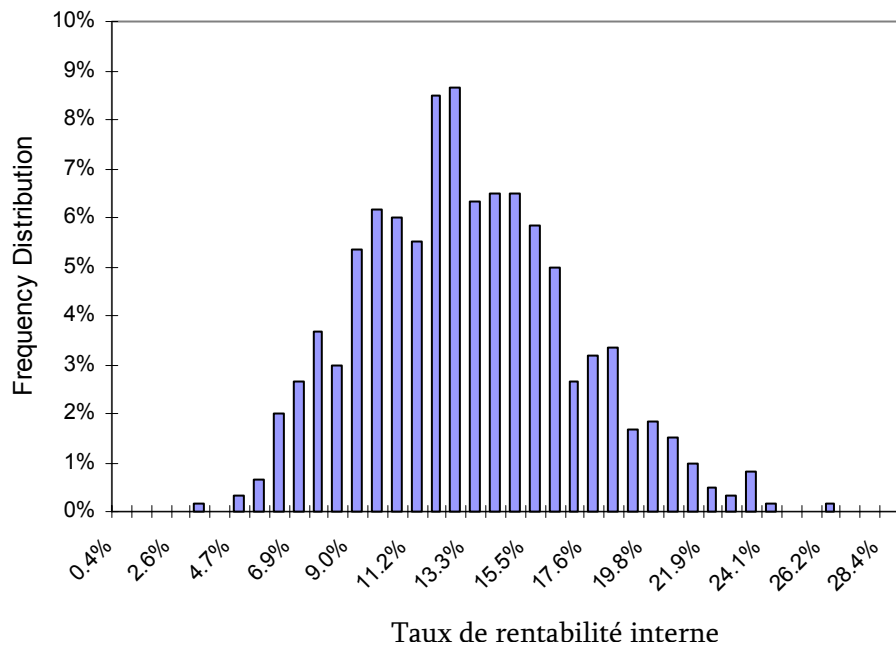
One can also define a best-case scenario and a worst-case scenario. The worst-case scenario is defined, for example in this case study, as the 25 percent percentile, which means that there is only a 25 percent probability that the rate of return is lower than the worst case scenario rate of return. Similarly, the best-case scenario is defined as the 75 percent percentile indicating that there is only a 25 percent probability that the rate of return is higher than the best-case scenario rate of return. In this case study, the best-case scenario rate of return is 15 percent and the worst-case scenario rate of return is 10 percent. The probability that the rate of return is less than 12 percent is 56 percent; therefore, there is a high risk that the project will not be economically justified.

Note that the analysis did not take other benefits (and costs) into consideration, such as induced traffic due to economic development, benefits to non-motorized traffic or social services and environmental impacts, and compared the project with a good maintenance policy applied to the gravel road. Therefore, a final decision should be made after assessing if other net benefits are potentially present.

APPLICATION 2 - JUSTIFYING MAINTENANCE EXPENDITURES

On this second case study, the project road is a 10 kilometer two lane earth road with 40 vehicles per day, 60 percent trucks and buses with 3 percent growth rate, on a rolling terrain. The road is in bad condition with average cars speed of 45 km/hour during most of the year (dry season) and 35 km/hour during 30 days of the year (set season) due to disrupted passability. The

road agency proposes to improve the level of service by eliminating the critical days and increasing the average cars speed to 55 km/hour during all year. The basic inputs are given below.

	Without Project	Project-Option 1
Terrain Type	Rolling Earth	Rolling Earth
Base cars speed (km/hour)	45	55
Disrupted passability days (days)	30	0
Cars speed during disrupted passability days (km/hour)	35	NA

The analysis does not consider accidents benefits, induced traffic due to economic development, diverted traffic or other benefits. The analysis period is 10 years, discount rate is 12 percent, economic to financial costs multiplier is 0.85 and, for all vehicles, the price elasticity of demand is 1.0 (percent increase in traffic per percent decrease in transport).

In this case study, one enters the average speed of a reference vehicle (cars) instead of roughness to characterize the condition of the road and RED estimates the roughness of the road based on the average speed of the reference vehicle. The estimated roughness as a function of cars speed is given below.

	Without Project	Project-Option 1
Base roughness (IRI)	13.8	10.3
Roughness during critical passability days (IRI)	17.6	NA

Without project, the road agency annualized maintenance costs are 700$/km per year for routine maintenance and 1 grading per year. For project-alternative 1, that provides an all weather road, the estimated road agency annualized maintenance costs are 2,900$/km for routine maintenance, two gradings per year, and regravelling every six years. Note that in this case we are not separating the maintenance costs into a fixed and variable components, all costs are considered fixed costs. In these circumstances, project-alternative 1 yields a negative net present value of –0.04 million USD.

One can use the Main Economic Evaluation Module to evaluate the level of maintenance expenditures economically justified to achieve the proposed level of service by using the switching values analysis.

Using the switching values analysis of the maintenance costs, one finds that the maximum an-
nual maintenance expenditures economically justified to achieve the proposed level of service
is 2,200$/km per year. The results are the following.

	Project-Option 1
Maintenance costs ($/km/year)	2,900
Maintenance costs ($/km/year) that yield net present value equal to zero	2,200

This means that that to achieve the level of service of 60 km/hour car speeds all year, annual
expenditures should not be more that 2,200$/km per year for the given 40 vehicles per day,
from an economic point of view. The proposed expenditures (2,900$/km/year) are higher than
the estimated maximum economically allowable (2,200$/km/year), but the agency proceeds
with the implementing the project because the difference (700$/km/year) is considered to be
covered by the other social benefits not included in the analysis based on the number of people
that will be served by the all weather road.

4. CONCLUSIONS

RED is easy to use and requires limited number of input data requirements consistent with the
level of data likely to be available for the analysis of low-volume roads in developing countries.
The model can be used to evaluate road investments and maintenance of low-volume roads and
estimate benefits accruing to motorized road users to which other benefits or costs can be exo-
genously added. Particular attention was given to the presentation of the results, with a view to
highlight all input assumptions and to comprehensively integrate them with sensitivity,
switching values and stochastic risk analyzes. This would assist the analyst in addressing the
high variability and uncertainty, which normally surrounds the economic analysis of low-
volume roads.

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ANNEX. LIST OF FIGURES

Figure 1. RED Model Excel Workbooks and Worksheets

Workbook	Worksheets			
	First Worksheet	Input Worksheets	Output Worksheets	Support Worksheets
Main Economic Evaluation Module RED - Main (version 3.2).XLS	Logo	Control and Setup Unit VOC and Speeds Time and Accidents Traffic Multi-Criteria Indicators Project-Alter. Main Features Project-Alter. Other Benefits	Project Options Solution Efficiency Frontier Graph Alter. 1 Feasibility Alter. 1 User Impact Alter. 1 Benefits Distribution Alter. 1 Sensitivity Alter. 1 Switching Values *** Same for Alter. 2 and Alter. 3.	Benefits 0 Benefits 1 Benefits 2 Benefits 3 Constants Module1
HDM-III Vehicle Operating Costs Module RED - HDM-III VOC (version 3.2).XLS	First Worksheet Logo	Input Worksheets Basic Input Data Calibration Data Compute Results	Output Worksheets Coefficients Speeds VOC HDM-III & Equations Comparison Typical VOC and Speeds	Support Worksheets Roads Macros - Global Macros - RUC
HDM-4 Vehicle Operating Costs Module RED - HDM-4 VOC (version 3.2).XLS	First Worksheet Logo	Input Worksheets Basic Input Data Calibration Data Compute Results	Output Worksheets Coefficients Speeds VOC VOC Components HDM-4 & Equations Comparison Typical VOC and Speeds	Support Worksheets Road Data Vehicle Fleet Data Vehicle Fleet Calibration Module1
Risk Analysis Module RED - Risk (version 3.2).XLS	First Worksheet Logo	Input Worksheets Basic Input Data Compute Results	Output Worksheets Risk Analysis Solution Option 1 - Net Present Value Option 2 - Net Present Value Option 3 - Net Present Value Option 1 - Rate of Return Option 2 - Rate of Return Option 3 - Rate of Return Inputs Distribution	Support Worksheets RiskFactors RiskOutputs Module1
Program Evaluation Module RED - Program (version 3.2).XLS	First Worksheet Logo	Input Worksheets RED Inputs	Output Worksheets RED Outputs Road Section Net Present Value Unconstrained Budget Budget Constraint A Budget Constraint B Budget Constraint C Budget Constraint D Budget Constraint E Recommended Program Program Net Present Value Multi-Criteria	Support Worksheets Capital Recurrent Traffic Roughness Net Benefits Names Current Condition Alternatives

Figure 2. Vehicle Operating Costs and Speeds as a Function of Road Roughness for Nine Terrain-Road Types and Nine Vehicle Types

Terrain Type

		A	B	C
Road	X			
Type	Y			
	Z	AZ		

Vehicle Type	Car
	Utility
	Light Bus
	Medium Bus
	Heavy Bus
	Light Truck
	Medium Truck
	Heavy Truck
	Articulated Truck

Vehicle Operating Costs ($/veh-km)

$y = -2E\text{-}05x^3 + 0.0009x^2 - 0.0004x + 0.1153$

$R^2 = 0.9997$

Roughness (IRI)

Vehicle Speeds (km/hour)

$y = 0.0073x^3 - 0.2767x^2 + 0.2562x + 86.24$

$R^2 = 0.998$

Roughness (IRI)
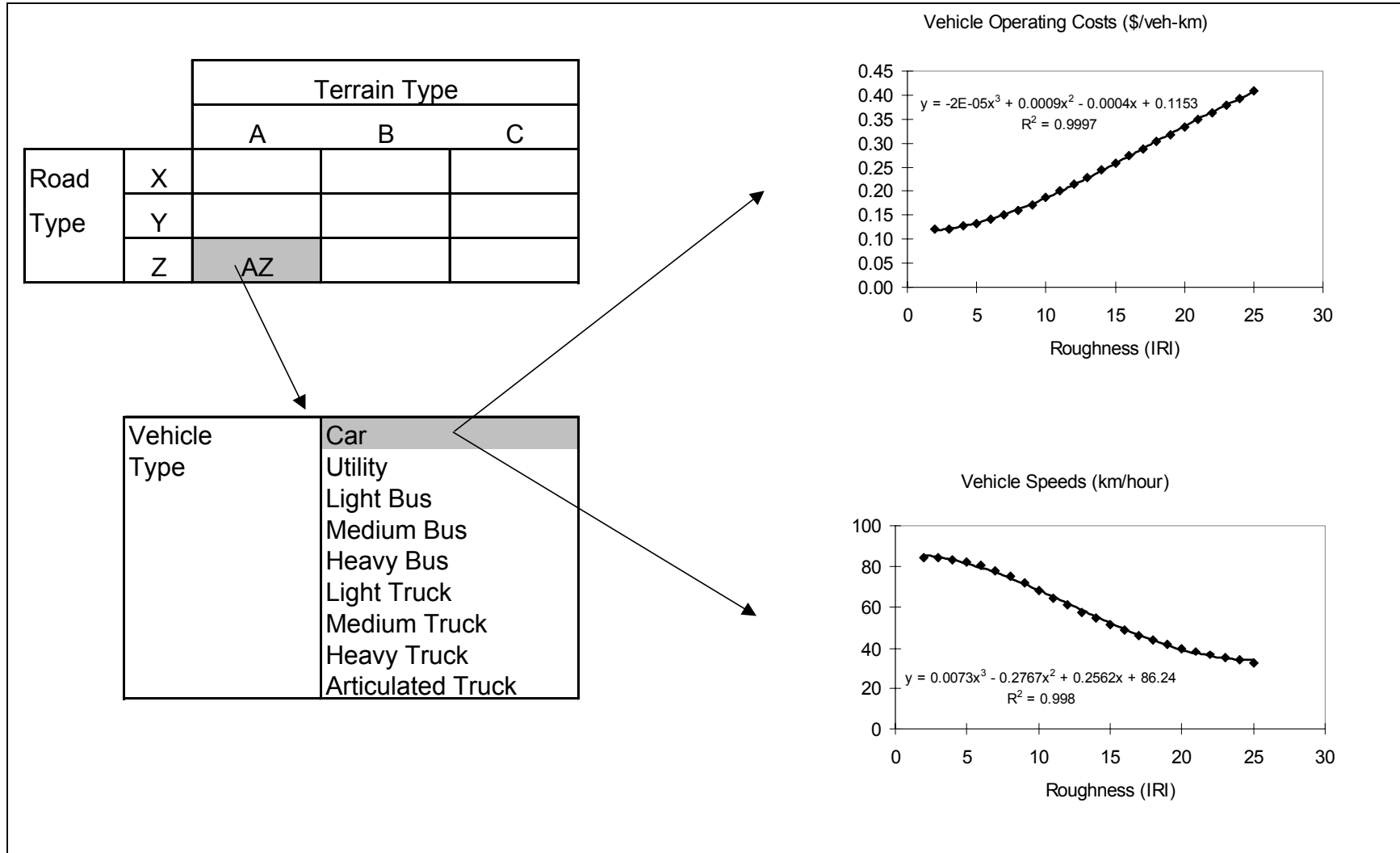
Figure 3. Options for Defining Road Condition

Equations for each vehicle type and each terrain-road type:
 a) Vehicle Operating Costs = a0 + a1 * Roughness + a2 * Roughness^2 + a3 * Roughness^3
 b) Speed = b0 + b1 * Roughness + b2 * Roughness^2 + b3 * Roughness^3

Equation for each terrain-road type and for the defined reference vehicle:
 c) Roughness = c0 + c1 * Speed + c2 * Speed^2 + a3 * Speed^3
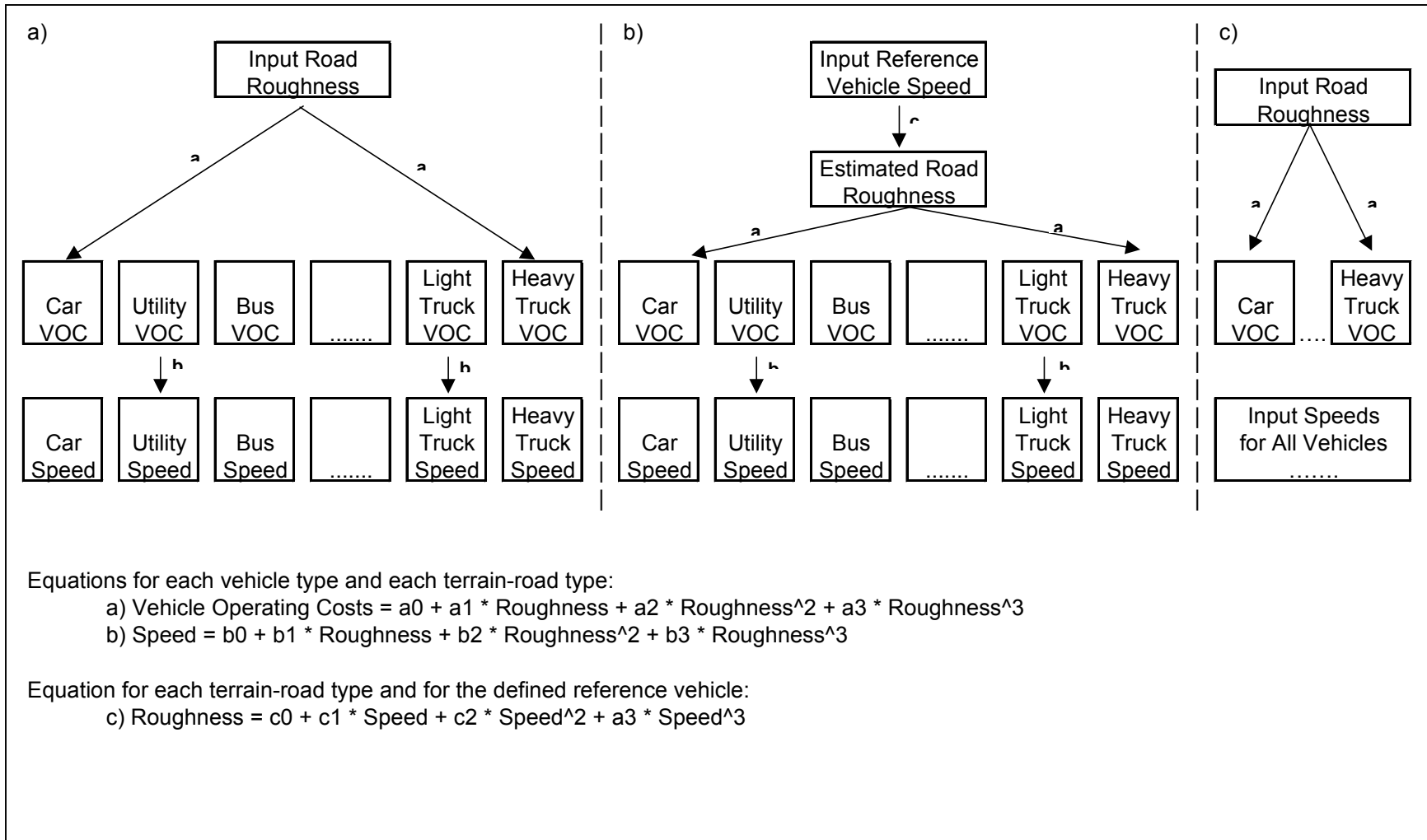
Figure 4. Generated Traffic and Induced Traffic

