Roads Economic Decision Model (RED) for Economic Evaluation of Low Volume Roads

RMI Brown-bag Lunch Series
February 14, 2001, Washington, DC

Rodrigo Archondo-Callao
The World Bank

Road Management Initiative and RED

- RED is a product of the Road Management Initiative (RMI), a key component of the Sub-Saharan Africa Transport Policy Program (SSATP)
- RMI is a cooperative framework set up to assist road sector reform and to foster improved resource allocation and use in Africa, currently being coordinated by Stephen Brushett
- RED was developed by Rodrigo Archondo-Callao, under the supervision of Pedro Geraldes, with the first version released in June 1999 and a second version to be released March 2001

RED Objectives

- Simplify the economic evaluation of low volume roads
- Better capture the economic benefits of a project
- Include in the analysis the high level of uncertainty related to low volume roads (risk analysis)
- Produce proper sensitivity, switching values, user impacts, and distribution of benefits evaluations

RED Development

- RED was developed on the same period as the Design and Appraisal of Rural Transport Infrastructure Paper by Jerry Lebo and Dieter Schelling
- RED was reviewed by external experts and presented at the TRB Seventh International Conference on Low-Volume Roads in 1999
- RED was presented to the AfDB staff on a one-day workshop in Abidjan
- RED was used at a network level in Nicaragua (Third Rehab. Project) and is being used at project level in many countries worldwide

RED Products

- Software tool: RED - Roads Economic Decision Model
- SSATP Africa Transport Technical Note 18: Roads Economic Decision Model (RED) for Economic Evaluation of Low Volume Roads

World Bank Rural Transport Infrastructure Notes

- RT1 - Typical Unpaved Roads: Roughness Predicted by the HDM-III Model
- RT2 - Unpaved Roads: Roughness Estimation by Subjective Evaluation
- RT3 - Paving of Unpaved Roads: Economically Justified Paving Costs

Software tool: DETOUR - Deterioration of Unpaved Roads Model

Web Sites

- Software Tools
  http://www.worldbank.org/html/fpd/transport/roads/tools.htm#rttools
- Sub-Saharan Africa Transport Policy Program (SSATP)
  http://www.worldbank.org/afr/ssatp/
- SSATP Africa Transport Technical Note 18
  http://www.worldbank.org/afr/transport/newsletter/web18.pdf
- World Bank Infrastructure Notes
  http://www.worldbank.org/html/fpd/transport/publicat/tdinflst.htm#rural
- Design and Appraisal of Rural Transport Infrastructure Topic
  http://www.worldbank.org/html/fpd/transport/rural_tr/des&appr.htm#aspects

Economic Evaluation of Low Volume Roads

- Low Volume Road X High Volume Roads (> 300? AADT paved roads: HDM-4 evaluation)
- Low Volume Roads X Very Low Volume Roads (< 30? AADT unpaved roads: social evaluation, maximize population served per investment)
- Consumer Surplus Approach X Producer Surplus Approach (difficult to judge the assumptions made, concern of double counting benefits)
- Customized Excel Model for Low Volume Roads X HDM Models (HDM-III and HDM-4 models have essentially the same features with relation to low volume unpaved roads, which are not particularly customized for low volume roads)

HDM Models and RED Benefits

Benefits	HDM-III	HDM-4	RED
VOC Normal Traffic	Yes	Yes	Yes
VOC Generated Traffic	Yes	Yes	Yes
VOC Diverted Traffic	No	Yes	Yes
Passenger Time	Yes	Yes	Yes
Cargo Delay Time	Yes	Yes	Yes
Accidents	No	Yes	Yes
Non Motorized Traffic	No	Yes	Yes
Social and Other	External	External	External

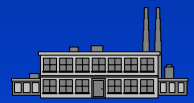
High and Low Volume Roads Focus

High Volume Roads

focus mostly on normal traffic

Low Volume Roads

focus on
- normal traffic
- economic development
- passability
- uncertainty
- people served
- importance of cargo
- social services



Needs Addressed by RED

- The need to reduce the input data requirements for low volume roads
- The need to take into account the high uncertainty related to the input requirements
- The need to clearly state the assumptions made, particularly on the road condition assessment and the economic development forecast
- The need to compute benefits as a result of generated traffic due to decrease in transport costs and generated traffic (induced) due to local economic development

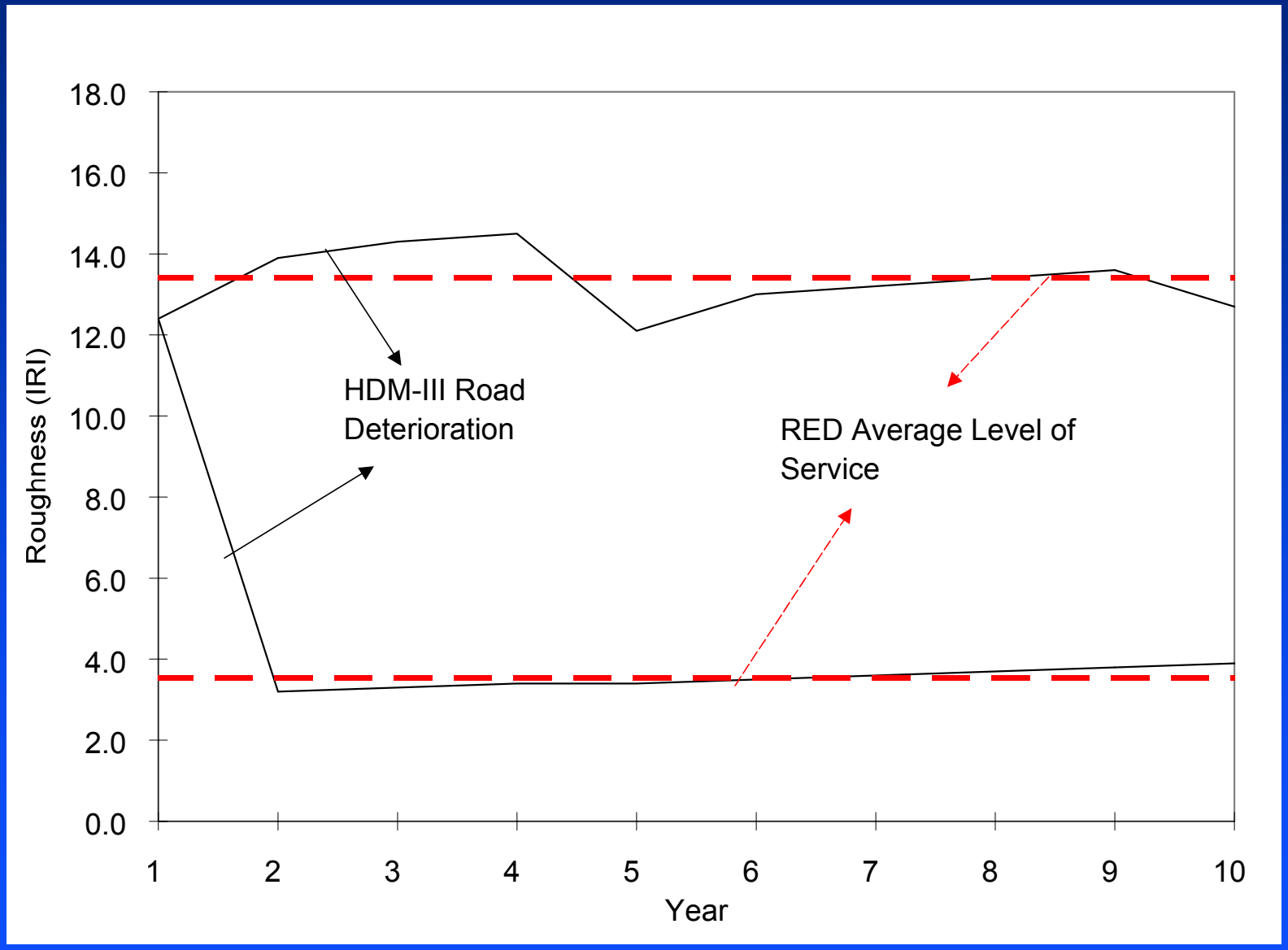
Needs Addressed by RED

- The need to quantify the economic costs of the days per year when the passage of vehicles is further disrupted by a highly deteriorated condition (wet/dry seasons)
- The need to define the level of service of unpaved roads with other parameters other than roughness
- The need to include in the analysis other benefits such as non-motorized traffic, social services, and environmental impacts
- The need to present the results with sensitivity, switching values, and risk analyses

RED Characteristics

- Considers a constant average level of service over the evaluation period for each project-alternative
- Has three options to define the average level of service of a project-alternative
- Evaluates two periods in a year: period with and period without direct passability (wet/dry seasons)
- Works with user defined equations relating road user costs and speeds to roughness
- Computes benefits as a result of generated traffic due to decrease in transport costs and induced traffic due to local economic development
- Performs risk analysis based on triangle distributions