Generated Traffic Due to Decrease in Transport Costs

Transport Costs

Consumer Surplus

COST1

COST2

ADT1 ADT2 Traffic

| Normal Traffic | Generated Traffic Due to Decrease in Transport Costs |

d1

User enters:
- Percent of normal traffic or
  or
- Price elasticity of demand = $\dfrac{\text{Percent Increase in Traffic}}{\text{Percent Decrease in Transport Cost}}$

Induced Traffic Due to Local Economic Development

Transport Costs

Consumer Surplus

COST1

COST2

ADT2 ADT3 Traffic

Induced Traffic Due to Local Economic Development

d2

d1

User enters:
- Amount of induced traffic due to local economic development

Figure 5. RED Average Level of Service and HDM-III Road Deterioration

HDM-III Road
Deterioration

Average
Level of
Service
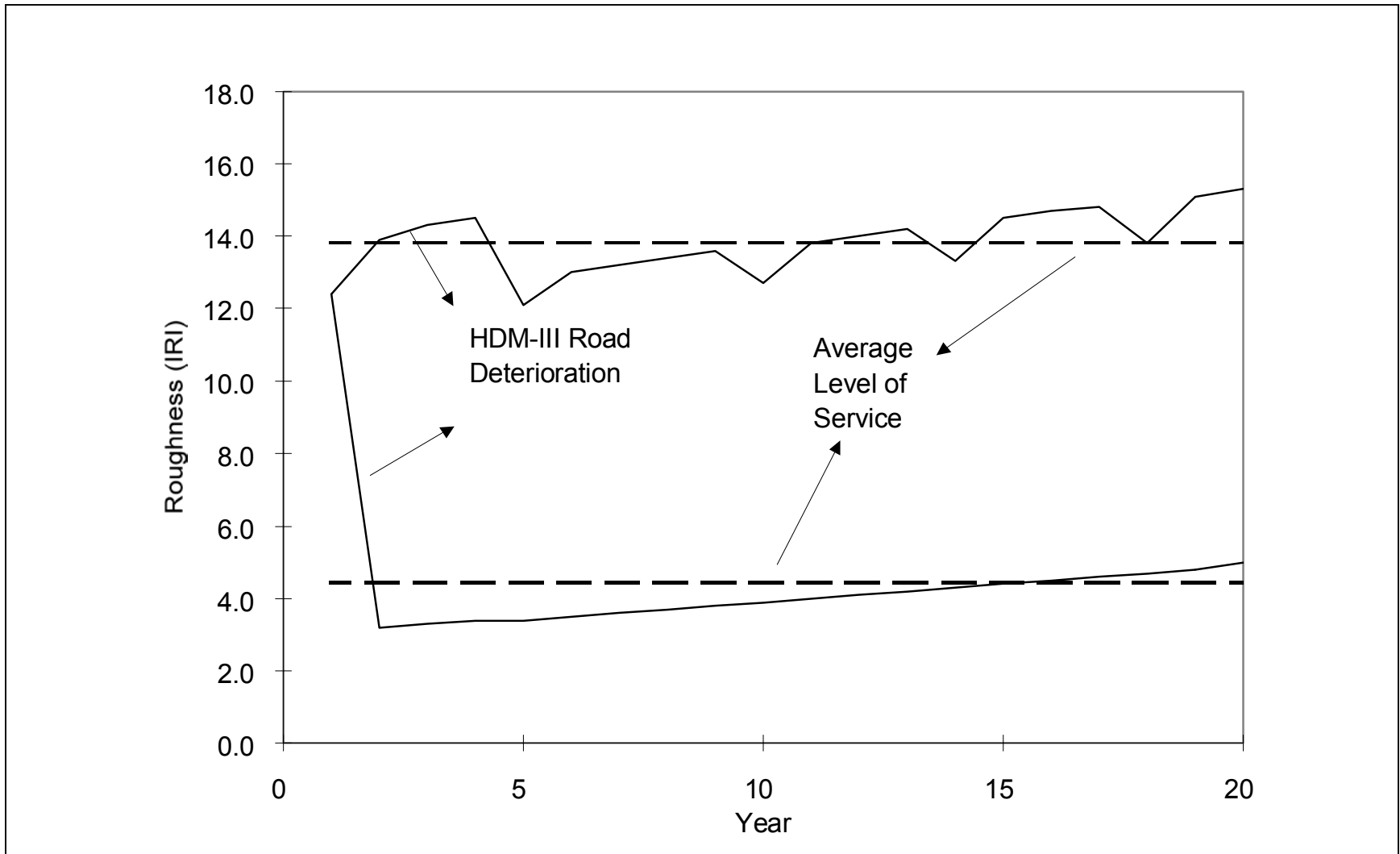
Figure 6. Days per Year With Disrupted Passability

Good Passability
Period

Disrupted Passability
Period

- Different Length
- Different Roughness
- Different Speeds

Higher Road User Costs
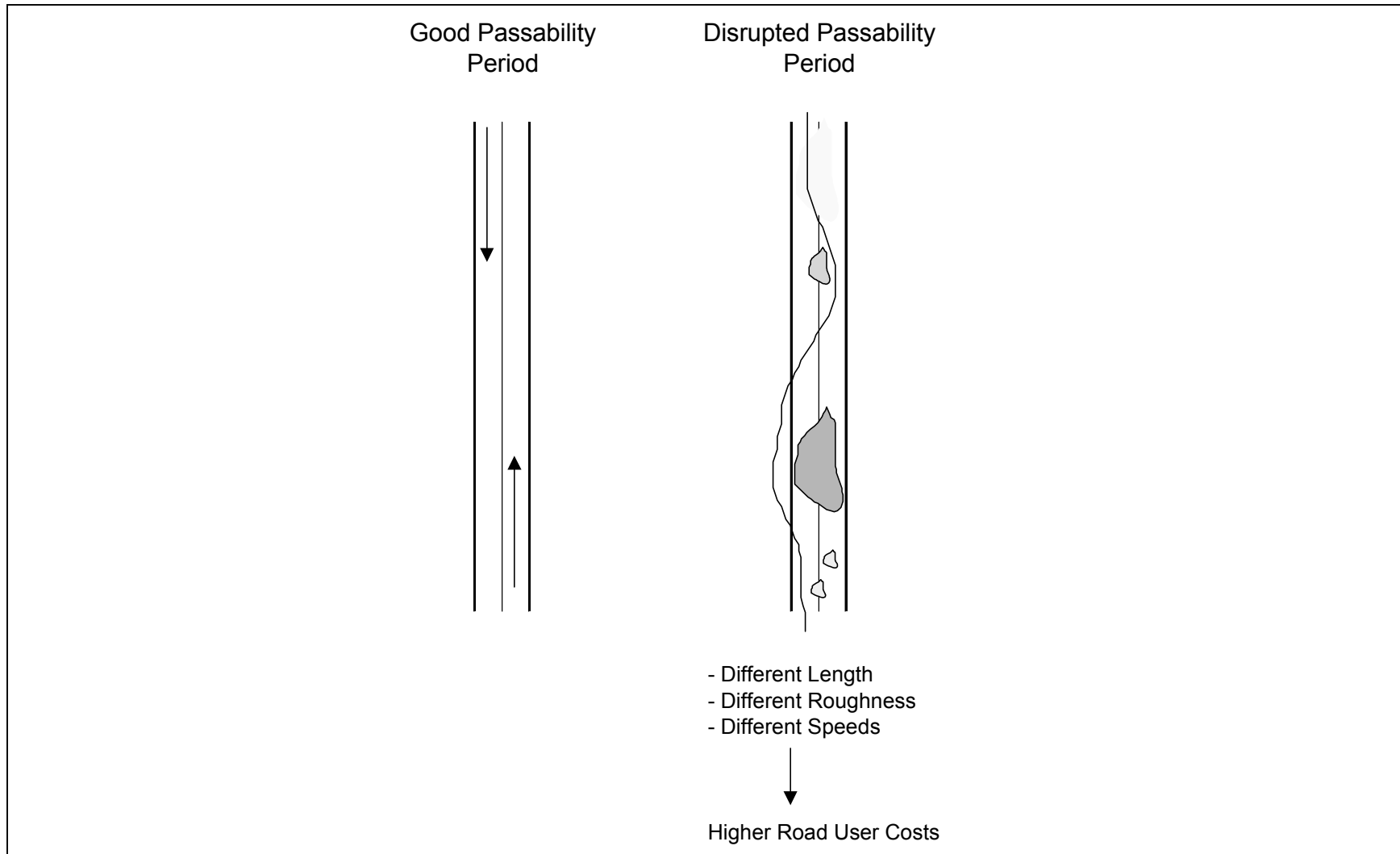
Figure 7. Project-Alternatives Solution

	Africa Region Road Management Initiative Case Study 1			
	Without Project Alternative	Possible Project Alternatives		
	Alternative 0	Alternative 1	Alternative 2	Alternative 3
	Gradings Every 60 Days	Gradings Every 45 Days	Upgrade to Surface Treatment Standard	Upgrade to Asphalt Concrete Standard
Net Present Value (million $) at 12% Discount Rate	0.000	0.151	0.097	-0.014
Internal Rate of Return (%)	#N/A	23%	14%	12%
Equivalent Annual Net Benefits ($/km) at 12% Discount Rate	0	1806	1160	-164
Modified Rate of Return at 12% Reinvestment Rate (%)	#N/A	16%	13%	12%
Net Present Value per Financial Investment Costs (ratio)	0.00	0.85	0.11	-0.01
Net Present Value per PV of Economic Agency Costs (ratio)	0.00	0.27	0.08	-0.01
First-Year Benefits per Economic Investment Cost (ratio)	0.00	0.22	0.12	0.09
Financial Investment Costs (million $)	0.00	0.21	1.00	1.50
PV of Economic Agency Costs (million $)	0.41	0.56	1.18	1.37
PV of Economic Normal Traffic User Costs (million $)	2.71	2.38	1.90	1.84
PV of Economic Generated Traffic User Costs (million $)	0.00	0.30	0.53	0.56
PV of Economic Society Costs (million $)	3.11	3.23	3.61	3.77
Number of Fatalities per km-year After Investment	0.0165	0.0165	0.0060	0.0060
Investment per Population Served ($/person)	0	210	1000	1500
Population Served per Investment (persons/1000$)	0.0	4.8	1.0	0.7

Figure 8. Project-Alternative Economic Feasibility

Country	Africa Region		Project	Road Management Initiative		1/1/2002
Road	Case Study 1		Alternative	Upgrade to Surface Treatment Standard		

Alternatives	Description	Terrain Type	Road Type	Wet Season Duration (days/year)	
Without Project	Gradings Every 60 Days	B: Rolling	Y: Gravel		
Project	Upgrade to Surface Treatment Standard	B: Rolling	X: Paved		0

Alternatives		Dry Season		Wet Season		Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
		Length (km)	Roughness (IRI)	Length (km)	Roughness (IRI)					Average Speeds (km/hr)				
Without Project		10.0	10	0.0	0.0	62.0	60.8	58.1	57.0	56.3	54.8	56.4	56.6	50.1
Project		10.0	3	0.0	0.0	93.7	90.6	82.2	79.3	79.9	75.1	77.2	81.0	71.9
									Traffic Composition in 2002 (%)					
		Eco. Investment (years)	E. Maintenance ('000$/km)	E. Maintenance ('000$/km/year)	Accidents (#/m veh-km)	20%	20%	5%	10%	5%	5%	15%	15%	5%
Alternatives		(years)	('000$/km)	('000$/km/year)	(#/m veh-km)					Average Travel Time (hours)				
Without Project		0	0	4.3	2.0	0:09	0:09	0:10	0:10	0:10	0:10	0:10	0:10	0:11
Project		1	85	4.4	1.0	0:06	0:06	0:07	0:07	0:07	0:07	0:07	0:07	0:08

Year	Annual Normal Daily Traffic (veh/day)	Annual Generated Daily Traffic (veh/day)	Annual Induced Daily Traffic (veh/day)	Agency Benefits — Investment Costs (M$/year)	Agency Benefits — Maintenance Costs (M$/year)	Normal Traffic VOC (M$/year)	Normal Traffic Time (M$/year)	Generated Traffic VOC (M$/year)	Generated Traffic Time (M$/year)	Road Safety (M$/year)	Other Benefits (M$/year)	Total (M$/year)	A Agency * 1.25 (M$/year)	B User * 0.75 (M$/year)	A & B (M$/year)
2002	200	0	0	-0.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.850	-1.063	-0.850	-1.063
2003	206	58	0	0.000	0.004	0.070	0.011	0.010	0.002	0.009	0.000	0.107	0.108	0.081	0.082
2004	212	60	0	0.000	0.004	0.073	0.012	0.011	0.002	0.010	0.000	0.110	0.111	0.083	0.084
2005	219	61	0	0.000	0.004	0.075	0.012	0.011	0.002	0.010	0.000	0.113	0.114	0.086	0.087
2006	225	63	0	0.000	0.004	0.077	0.013	0.011	0.002	0.010	0.000	0.117	0.118	0.089	0.090
2007	232	65	0	0.000	0.004	0.079	0.013	0.012	0.002	0.010	0.000	0.120	0.121	0.091	0.092
2008	239	67	0	0.000	0.004	0.082	0.013	0.012	0.002	0.011	0.000	0.124	0.125	0.094	0.095
2009	246	69	0	0.000	0.005	0.084	0.014	0.012	0.002	0.011	0.000	0.128	0.129	0.097	0.098
2010	253	71	0	0.000	0.005	0.087	0.014	0.013	0.002	0.011	0.000	0.132	0.133	0.100	0.101
2011	261	73	0	0.000	0.005	0.089	0.015	0.013	0.002	0.012	0.000	0.136	0.137	0.103	0.104
2012	269	76	0	0.000	0.005	0.092	0.015	0.014	0.002	0.012	0.000	0.140	0.141	0.106	0.107
2013	277	78	0	0.000	0.005	0.095	0.015	0.014	0.002	0.012	0.000	0.144	0.145	0.109	0.111
2014	285	80	0	0.000	0.006	0.097	0.016	0.014	0.002	0.013	0.000	0.148	0.150	0.113	0.114
2015	294	83	0	0.000	0.006	0.100	0.016	0.015	0.002	0.013	0.000	0.153	0.154	0.116	0.118
2016	303	85	0	0.000	0.006	0.103	0.017	0.015	0.002	0.014	0.000	0.158	0.159	0.120	0.121
2017	312	88	0	0.000	0.006	0.107	0.017	0.016	0.003	0.014	0.000	0.162	0.164	0.123	0.125
2018	321	90	0	0.000	0.006	0.110	0.018	0.016	0.003	0.014	0.000	0.167	0.169	0.127	0.129
2019	331	93	0	0.000	0.007	0.113	0.018	0.017	0.003	0.015	0.000	0.172	0.174	0.131	0.133
2020	340	96	0	0.000	0.007	0.116	0.019	0.017	0.003	0.015	0.000	0.178	0.179	0.135	0.137
2021	351	99	0	0.000	0.007	0.120	0.020	0.018	0.003	0.016	0.000	0.183	0.185	0.139	0.141

3.0% Growth

Evaluation Period (years) — 20

Net Present Value (million $) at 12% Discount Rate	0.097	-0.107	-0.131	-0.335
Internal Rate of Return (%)	14%	10%	10%	7%
Equivalent Annual Net Benefits ($/km) at 12% Discount Rate	1160	-1279	-1569	-4007
Modified Rate of Return at 12% Reinvestment Rate (%)	13%	11%	11%	10%
Net Present Value per Financial Investment Costs (ratio)	0.11	-0.13	-0.15	-0.39
First-Year Benefits per Economic Investment Cost (ratio)	0.12	0.10	0.09	0.07

Figure 9. Project-Alternative User Impact

Country	Africa Region			Project	Road Management Initiative				1/1/2002
Road	Case Study 1			Alternative	Upgrade to Surface Treatment Standard				

Alternatives	Description	Terrain Type	Road Type	Wet Season Duration
Without Project	Gradings Every 60 Days	B: Rolling	Y: Gravel	(days/year) 0
Project	Upgrade to Surface Treatment Standard	B: Rolling	X: Paved	

		Dry Season		Wet Season		Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
		Length	Roughness	Length	Roughness									
Alternatives		(km)	(IRI)	(km)	(IRI)	Average Speeds (km/hr)								
Without Project		10.0	10	0.0	0.0	62.0	60.8	58.1	57.0	56.3	54.8	56.4	56.6	50.1
Project		10.0	3	0.0	0.0	93.7	90.6	82.2	79.3	79.9	75.1	77.2	81.0	71.9
						Traffic Composition in 2002 (%)								
		Eco. Investment	E. Maintenance	Accidents		20%	20%	5%	10%	5%	5%	15%	15%	5%
Alternatives		(years)	('000$/km)	('000$/km/year)	(#/m veh-km)	Average Travel Time (hours)								
Without Project		0	0	4.3	2.0	0:09	0:09	0:10	0:10	0:10	0:10	0:10	0:10	0:11
Project		1	85	4.4	1.0	0:06	0:06	0:07	0:07	0:07	0:07	0:07	0:07	0:08