Constant Average Level of Service (road condition) over Evaluation Period



HDM-III/HDM-4 Roughness Estimates for Unpaved Roads

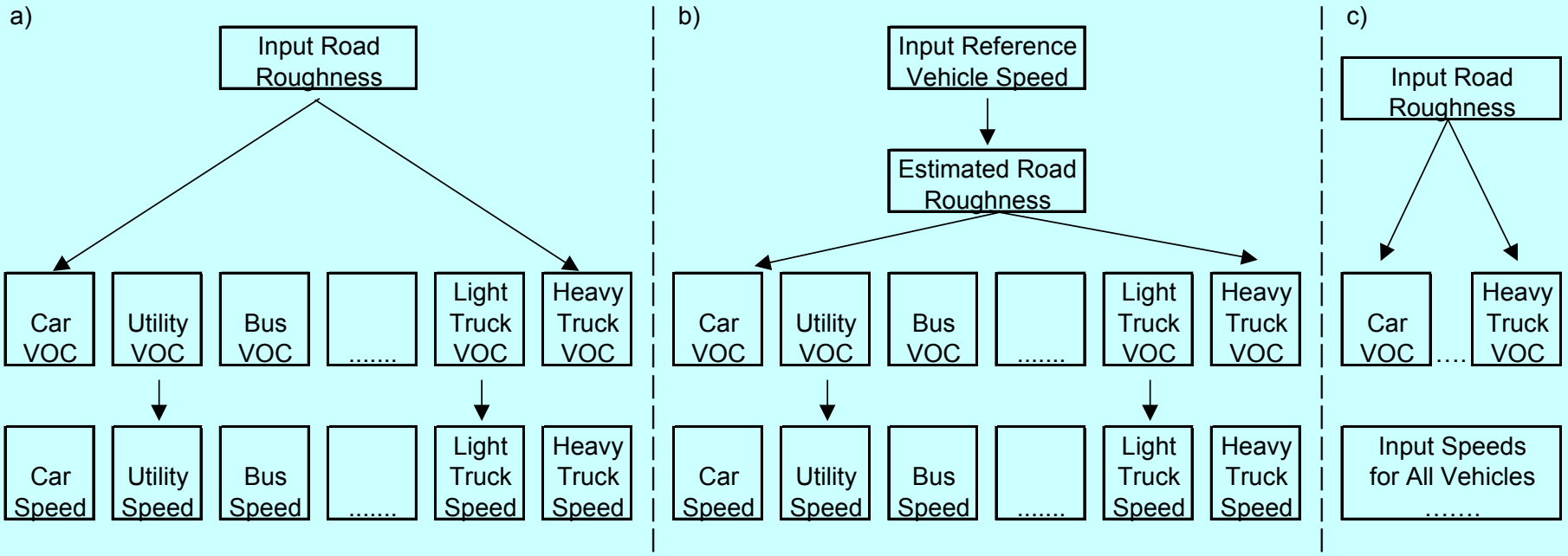
- Valid for engineered unpaved roads with good maintenance (good drainage). Therefore:
  - Higher rainfall yields lower roughness
  - Higher percent of trucks yields lower roughness
  - Earth roads (finer soils) have lower roughness than gravel roads
- In practice, the condition of a road can be different from what is being predicted by the HDM models

Three Options to Define the Level of Service

a) Roughness

b) Speed of a Reference Vehicle

c) Roughness & Speeds of All Vehicles



Equations for each vehicle type and each terrain-road type:

a) Vehicle Operating Costs = a0 + a1 * Roughness + a2 * Roughness^2 + a3 * Roughness^3

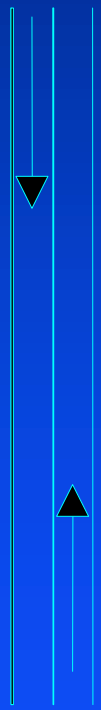
b) Speed = b0 + b1 * Roughness + b2 * Roughness^2 + b3 * Roughness^3

Equation for each terrain-road type and for the defined reference vehicle:

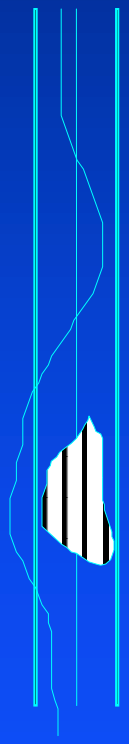
c) Roughness = c0 + c1 * Speed + c2 * Speed^2 + a3 * Speed^3

Two Periods During a Year

Days Per Year
With Direct Passability



Days Per Year
Without Direct Passability



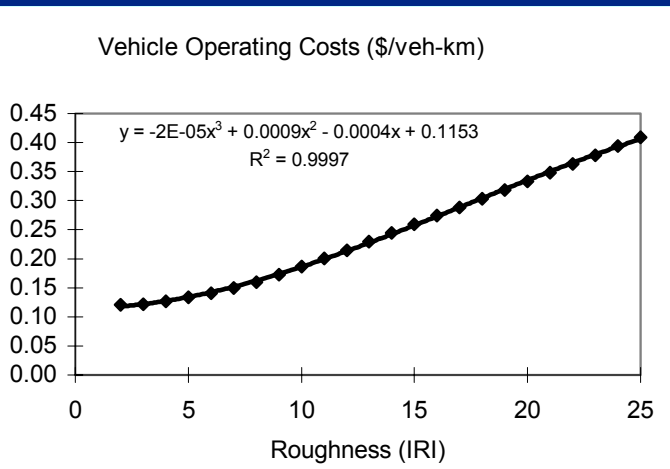
- Different Length
- Different Roughness
- Different Speeds

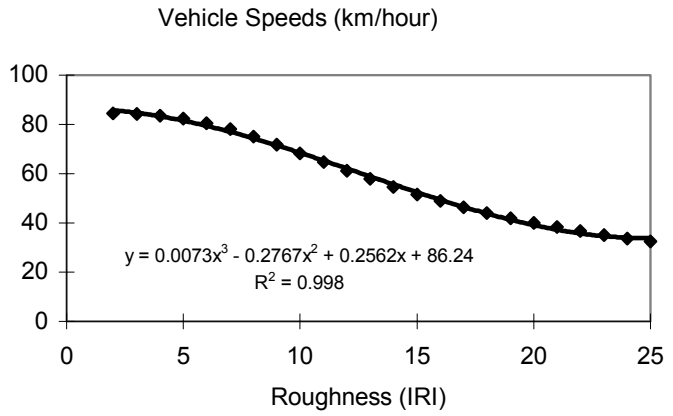
<u>Higher Transport Costs</u>

User Defined Equations Relating Vehicle Operating Costs and Speeds to Roughness

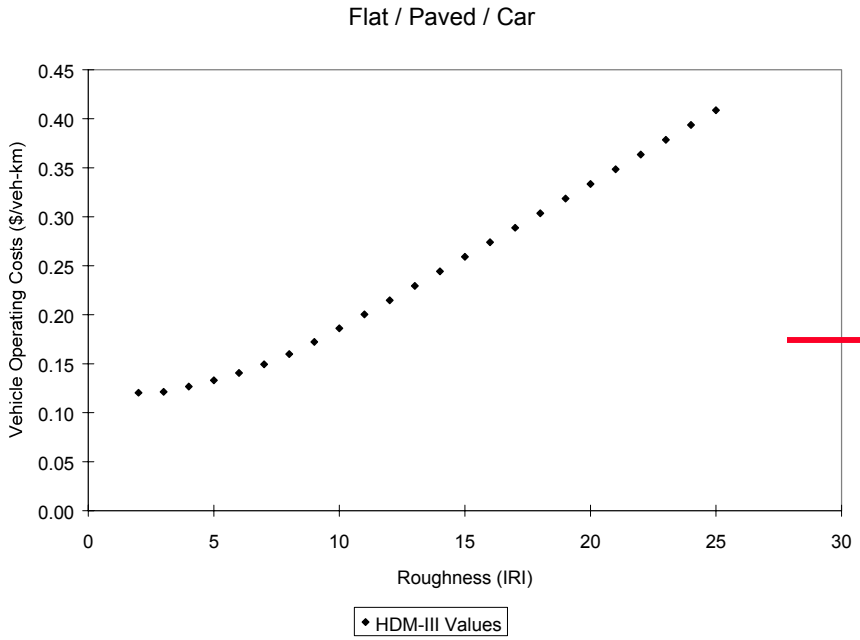
		Terrain Type		
		A	B	C
Road Type	X			
	Y			
	Z	AZ		

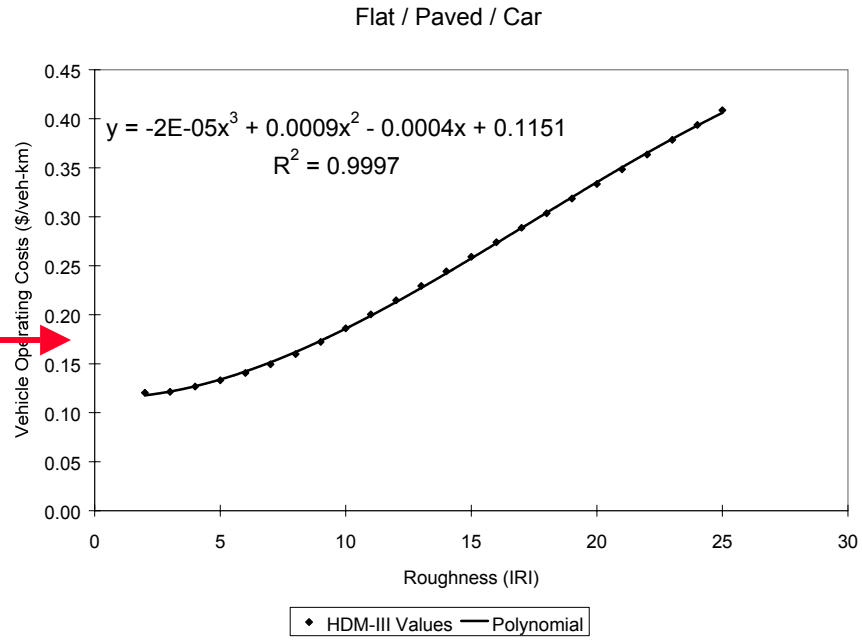
Vehicle Type
Car
Utility
Light Bus
Medium Bus
Heavy Bus
Light Truck
Medium Truck
Heavy Truck
Articulated Truck