	Economic R.U.C. Savings (%)	Financial Unit Trip Costs (2002 Dollars)											
		Without Project			With Project			Variation					
		VOC ($/veh-trip)	TIME ($/veh-trip)	TOTAL ($/veh-trip)	VOC ($/veh-trip)	TIME ($/veh-trip)	TOTAL ($/veh-trip)	VOC ($/veh-trip)	TIME ($/veh-trip)	TOTAL ($/veh-trip)	VOC (%)	TIME (%)	TOTAL (%)
Car Medium	-23%	1.72	0.57	2.29	1.38	0.38	1.76	-0.34	-0.19	-0.53	-20%	-34%	-23%
Goods Vehicle	-25%	2.12	0.10	2.22	1.60	0.06	1.66	-0.53	-0.03	-0.56	-25%	-33%	-25%
Bus Light	-26%	2.31	1.01	3.32	1.74	0.72	2.46	-0.57	-0.30	-0.86	-24%	-29%	-26%
Bus Medium	-30%	3.12	2.06	5.18	2.15	1.48	3.64	-0.96	-0.58	-1.54	-31%	-28%	-30%
Bus Heavy	-30%	4.39	4.18	8.57	3.02	2.94	5.97	-1.37	-1.24	-2.60	-31%	-30%	-30%
Truck Light	-32%	3.28	0.00	3.28	2.23	0.00	2.23	-1.05	0.00	-1.05	-32%	0%	-32%
Truck Medium	-30%	4.89	0.00	4.89	3.44	0.00	3.44	-1.45	0.00	-1.45	-30%	0%	-30%
Truck Heavy	-28%	7.18	0.00	7.18	5.14	0.00	5.14	-2.04	0.00	-2.04	-28%	0%	-28%
Truck Articulated	-30%	10.64	0.00	10.64	7.44	0.00	7.44	-3.20	0.00	-3.20	-30%	0%	-30%

	2002 Daily Traffic (veh/day)	Financial Annual Trip Costs (M Dollars)											
		Without Project			With Project			Variation					
		VOC (M$/year)	TIME (M$/year)	TOTAL (M$/year)	VOC (M$/year)	TIME (M$/year)	TOTAL (M$/year)	VOC (M$/year)	(%)	TIME (M$/year)	(%)	TOTAL (M$/year)	(%)
Car Medium	40	0.025	0.008	0.033	0.020	0.005	0.026	-0.005	6%	-0.003	21%	-0.008	8%
Goods Vehicle	40	0.031	0.001	0.032	0.023	0.001	0.024	-0.008	10%	0.000	4%	-0.008	9%
Bus Light	10	0.008	0.004	0.012	0.006	0.003	0.009	-0.002	3%	-0.001	8%	-0.003	3%
Bus Medium	20	0.023	0.015	0.038	0.016	0.011	0.027	-0.007	9%	-0.004	32%	-0.011	12%
Bus Heavy	10	0.016	0.015	0.031	0.011	0.011	0.022	-0.005	6%	-0.005	34%	-0.010	10%
Truck Light	10	0.012	0.000	0.012	0.008	0.000	0.008	-0.004	5%	0.000	0%	-0.004	4%
Truck Medium	30	0.054	0.000	0.054	0.038	0.000	0.038	-0.016	20%	0.000	0%	-0.016	17%
Truck Heavy	30	0.079	0.000	0.079	0.056	0.000	0.056	-0.022	28%	0.000	0%	-0.022	24%
Truck Articulated	10	0.039	0.000	0.039	0.027	0.000	0.027	-0.012	15%	0.000	0%	-0.012	12%
Total	200	0.286	0.044	0.330	0.206	0.031	0.236	-0.080	100%	-0.013	100%	-0.094	100%

Figure 10. Project-Alternative Benefits Distribution

Country	Africa Region		Project	Road Management Initiative		1/1/2002
Road	Case Study 1		Alternative	Upgrade to Surface Treatment Standard		

Alternatives	Description	Terrain Type	Road Type		Wet Season Duration
Without Project	Gradings Every 60 Days	B: Rolling	Y: Gravel		(days/year)
Project	Upgrade to Surface Treatment Standard	B: Rolling	X: Paved		0

Alternatives		Dry Season		Wet Season		Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
		Length (km)	Roughness (IRI)	Length (km)	Roughness (IRI)									
						Average Speeds (km/hr)								
Without Project		10.0	10	0.0	0.0	62.0	60.8	58.1	57.0	56.3	54.8	56.4	56.6	50.1
Project		10.0	3	0.0	0.0	93.7	90.6	82.2	79.3	79.9	75.1	77.2	81.0	71.9
						Traffic Composition in 2002 (%)								
		Eco. Investment		E. Maintenance	Accidents	20%	20%	5%	10%	5%	5%	15%	15%	5%
Alternatives		(years)	('000$/km)	('000$/km/year)	(#/m veh-km)	Average Travel Time (hours)								
Without Project		0	0	4.3	2.0	0:09	0:09	0:10	0:10	0:10	0:10	0:10	0:10	0:11
Project		1	85	4.4	1.0	0:06	0:06	0:07	0:07	0:07	0:07	0:07	0:07	0:08

	Net Economic Benefits								
	Agency Benefits		User Benefits						
	Investment Costs	Maintenance Costs	Normal Traffic		Generated Traffic		Road Safety	Other Benefits	Total
			VOC	Time	VOC	Time			
	(M$/year)	(M$/year)	(M$/year)	(M$/year)	(M$/year)	(M$/year)	(M$/year)	(M$/year)	(M$/year)
Present Value (million $) at 12%	-0.850	0.034	0.623	0.102	0.092	0.015	0.082	0.000	0.097
	-0.816		0.913						0.097

Total User Benefits	0.913					
User Benefits Components	0.623	0.102	0.092	0.015	0.082	0.000
User Benefits Percent	68%	11%	10%	2%	9%	0%

User Benefits Components	0.623	0.102	0.092	0.015	0.082	0.000
Car Medium	0.038	0.022	0.005	0.003	0.016	0.000
Goods Vehicle	0.060	0.004	0.008	0.000	0.016	0.000
Bus Light	0.016	0.008	0.002	0.001	0.004	0.000
Bus Medium	0.055	0.033	0.008	0.005	0.008	0.000
Bus Heavy	0.039	0.035	0.006	0.005	0.004	0.000
Truck Light	0.030	0.000	0.005	0.000	0.004	0.000
Truck Medium	0.123	0.000	0.019	0.000	0.012	0.000
Truck Heavy	0.173	0.000	0.025	0.000	0.012	0.000
Truck Articulated	0.090	0.000	0.014	0.000	0.004	0.000
Car Medium	6%	21%	5%	18%	19%	0%
Goods Vehicle	10%	4%	8%	3%	20%	0%
Bus Light	3%	8%	2%	8%	5%	0%
Bus Medium	9%	32%	9%	34%	10%	0%
Bus Heavy	6%	34%	7%	37%	5%	0%
Truck Light	5%	0%	5%	0%	5%	0%
Truck Medium	20%	0%	20%	0%	15%	0%
Truck Heavy	28%	0%	28%	0%	15%	0%
Truck Articulated	15%	0%	15%	0%	5%	0%

Figure 11. Project-Alternative Sensitivity

Country	Africa Region			Project	Road Management Initiative			1/1/2002
Road	Case Study 1			Alternative	Upgrade to Surface Treatment Standard			

Alternatives	Description		Terrain Type		Road Type		Wet Season Duration	
Without Project	Gradings Every 60 Days		B: Rolling		Y: Gravel		(days/year)	0
Project	Upgrade to Surface Treatment Standard		B: Rolling		X: Paved			

		Dry Season		Wet Season		Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
		Length (km)	Roughness (IRI)	Length (km)	Roughness (IRI)									
Alternatives						Average Speeds (km/hr)								
Without Project		10.0	10	0.0	0.0	62.0	60.8	58.1	57.0	56.3	54.8	56.4	56.6	50.1
Project		10.0	3	0.0	0.0	93.7	90.6	82.2	79.3	79.9	75.1	77.2	81.0	71.9
						Traffic Composition in 2002 (%)								
		Eco. Investment	E. Maintenance	Accidents		20%	20%	5%	10%	5%	5%	15%	15%	5%
Alternatives		(years)	('000$/km)	('000$/km/year)	(#/m veh-km)	Average Travel Time (hours)								
Without Project		0	0	4.3	2.0	0:09	0:09	0:10	0:10	0:10	0:10	0:10	0:10	0:11
Project		1	85	4.4	1.0	0:06	0:06	0:07	0:07	0:07	0:07	0:07	0:07	0:08

	Multiplier Factor	Net Present Value (million $)	Internal Rate of Return (%)	Equivalent Annual Net Benefits ($/km)	Modified Internal Rate of Return (%)	Multiplier Factor	Net Present Value (million $)	Internal Rate of Return (%)	Equivalent Annual Net Benefits ($/km)	Modified Internal Rate of Return (%)
Base Case		0.097	14%	1160	13%		0.097	14%	1160	13%
Sensitivity Cases:										
Normal Traffic (vpd)	0.75	-0.143	9%	-1707	11%	1.25	0.337	17%	4028	14%
Normal Traffic Growth Rate (%)	0.75	0.045	13%	540	12%	1.25	0.153	14%	1828	13%
Generated Traffic (vpd)	0.75	0.070	13%	842	12%	1.25	0.124	14%	1478	13%
Induced Traffic (vpd)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Passenger Time Costs ($/hr)	0.75	0.068	13%	811	12%	1.25	0.126	14%	1509	13%
Cargo Time Costs ($/hr)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Wet Season Duration (days)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Without Project Dry Season Length (km)	0.75	-0.773	#NUM!	-9245	-1%	1.25	1.058	28%	12643	17%
Without Project Dry Season Roughness (IRI)	0.75	-0.243	7%	-2906	10%	1.25	0.494	20%	5907	15%
Without Project Wet Season Length (km)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Without Project Wet Season Roughness (IRI)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Without Project Accidents Rate (#/m veh-km)	0.75	0.059	13%	709	12%	1.25	0.135	14%	1611	13%
Without Project Investment Costs (000$/km)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Without Project Maintenance Costs (000/km/yr)	0.75	0.007	12%	86	12%	1.25	0.187	15%	2234	13%
Project Dry Season Road Length (km)	0.75	1.042	33%	16606	18%	1.25	-0.763	-2%	-7298	5%
Project Dry Season Roughness (IRI)	0.75	0.160	15%	1909	13%	1.25	0.031	13%	365	12%
Project Wet Season Road Length (km)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Project Wet Season Roughness (IRI)	0.75	0.097	14%	1160	13%	1.25	0.097	14%	1160	13%
Project Accidents Rate (#/m veh-km)	0.75	0.114	14%	1367	13%	1.25	0.080	13%	953	13%
Project Investment Costs (000$/km)	0.75	0.310	19%	3700	14%	1.25	-0.115	10%	-1380	11%
Project Maintenance Costs (000/km/yr)	0.75	0.178441	0.150053	2132.989	13%	1.25	0.02	0.12	187.16	0.12

Figure 12. Project-Alternative Switching Values

Country	Africa Region		Project	Road Management Initiative		1/1/2002
Road	Case Study 1		Alternative	Upgrade to Surface Treatment Standard		

Alternatives	Description	Terrain Type	Road Type		Wet Season Duration
Without Project	Gradings Every 60 Days	B: Rolling	Y: Gravel		(days/year) 0
Project	Upgrade to Surface Treatment Standard	B: Rolling	X: Paved		

Alternatives		Dry Season		Wet Season		Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
		Length (km)	Roughness (IRI)	Length (km)	Roughness (IRI)									
						Average Speeds (km/hr)								
Without Project		10.0	10	0.0	0.0	62.0	60.8	58.1	57.0	56.3	54.8	56.4	56.6	50.1
Project		10.0	3	0.0	0.0	93.7	90.6	82.2	79.3	79.9	75.1	77.2	81.0	71.9
						Traffic Composition in 2002 (%)								
Alternatives		Eco. Investment		E. Maintenance	Accidents	20%	20%	5%	10%	5%	5%	15%	15%	5%
		(years)	('000$/km)	('000$/km/year)	(#/m veh-km)	Average Travel Time (hours)								
Without Project		0	0	4.3	2.0	0:09	0:09	0:10	0:10	0:10	0:10	0:10	0:10	0:11
Project		1	85	4.4	1.0	0:06	0:06	0:07	0:07	0:07	0:07	0:07	0:07	0:08

	Base Case	Case that Yields Net Present Value = 0		
	Value	Value	Factor	Change
Normal Traffic (vpd)	200	180	0.90	-10.1%
Normal Traffic Growth Rate (%)	3.0%	1.5%	0.52	-48.4%
Generated Traffic (vpd)	58	5	0.09	-91.1%
Induced Traffic (vpd)	1.0	0.0	0.00	#N/A
Wet Season Duration (days)	0.0	0.0	0.00	#N/A
Without Project Dry Season Length (km)	10.0	9.7	0.97	-2.6%
Without Project Dry Season Roughness (IRI)	10.0	9.3	0.93	-6.7%
Without Project Wet Season Length (km)	0.0	0.0	0.00	#N/A
Without Project Wet Season Roughness (IRI)	0	0	0.00	#N/A
Without Project Accidents Rate (#/m veh-km)	2	1	0.36	-64.3%
Without Project Investment Costs (000$/km)	0.0	0.0	0.00	#N/A
Without Project Maintenance Costs (000/km/yr)	4.3	3.1	0.73	-27.0%
Project Dry Season Road Length (km)	10.0	10.3	1.03	2.7%
Project Dry Season Roughness (IRI)	3.0	4.1	1.36	36.2%
Project Wet Season Road Length (km)	0	0	0.00	#N/A
Project Wet Season Roughness (IRI)	0	0	0.00	#N/A
Project Accidents Rate (#/m veh-km)	1.0	2.4	2.40	140.1%
Project Investment Costs (000$/km)	85.0	94.7	1.11	11.4%
Project Maintenance Costs (000/km/yr)	4.42	5.7375698	1.30	0.30

Figure 13a. HDM-III Vehicle Operating Costs Module Basic Input Data

Country/Region	North Region		Currency Name	US$
Year	2000		Exchange Rate Divider to US$	1.00

	Terrain Type	Rise & Fall (m/km)	Horizontal Curvature (deg/km)		Environment	Altitude (m)
A	Flat	10.0	50.0			500
B	Rolling	20.0	150.0			
C	Mountainous	40.0	300.0			

	Road Type	Desired Speed (km/hr)								
		Car	Pickup	Small Bus	Medium Bus	Large Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
X	Paved	100.0	95.0	95.0	90.0	90.0	95.0	90.0	90.0	85.0
Y	Gravel	80.0	75.0	75.0	70.0	70.0	75.0	70.0	70.0	50.0
Z	Earth	70.0	65.0	65.0	60.0	60.0	65.0	60.0	60.0	45.0

Economic Unit Costs	Car	Pickup	Small Bus	Medium Bus	Large Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
New Vehicle Cost ($/vehicle)	10000	14000	20000	35000	50000	26000	42000	60000	89000
Fuel Cost ($/liter)	0.30	0.30	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Lubricant Cost ($/liter)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
New Tire Cost ($/tire)	45.00	75.00	220.00	220.00	220.00	170.00	255.00	255.00	320.00
Maintenance labor Cost ($/hour)	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Crew Cost ($/hour)	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Interest Rate (%)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Utilization	Car	Pickup	Small Bus	Medium Bus	Large Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
Kilometers driven per year (km)	18000	35000	80000	80000	80000	50000	50000	70000	80000
Hours driven per year (hr)	500	1100	2000	2000	2000	1300	1800	2000	2000

Service Life	Car	Pickup	Small Bus	Medium Bus	Large Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
Service life (years)	10	9	9	9	9	9	10	10	10

Gross Vehicle Weight	Car	Pickup	Small Bus	Medium Bus	Large Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
Gross vehicle weight (tons)	1.2	2.0	3.0	6.0	11.0	6.0	12.0	20.0	30.0

Reference Vehicle Adopted to Estimate Roughness as a Function of Speed of Reference Vehicle

○ Car	○ Medium Bus	○ Medium Truck
○ Pickup	○ Large Bus	○ Heavy Truck
○ Small Bus	○ Light Truck	○ Articulated Truck

Figure 13b. HDM-4 Vehicle Operating Costs Module Basic Input Data

Basic Input Data

Country/Region	North Region		Currency Name	US$
Year	2002		Exchange Rate Divider to US$	1.00

Terrain Types

Code	Description	Rise & Fall (m/km)	Horizontal Curvature (deg/km)	Number of Rises & Falls (#)	Super_ elevation (%)
A	Flat	10	50	1	2
B	Rolling	20	150	1	2
C	Mountainous	40	300	1	2