Vehicle operating costs and speeds as a function of roughness from HDM-III, HDM-4 or other model



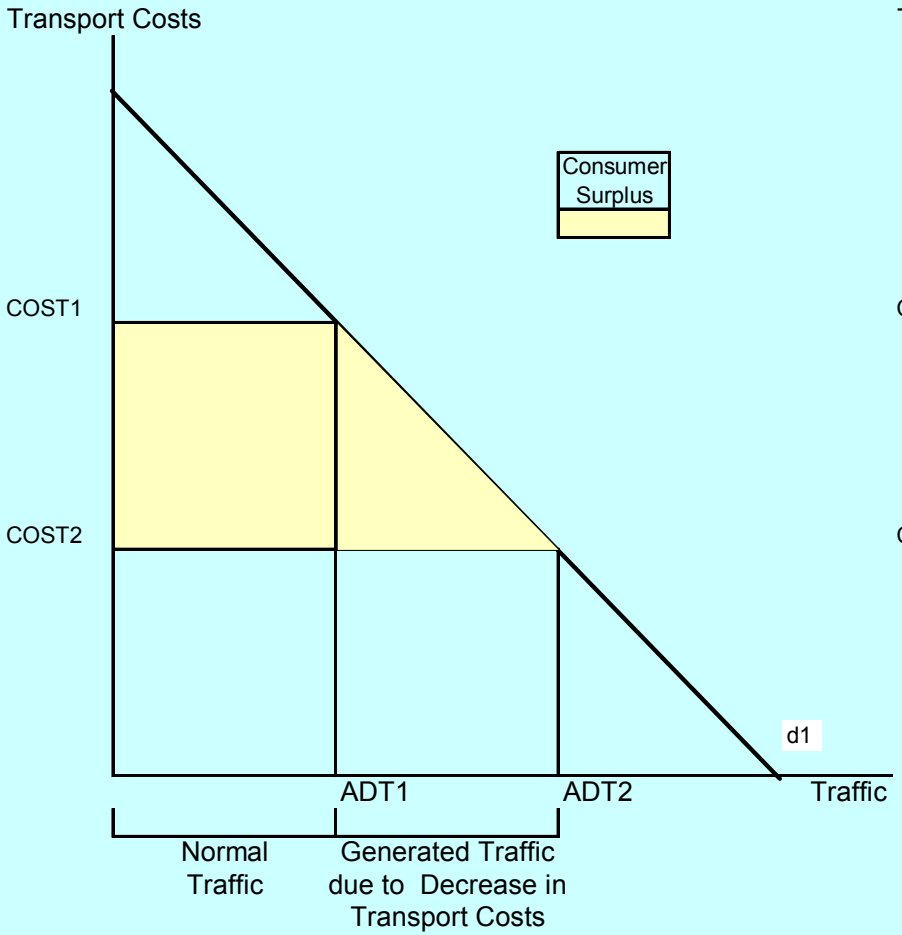


Results from HDM (VOC X IRI)

Fitted Cubic Polynomial

Generated Traffic <> Decrease in Transport Costs
Induced Traffic <> Local Economic Development

Decrease in Transport Costs



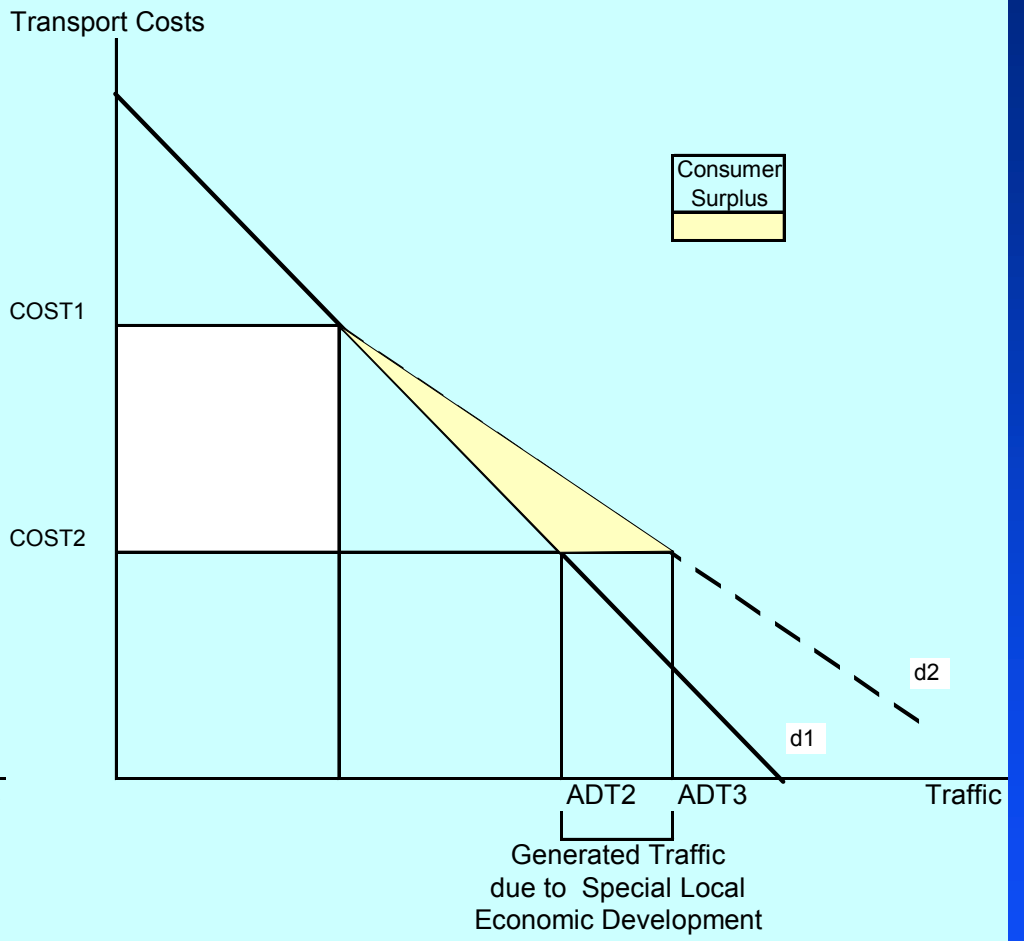
User enters:

- Percent of normal traffic or

  or

- Price elasticity of demand = $\frac{\text{Percent Increase in Traffic}}{\text{Percent Decrease in Transport Cost}}$

Special Local Economic Development (Induced Traffic)



User enters:

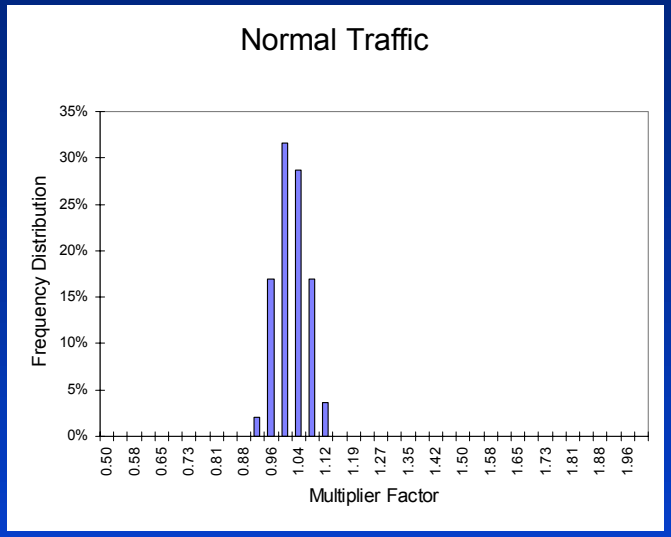
- Amount of generated traffic due to special local economic development