Road Characteristics

Altitude (m)	500.0
Percent Time Driven on Water	20.0
Percent Time Driven on Snow	0.0
Texture Depth (mm)	0.69

Road Types

Code	Description	Surface Type 1-Bituminous 2-Concrete 3-Unsealed	Carriageway Width (m)	Speed Limit (km/hour)	Speed Limit Enforcement (#)	Roadside Friction (#)	NMT Friction (#)
X	Paved	1	7.0	100.0	1.1	1.0	1.0
Y	Gravel	3	6.0	80.0	1.1	1.0	1.0
Z	Earth	3	5.0	70.0	1.1	1.0	1.0

Vehicle Types

Code	Description	Number of Wheels	Number of Axles
1	Car Medium	4	2
2	Goods Vehicle	4	2
3	Bus Light	4	2
4	Bus Medium	6	2
5	Bus Heavy	10	3
6	Truck Light	4	2
7	Truck Medium	6	2
8	Truck Heavy	10	3
9	Truck Articulated	18	5

Vehicle Fleet Characteristics

	Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
Economic Unit Costs									
New Vehicle Cost ($/vehicle)	10000	14000	20000	35000	50000	26000	42000	60000	89000
Fuel Cost ($/liter for MT, $/MJ for NMT)	0.30	0.30	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Lubricant Cost ($/liter)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
New Tire Cost ($/tire)	45.00	75.00	220.00	220.00	220.00	170.00	255.00	255.00	320.00
Maintenance Labor Cost ($/hour)	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Crew Cost ($/hour)	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Interest Rate (%)	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Utilization and Loading									
Kilometers Driven per Year (km)	18000	35000	80000	80000	80000	50000	50000	70000	80000
Hours Driven per Year (hr)	500	1100	2000	2000	2000	1300	1800	2000	2000
Service Life (years)	10	9	9	9	9	9	10	10	10
Percent of Time for Private Use (%)	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gross Vehicle Weight (tons)	1.20	2.00	3.00	6.00	11.00	6.00	12.00	20.00	30.00

Reference Vehicle Adopted to Estimate Roughness as a Function of Speed of Reference Vehicle

Car Medium

Figure 14. Risk Analysis Module Basic Input Data

		Triangular Distributions				
		Multiplying Factors				
Variable Number	Variable Description	Minimum Possible Value	Model Input Value	Maximum Possible Value	Probability Value < 1 (%)	Probability Value > 1 (%)
1	Normal Traffic (vpd)	0.70	1.00	1.30	50.0%	50.0%
2	Normal Traffic Growth Rate (%)	1.00	1.00	1.00	#N/A	#N/A
3	Generated Traffic (vpd)	0.25	1.00	1.75	50.0%	50.0%
4	Induced Traffic (vpd)	1.00	1.00	1.00	#N/A	#N/A
5	Passenger Time Costs ($/hr)	1.00	1.00	1.00	#N/A	#N/A
6	Cargo Time Costs ($/hr)	1.00	1.00	1.00	#N/A	#N/A
7	Wet Season Duration (days)	1.00	1.00	1.00	#N/A	#N/A
8	Without Project Dry Season Length (km)	1.00	1.00	1.00	#N/A	#N/A
9	Without Project Dry Season Roughness (IRI)	0.70	1.00	1.30	50.0%	50.0%
10	Without Project Wet Season Length (km)	1.00	1.00	1.00	#N/A	#N/A
11	Without Project Wet Season Roughness (IRI)	1.00	1.00	1.00	#N/A	#N/A
12	Without Project Accidents Rate (#/m veh-km)	1.00	1.00	1.00	#N/A	#N/A
13	Without Project Investment Costs (000$/km)	1.00	1.00	1.00	#N/A	#N/A
14	Without Project Maintenance Costs (000/km/yr)	1.00	1.00	1.00	#N/A	#N/A
15	Alternative 1 Dry Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
16	Alternative 1 Dry Season Roughness (IRI)	0.90	1.00	1.10	50.0%	50.0%
17	Alternative 1 Wet Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
18	Alternative 1 Wet Season Roughness (IRI)	1.00	1.00	1.00	#N/A	#N/A
19	Alternative 1 Accidents Rate (#/m veh-km)	1.00	1.00	1.00	#N/A	#N/A
20	Alternative 1 Investment Costs (000$/km)	0.85	1.00	1.35	30.0%	70.0%
21	Alternative 1 Maintenance Costs (000/km/yr)	1.00	1.00	1.00	#N/A	#N/A
22	Alternative 2 Dry Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
23	Alternative 2 Dry Season Roughness (IRI)	0.90	1.00	1.10	50.0%	50.0%
24	Alternative 2 Wet Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
25	Alternative 2 Wet Season Roughness (IRI)	1.00	1.00	1.00	#N/A	#N/A
26	Alternative 2 Accidents Rate (#/m veh-km)	1.00	1.00	1.00	#N/A	#N/A
27	Alternative 2 Investment Costs (000$/km)	0.85	1.00	1.35	30.0%	70.0%
28	Alternative 2 Maintenance Costs (000/km/yr)	1.00	1.00	1.00	#N/A	#N/A
29	Alternative 3 Dry Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
30	Alternative 3 Dry Season Roughness (IRI)	0.90	1.00	1.10	50.0%	50.0%
31	Alternative 3 Wet Season Road Length (km)	1.00	1.00	1.00	#N/A	#N/A
32	Alternative 3 Wet Season Roughness (IRI)	1.00	1.00	1.00	#N/A	#N/A
33	Alternative 3 Accidents Rate (#/m veh-km)	1.00	1.00	1.00	#N/A	#N/A
34	Alternative 3 Investment Costs (000$/km)	0.85	1.00	1.35	30.0%	70.0%
35	Alternative 3 Maintenance Costs (000/km/yr)	1.00	1.00	1.00	#N/A	#N/A

Figure 15. Risk Analysis Solution

	Country	Africa Region		
	Project	Road Management Initiative		
	Road	Case Study 1		

	Without Project Alternative	Possible Project Alternatives		
	Alternative 0	Alternative 1	Alternative 2	Alternative 3
	Gradings Every 60 Days	Gradings Every 45 Days	Upgrade to Surface Treatment Standard	Upgrade to Asphalt Concrete Standard
Net Present Value (million $) at 12% Discount Rate				
Point Estimate	0.000	0.151	0.097	-0.014
Average	0.000	0.146	0.052	-0.105
Standard Deviation	0.000	0.174	0.247	0.276
Minimum	0.000	-0.226	-0.492	-0.821
Maximum	0.000	0.720	0.862	0.782
Median	0.000	0.132	0.039	-0.115
Probability < 0 (%)	#N/A	21%	44%	61%
Internal Rate of Return (%)				
Point Estimate	#N/A	23%	14%	12%
Average	#N/A	22%	13%	11%
Standard Deviation	#N/A	12%	4%	3%
Minimum	#N/A	-4%	5%	3%
Maximum	#N/A	60%	25%	21%
Median	#N/A	22%	13%	11%
Probability < 12% (%)	#N/A	17%	44%	66%

Figure 16. Risk Analysis Internal Rate of Return Frequency Distribution

Country	Africa Region
Project	Road Management Initiative
Road	Case Study 1

Internal Rate of Return Upgrade to Surface Treatment Standard		
Point Estimate		14%
Average		13%
Standard Deviation		4%
Minimum		5%
Maximum		25%
Median		13%
Percentile	25%	10%
Percentile	50%	13%
Percentile	75%	15%
Probability that value is less than	12%	44%
Probability that value is greater than	12%	56%

Frequency Distribution					
		Scenarios			
From	To	Count	%	Cumulative	%
<	2.8%	0	0%	0	0%
2.8%	3.4%	0	0%	0	0%
3.4%	4.0%	0	0%	0	0%
4.0%	4.6%	0	0%	0	0%
4.6%	5.2%	6	1%	6	1%
5.2%	5.8%	9	2%	15	3%
5.8%	6.4%	11	2%	26	4%
6.4%	7.1%	15	3%	41	7%
7.1%	7.7%	17	3%	58	10%
7.7%	8.3%	22	4%	80	13%
8.3%	8.9%	18	3%	98	16%
8.9%	9.5%	29	5%	127	21%
9.5%	10.1%	34	6%	161	27%
10.1%	10.7%	38	6%	199	33%
10.7%	11.3%	27	5%	226	38%
11.3%	12.0%	40	7%	266	44%
12.0%	12.6%	30	5%	296	49%
12.6%	13.2%	41	7%	337	56%
13.2%	13.8%	45	8%	382	64%
13.8%	14.4%	29	5%	411	69%
14.4%	15.0%	28	5%	439	73%
15.0%	15.6%	26	4%	465	78%
15.6%	16.3%	16	3%	481	80%
16.3%	16.9%	19	3%	500	83%
16.9%	17.5%	20	3%	520	87%
17.5%	18.1%	16	3%	536	89%
18.1%	18.7%	15	3%	551	92%
18.7%	19.3%	10	2%	561	94%
19.3%	19.9%	6	1%	567	95%
19.9%	20.6%	9	2%	576	96%
20.6%	21.2%	8	1%	584	97%
21.2%	21.8%	2	0%	586	98%
21.8%	22.4%	5	1%	591	99%
22.4%	23.0%	2	0%	593	99%
23.0%	23.6%	4	1%	597	100%
23.6%	24.2%	2	0%	599	100%
24.2%	24.8%	1	0%	600	100%
24.8%	25.5%	0	0%	600	100%
25.5%	26.1%	0	0%	600	100%
26.1%	26.7%	0	0%	600	100%
26.7%	>	0	0%	600	100%
Total		600	100%		

Figure 17. Program Results per Road Section or Road Class

| Define Uncertainty Margin: | 5% | | Select Road Section: | ◄ | ► |

Road Section Net Present Value

Road No	5	Road ID	R05	Road Name	Road R05 with 300 AADT
Terrain Type	B	Road Type	Y		
Length (km)	10	Traffic (AADT)	300	Roughness (IRI)	20

5% Margin

Road R05 with 300 AADT

[Scatter plot: Net Present Value (M$) on y-axis (0.000 to 3.000) vs PV Economic Agency Costs (M$) on x-axis (0.00 to 3.00). Data points labeled 0 through 6.]

Road Section-Alternative		Net Present Value (M$)	Internal Rate of Return (%)	Equivalent Annual Benefits ($/km)	Modified Internal Rate of Return (%)	PV of Economic Agency Costs (M$)	Financial Investment Cost (M$)	NPV per PV Agency (#)	NPV per Investment (#)
Number	Description								
0	Current Poor Condition	0.000	#N/A	0	#N/A	0.02	0.00	0.00	0.00
1	Bring to Fair Condition	0.986	178%	15578	46%	0.22	0.12	4.58	9.66
2	Bring to Good Condition	1.875	110%	29631	38%	0.54	0.40	3.45	5.52
3	Pave with ST	2.626	50%	41501	26%	1.59	1.60	1.66	1.93
4	Pave with AC 6m	2.482	42%	39226	24%	1.88	2.00	1.32	1.46
5	Pave with AC 7m	2.142	34%	33853	21%	2.22	2.40	0.96	1.05
6	Pave with AC 9m	1.632	26%	25794	18%	2.73	3.00	0.60	0.64
Alternative with Highest NPV									
3	Pave with ST	2.626	50%	41501	26%	1.59	1.60	1.66	1.93
Recommended Alternative									
3	Pave with ST	2.626	50%	41501	26%	1.59	1.60	1.66	1.93

CASE STUDIES

TABLE OF CONTENTS

ABSTRACT

This paper presents a number of case studies demonstrating the use of the Roads Economic Decision Model (RED). The five case studies are designed to teach the practical application of the software as well as the main concepts. These case studies are presented as practical exercises that can be followed in sequence, entering the required information and performing the required outlined steps.

INSTALLING THE RED MODEL PROGRAM FILES

From the RED CD-ROM, follow the instructions for installing RED. If you obtained the English version of RED by Internet, execute the file named "RED32EN.EXE" that installs the English version of RED on your computer. The installation program asks for a hard disk folder to install the RED components, which are installed on different corresponding subfolders according to the type of contents. If you select the suggested "C:\" folder, the installation program creates a folder named "C:\RED - RED Model Version 3.2\" on your hard disk, where you will find the RED model Excel workbooks and associated documentation in English.

DEFINING UNIT ROAD USER COSTS WITH THE HDM-4 VOC MODULE

Your first step should be to define unit road user costs applicable to your country with either the HDM-III VOC Module or, preferably, the HDM-4 VOC Module. The HDM-III VOC Module is a stand-alone Excel worksheet that implements the HDM-III relationships regarding road user costs, while the HDM-4 VOC Module implements the HDM-4 relationships.

To use the HDM-4 VOC Module, double-click on the corresponding Excel workbook "RED – HDM-4 VOC (version 3.2).xls" within Windows Explorer. This will open the file in Excel, which will display the message immediately below. You should press the Enable Macros button to activate the macros needed to compute the road user costs.
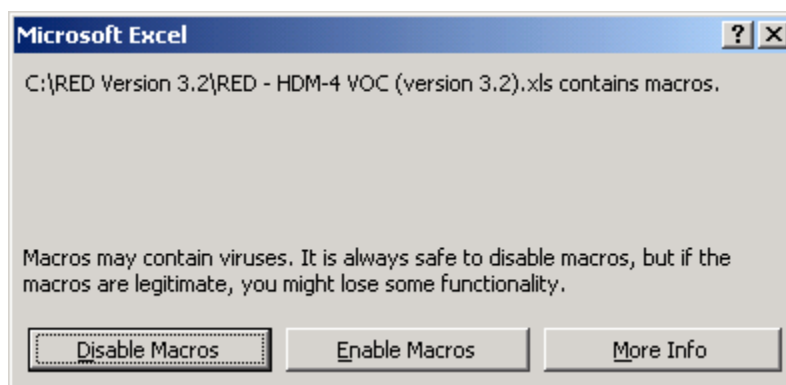
Once the Excel workbook has been opened, go to the Basic Input Data worksheet, where you should enter the corresponding inputs for your country on the cells with a yellow background. For our case studies, enter the information given on Table 1. Once you have entered the basic input data on the cells with yellow background, save the workbook, assigning to it a new name in order to keep the original file without changes. Use the Save As option of Excel and, for example, save the file at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name to represent that the road user costs are for the "South Region".

<center>RED HDM-4 VOC (South Region).xls</center>

Note the following:

a) The Country/Region, Year, Currency Name, and Exchange Rate Divider to US$ inputs are entered for future reference purposes; they are not used on the road user costs calculations.

b) The remaining numerical inputs are the basic HDM-4 inputs needed to estimate road user costs. You can obtain a description of these inputs on the HDM-4 Model documentation.

c) If you don't have all the nine vehicle types listed on your vehicle fleet, you can define some vehicle types as "Not Used". Later you will define that the daily traffic for this vehicle type number is zero.

Once you have entered the basic input data, you have the option to go to the Calibration Data worksheet to calibrate the model editing the cells with a yellow background, referring to the HDM-4 documentation for a description of the calibration parameters. In these case studies, we will not calibrate the model; therefore, you can now go to the Compute Results worksheet where you will press the Compute Results button. Once you press the button, the model computes the corresponding speeds and vehicle operating costs and once the calculations are done, it presents a message indicating the computations are done.

At this stage you have the following options: a) review the results on the remaining worksheets or b) copy and paste the results into the Main Economic Evaluation Module by pressing the Copy and Paste Results into Main Module button located also on the Compute Results worksheet.

You can review the results by exploring the following worksheets.

a) Coefficients – Contains the coefficients of cubic polynomials relating road user costs to roughness and speeds to roughness. These coefficients are needed by the Main Economic Evaluation Module and are copied and pasted into that module once you press the Copy and Paste Results into Main Module button located also on the Compute Results worksheet.

b) Speeds - Presents speeds (km/hr) for each road terrain and road type for roughness varying from 2 to 25 IRI.

c) VOC – Presents unit road user costs ($ per vehicle-km) for each road terrain and road type for roughness varying from 2 to 25 IRI.

d) VOC Components – Presents unit road user costs components (dollar per vehicle-km), such as fuel consumption, tire wear, etc., for each road terrain and road type for roughness varying from 2 to 25 IRI.

e) HDM-4 & Equations Comparison – Presents the comparison of the HDM-4 relationships results, for each roughness level, and the corresponding cubic polynomials computed by Excel.

f) Typical VOC and Speeds – Presents unit road user costs (dollar per vehicle-km) and speeds (km/hr) for each road terrain and road type and for different road condition levels (very good, good, fair, poor, very poor). Here you can define the roughness of each road condition class and a typical traffic composition to compute the average fleet speeds and vehicle operating costs, and press the "Update Results" button.

In this case, let's Copy and Paste the Results into the Main Economic Evaluation Module. Follow the steps below.

a) Open the Main Module by double-clicking on the corresponding Excel workbook "RED – MAIN (Version 3.2).xls", within Windows Explorer and enable the macros.

b) Use the Save As option of Excel and save the Main Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name to represent that the Main Module is for case study number 1.