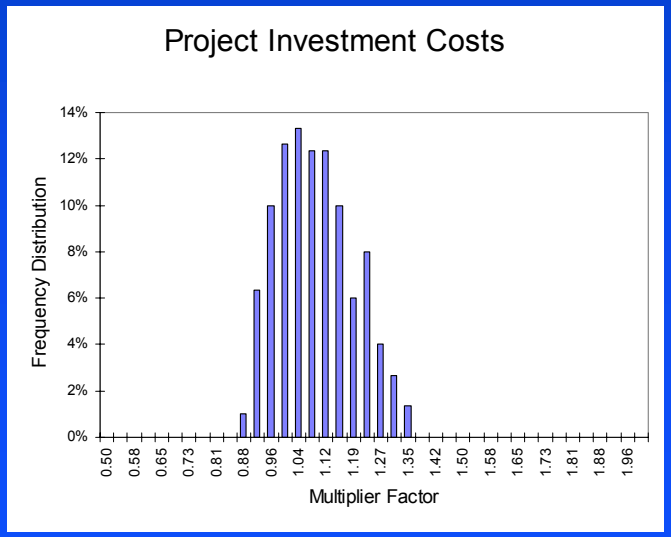
Risks Analysis

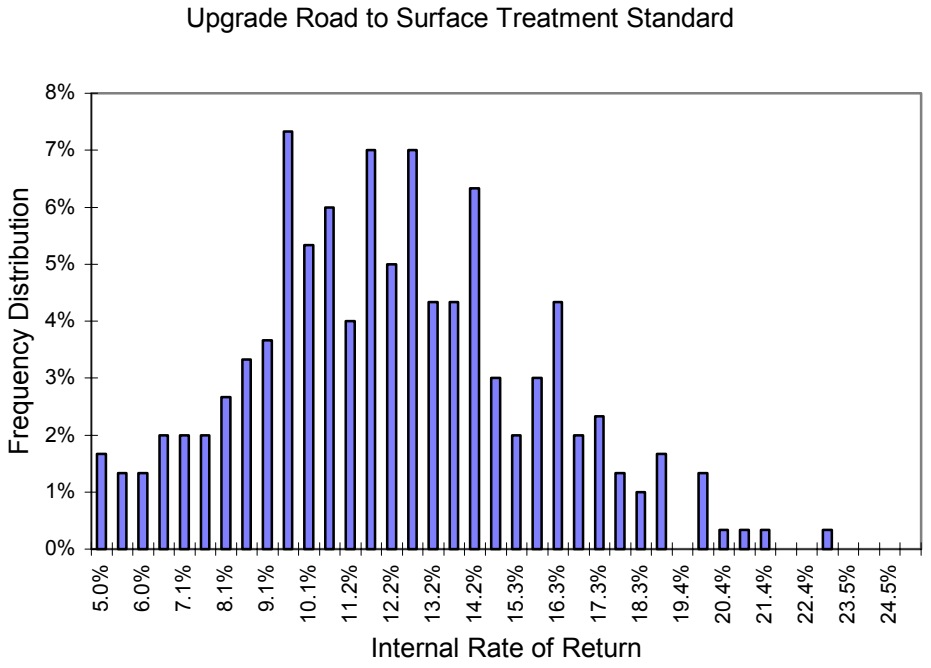
Country	Africa Region	
Project	Road Management Initiative	
Road	Road from Point A to Point B	
Option	2	Upgrade to ST

Internal Rate of Return Upgrade Road to Surface Treatment Standard		
Minimum		4.2%
Maximum		22.7%
Average		11.9%
Standard Deviation		3.5%
Median		11.7%
Percentile	25%	9.4%
Percentile	50%	11.7%
Percentile	75%	14.1%

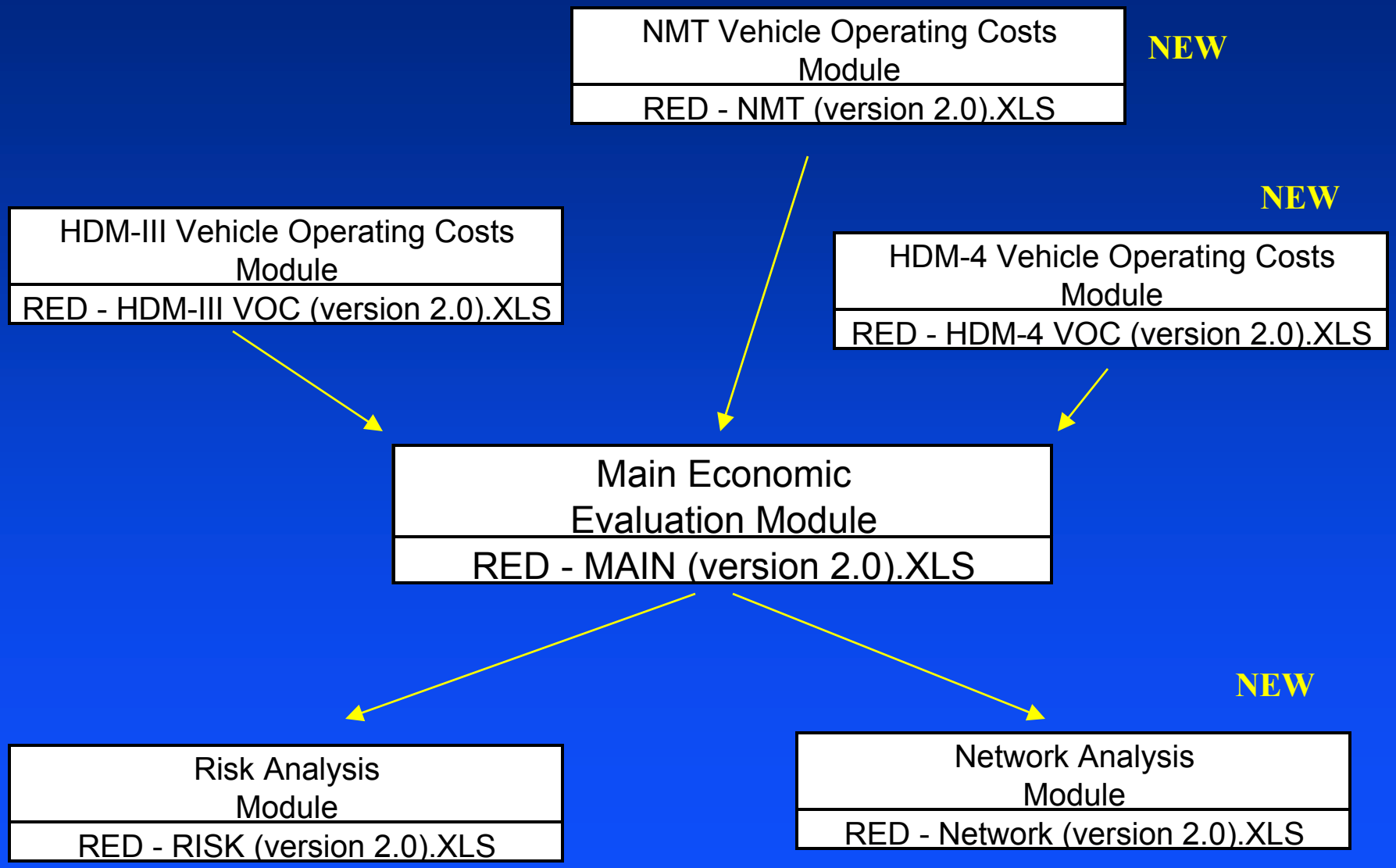
Probability that IRR is less than	12%	50%
Probability that IRR is greater than	12%	50%







RED Excel Software Components



Cape Verde Case Studies

- A RED training course was given in Cape Verde for 3 days for 10 public officials of Cape Verde, Guinea Bissau and Angola (an extra day was used to demonstrate HDM-4)
- Prior to the course, two case studies were prepared with Cape Verde data at project and network level:
  - Paving a Cobblestone Road Project
  - Santiago Island Road Network Economic Evaluation
- The course was very well received, with a grade of satisfaction with the course of 4.8 out of 5.0

Case Study 1, Project Evaluation: Setup Inputs

Country Name	Republica de Cabo Verde
Project Name	Rebilitacao de Estradas
Road Name	Sao Domingos - Assomada
Currency Name	Escudos CV
Currency Symbol	ECV
Evaluation Date	December 12, 2000
Financial to Economic Costs Multiplier	0.90
Discount Rate (%)	12%
Evaluation Period (years)	15
Initial Calendar Year	2001
Terrain Type A	Plano
Terrain Type B	Acidentado
Terrain Type C	Montanhoso
Road Type X	Asfaltada
Road Type Y	Calcada de Paralelos/Portugesa
Road Type Z	Terra
Road Condition Indicator Option	○ Roughness ○ Speed of a Reference Vehicle ◉ Both Roughness and Speeds of Vehicle Fleet

Travel Time and Accidents Inputs

Travel Time Costs

	Number of Passengers (#)	Passengers Time Cost (ECV/pas-hr)	Cargo Holding Time Cost (ECV/veh-hr)
Car	3	170.00	0.00
Utility	2	170.00	0.00
Light Bus	15	85.00	0.00
Medium Bus	25	85.00	0.00
Heavy Bus	40	85.00	0.00
Light Truck	0	0.00	0.00
Medium Truck	0	0.00	0.00
Heavy Truck	0	0.00	0.00
Artic. Truck	0	0.00	0.00

Accidents Costs

	Costs in Escudos CV
Average Cost per Accident	
OR	
Costs per Accident Type:	
With Fatality	15000000
With Injury	400000
Damage Only	100000

Exchange Rate:
1US$ = 120ECV

Traffic Inputs

Normal Traffic

	Daily Traffic 2001 (veh/day)	Composition 2001 (%)	Daily Traffic 2020 (v/day)	Composition 2020 ($)
Car	248	31%	474	31%
Utility	80	10%	153	10%
Light Bus	400	50%	765	50%
Medium Bus	8	1%	15	1%
Heavy Bus	40	5%	77	5%
Light Truck	0	0%	0	0%
Medium Truck	16	2%	31	2%
Heavy Truck	8	1%	15	1%
Artic. Truck	0	0%	0	0%
Total	800	100%	1530	100%
Weighted Average				

Normal & Generated Traffic Growth Rate

Traffic Growth Rate (%)			
2001 - 2005	2006 - 2010	2011 - 2015	2016 - 2020
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	0		1.0
Utility	0		1.0
Light Bus	0		1.0
Medium Bus	0	**OR**	1.0
Heavy Bus	0		1.0
Light Truck	0		1.0
Medium Truck	0		1.0
Heavy Truck	0		1.0
Artic. Truck	0		1.0

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

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

Project Options Inputs 1

	Without Project Case	Project Alternatives		
	Option 0	Option 1	Option 2	Option 3
Option Description	Calcada Paralelos	Asfaltar/0.5 acos	Asfaltar/1.0 acos	Asfaltar/2.0 acos
Road Length (km)	21.0	21.0	21.0	21.0
Terrain Type (A/B/C)	C	C	C	C
Road Type (X/Y/Z)	Y	X	X	X
Period With Good Passability (Dry Season):				
Roughness (IRI)	11.0	2.5	2.5	2.5
Vehicle Fleet Speeds (km/hr):				
Car	40.0	44.0	46.0	48.0
Utility	40.0	44.0	46.0	48.0
Light Bus	40.0	44.0	46.0	48.0
Medium Bus	30.0	33.0	34.5	36.0
Heavy Bus	25.0	27.5	28.8	30.0
Light Truck	30.0	33.0	34.5	36.0
Medium Truck	25.0	27.5	28.8	30.0
Heavy Truck	25.0	27.5	28.8	30.0
Artic. Truck	25.0	27.5	28.8	30.0
Period With Disrupted Passability (Wet Season):				
Days per Year (days/year)	0	0	0	0
Road Length (km)				
Roughness (IRI)				
N.A.				
Vehicle Fleet Speeds (km/hr):				
Car				

Project Options Inputs 2

	Without Project Case	Project Alternatives		
	Option 0	Option 1	Option 2	Option 3
Option Description	Calcada Paralelos	Asfaltar/0.5 acos	Asfaltar/1.0 acos	Asfaltar/2.0 acos
Investment Duration in Years (0/1/2/3)	0	2	2	2
Percent of Investment Costs in Year 1 (%)	0	60	60	60
Percent of Investment Costs in Year 2 (%)	0	40	40	40
Percent of Investment Costs in Year 3 (%)	0	0	0	0
Financial Investment Costs ('000ECV/km)	0	31212	33816	38567
Fixed Fin. Maint. Costs ('000ECV/km/year)	213.5	846.7	846.7	846.7
Variable Fin. Maint. Costs ('000ECV/km/year/	0.000	0.000	0.000	0.000
Accidents Rate (No. per 100 million veh-km)	180.0	160.0	150.0	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
Diverted Traffic from Alternative Road (veh/day):				
Car		0	0	0
Utility		0	0	0
Light Bus		0	0	0
Alternative Road Characteristics:				
Road Length (km)		100.0	100.0	100.0
Road Terrain Type (A/B/C)		B	B	B
Road Type (X/Y/Z)		X	X	X
Car Speed (km/hr)		3.0	3.0	3.0
Days without Direct Passability in One Year (days/year)		0	0	0
Road Length on Days without Direct Passability (km)		0.0	0.0	0.0
Roughness on Days without Direct Passability (IRI)		0.0	0.0	0.0

Project Options Solution

Net present value,
internal rate of return,
and other indicators for all options

	Without Project Case	Possible Project Alternatives		
	Option 0	Option 1	Option 2	Option 3
	Calcada Paralelos	Asfaltar/0.5 acos	Asfaltar/1.0 acos	Asfaltar/2.0 acos
Net Present Value (million ECV) at 12% Discount Rate	0.000	119.205	**140.910**	119.539
Internal Rate of Return (%)	#N/A	15%	16%	15%
Equivalent Annual Net Benefits (ECV/km) at 12%	0	744141	879638	746226
Modified Rate of Return at 12% Reinvestment Rate (%)	#N/A	14%	14%	13%
Net Present Value per Fin. Investment Costs (ratio)	0.00	0.18	0.20	0.15
Net Present Value per PV of Eco. Agency Costs (ratio)	0.00	0.17	0.19	0.15
First-Year Benefits per Eco. Investment Cost (ratio)	0.00	0.19	0.19	0.18
Financial Investment Costs (million ECV)	0.00	655.45	710.14	809.91
PV of Economic Agency Costs (million ECV)	30.78	686.70	733.80	819.75
Number of Fatalities per km-year After Investment	0.0547	0.0505	0.0474	0.0442

Feasibility

Economic Feasibility: Asfaltar/1.0 acos

Country	Republica de Cabo Verde	Project	Rebilitacao de Estradas
Road	Sao Domingos - Assomada	Option	Asfaltar/1.0 acos

Alternatives	Description	Terrain Type	Road Type
Without Project	Calcada Paralelos	C: Montanhoso	Y: Calcada de Paralelos/Portugesa
Project	Asfaltar/1.0 acos	C: Mo	

All important inputs

Alternatives	Length (km)	Roughness (IRI)	Period without Direct Passabi Days (days/year)	Length (km)	Rou	Heavy Bus	Light Truck	Medium Truck	Heavy Truck	Artic. Truck
						erage Speeds (km/hr)				
Without Project	21.0	11.0	0	0.0		25.0	30.0	25.0	25.0	25.0
Project	21.0	2.5	0	0.0		28.8	34.5	28.8	28.8	28.8

Alternatives	Investment (years)	Investment ('000ECV/km)	Maintenance 000ECV/km/yea	Accidents (#/m veh-km)	31%	10%	50%	1%	5%	0%	2%	1%	0%
					Average Travel Time (hours)								
Without Project	0	0	213.5	1.8	0:31	0:31	0:31	0:42	0:50	0:42	0:50	0:50	0:50
Project	2	33816	846.7	1.5	0:27	0:27	0:27	0:36	0:43	0:36	0:43	0:43	0:43

Cash flow of net benefits

Basic sensitivity analysis

Normal and generated traffic

Year	Normal Daily Traffic (veh/day)	Generated Daily Traffic (veh/day)	Induced Daily Traffic (veh/day)	Net Economic Benefits: Agency Benefits: Investment Costs (MECV/year)	Agency Benefits: Maintenance Costs (MECV/year)	User Benefits: Normal Traffic VOC (MECV/year)	Normal Traffic Time MECV/year	Generated Traffic VOC MECV/year	Generated Traffic Time MECV/year	Road Safety MECV/year	Other Benefits (MECV/year)	Total MECV/year	Sensitivity Analysis: A Agency * 1.25 MECV/year	B User * 0.75 MECV/year	A & B MECV/year
2001	800	0	0	-383.473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-383.473	-479.342	-383.473	-479.342
2002	832	0	0	-255.649	0.000	0.000					0.000	-255.649	-319.561	-255.649	-319.561
2003	865	217	0	0.000	-11.967	79.45					0.000	107.925	104.933	77.952	74.960
2004	900	226	0	0.000	-11.967	82.63					0.000	112.721			7
2005	936	235	0	0.000	-11.967	85.93					0.000	117.708			7
2006	973	244	0	0.000	-11.967	89.37					0.000	122.895			8
				000	-11.967	92.94					0.000	128.290			4
				000	-11.967	96.666	29.732	12.239	3.265	3.965	0.000	133.900			1
				000	-11.967	100.533	30.921	12.729	3.396	4.124	0.000	139.735			7
				000	-11.967	104.554	32.158	13.238	3.532	4.289	0.000	145.803			8
				000	-11.967	107.691	33.123	13.635	3.638	4.417	0.000	150.536			8
				000	-11.967	110.921	34.116	14.044	3.747	4.550	0.000	155.411			5
2013	1244	312	0	0.000	-11.967	114.249	35.140	14.465	3.859	4.687	0.000	160.432	157.441	117.332	114.341
2014	1282	321	0	0.000	-11.967	117.677	36.194	14.899	3.975	4.827	0.000	165.604	162.613	121.211	118.220
2015	1320	331	0	0.000	-11.967	121.207	37.280	15.346	4.094	4.972	0.000	170.932	167.940	125.207	122.215

3.5% Growth

Evaluation Period (years)
15

Economic indicators

Net Present Value (million ECV) at 12% Discount Rate	140.910	-29.182	-64.409	-234.501
Internal Rate of Return (%)	16%	11%	10%	6%
Equi	879638	-182167	-402077	-1463882
Modi	14%	12%	11%	9%
Net P	0.20	-0.04	-0.09	-0.33
First-Year Benefits per Economic Investment Cost (ratio)	0.19	0.15	0.14	0.11