RED - MAIN (Case 1).xls

c) Close the Main Module.

d) In the HDM-4 VOC Module, at the Compute Results worksheet, in cell F23, enter the name of the Main Module in which you want to copy and paste the road user costs results. Enter: RED - MAIN (Case 1).xls

e) In the HDM-4 VOC Module, at the Compute Results worksheet, press the Copy and Paste Results into Main Module button, and wait for the process to finish with the message indicated below. The HDM-4 VOC Module will open the Main Module and then will copy and paste the results into it. Once the paste process is done, the HDM-4 VOC Module will close the Main Module and present the following message.
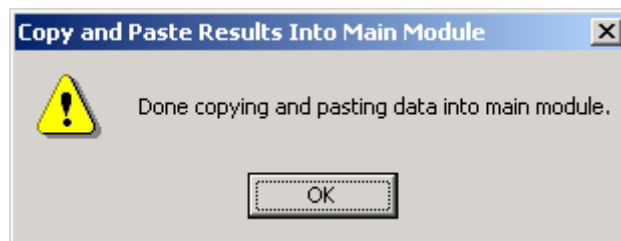
f) Save and close the HDM-4 VOC Module.

CASE STUDY 1 – UNSEALED ROAD IN POOR CONDITION WITH 100 AADT

The first case study evaluates different investment alternatives for an unsealed road that is currently in poor condition with an annual average daily traffic of 100 vehicles per day. The investment alternatives are the following.

a) Keep the road in poor condition
b) Keep the road in fair condition
c) Keep the road in good condition
d) Upgrade the road to surface treatment standard

Follow the steps below.

a) Locate and open the following Main Economic Evaluation Module that you created while working with the HDM-4 VOC Module and that should be located on the "C:\RED Model Version 3.2" folder. Don't forget to enable the macros.

<div align="center">RED - MAIN (Case 1).xls</div>

b) Go to the Control and Setup worksheet and enter the information required in Table 2. In this case study: a) the wet season duration is 90 days; b) the evaluation period is 15 years and the discount rate is 12%; and c) we are going to use roughness to characterize the road condition.

c) Go to the Unit VOC and Speeds worksheet. Here you don't have to make any changes. Note that the coefficients of the polynomials came from the HDM-4 VOC Module, when you pressed the Copy and Paste Results into Main Module button.

d) Go to the Time and Accidents worksheet and enter the information from Table 3. Here you define the number of passengers per vehicle and the corresponding value of time per hour. In this case, the value of time of passengers of buses and trucks is half that of passengers of cars and utility vehicles. For accident costs, you have two choices: a) enter a global accident cost per accident figure or b) enter separately the cost per accident for: fatalities, accident with injuries or accident with damage only. In this case, we are entering the accident costs per accident type.

e) Go to the Traffic worksheet and enter the information from Table 4. In this case: a) the daily traffic in the dry and wet seasons are the same; b) the traffic growth rate is 4% for all vehicles during the first 10 years and thereafter 3%; c) the price elasticity of demand is set to 0.5, implying that for a one percent reduction in road user costs there will be an increase of one half of one percent in daily traffic, the added traffic representing the generated traffic; and d) there are no induced traffic benefits due to economic development.

f) Go to the Multi-Criteria Indicators worksheet. Here you don't have to make any changes. Note that the RED model stores the multi-criteria information for future reference; the information is not used in the economic evaluation.

g) Go to the Project Alter. Main Features worksheet and enter the information from Table 5. In this case: a) the road is in a hilly terrain; c) the road length is 10 km for all alternatives during the dry and wet seasons; d) on some alternatives, there are different roughness estimates for the dry and wet seasons, indicating the higher transport costs during the wet season; e) the investments needed to implement each alternative have been defined; f) the fixed financial maintenance costs needed to maintain the road at the proposed condition over the evaluation period has been defined, for each alternative; g) the optional variable financial maintenance costs (function of traffic) are set to zero; and h) no accident reduction benefits are being computed nor are benefits of diverted traffic from an alternative road.

h) Go to the Project Alter. Other Benefits worksheet. Here you don't have to make any changes. Note that here you could add any other exogenous costs or benefits for each alternative, which should be computed separately.

i) Go to the Project Alter. Solution worksheet to view the resulting economic comparison of the alternatives being evaluated. In this case, the option of keeping the road as an unsealed road but in good condition (alternative 2) has the highest Net Present Value (NPV); therefore, it is the recommended alternative. Alternative 1 has a higher Internal Rate of Return (IRR) than alternative 2, but the criteria used to compare alternatives is the NPV <u>and not</u> the IRR. The option of upgrading the road has a negative NPV, therefore cannot be justified economically. The following table summarizes the main results.

	Alternative 1	Alternative 2	Alternative 3
	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Net Present Value (million $)	0.125	0.172	-1.339
Internal Rate of Return (%)	32%	19%	-1%

j) Go to the Graph – Net Present Value worksheet to view the following graph comparing the alternatives Net Present Value against the Present Value of Agency Costs.

Net Present Value

Chart legend: ◆ Keep in Poor Condition ■ Keep in Fair Condition ▲ Keep in Good Condition ● Upgrade to S.T.

Y-axis: Net Present Value (million $) at 12% Discount Rate
X-axis: PV of Economic Agency Costs (million $)
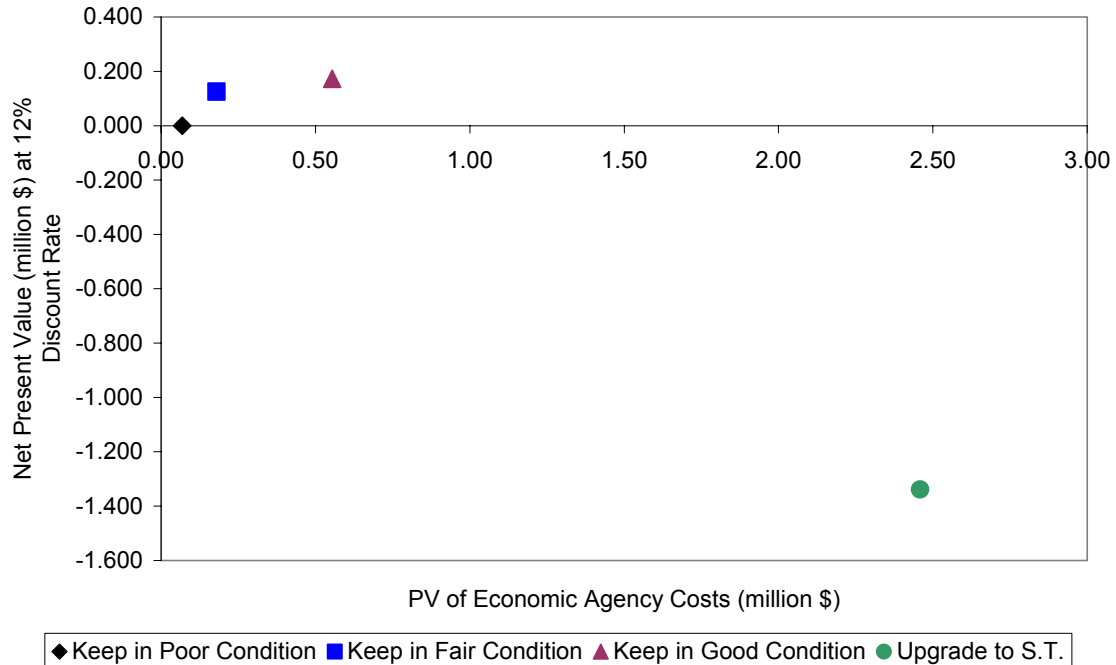
k) Go to the remaining worksheets to view the detailed results for each alternative. You can view the following information for each project alternative.

- Feasibility worksheet, which presents the main input data, the traffic, the flows of net benefits, and the resulting economic indicators.
- User Impacts worksheet, which presents the road user costs savings.
- Benefits Distribution worksheet, which presents the distribution of the NPV.
- Sensitivity worksheet, which performs a sensitivity analysis of all main inputs.
- Switching Values worksheet, which performs a switching values analysis of all main inputs.

Note that to view the corresponding sensitivity analysis results and switching values analysis results you have to press a button at the top of the corresponding worksheet.

l) Save and close the worksheet.

CASE STUDY 2 – UNSEALED ROAD IN POOR CONDITION WITH 300 AADT

The second case study evaluates different investment alternatives for an unsealed road that is currently in poor condition with an annual average daily traffic of 300 vehicles per day. The road investment alternatives and most of the other input data are the same as the first case study. Follow the steps below.

a) Locate and open the following Main Economic Evaluation Module that you saved while working with the first case study and that should be located on the "C:\RED Model Version 3.2" folder. Don't forget to enable the macros.

<center>RED - MAIN (Case 1). xls</center>

b) Use the Save As option of Excel and save the Main Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name to represent that the Main Module is for case study number 2.

<center>RED - MAIN (Case 2).xls</center>

c) Go to the Control and Setup worksheet and change the following information.

Road Identification Code	CS2
Road Name	Case Study 2

d) Go to the Traffic worksheet and change the daily traffic for the dry and wet seasons to the traffic of Table 6.

e) Go to the Project Alter. Main Features worksheet and change the required annual fixed maintenance costs ('000$/km/year) to the following values. Note that in this case, the maintenance costs are higher than on the first case study because the traffic is three times higher. An engineer should estimate the required annual maintenance costs for each road type and investment alternative (proposed level of service).

Keep in Poor Condition	1.20
Keep in Fair Condition	2.00
Keep in Good Condition	4.00
Upgrade to S.T.	5.00

f) Go to the Project Alter. Solution worksheet to view the results. In this case, the option of keeping the road as an unsealed road but in good condition (alternative 2) still has the highest NPV, but notice that the option of upgrading the road now also has a positive NPV and a satis-

factory rate of return; therefore, it could be implemented if it is required by other criteria. Maybe the road agency does not have the capacity to maintain the road in good condition with frequent gradings or maybe there is high uncertainty that the road agency will maintain the unsealed road in good condition; therefore, upgrading the road could be a better pragmatic option even if it has a lower NPV. The following table summarizes the results.

	Alternative 1	Alternative 2	Alternative 3
	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Net Present Value (million $)	0.598	1.428	0.705
Internal Rate of Return (%)	98%	60%	17%

Net Present Value
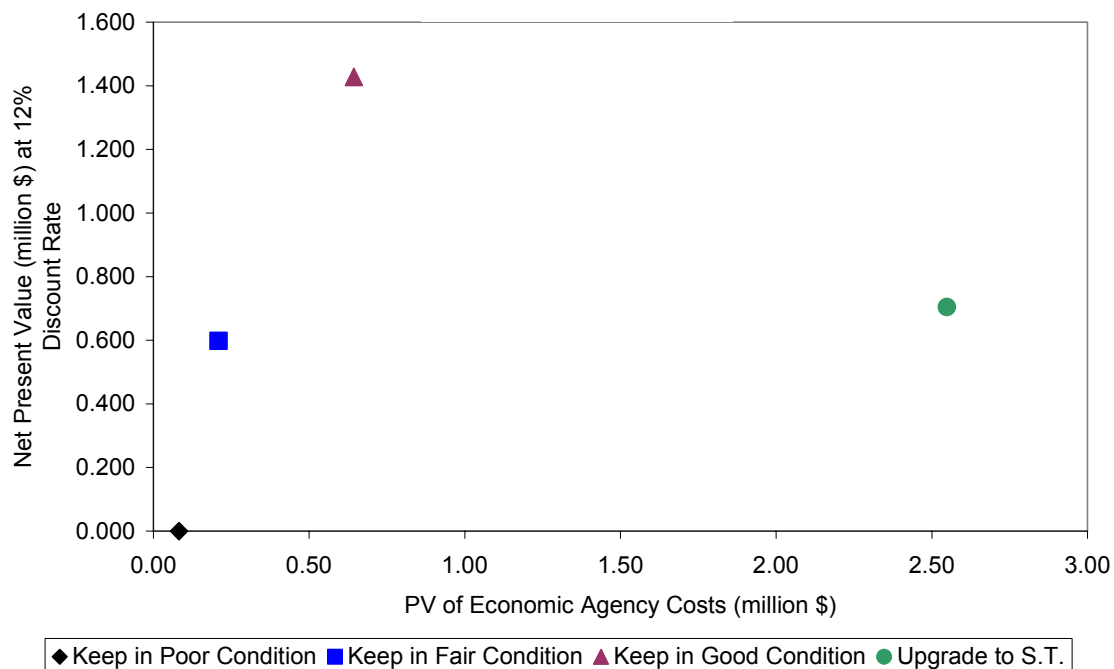
g) Go to the Graph – Net Present Value worksheet to view the following graph comparing the project alternatives Net Present Value against the Present Value of Agency Costs.

h) Go to the Alter. 3 Sensitivity worksheet and press the button at the top of the spreadsheet to perform the sensitivity analysis, of the upgrading alternative, for the twenty-one most important input variables. Note that on this worksheet you have the option of changing the sensitivity factors, starting on cell G36, which in this case are set to decrease the main inputs estimates

by 25% and alternately increase the main inputs estimates by 25%. The following table summarizes the sensitivity results obtained.

	Multiplier Factor	Net Present Value (million $)	Internal Rate of Return (%)	Multiplier Factor	Net Present Value (million $)	Internal Rate of Return (%)
Base Case		0.705	17%		0.705	17%
Sensitivity Cases:						
Normal Traffic (vpd)	0.75	-0.090	11%	1.25	1.500	23%
Normal Traffic Growth Rate (%)	0.75	0.521	16%	1.25	0.902	18%
Generated Traffic (vpd)	0.75	0.617	17%	1.25	0.793	18%
Induced Traffic (vpd)	0.75	0.705	17%	1.25	0.705	17%
Passenger Time Costs ($/hr)	0.75	0.518	16%	1.25	0.892	19%
Cargo Time Costs ($/hr)	0.75	0.705	17%	1.25	0.705	17%
Wet Season Duration (days)	0.75	0.594	16%	1.25	0.816	18%
Without Project Dry Season Length (km)	0.75	-0.532	8%	1.25	1.989	26%
Without Project Dry Season Roughness (IRI)	0.75	-0.114	11%	1.25	1.564	23%
Without Project Wet Season Length (km)	0.75	0.175	13%	1.25	1.247	21%
Without Project Wet Season Roughness (IRI)	0.75	0.379	15%	1.25	0.652	17%
Without Project Accidents Rate (#/m veh-km)	0.75	0.705	17%	1.25	0.705	17%
Without Project Investment Costs (000$/km)	0.75	0.705	17%	1.25	0.705	17%
Without Project Maintenance Costs (000/km/yr)	0.75	0.687	17%	1.25	0.723	17%
Project Dry Season Road Length (km)	0.75	1.944	28%	1.25	-0.490	9%
Project Dry Season Roughness (IRI)	0.75	0.794	18%	1.25	0.602	16%
Project Wet Season Road Length (km)	0.75	1.121	21%	1.25	0.300	14%
Project Wet Season Roughness (IRI)	0.75	0.736	17%	1.25	0.670	17%
Project Accidents Rate (#/m veh-km)	0.75	0.705	17%	1.25	0.705	17%
Project Investment Costs (000$/km)	0.75	1.267	24%	1.25	0.142	13%
Project Maintenance Costs (000/km/yr)	0.75	0.780	18%	1.25	0.630	17%

One can observe that: a) if normal traffic reduces by 25%, the IRR reduces to 11%; b) if normal traffic growth rate reduces by 25%, the IRR reduces to 16%; c) if investment costs increase by 25%, then the IRR reduces to 13%; and d) in the maintenance costs of the upgrading alternative increase by 25%, the IRR reduces to 17%.

i) Go to the Alter. 3 Switching Values worksheet and press the button at the top of the spreadsheet to perform the switching values analysis, of the upgrading alternative, for the twenty-one most important input variables. The following table summarizes the results for the traffic and investment and maintenance costs inputs.

	Base Case Value	Case that Yields Net Present Value = 0		
		Value	Factor	Change
Normal Traffic (vpd)	300	234	0.78	-22.2%
Normal Traffic Growth Rate (%)	3.5%	-0.3%	-0.07	-107.4%
Generated Traffic (vpd)	75	-76	-1.01	-200.8%
Project Investment Costs (000$/km)	225.0	295.5	1.31	31.3%
Project Maintenance Costs (000/km/yr)	4.5	15.1	3.36	236.4%

One can observe that the project will be justified even if: a) normal traffic reduces to 234 vehicle per day, b) the investment costs increase by 31.3% to 295,500 $/km; or c) maintenance costs increase to 15,100 $/km/yr.

j) Save and close the worksheet.

PERFORMING RISK ANALYSIS USING THE RISK ANALYSIS MODULE

To perform a risk analysis for the project evaluated on the second case study (road with 300 AADT), follow the steps below:

a) Locate and open the following Risk Analysis Module that should be located on the "C:\RED Model Version 3.2" folder. Don't forget to enable the macros.

<p style="text-align:center">RED - Risk (version 3.2).xls</p>

b) Use the Save As option of Excel and save the Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name to represent that the Risk Module is for case study number 2.