12/12/00

User Impacts

	Economic R.U.C. Savings (%)	Financial Unit Trip Costs (2001 Escudos CV)											
		Without Project			With Project			Variation					
		VOC (ECV/veh-trip)	TIME (ECV/veh-trip)	TOTAL (ECV/veh-trip)	VOC ECV/veh-trip	TIME ECV/veh-trip	TOTAL ECV/veh-trip	VOC ECV/veh-trip	TIME ECV/veh-trip	TOTAL ECV/veh-trip	VOC (%)	TIME (%)	TOTAL (%)
Car	-26%	87			13	258.70	862.82	-269.03	-38.80	-307.84	-31%	-13%	-26%
Utility	-26%	11			26	172.46	1012.73	-335.21	-25.87	-361.08	-29%	-13%	-26%
Light Bus	-21%	81			17	646.74	1221.91	-235.90	-97.01	-332.91	-29%	-13%	-21%
Medium Bus	-16%	14			09	1437.20	2586.29	-294.00	-215.58	-509.58	-20%	-13%	-16%
Heavy Bus	-14%	24			17	2759.42	4803.59	-360.97	-413.91	-774.88	-15%	-13%	-14%
Light Truck	-35%	16			80	0.00	1091.80	-580.21	0.00	-580.21	-35%	0%	-35%
Medium Truck	-30%	24			32	0.00	1723.32	-739.16	0.00	-739.16	-30%	0%	-30%
Heavy Truck	-23%	39			44	0.00	3019.44	-887.87	0.00	-887.87	-23%	0%	-23%
Artic. Truck	-23%	48			83	0.00	3757.83	-1111.75	0.00	-1111.75	-23%	0%	-23%

Unit trip costs with and without project, for each vehicle type

	2003 Daily Traffic (veh/day)	Financial Annual Trip Costs during Opening Year (2001 M Escudos CV)											
		Without Project			With Project			Variation					
		VOC (MECV/year)	TIME (MECV/year)	TOTAL (MECV/year)	VOC MECV/year	TIME MECV/year	TOTAL MECV/year	VOC MECV/year	(%)	TIME MECV/year	(%)	TOTAL MECV/year	(%)
Car	268	85.488	29.127	114.615	59.148	25.328	84.476	-26.340	30%	-3.799	14%	-30.139	26%
Utility	87	37.125	6.264	43.388	26.538	5.447	31.985	-10.587	12%	-0.817	3%	-11.404	10%
Light Bus	433	128.079	117.448	245.528	90.827	102.129	192.956	-37.252	42%	-15.319	56%	-52.571	46%
Medium Bus	9	4.558	5.220	9.778	3.629	4.539	8.168	-0.929	1%	-0.681	3%	-1.609	1%
Heavy Bus	43	37.980	50.111	88.092	32.280	43.575	75.855	-5.700	6%	-6.536	24%	-12.236	11%
Light Truck	0	0.000	0.000	0.000	0.000	0.000	0.				%)	0.000	0%
Medium Truck	17	15.554	0.000	15.554	10.885	0.000	10				%)	-4.669	4%
Heavy Truck	9	12.340	0.000	12.340	9.536	0.000	9.				%)	-2.804	2%
Artic. Truck	0	0.000	0.000	0.000	0.000	0.000	0.				%)	0.000	0%
Total	865	321.124	208.170	529.295	232.844	181.018	41				00%	-115.433	100%

Annual trip costs with and without project, for each vehicle type

Benefits Distribution

	Net Economic Benefits								
	Agency Benefits		User Benefits						
	Investment Costs	Maintenance Costs	Normal Traffic		Generated Traffic		Road Safety	Other Benefits	Total
			VOC	Time	VOC	Time			
	(MECV/year)	(MECV/year)	(MECV/year)	MECV/year	MECV/year	MECV/year	MECV/year	(MECV/year)	MECV/year
Present Value	-611.731	-68.637	544.260	167.399	68.910	18.384	22.326	0.000	140.910
	-680.369		821.279						140.910

Total User Benefits	821.279					
User Benefits Components	544.260	167.399	68.910	18.384	22.326	0.000
User Benefits Percent	66%	20%	8%	2%	3%	0%

User Benefits Components	544.260	167.399	68.910	18.384	22.326	0.000
Car	181.876	26.233	25.864	3.731	7.108	0.000
Utility	73.100	5.642	10.390	0.802	2.293	0.000
Light Bus	257.223	105.779	29.785	12.249	10.993	0.000
Medium Bus	6.411	4.701	0.571	0.418	0.210	0.000
Heavy Bus	39.360	45.132	2.957	3.390	1.027	0.000
Light Truck	0.000	0.00			0	0.000
Medium Truck	32.239	0.00			3	0.000
Heavy Truck	19.362	0.00			2	0.000
Artic. Truck	0.000	0.00			0	0.000
Car	33%	16%				0%
Utility	13%	3%				0%
Light Bus	47%	63%				0%
Medium Bus	1%	3%				0%
Heavy Bus	7%	27%	4%	18%	5%	0%
Light Truck	0%	0%	0%	0%	0%	0%
Medium Truck	6%	0%	8%	0%	2%	0%
Heavy Truck	4%	0%	3%	0%	1%	0%
Artic. Truck	0%	0%	0%	0%	0%	0%

Distribution of project benefits by vehicle type ands source

Sensitivity Analysis

	Multiplier Factor	Net Present Value million ECV	Internal Rate of Return (%)	Equivalent Annual Net Benefits (ECV/km)	Modified Internal Rate of Return (%)	Multiplier Factor	Net Present Value million ECV	Internal Rate of Return (%)	Equivalent Annual Net Benefits (ECV/km)	Modified Internal Rate of Return (%)
Base Case		140.910	16%	879638	14%		140.910	16%	879638	14%
Sensitivity Cases:										
Base Normal Traffic	0.75	-64.409	10%	-402077	11%	1.25	346.230	20%	2161352	16%
Normal Traffic Growth Rate	0.75	87.902	14%	548732	13%	1.25	197.967	17%	1235817	14%
Generated Traffic	0.75	119.087	15%	743403	13%	1.25	162.734	16%	1015872	14%
Induced Traffic	0.75	140.910	16%	879638	14%	1.25	140.910	16%	879638	14%
Without Project Road Length	0.75	-794.574	#DIV/0!	-4960147	-100%	1.25	1220.699	37%	7620246	21%
Project Road Length	0.75	1199.000	43%	9979719	23%	1.25	-781.894	#DIV/0!	-3904793	-39%
Without Project Car Speed	0.75	-129.660	8%	-809408	10%	1.25	487.950	24%	3046039	17%
Project Car Speed	0.75	162.818	16%	1016398	14%	1.25	115.327	15%	719930	13%
Without Project Days without Passability	0.75	140.910	16%				.910	16%	879638	14%
Project Days without Passability	0.75	140.910	16%				.910	16%	879638	14%
Without Project Length without Passability	0.75	140.910	16%				.910	16%	879638	14%
Project Length without Passability	0.75	140.910	16%				.910	16%	879638	14%
Without Project Accidents Rate	0.75	107.422	15%				.399	17%	1088690	14%
Project Accidents Rate	0.75	168.817	16%	1053848	14%	1.25	113.004	15%	705427	13%
Without Project Investment Costs	0.75	140.910	16%	879638	14%	1.25	140.910	16%	879638	14%
Project Investment Costs	0.75	293.843	21%	1834325	16%	1.25	-12.022	12%	-75050	12%
Without Project Maintenance Costs	0.75	135.125	16%	843520	14%	1.25	146.696	16%	915755	14%
Project Maintenance Costs	0.75	163.855	16%	1022872	14%	1.25	117.965	15%	736403	13%
Passenger Time Costs	0.75	97.447	15%	608315	13%	1.25	184.604	17%	1152394	14%
Cargo Time Costs	0.75	140.910	16%	879638	14%	1.25	140.910	16%	879638	14%

Sensitivity to all main inputs

Switching Values

		Base Case	Case that Yields Net Present Value = 0		
		Value	Value	Factor	Change
Base Normal Traffic	veh/day	800	663	0.83	-17.2%
Normal Traffic Growth Rate	percent	3.5%	1.0%	0.29	-71.0%
Generated Traffic	veh/day	217	-133	-0.61	-161.4%
Induced Traffic Factor	#	1.0	0.0	0.00	#N/A
Without Project Road Length	km	21.0	20.3	0.97	-3.5%
Project Road Length	km	21.0	21.8	1.04	3.6%
Without Project Car Speed	km/hr	11.0	9.7	0.88	-12.1%
Project Car Speed	km/hr	2.5	5.3	2.11	111.5%
Without Project Days without Passability	days	0	0	0.00	#N/A
Project Days without Passability	days	0	0	0.00	#N/A
Without Project Length without Passability	km	0.0	0.0	0.00	#N/A
Project Length without Passability	km	0.0	0.0	0.00	#N/A
Without Project Accidents Rate	'000ECV/km	1.8	-0.1	-0.05	-105.2%
Project Accidents Rate	'000ECV/km	1.5	3.4	2.26	126.2%
Without Project Investment Costs	'000ECV/km	0	0	0.00	#N/A
Project Investment Costs	'000ECV/km	33816	41605	1.23	23.0%
Without Project Maintenance Costs	'000ECV/km/year	213.5	-1086.4	-5.09	-608.9%
Project Maintenance Costs	'000ECV/km/year	846.7	2146.6	2.54	153.5%

Switching values for all main inputs

Risk Analysis Inputs

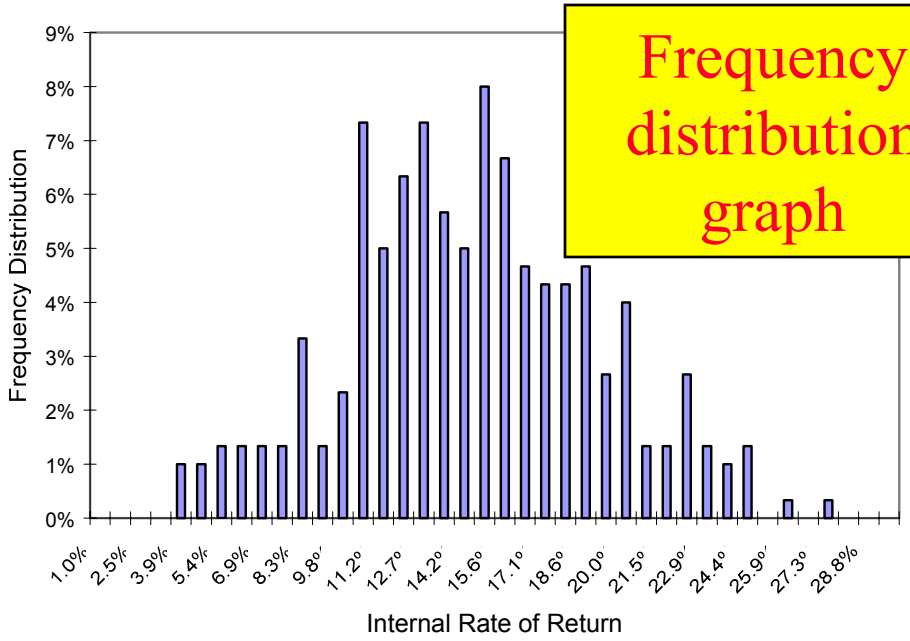
		Triangular Distributions				
		Multiplying Factors				
Variable Number	Variable Description	Minimum Possible Value	Model Input Value	Maximum Possible Value	Probability Value < 1 (%)	Probability Value > 1 (%)
1	Base Normal Traffic	0.70	1.00	1.30	50.0%	50.0%
2	Traffic Growth Rate	1.00	1.00	1.00	#N/A	#N/A
3	Generated Traffic	0.25	1.00	1.75	50.0%	50.0%
4	Induced Traffic	1.00	1.00	1.00	#N/A	#N/A
5	Without Project Road Length	1.00	1.00	1.00	#N/A	#N/A
6	Project Road Length	1.00	1.00	1.00	#N/A	#N/A
7	Without Project Roughness	0.70	1.00	1.30	50.0%	50.0%
8	Project Roughness	0.90	1.00	1.10	50.0%	50.0%
9	Without Project Days without Passability	1.00	1.00	1.00	#N/A	#N/A
10	Project Days without Passability	1.00	1.00	1.00	#N/A	#N/A
11	Without Project Length without Passability	1.00	1.00	1.00	#N/A	#N/A
12	Project Length without Passability	1.00	1.00	1.00	#N/A	#N/A
13	Without Project Accidents Rate	1.00	1.00	1.00	#N/A	#N/A
14	Project Accidents Rate	1.00	1.00	1.00	#N/A	#N/A
15	Without Project Investment Costs	1.00	1.00	1.00	#N/A	#N/A
16	Project Investment Costs	0.85	1.00	1.35	30.0%	70.0%
17	Without Project Maintenance Costs	1.00	1.00	1.00	#N/A	#N/A
18	Project Maintenance Costs	1.00	1.00	1.00	#N/A	#N/A
19	Passenger Time Costs	1.00	1.00	1.00	#N/A	#N/A
20	Cargo Time Costs	1.00	1.00	1.00	#N/A	#N/A

Risk Analysis Results

Country	Republica de Cabo Verde
Project	Rebilitacao de Estradas
Road	Sao Domingos - Assomada

Internal Rate of Return Asfaltar con BB 1.0 acos		
Point Estimate		16%
Average		14%
Standard Deviation		5%
Minimum		3%
Maximum		27%
Median		14%
Percentile	10%	8%
Percentile	50%	14%
Percentile	90%	20%
Probability that value is less than	12%	33%
Probability that value is greater than	12%	67%

Summary statistics here



Frequency distribution graph

Frequency Distribution					
		Scenarios			
From	To	Count	%	Cumulative	%
<	1.0%	0	0%	0	0%
1.0%	1.7%	0	0%	0	0%
			0%	0	0%
			0%	0	0%
			1%	3	1%
			1%	6	2%
			1%	10	3%
			1%	14	5%
6.1%	6.9%	4	1%	18	6%
6.9%	7.6%	4	1%	22	7%
7.6%	8.3%	10	3%	32	11%
8.3%	9.0%	4	1%	36	12%
9.0%	9.8%	7	2%	43	14%
9.8%	10.5%	22	7%	65	22%
10.5%	11.2%	15	5%	80	27%
11.2%	12.0%	19	6%	99	33%
12.0%	12.7%	22	7%	121	40%
12.7%	13.4%	17	6%	138	46%
13.4%	14.2%	15	5%	153	51%
14.2%	14.9%	24	8%	177	59%
14.9%	15.6%	20	7%	197	66%
15.6%	16.4%	14	5%	211	70%
16.4%	17.1%	13	4%	224	75%
17.1%	17.8%	13	4%	237	79%
17.8%	18.6%	14	5%	251	84%
18.6%					
19.3%					
20.0%					
20.7%					
21.5%					
22.2%	22.9%	4	1%	291	97%
22.9%	23.7%	3	1%	294	98%
23.7%	24.4%	4	1%	298	99%
24.4%	25.1%	0	0%	298	99%
25.1%	25.9%	1	0%	299	100%
25.9%	26.6%	0	0%	299	100%
26.6%	27.3%	1	0%	300	100%

Frequency distribution data

A Different Kind of Project Evaluation

Two Lane Gravel Road With 40 AADT and 60% Commercial Vehicles		
	Without Project	Project-Option 1
Car speeds (km/hour)	45.0	55.0
Critical passability days	30.0	
Car speeds on critical days (km/hour)	35.0	
Roughness (IRI)	17.3	13.7
Roughness on critical days (IRI)	23.0	
Maintenance costs:		
Fixed ($/km/year)	700	3400
Variable ($/km/year/ADT)	0	0
Internal Rate of Return (%)		12.0
Agency expenditures for Option 1	3700	
Economically justifies expenditures	3400	
Difference justified by social benefits	300	

Case Study 2, Network Evaluation: Agency Costs

Annual Maintenance Costs				
		to Maintain Level of Service		
	Surface Type	Good	Fair	Poor
Annual Maintenance (ECV/km/year)	Asphalt Concrete	846,667	615,833	504,191
	Surface Treatment	730,000	522,500	401,250
	Cobblestone Pavement	665,000	385,000	213,500
	Gravel	360,000	180,000	110,000
	Earth	60,000	30,000	15,000

Investment Costs (ECV/km)					
FROM	TO	A.C. Good	S.T. Good	Cobblestone Good	Cobblestone Fair
Surface Treatment	Good	11,900,000			
	Fair	11,900,000	6,000,000		
	Poor	11,900,000	9,600,000		
Cobblestone Pavement	Good	22,860,000	10,000,000		
	Fair	22,860,000	10,000,000	2,555,000	
	Poor	22,860,000	10,000,000	5,740,000	2,411,500

Network Data

Island	Road	Code
SANTIAGO	**PRAIA / TARRAFAL**	
Length	69.5 km	

Traffic	Pavemen Pavement	
1 0 - 50	Types	Condition
2 50 - 150	a - asphalt concrete	b - good
3 150 - 300	p - cobblestone	r - fair
4 300 - 600	g - gravel	m - poor
5 > 600	t-earth	

Geometry
P - level
a - hilly
m - mountainous

Section Origin	Section Destination	km Initial	km Final	Length (km)	Width (m)	Geometry	Pavement Type	Pavement Condition	Traffic Level
Praia	Ribeirão Chiqueiro	0	9.9	9.9	7	a	p	r	5
Ribeirão Chiqueiro	Milho Branco # ST-201	9.9	11.1	1.2	7	a	p	b	5
Milho Branco # ST-201	S.Domongos # ST-302	11.1	15.8	4.7	7	P	p	b	5
S.Domongos # ST-302	V.Igreja # ST-205	15.8	23.4	7.6	7	m	p	r	5
V.Igreja # ST-205	Purgueira	23.4	29	5.6	7	m	p	r	5
Purgueira	Picos (ent. da povoaç)	29	33.4	4.4	7	m	p	r	5
Picos (ent. da povoaç)	Assomada (frente BCA	33.4	38.9	5.5	7	m	p	m	5