<p style="text-align:center">RED - Risk (Case 2).xls</p>

c) Go to the Basic Input Data worksheet and enter the information contained on Table 7. In this case, there is some uncertainty on the normal and generated traffic and on the investment costs. For the normal traffic, the minimum and maximum possible values are respectively 30% lower and 30% higher than the point estimate, indicating that there is no bias. For the generated traffic, the minimum and maximum possible values are respectively 75% lower and 75% higher than the point estimate, indicating that there is also no bias, but a higher uncertainty comparing to the normal traffic. For the investment, the minimum possible value is 25% lower than the point estimate and the maximum possible value is 100% higher than the point estimate, indicating a bias on the cost estimate and that there is a 80% probability that the actual costs will be higher than the point estimate.

d) Go to the Compute Results worksheet and define a) the number of scenarios to evaluate, which in this case is 600; and b) the name of the Main Economic Evaluation Module of the project being evaluated, which in this case is the following name.

<p style="text-align:center">RED - Main (Case 2).xls</p>

Once you define the number of scenarios and the name of the Main Module, press the Compute Risk Analysis button. The Risk Analysis Module will evaluate the Main Module 600 times, varying the uncertainty inputs randomly according to the defined probability distributions, and collect the corresponding results for each evaluation. You will get the following message when the analysis is completed.

Compute Risk Analysis

⚠ Risk analysis done.

OK
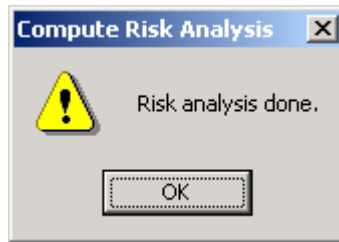
e) Go to the Risk Analysis Solution to view the results, which are summarized below.

	Alternative 0	Alternative 1	Alternative 2	Alternative 3
	Keep in Poor Condition	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Net Present Value (million $)				
Point Estimate	0.000	0.598	1.428	0.705
Average	0.000	0.572	1.318	0.123
Standard Deviation	0.000	0.090	0.262	0.714
Minimum	0.000	0.339	0.588	-1.959
Maximum	0.000	0.796	1.963	1.675
Median	0.000	0.571	1.313	0.208
Probability < 0 (%)	#N/A	**0%**	**0%**	37%
Internal Rate of Return (%)				
Point Estimate	#N/A	98%	60%	17%
Average	#N/A	82%	50%	13%
Standard Deviation	#N/A	19%	12%	5%
Minimum	#N/A	41%	24%	2%
Maximum	#N/A	143%	87%	27%
Median	#N/A	81%	49%	13%
Probability < 12% (%)	#N/A	**0%**	**0%**	39%

The results presented in the table above <u>will not</u> be exactly the same ones as the ones you will get from your risk analysis due to random nature of the analysis, but should be very similar. The point estimates are the results obtaining from the base estimates of traffic and investment costs, and the other results are statistics of the resulting frequency distributions of the NPV and IRR of the 600 scenarios being evaluated.

Note that the point estimate IRR for the upgrading alternative is 17%, but the most likely IRR is 13%, represented by the median and that there is a 39% probability that the IRR of the up-grading alternative will be less than 12%.

f) Go to the remaining worksheets to view in detail the risk analysis results for each alternative. Here you can see the resulting frequency distribution, the cumulative frequency distribution, and the frequency distribution statistics, which include the statistics presented on the table above and three possible percentiles that could represent the worst case scenario, the most likely scenario, and the best scenario. In this case, if one defines the worst case scenario as the 25% percentile, the most likely scenario the 50% percentile, and the best scenario the 75% per-centile, then for the upgrading alternative we obtain the corresponding Internal Rates of Re-turn 10%, 13% and 17%.

g) Save and close the worksheet.

EVALUATING MANY ROADS USING THE PROGRAM MODULE

To evaluate many roads, you can use the Main Economic Evaluation Module for each road following the same steps you followed analyzing the grave roads with 100 AADT and 300 AADT. The other alternative is to use the Program Module, which expedites the process by evaluating many roads at once and allowing you to define the inputs for all roads on a single worksheet. The Program Module has these advantages: a) it presents the results for each road and the totals for the entire program; b) it allows you to evaluate seven alternatives per road, while the Main Module evaluates four alternatives; and c) you can find recommended alternatives with or without budget constrains.

In this case study, you will evaluate the same roads evaluated before (100 AADT and 300 ADDT) plus other roads with the same road condition but with other traffic levels. The traffic levels to be evaluated are 25, 50, 100, 200, 300, 600 and 900 AADT.

In this case study, you are evaluating roads in poor condition with same road characteristics but with different traffic levels, but note that typically you will use the Program Module to evaluate a series of road sections, which will have a different current road condition, length, terrain type road type, traffic level, traffic growth rate, etc.; therefore, each road section will have unique characteristics and will require the evaluation of customized project alternatives.

The Program Module evaluates seven alternatives per road (the base alternative plus six project alternatives), performing two Main Economic Evaluation runs per road. In this case study, we will first define project alternatives 4, 5, and 6 with the same characteristics as project alternatives 1, 2 and 3, which are the same ones we evaluated before for the roads with 100 AADT and 300 AADT (keep in fair condition, keep in good condition, and upgrade to S.T.). Later we will define different alternatives 4, 5 and 6.

Follow the steps below:

a) Locate and open the following Program Module that should be located on the "C:\RED Model Version 3.2" folder. Don't forget to enable the macros.

<div align="center">RED - Program (version 3.2).xls</div>

b) Use the Save As option of Excel and save the Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name to represent that the Program Module is for a case study related to unsealed roads in poor condition.

<div align="center">RED - Poor (Poor Condition).xls</div>

c) Go do the RED Inputs worksheet to define the roads to be evaluated. Follow the steps below.

1) Delete the current rows 11 to 18.

2) To facilitate the inputs, first import the data of the road with 100 AADT. Place the cursor on cell A11 and press Ctrl-R to import the input data contained on the Main Module "RED - MAIN (Case 1).xls". You will get the following message.
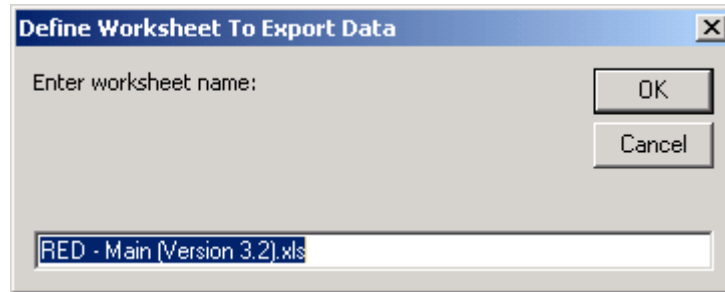
Enter the following and press OK.

RED - MAIN (Case 1).xls

You will get the following message.
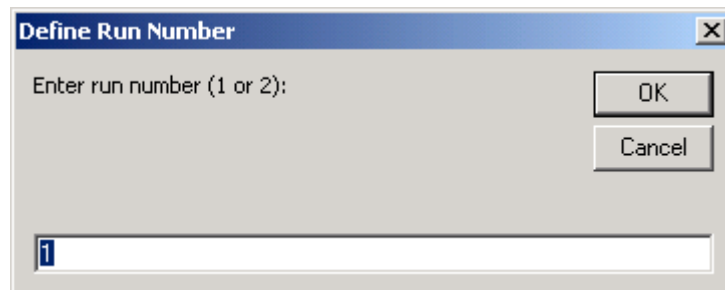
Enter 1 and press OK to indicate that you are importing data corresponding to the first evaluation to be done for this road, corresponding to alternatives 0, 1, 2 and 3. Once you press OK, the corresponding inputs will be imported.

3) The Program Module evaluates 7 alternatives per road, evaluating the Main Economic Evaluation Module twice for each road; therefore, we need to define alternatives 4, 5 and 6 for this road. In this case, as a simplification, let's define alternatives 4, 5 and 6 the same as alternatives 1, 2 and 3. To do that, press Ctrl-R again at cell A11 to import the input data contained on the Main Module "RED - MAIN (Case 1).xls", but this time entering 2 as the run number.

4) Now let's import the data of the road with 300 AADT, alternatives 0, 1, 2 and 3. Place the cursor on cell A12 and press Ctrl-R to import the input data contained on the Main Module "RED - MAIN (Case 2).xls", repeating the step number 2 described above, but replacing the

worksheet name with "RED - MAIN (Case 2).xls", the run number is 1. Now, import the data for alternatives 4, 5, and 6 by repeating step number 3 on cell A12, but replacing the worksheet name with "RED - MAIN (Case 2).xls", the run number is 2.

You should now have rows 11 and 12 filled with information. Now it is a good time to explore all the columns of the RED Inputs worksheet, notice that each column corresponds to one input on the Main Economic Evaluation Module.

5) Place on cell B3 the name of the following Master Economic Evaluation Module, which contains the road user costs data that is applicable to all roads (vehicle operating costs, speeds, and time and accident costs).

RED - MAIN (Case 1).xls

6) Execute the RED model for these two roads to check that the process is working and that you get the same results as before when you analyzed each road individually. Press the Execute RED Model button and when the process is done you will get the following message.
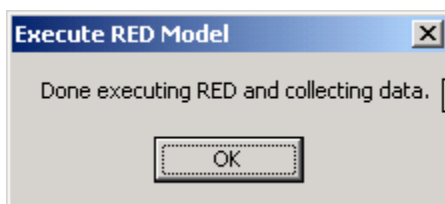
7) Go to the RED Outputs worksheet and you should have the following results, which indicate that a) alternatives 1, 2 and 3 have the same results as alternatives 4, 5 and 6, as expected; and b) we obtained the same results as before for each alternative and road.

Road ID	Net Present Value (million $) at 12% Discount Rate						
	Alter. 0	Alter. 1	Alter. 2	Alter. 3	Alter. 4	Alter. 5	Alter. 6
CS1	0.000	0.125	0.172	-1.339	0.125	0.172	-1.339
CS2	0.000	0.598	1.428	0.705	0.598	1.428	0.705

8) Now, go back to the RED Inputs worksheet to define the other roads. Follow the steps below.

i) Insert two blank rows before row 12 and copy the contents of the Case study 1 Road to these new roads.

ii) Copy the contents of the Case study 2 Road to rows 15 to 17. You will get something like the following.

Road ID	Road Name	Duration of Wet Season (days)	Road Agency Economic Cost Factor
CS1	Case Study 1	90	0.9
CS1	Case Study 1	90	0.9
CS1	Case Study 1	90	0.9
CS2	Case Study 2	90	0.9
CS2	Case Study 2	90	0.9
CS2	Case Study 2	90	0.9
CS2	Case Study 2	90	0.9

iii) Edit the Road ID and the Road Name to the following text.

Road ID	Road Name
P025	Poor Condition 25 AADT
P050	Poor Condition 50 AADT
P100	Poor Condition 100 AADT
P200	Poor Condition 200 AADT
P300	Poor Condition 300 AADT
P600	Poor Condition 600 AADT
P900	Poor Condition 900 AADT

Note that a road identification code can have a maximum of 4 characters and the first character should be a letter.

iv) Edit the daily traffic for the dry and wet seasons to the following numbers. For the dry season change the traffic starting in cell I11 and for the wet season starting in cell BB11.

Dry Season Average Daily Traffic (AADT)								
Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5	Vehicle 6	Vehicle 7	Vehicle 8	Vehicle 9
2	13	1	2	1	2	2	2	0
5	25	3	3	2	4	5	3	0
10	50	6	6	4	7	10	7	0
20	100	12	12	8	14	20	14	0
30	150	18	18	12	21	30	21	0
60	300	36	36	24	42	60	42	0
90	450	54	54	36	63	90	63	0

The annual maintenance cost needed to keep a road on a given condition varies according to the traffic; therefore, we need to adjust the fixed annual maintenance costs for each traffic level and for each alternative. Enter the information below in the corresponding columns.

Fixed Financial Maintenance Costs ('000$/km/year)				
	Alternative 0	Alternative 1 & 4	Alternative 2 & 5	Alternative 3 & 6
	Keep in Poor Condition	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Traffic	Columns DR	Columns EL & GT	Columns FF & HN	Columns FZ & IH
25 AADT	0.80	1.30	2.00	3.50
50 AADT	0.90	1.40	2.25	3.50
100 AADT	1.00	1.50	2.50	3.50
200 AADT	1.10	1.75	3.25	4.25
300 AADT	1.20	2.00	4.00	5.00
600 AADT	1.30	2.50	4.25	5.25
900 AADT	1.40	3.00	4.50	5.50

Note that in this case, for each traffic level, we are leaving the variable financial maintenance cost ('000$/km/year/ADT) zero and we are adjusting the fixed maintenance cost. Another alternative would have been to define, for each alternative, a unique fixed maintenance cost and a variable maintenance cost function of traffic.

Once all the program inputs have been defined in the RED Inputs worksheet, you are ready to evaluate the entire program.

d) At the RED Inputs worksheet, press the Execute RED Model button to compute the results. You will get the following results at the RED Outputs worksheet.

Road ID	Net Present Value (million $) at 12% Discount Rate						
	Alter. 0	Alter. 1	Alter. 2	Alter. 3	Alter. 4	Alter. 5	Alter. 6
P025	0.000	-0.057	-0.306	-2.140	-0.057	-0.306	-2.140
P050	0.000	0.002	-0.155	-1.879	0.002	-0.155	-1.879
P100	0.000	0.125	0.172	-1.339	0.125	0.172	-1.339
P200	0.000	0.362	0.800	-0.317	0.362	0.800	-0.317
P300	0.000	0.598	1.428	0.705	0.598	1.428	0.705
P600	0.000	1.310	3.418	3.878	1.310	3.418	3.878
P900	0.000	2.021	5.409	7.050	2.021	5.409	7.050

Note that the recommended alternatives (highest NPV) are the following.

25 AADT   Alt. 0 – Keep the road in poor condition

50 AADT	Alt. 1 – Keep the road in fair condition
100 AADT	Alt. 2 – Keep the road in good condition
200 AADT	Alt. 2 – Keep the road in good condition
300 AADT	Alt. 2 – Keep the road in good condition
600 AADT	Alt. 3 – Upgrade the road to S.T.
900 AADT	Alt. 3 – Upgrade the road to S.T.

e) Go to the Road Section Net Present Value worksheet to view the results for each road individually. Select a road by pressing the left or right arrows at cell H2, and view the corresponding results in the area below. The worksheet presents, for each road, a graph of the Net Present Value against Present Value of Agency Costs and the economic indicators for each alternative.

f) Go to the Unconstrained Budget worksheet to view the work program and economic indicators for the scenario without budget constraints, which represents selecting for each road the alternative with higher NPV. You will get the following indicators, which show that the capital expenditures needed for the entire program is 6.45 million and that the program NPV is 13.33 million.

Unconstrained Budget Scenario	
Available Capital Expenditures (M$)	6.45
Required Capital Expenditures (M$)	6.45
Network Length (km)	70.0
Network Average Roughness (IRI)	10.9
Network Net Present Value (M$)	13.33
Network Internal Rate of Return (%)	44%
Network Equivalent Annual Benefits	174740
Network Modified Internal Rate of Return	19%
Network PV of Economic Agency costs (M$)	7.17
Financial Investment Costs (M$)	5.81
Network NPV per PV Agency Costs	1.86
Network NPV per Investment Costs	2.30
Network Recurrent Maintenance Costs	0.23
Network Population Served (persons)	7000
Network Investment per Population Served ($/person)	829

g) Go to the Budget Constraint A worksheet to obtain an optimized program that requires only 6.0 million. Follow the steps below.

  1) Enter in cell E7 the value of 6.0.

2) Press the Perform Budget Optimization Button and wait for the optimization to be completed, it should take less than one minute.

3) Once you receive the message that the optimization is completed, press the Collect Budget Results button to bring the results to the Excel workbook. You <u>will not</u> get a message from Excel when this process has finished, but you will know the process has finished when the cursor goes back to an arrow. Note that a) to be able to perform the budget optimization, the file EBM-32.EXE should be located in the Windows Folder where all the case studies RED workbooks are located; and b) the EBM-32 optimization process creates some temporary files that start with pms*.*, in the same Windows Folder - these you can delete when you finish your study.

The optimization algorithm finds a solution that uses the 6.0 million. With that amount of capital resources, the recommended program is the following and the NPV reduces to 13.28 million.

25 AADT	Alt. 0 – Keep the road in poor condition
50 AADT	Alt. 1 – Keep the road in poor condition
100 AADT	Alt. 2 – Keep the road in fair condition
200 AADT	Alt. 2 – Keep the road in good condition
300 AADT	Alt. 2 – Keep the road in good condition
600 AADT	Alt. 3 – Upgrade the road to S.T.
900 AADT	Alt. 3 – Upgrade the road to S.T.

h) Go to the Budget Constraint B, Budget Constraint C, Budget Constraint D, and Budget Constraint E worksheets and repeat the previous step for different budget constraints. Define the following budget constraints.

Budget Constraint B	5.0 million
Budget Constraint C	4.0 million
Budget Constraint D	2.0 million
Budget Constraint E	1.0 million

i) Go to the Recommended Program worksheet and notice that here you can, optionally, define a work program manually. To define a program, you would enter the desired alternative number per road, starting in cell I41, and then press the Update Recommended Program button. In this case, the recommended program will be the same as the unconstrained budget program, and therefore no changes are needed.

j) Go to the Program Net Present Value worksheet to view the following graph of the Program Net Present Value against the Present Value of Agency Costs of each budget constraint scenario. This worksheet also presents the program economic indicators for each budget constraint scenario, which are summarized in the table below.

Program-Alternative		Net Present Value (M$)	Internal Rate of Return (%)
Code	Description		
U	Unconstrained Budget	13.33	44%
A	Budget Constraint A	13.28	47%
B	Budget Constraint B	12.87	56%
C	Budget Constraint C	12.82	61%
D	Budget Constraint D	11.18	93%
E	Budget Constraint E	9.43	146%
R	Recommended Program	13.33	44%
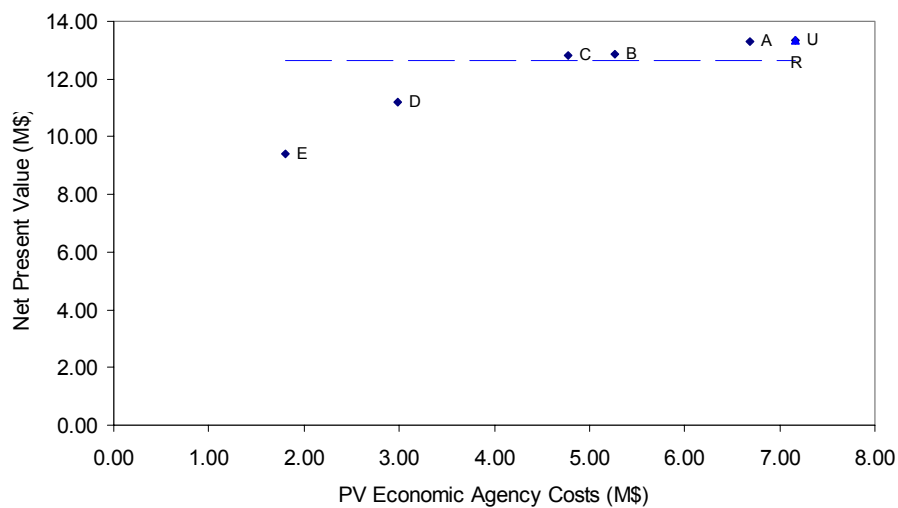
The recommended alternatives per budget scenario are given in the table below, which were collected from the different budget scenario worksheets.

	Budged Unconstrained	Budget A	Budget B	Budget C	Budget D	Budget E
Capital Investments (M$)	6.45	6.00	4.40	3.95	2.00	1.00
	Recommended Alternative					
Poor Condition 25 AADT	Poor	Poor	Poor	Poor	Poor	Poor
Poor Condition 50 AADT	Fair	Poor	Fair	Poor	Fair	Poor
Poor Condition 100 AADT	Good	Fair	Good	Fair	Fair	Poor
Poor Condition 200 AADT	Good	Good	Good	Good	Good	Poor
Poor Condition 300 AADT	Good	Good	Good	Good	Good	Fair
Poor Condition 600 AADT	Upgrade	Upgrade	Good	Good	Good	Good
Poor Condition 900 AADT	Upgrade	Upgrade	Upgrade	Upgrade	Good	Good

k) Save the worksheet.

Now follow the steps below to modify alternatives 4, 5 and 6 to evaluate the alternatives of upgrading the road to Asphalt Concrete, upgrading the road to Cobblestones, and allowing the road to deteriorate to a very poor condition respectively.

a) Use the Save As option of Excel to save the Module with the following name to indicate that the Program Module is for a case study related to unsealed roads in poor condition with seven alternatives being evaluated per road.

<div align="center">RED - Poor (Poor Condition - 7 Alt).xls</div>

b) Go to the RED Inputs worksheet and define alternatives 4, 5 and 6 with the information from Table 9, which presents for each alternative and for each traffic level: a) the alternative name, b) the road type, c) the dry season roughness, d) the wet season roughness, e) the financial investment costs, and f) the fixed maintenance costs. Note that Table 9 also presents the corresponding RED Inputs worksheet columns.

c) At the RED Inputs worksheet, press the Execute RED Model button to compute the results. You will get the following results at the RED Outputs worksheet.

Road	Net Present Value (million $) at 12% Discount Rate						
ID	Alter. 0	Alter. 1	Alter. 2	Alter. 3	Alter. 4	Alter. 5	Alter. 6
P025	0.000	-0.057	-0.306	-2.140	-2.668	-1.423	-0.006
P050	0.000	0.002	-0.155	-1.879	-2.397	-1.193	-0.034
P100	0.000	0.125	0.172	-1.339	-1.833	-0.732	-0.092
P200	0.000	0.362	0.800	-0.317	-0.767	0.176	-0.208
P300	0.000	0.598	1.428	0.705	0.300	1.069	-0.324
P600	0.000	1.310	3.418	3.878	3.608	3.857	-0.673
P900	0.000	2.021	5.409	7.050	6.915	6.644	-1.021

d) Go to the Road Section Net Present Value worksheet to view the results for each road individually. The graph below shows the results for the road with 600 AADT, which shows that a) the alternative with highest NPV is alternative 3 (upgrade to S.T.); b) alternative 5 has a NPV within 5% below alternative 3, therefore, it is within the user defined uncertainty margin and could be recommended instead of alternative 5, due its lower agency costs; c) alternative 6 (deteriorate to very poor condition) has a negative NPV, therefore, it is not economically justified.

Poor Condition 600 AADT
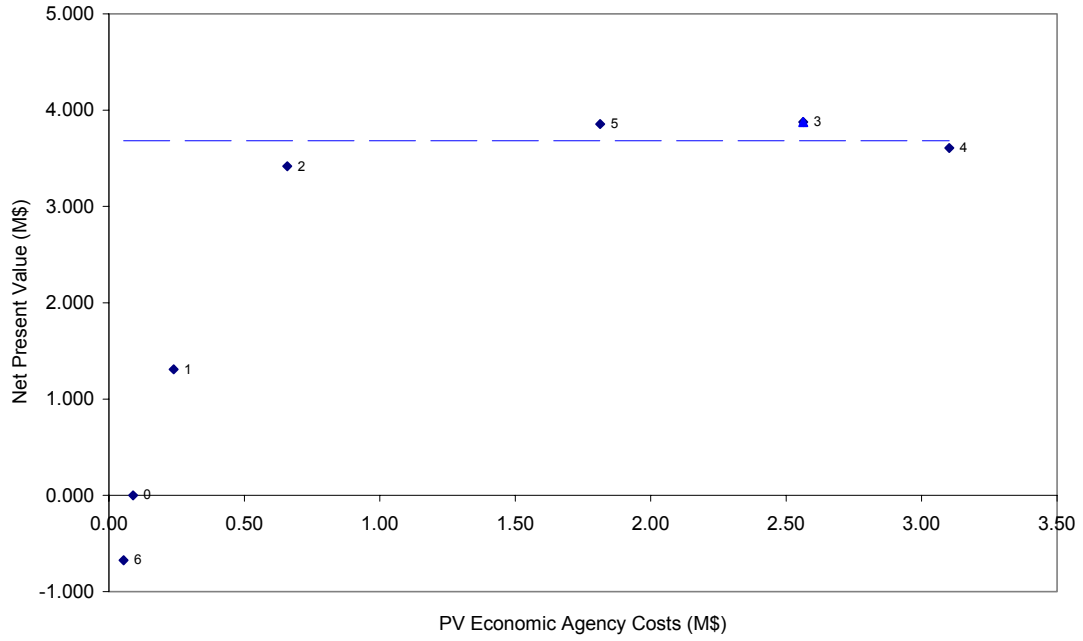
e) If you wish, you can repeat the budget optimization exercise.

f) Save and close the worksheet.

CASE STUDY 3 – UNSEALED ROAD IN VERY POOR CONDITION WITH 50 AADT

The third case study evaluates an unsealed road on a level terrain that is currently in very poor condition (cars travel at 25 km/hr on the wet season and at 35 km/hr on the dry season) with an annual daily traffic of 50 vehicles per day. The proposed investment consists of rehabilitating the road to make it into an all-year passable road in good to fair condition (cars travel at 55 km/hr on the dry and wet seasons). You follow the steps below.

a) Locate and open the following Main Economic Evaluation Module that you saved while working with the first case study. Don't forget to enable the macros.

RED - MAIN (Case 1).xls

b) Use the Save As option of Excel and save the Main Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name.

RED - MAIN (Case 3).xls

c) Go to the Control and Setup worksheet and change the following information.

Road Identification Code	CS3
Road Name	Case Study 3
Road Condition Indicator Option	Speed of a Reference Vehicle

Note that this time you will define the road condition using the speed of a reference vehicle instead of roughness. The reference vehicle is a car, which is defined in the HDM-4 VOC Module.

d) Go to the Traffic worksheet and change the daily traffic for the dry and wet seasons to the traffic of Table 10. Note that the traffic remains the same on the dry and wet seasons.

e) Go to the Project Alter. Main Features worksheet and enter the information from Table 10.

f) Go to the Project Alter. Solution worksheet to view the results. In this case, the proposed investment of US$ 20,000 is justified with a rate of return of 14%.

g) Go to the Alter. 1 Feasibility worksheet and notice, starting in cell E16, the roughness values estimated by the model, for both alternatives and for the dry and wet seasons. Roughness is estimated as a function of the speed of the reference vehicle, and the speeds of the remaining vehicles are estimated as a function of the estimated roughness.

h) Save and close the worksheet.

CASE STUDY 4 – UNSEALED ROAD WITH PASSABILITY PROBLEMS

The fourth case study evaluates an unsealed road on a level terrain that currently has passability problems in the wet season (cars travel at 25 km/hr in the wet season and at 50 km/hr in the dry season) and, therefore, has an annual daily traffic of 75 vehicles per day in the dry season and 50 vehicles per day in the wet season. The proposed investment consists of rehabilitating critical spots to make it an all-year passable road in good to fair condition (cars traveling at 55 km/hr on the dry and wet seasons). You follow the steps below.

a) Locate and open the following Main Economic Evaluation Module that you saved while working with the <u>third</u> case study. Don't forget to enable the macros.

<div align="center">RED - MAIN (Case 3).xls</div>

b) Use the Save As option of Excel and save the Main Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name.

<div align="center">RED - MAIN (Case 4).xls</div>

c) Go to the Control and Setup worksheet and change the following information.

Road Identification Code	CS4
Road Name	Case Study 4

d) Go to the Traffic worksheet and change the daily traffic for the dry and wet seasons to the traffic of Table 11. Note that the traffic is different in the dry and wet seasons.

e) Go to the Project Alter. Main Features worksheet and enter the information from Table 11.

f) Go to the Project Alter. Solution worksheet to view the results. In this case, the proposed investment of US$ 6,000 is justified with a rate of return of 15%.

g) Go to the Alter. 1 Feasibility worksheet and notice that, starting on cell B3, we can check the weighted annual average daily normal and generated traffic of the dry and wet seasons. Starting on cell T30, we can check the dry and wet season traffic separately. Note that, in this case, the generated traffic on the wet season as a proportion of the normal traffic on the wet season (23%) is higher than the generated traffic on the dry season a proportion of the normal traffic on the dry season (6%).

h) Save and close the worksheet.

CASE STUDY 5 – COBBLESTONE ROAD WITH 800 AADT

The fifth case study evaluates a cobblestone road in mountainous terrain with 800 AADT. The proposed project alternatives consist of upgrading the road to asphalt concrete standard but with three possible shoulder widths (0.5 m, 1.0 m, and 1.5m) to be evaluated. These different widths yield different accident rates. You follow the steps below.

a) Locate and open the following Main Economic Evaluation Module that you saved while working with the first case study. Don't forget to enable the macros.

<div align="center">RED - MAIN (Case 1).xls</div>

b) Use the Save As option of Excel and save the Main Module at the same C:\RED Model Version 3.2 Windows Folder assigning to it the following name.

<div align="center">RED - MAIN (Case 5).xls</div>

c) Go to the Control and Setup worksheet and change the following information.

Road Identification Code	CS5
Road Name	Case Study 5
Duration of the Wet Season (days)	0
Road Condition Indicator Option	Both Roughness and Speeds of Vehicle Fleet

Note that you will define the road condition using both the roughness and the speeds of all vehicles. This is desirable for mountainous terrain because on this type of terrain the speed of a vehicle is highly influenced by the terrain, independently of the road roughness. Note also that, in this case, the number of days per year with disrupted passability (wet season) is zero.

d) Go to the Traffic worksheet and change the daily traffic for the dry season to the traffic from Table 12. In this case, the traffic of the wet season is not applicable.

e) Go to the Project Alter. Main Features worksheet and enter the data from Table 12.

f) Go to the Project Alter. Solution worksheet to view the results. In this case, the proposed investment of US$ 200,000 for upgrading the road with a 0.5 m shoulder is the recommended alternative, with a rate of return of 13%.

g) Go to the Alter. 1 Feasibility worksheet and notice that the speeds and the roughness for both alternatives are the ones you defined. Notice also that there are some safety benefits on the flow of net benefits. You can check the number of fatalities, per km-year, after the investments on the Project Alter. Solution worksheet.

h) Save and close the worksheet.

Table 1 – Road User Costs Basic Input Data

Basic Input Data

Country/Region	South Region
Year	2002

Currency Name	US$
Exchange Rate Divider to US$	1.00

Terrain Types

Code	Description	Rise & Fall (m/km)	Horizontal Curvature (deg/km)	Number of Rises & Falls (#)	Super_elevation (%)
A	Level	20	150	1	2
B	Hilly	50	300	1	2
C	Mountainous	80	500	1	2

Road Characteristics

Altitude (m)	500.0
Percent Time Driven on Water	20.0
Percent Time Driven on Snow	0.0
Texture Depth (mm)	0.69

Road Types

Code	Description	Surface Type 1-Bituminous 2-Concrete 3-Unsealed	Carriageway Width (m)	Speed Limit (km/hour)	Speed Limit Enforcement (#)	Roadside Friction (#)	NMT Friction (#)
X	Paved	1	7.0	100.0	1.1	1.0	1.0
Y	Cobblestone	3	7.0	80.0	1.1	1.0	1.0
Z	Unsealed	3	7.0	70.0	1.1	1.0	1.0

Vehicle Types

Code	Description	Number of Wheels	Number of Axles
1	Car Medium	4	2
2	Goods Vehicle	4	2
3	Bus Light	4	2
4	Bus Medium	6	2
5	Bus Heavy	10	3
6	Truck Light	4	2
7	Truck Medium	6	2
8	Truck Heavy	10	3
9	Truck Articulated	18	5

Vehicle Fleet Characteristics

	Car Medium	Goods Vehicle	Bus Light	Bus Medium	Bus Heavy	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
Economic Unit Costs									
New Vehicle Cost ($/vehicle)	12700	14700	14700	40000	67000	30000	46700	67000	80000
Fuel Cost ($/liter for MT, $/MJ for NMT)	0.33	0.33	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Lubricant Cost ($/liter)	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
New Tire Cost ($/tire)	40.00	67.00	53.00	113.00	167.00	100.00	133.00	167.00	285.00
Maintenance Labor Cost ($/hour)	5.83	5.83	5.83	5.83	5.83	5.83	5.83	5.83	5.83
Crew Cost ($/hour)	0.00	1.83	1.83	1.83	2.08	1.83	1.83	1.83	2.08
Interest Rate (%)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Utilization and Loading									
Kilometers Driven per Year (km)	18000	25000	80000	50000	35000	60000	40000	45000	45000
Hours Driven per Year (hr)	400	600	1800	1200	1400	1000	1100	1500	1500
Service Life (years)	8	7	5	8	8	6	8	8	10
Percent of Time for Private Use (%)	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gross Vehicle Weight (tons)	1.20	2.50	2.50	5.00	11.00	3.00	10.00	18.00	25.00

Reference Vehicle Adopted to Estimate Roughness as a Function of Speed of Reference Vehicle

Car Medium

Table 2 – Control and Setup

Control Data

Country Name	South
Project Name	RED Model Case Studies
Road Identification Code	CS1
Road Name	Case Study 1
Currency Name	Dollars
Currency Symbol	$

Duration of the Wet Season (days)	90
Evaluation Date	January 1, 2002
Road Agency Economic Costs Factor	0.90
Discount Rate (%)	12%
Evaluation Period (years)	15
Initial Calendar Year	2002
Population Served (persons)	1000

Setup Data

	Name of Each Vehicle Type (two words max.)
Vehicle Type 1	Car Medium
Vehicle Type 2	Goods Vehicle
Vehicle Type 3	Bus Light
Vehicle Type 4	Bus Medium
Vehicle Type 5	Bus Heavy
Vehicle Type 6	Truck Light
Vehicle Type 7	Truck Medium
Vehicle Type 8	Truck Heavy
Vehicle Type 9	Truck Articulated

	Name of Each Terrain Type
Terrain Type A	Level
Terrain Type B	Hilly
Terrain Type C	Mountainous

	Name of Each Road Type
Road Type X	Paved
Road Type Y	Cobblestone
Road Type Z	Unsealed

Road Condition Indicator Option	● Roughness ○ Speed of a Reference Vehicle ○ Both Roughness and Speeds of Vehicle Fleet

Table 3 – Time and Accidents

Travel Time Costs

	Number of Passengers (#)	Passengers Time Cost ($/pas-hr)	Cargo Holding Time Cost ($/veh-hr)
Car Medium	2	1.50	0.00
Goods Vehicle	2	1.50	0.00
Bus Light	10	0.75	0.00
Bus Medium	20	0.75	0.00
Bus Heavy	40	0.75	0.00
Truck Light	0	0.00	0.00
Truck Medium	0	0.00	0.00
Truck Heavy	0	0.00	0.00
Truck Articulated	0	0.00	0.00

Accident Costs

	Costs in Dollars
Average Cost per Accident	0
OR	
Costs per Accident Type:	
With Fatality	150000
With Injury	5000
Damage Only	500

Table 4 – Traffic

Normal Traffic

Dry Season

	Daily Traffic 2002 (veh/day)	Composition 2002 (%)	Daily Traffic 2021 (veh/day)	Composition 2021 (%)
Car Medium	10	10%	19	10%
Goods Vehicle	50	50%	96	50%
Bus Light	6	6%	11	6%
Bus Medium	6	6%	11	6%
Bus Heavy	4	4%	8	4%
Truck Light	7	7%	13	7%
Truck Medium	10	10%	19	10%
Truck Heavy	7	7%	13	7%
Truck Articulated	0	0%	0	0%
Total	100	100%	191	100%
Weighted Average				

Normal, Generated and Diverted Traffic Growth

Traffic Growth Rate (%)			
2002 - 2006	2007 - 2011	2012 - 2016	2017 - 2021
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0

Wet Season

	Daily Traffic 2002 (veh/day)	Composition 2002 (%)	Daily Traffic 2021 (veh/day)	Composition 2021 (%)
Car Medium	10	10%	19	10%
Goods Vehicle	50	50%	96	50%
Bus Light	6	6%	11	6%
Bus Medium	6	6%	11	6%
Bus Heavy	4	4%	8	4%
Truck Light	7	7%	13	7%
Truck Medium	10	10%	19	10%
Truck Heavy	7	7%	13	7%
Truck Articulated	0	0%	0	0%
Total	100	100%	191	100%
Weighted Average				

Traffic Growth Rate (%)			
2002 - 2006	2007 - 2011	2012 - 2016	2017 - 2021
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0
4.0	4.0	3.0	3.0

Generated Traffic Due to Decrease in Transport Costs

	Percent of Normal Traffic (%)		Price Elasticity of Demand for Transport
Car Medium	0		0.5
Goods Vehicle	0		0.5
Bus Light	0		0.5
Bus Medium	0	**OR**	0.5
Bus Heavy	0		0.5
Truck Light	0		0.5
Truck Medium	0		0.5
Truck Heavy	0		0.5
Truck Articulated	0		0.5

$$\text{Price Elasticity of Demand for Transport} = \frac{\text{Percent Increase in Traffic}}{\text{Percent Decrease in Transport Cost}}$$

Note: Enter percent of normal traffic **OR** price elasticity of demand. If you enter both, the model uses the percent of normal traffic.

Table 5 – Project Alter. Main Features

Option Description	Without Project Alternative 0	Project Alternatives Alternative 1	Alternative 2	Alternative 3
	Keep in Poor Condition	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Terrain Type (A/B/C)	B	B	B	B
A: Level				
B: Hilly				
C: Mountainous				
Road Type (X/Y/Z)	Z	Z	Z	X
X: Paved				
Y: Cobblestone				
Z: Unsealed				
Dry Season				
Road Length (km)	10.0	10.0	10.0	10.0
Roughness (IRI)	17.0	14.0	10.0	4.0
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
Wet Season				
Road Length (km)	10.0	10.0	10.0	10.0
Roughness (IRI)	25.0	20.0	10.0	4.0
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
N.A.				
Investment Duration in Years (0/1/2/3)	0	1	1	1
Percent of Investment Costs in Year 1 (%)	0%	100%	100%	100%
Percent of Investment Costs in Year 2 (%)	0%	0%	0%	0%
Percent of Investment Costs in Year 3 (%)	0%	0%	0%	0%
Financial Investment Costs ('000$/km)	0.00	10.00	45.00	250.00
Fixed Financial Maintenance Costs ('000$/km/year)	1.00	1.50	2.50	3.50
Variable Financial Maintenance Costs ('000$/km/year/ADT)	0.000	0.000	0.000	0.000
Accidents Rate (Accidents per 100 million vehicle-km)				
And Optionally				
Percent With Fatality (%)				
Percent With Injury (%)				
Percent Damage Only (%)				
Diverted Traffic from Alternative Road (veh/day):				
Car				
Utility				
Light Bus				
Medium Bus				
Heavy Bus				
Light Truck				
Medium Truck				
Heavy Truck				
Artic. Truck				
Alternative Road Characteristics:				
Road Terrain Type (A/B/C)		B	B	B
Road Type (X/Y/Z)		X	X	X
Road Length (km)				
Road Roughness (IRI)				

Table 6 – Case Study 2 Input Data

<u>Control and Setup Worksheet</u>

Road Identification Code	CS2
Road Name	Case Study 2

<u>Traffic Worksheet</u>

Dry and Wet Season Traffic

Car	30
Utility	150
Light Bus	18
Medium Bus	18
Heavy Bus	12
Light Truck	21
Medium Truck	30
Heavy Truck	21
Artic. Truck	0

<u>Project Alter. Main Features Worksheet</u>

Fixed Maintenance Costs ('000$/km/year)

Keep in Poor Condition	1.20
Keep in Fair Condition	2.00
Keep in Good Condition	4.00
Upgrade to S.T.	5.00

Table 7 – Risk Analysis Basic Input Data

Variable Number	Variable Description	Triangular Distributions		
		Multiplying Factors		
		Minimum Possible Value	Model Input Value	Maximum Possible Value
1	Normal Traffic (vpd)	0.70	1.00	1.30
2	Normal Traffic Growth Rate (%)	1.00	1.00	1.00
3	Generated Traffic (vpd)	0.25	1.00	1.75
4	Induced Traffic (vpd)	1.00	1.00	1.00
5	Passenger Time Costs ($/hr)	1.00	1.00	1.00
6	Cargo Time Costs ($/hr)	1.00	1.00	1.00
7	Wet Season Duration (days)	1.00	1.00	1.00
8	Without Project Dry Season Length (km)	1.00	1.00	1.00
9	Without Project Dry Season Roughness (IRI)	1.00	1.00	1.00
10	Without Project Wet Season Length (km)	1.00	1.00	1.00
11	Without Project Wet Season Roughness (IRI)	1.00	1.00	1.00
12	Without Project Accidents Rate (#/m veh-km)	1.00	1.00	1.00
13	Without Project Investment Costs (000$/km)	1.00	1.00	1.00
14	Without Project Maintenance Costs (000/km/yr)	1.00	1.00	1.00
15	Project Dry Season Road Length (km)	1.00	1.00	1.00
16	Project Dry Season Roughness (IRI)	1.00	1.00	1.00
17	Project Wet Season Road Length (km)	1.00	1.00	1.00
18	Project Wet Season Roughness (IRI)	1.00	1.00	1.00
19	Project Accidents Rate (#/m veh-km)	1.00	1.00	1.00
20	Project Investment Costs (000$/km)	0.75	1.00	2.00
21	Project Maintenance Costs (000/km/yr)	1.00	1.00	1.00

Table 8 – Program Module Road ID and Name, Traffic and Fixed Maintenance Costs

Road ID	Road Name
P025	Poor Condition 25 AADT
P050	Poor Condition 50 AADT
P100	Poor Condition 100 AADT
P200	Poor Condition 200 AADT
P300	Poor Condition 300 AADT
P600	Poor Condition 600 AADT
P900	Poor Condition 900 AADT

Dry Season Average Daily Traffic (AADT)								
Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5	Vehicle 6	Vehicle 7	Vehicle 8	Vehicle 9
2	13	1	2	1	2	2	2	0
5	25	3	3	2	4	5	3	0
10	50	6	6	4	7	10	7	0
20	100	12	12	8	14	20	14	0
30	150	18	18	12	21	30	21	0
60	300	36	36	24	42	60	42	0
90	450	54	54	36	63	90	63	0

Fixed Financial Maintenance Costs ('000$/km/year)				
	Alternative 0	Alternative 1 & 4	Alternative 2 & 5	Alternative 3 & 6
	Keep in Poor Condition	Keep in Fair Condition	Keep in Good Condition	Upgrade to S.T.
Traffic	Columns DR	Columns EL & GT	Columns FF & HN	Columns FZ & IH
25 AADT	0.80	1.30	2.00	3.50
50 AADT	0.90	1.40	2.25	3.50
100 AADT	1.00	1.50	2.50	3.50
200 AADT	1.10	1.75	3.25	4.25
300 AADT	1.20	2.00	4.00	5.00
600 AADT	1.30	2.50	4.25	5.25
900 AADT	1.40	3.00	4.50	5.50

Table 9 – Program Module Alternatives 4, 5 and 6

Column	GF	GH	GJ	GM	GS	GT
Alternative 4 Data						
Traffic	Alternative 4 Description	Road Type (X/Y/Z)	Dry Season Roughness (IRI)	Wet Season Roughness (IRI)	Financial Investment Cost ('000$/km)	Fixed Financial Maint. Costs ('000$/km/year)
25 AADT	Upgrade to A.C.	Z	2	2	300	5.00
50 AADT	Upgrade to A.C.	Z	2	2	300	5.00
100 AADT	Upgrade to A.C.	Z	2	2	300	5.00
200 AADT	Upgrade to A.C.	Z	2	2	300	5.75
300 AADT	Upgrade to A.C.	Z	2	2	300	6.50
600 AADT	Upgrade to A.C.	Z	2	2	300	6.75
900 AADT	Upgrade to A.C.	Z	2	2	300	7.00

Column	GZ	HB	HD	HG	HM	HN
Alternative 5 Data						
Traffic	Alternative 5 Description	Road Type (X/Y/Z)	Dry Season Roughness (IRI)	Wet Season Roughness (IRI)	Financial Investment Cost ('000$/km)	Fixed Financial Maint. Costs ('000$/km/year)
25 AADT	Upgrade to Cobblestone	Y	6	6	170	3.00
50 AADT	Upgrade to Cobblestone	Y	6	6	170	3.00
100 AADT	Upgrade to Cobblestone	Y	6	6	170	3.25
200 AADT	Upgrade to Cobblestone	Y	6	6	170	3.75
300 AADT	Upgrade to Cobblestone	Y	6	6	170	4.50
600 AADT	Upgrade to Cobblestone	Y	6	6	170	4.75
900 AADT	Upgrade to Cobblestone	Y	6	6	170	5.00

Column	HT	HV	HK	IA	IG	IH
Alternative 6 Data						
Traffic	Alternative 6 Description	Road Type (X/Y/Z)	Dry Season Roughness (IRI)	Wet Season Roughness (IRI)	Financial Investment Cost ('000$/km)	Fixed Financial Maint. Costs ('000$/km/year)
25 AADT	Keep in Very Poor Condition	X	20	25	0	0.40
50 AADT	Keep in Very Poor Condition	X	20	25	0	0.50
100 AADT	Keep in Very Poor Condition	X	20	25	0	0.60
200 AADT	Keep in Very Poor Condition	X	20	25	0	0.70
300 AADT	Keep in Very Poor Condition	X	20	25	0	0.80
600 AADT	Keep in Very Poor Condition	X	20	25	0	0.90
900 AADT	Keep in Very Poor Condition	X	20	25	0	1.00

Table 10 – Case Study 3 Input Data

Control and Setup Worksheet

    Road Identification Code   CS3
    Road Name   Case Study 3
    Road Condition Indicator Option   Speed of a Reference Vehicle

Traffic Worksheet

    Dry and Wet Season Traffic

Car	5
Utility	25
Light Bus	3
Medium Bus	3
Heavy Bus	2
Light Truck	4
Medium Truck	5
Heavy Truck	3
Artic. Truck	0

Project Alter. Main Features Worksheet

	Without Project Alternative	Project Alternatives
	Alternative 0	Alternative 1
Alternative Description	Very Poor Condition Gravel Road	Good to Fair Condition Gravel Road
Terrain Type (A/B/C)	A	A
Road Type (X/Y/Z)	Z	Z
Dry Season		
Road Length (km)	10.0	10.0
Car Medium Speed (km/hr)	35.0	55.0
Wet Season		
Road Length (km)	10.0	10.0
Car Medium Speed (km/hr)	25.0	55.0
Investment Duration in Years (0/1/2/3)	0	1
Percent of Investment Costs in Year 1 (%)	0%	100%
Percent of Investment Costs in Year 2 (%)	0%	0%
Percent of Investment Costs in Year 3 (%)	0%	0%
Financial Investment Costs ('000$/km)	0.00	20.00
Fixed Financial Maintenance Costs ('000$/km/year)	0.50	2.25
Variable Financial Maintenance Costs ('000$/km/year/ADT)	0.000	0.000

Table 11 – Case Study 4 Input Data

<u>Control and Setup Worksheet</u>

Road Identification Code	CS4
Road Name	Case Study 4

<u>Traffic Worksheet</u>

	Dry Season Traffic	Wet Season Traffic
Car	7	5
Utility	37	25
Light Bus	5	3
Medium Bus	5	3
Heavy Bus	3	2
Light Truck	6	4
Medium Truck	7	5
Heavy Truck	5	3
Artic. Truck	0	0

<u>Project Alter. Main Features Worksheet</u>

	Without Project Alternative	Project Alternatives
	Alternative 0	Alternative 1
Alternative Description	Wet Season Passability Problems	Good to Fair Condition Gravel Road
Terrain Type (A/B/C)	A	A
Road Type (X/Y/Z)	Z	Z
Dry Season		
Road Length (km)	10.0	10.0
Car Medium Speed (km/hr)	50.0	55.0
Wet Season		
Road Length (km)	10.0	10.0
Car Medium Speed (km/hr)	25.0	55.0
Investment Duration in Years (0/1/2/3)	0	1
Percent of Investment Costs in Year 1 (%)	0%	100%
Percent of Investment Costs in Year 2 (%)	0%	0%
Percent of Investment Costs in Year 3 (%)	0%	0%
Financial Investment Costs ('000$/km)	0.00	6.00
Fixed Financial Maintenance Costs ('000$/km/year)	0.50	2.25
Variable Financial Maintenance Costs ('000$/km/year/ADT)	0.000	0.000

Table 12 – Case Study 5 Input Data

Control and Setup Worksheet

Road Identification Code	CS5
Road Name	Case Study 5
Duration of the Wet Season (days)	0
Road Condition Indicator Option	Both Roughness and Speeds of Vehicle Fleet

Traffic Worksheet

Dry Season Traffic

Car	248
Utility	480
Heavy Bus	48
Medium Truck	16
Heavy Truck	8

Project Alter. Main Features Worksheet

	Without Project	Project Alternatives		
	Alternative 0	Alternative 1	Alternative 2	Alternative 3
Alternative Description	Cobblestone Pavement	Pave with 0.5m shoulder	Pave with 1.0m shoulder	Pave with 1.5m shoulder
Terrain Type (A/B/C)	C	C	C	C
Road Type (X/Y/Z)	Y	X	X	X
Dry Season				
Road Length (km)	10.0	10.0	10.0	10.0
Roughness (IRI)	10.0	2.0	2.0	2.0
Vehicle Fleet Speeds (km/hr):				
Car Medium	60.0	66.0	72.0	78.0
Goods Vehicle	60.0	66.0	72.0	78.0
Bus Light	60.0	66.0	72.0	78.0
Bus Medium	50.0	55.0	60.0	65.0
Bus Heavy	40.0	44.0	48.0	52.0
Truck Light	60.0	66.0	72.0	78.0
Truck Medium	50.0	55.0	60.0	65.0
Truck Heavy	40.0	44.0	48.0	52.0
Truck Articulated	30.0	33.0	36.0	39.0
Investment Duration in Years (0/1/2/3)	0	1	1	1
Percent of Investment Costs in Year 1 (%)	0%	100%	100%	100%
Percent of Investment Costs in Year 2 (%)	0%	0%	0%	0%
Percent of Investment Costs in Year 3 (%)	0%	0%	0%	0%
Financial Investment Costs ('000$/km)	0.00	200.00	220.00	270.00
Fixed Financial Maintenance Costs ('000$/km/ye	5.00	7.00	7.00	7.00
Variable Financial Maintenance Costs ('000$/km	0.000	0.000	0.000	0.000
Accidents Rate (Accidents per 100 million vehicl	180.0	170.0	160.0	140.0
And Optionally				
Percent With Fatality (%)	10%	10%	10%	10%
Percent With Injury (%)	16%	16%	16%	16%
Percent Damage Only (%)	74%	74%	74%	74%