Island	Road	Code
SANTIAGO	**MILHO BRANCO / TARRAFAL**	
Length	59 km	

Traffic	Pavemen Pavement	
1 0 - 50	Types	Condition
2 50 - 150	a - asphalt concrete	b - good
3 150 - 300	p - cobblestone	r - fair
4 300 - 600	g - gravel	m - poor
5 > 600	t-earth	

Geometry
P - level
a - hilly
m - mountainous

Section Origin	Section Destination	km Initial	km Final	Length (km)	Width (m)	Geometry	Pavement Type	Pavement Condition	Traffic Level
Milho Branco # ST-101	Nazaré # ST-204	0	2.8	2.8			p	r	4
Nazaré # ST-204	Jaracunda # ST-205	2.8	14.7	11.9			p	r	4
Jaracunda # ST-205	Pedra Badejo	14.7	16.9	2.2			p	r	4
Pedra Badejo	Justino Lopes	16.9	24.8	7.9			p	m	4

Network Database

Pavement	Traffic	Geometry	Condition
A - Asphalt Concrete	1 0 - 50	X - level	A - good
B - Surface Treatment	2 50 - 150	Y - hilly	B - fair
C - Cobblestone	3 150 - 300	Z - mountainous	C - poor
D - Stones	4 300 - 600		
E - Gravel	5 > 600		
F - Earth			

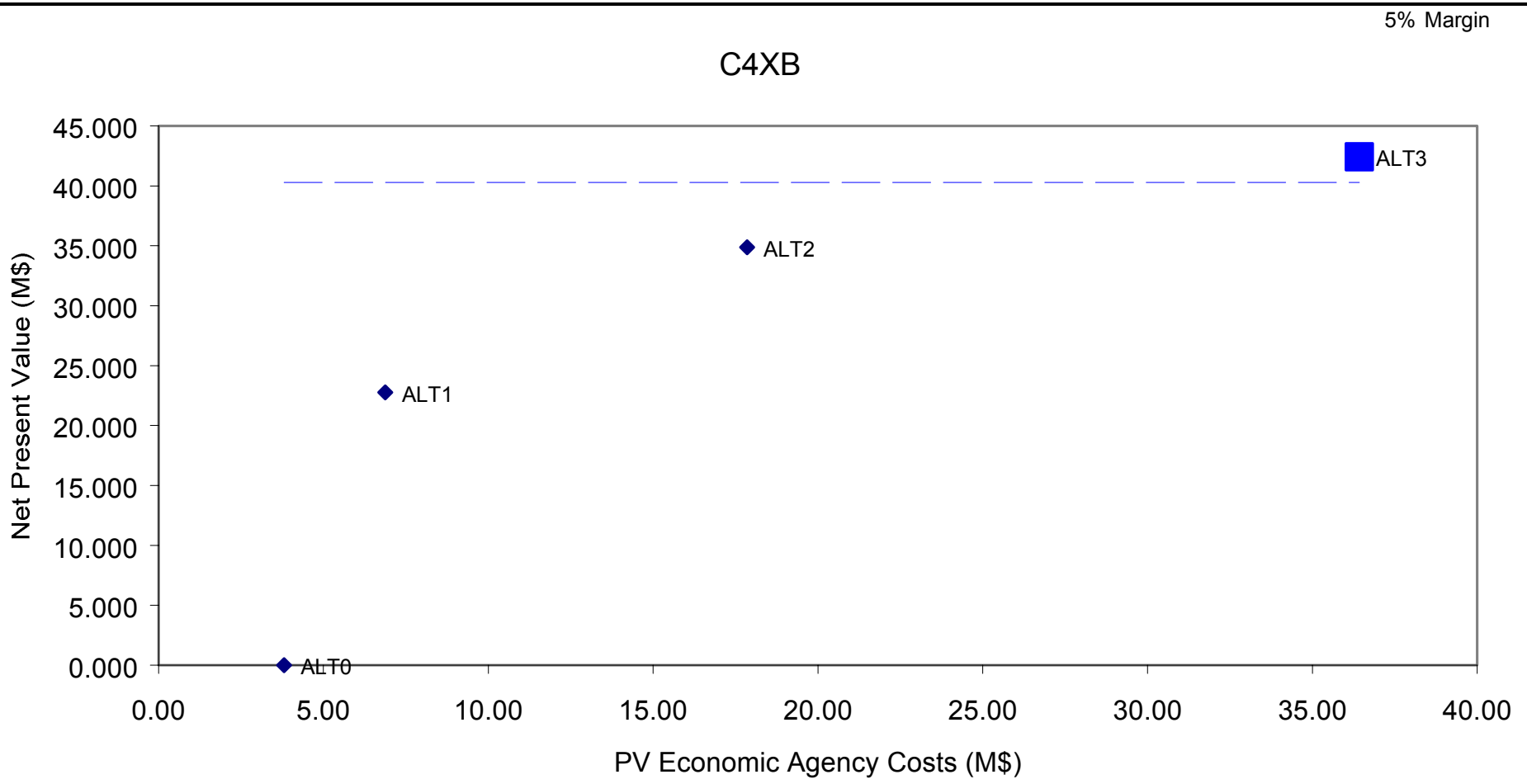
Section	Road	Section Origin	Section Destination	km Initial	km Final	Length (km)	Width (m)	Roads Classification				Road Class
								Pavement	Traffic	Geometry	Condition	
1	Praia - Ta	Praia	Ribeirão Chiqueir	0.0	9.9	9.9	7.0	C	5	Y	B	C5YB
2	Praia - Ta	Ribeirão Chiqueir	Milho Branco # ST	9.9	11.1	1.2	7.0	C	5	Y	A	C5YA
3	Praia - Ta	Milho Branco # ST	S.Domongos # ST	11.1	15.8	4.7	7.0	C	5	X	A	C5XA
4	Praia - Ta	S.Domongos # ST	V.Igreja # ST-205	15.8	23.4	7.6	7.0	C	5	Z	B	C5ZB
5	Praia - Ta	V.Igreja # ST-205	Purgueira	23.4	29.0	5.6	7.0	C	5	Z	B	C5ZB
6	Praia - Ta	Purgueira	Picos (ent. da pov	29.0	33.4	4.4	7.0	C	5	Z	B	C5ZB
7	Praia - Ta	Picos (ent. da pov	Assomada (frente	33.4	38.9	5.5	7.0	C	5	Z	C	C5ZC
8	Praia - Ta	Assomada (frente	Cemitério de S.Ca	38.9	40.7	1.8	7.0	C	5	X	C	C5XC
9	Praia - Ta	Cemitério de S.Ca	Cruz Grande # ST	40.7	42.8	2.1	7.0	C	5	Y	B	C5YB
10	Praia - Ta	Cruz Grande # ST	V.do Monte # ST-	42.8	47.6	4.8	7.0	C	4	Y	A	C4YA
11	Praia - Ta	V.do Monte # ST-	Chão Bom # ST-2	47.6	66.9	19.3	7.0	C	3	Z	A	C3ZA
12	Praia - Ta	Chão Bom # ST-2	Tarrafal (Praça)	66.9	69.5	2.6	7.0	C	4	X	B	C4XB
13	Milho Brar	Milho Branco # ST	Nazaré # ST-204	0.0	2.8	2.8		C	4	Y	B	C4YB
14	Milho Brar	Nazaré # ST-204	Jaracunda # ST-2	2.8	14.7	11.9		C	4	Y	B	C4YB
15	Milho Brar	Jaracunda # ST-2	Pedra Badejo	14.7	16.9	2.2		C	4	Y	B	C4YB
16	Milho Brar	Pedra Badejo	Justino Lopes	16.9	24.8	7.9		C	4	Y	C	C4YC
17	Milho Brar	Justino Lopes	Calheta # ST-207	24.8	29.8	5.0		C	4	Y	B	C4YB
18	Milho Brar	Calheta # ST-207	Calheta	29.8	31.5	1.7		C	3	Y	C	C3YC
19	Milho Brar	Calheta	# ST-201 / Pilão C	31.5	36.9	5.4		C	3	Y	B	C3YB
20	Milho Brar	# ST-201 / Pilão C	# ST-201 / R.Prin	36.9	44.9	8.0		C	3	Y	A	C3YA
21	Milho Brar	# ST-201 / R.Prin	Tarrafal (Praça)	44.9	59.0	14.1		C	3	Y	B	C3YB
22	Praia - Po	Praia (LEC)	Cidade Velha	0.0	11.7	11.7		C	3	Y	B	C3YB

Network Road Classes

		Geometry and Condition								
		Level			Hilly			Mountainous		
Pavement	Traffic	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Cobblestone	1 - de 0 - 50								1	
	2 - de 50 - 150	3.6	9.8		5.1	22.1	6	10.2	1.4	
	3 - de 150 - 300				8	31.2	1.7	19.3		
	4 - de 300 - 600		2.6		4.8	21.9	7.9			
	5 - > 600	4.7		1.8	1.2	12			17.6	5.5
Natural Stone	1 - de 0 - 50		3.9	8		19.2	27.7			
	2 - de 50 - 150					8.1	7.9			5
	3 - de 150 - 300									
	4 - de 300 - 600					10.6				
	5 - > 600									
Earth	1 - de 0 - 50			3.9			53.2			8.8
	2 - de 50 - 150									
	3 - de 150 - 300									
	4 - de 300 - 600									
	5 - > 600									

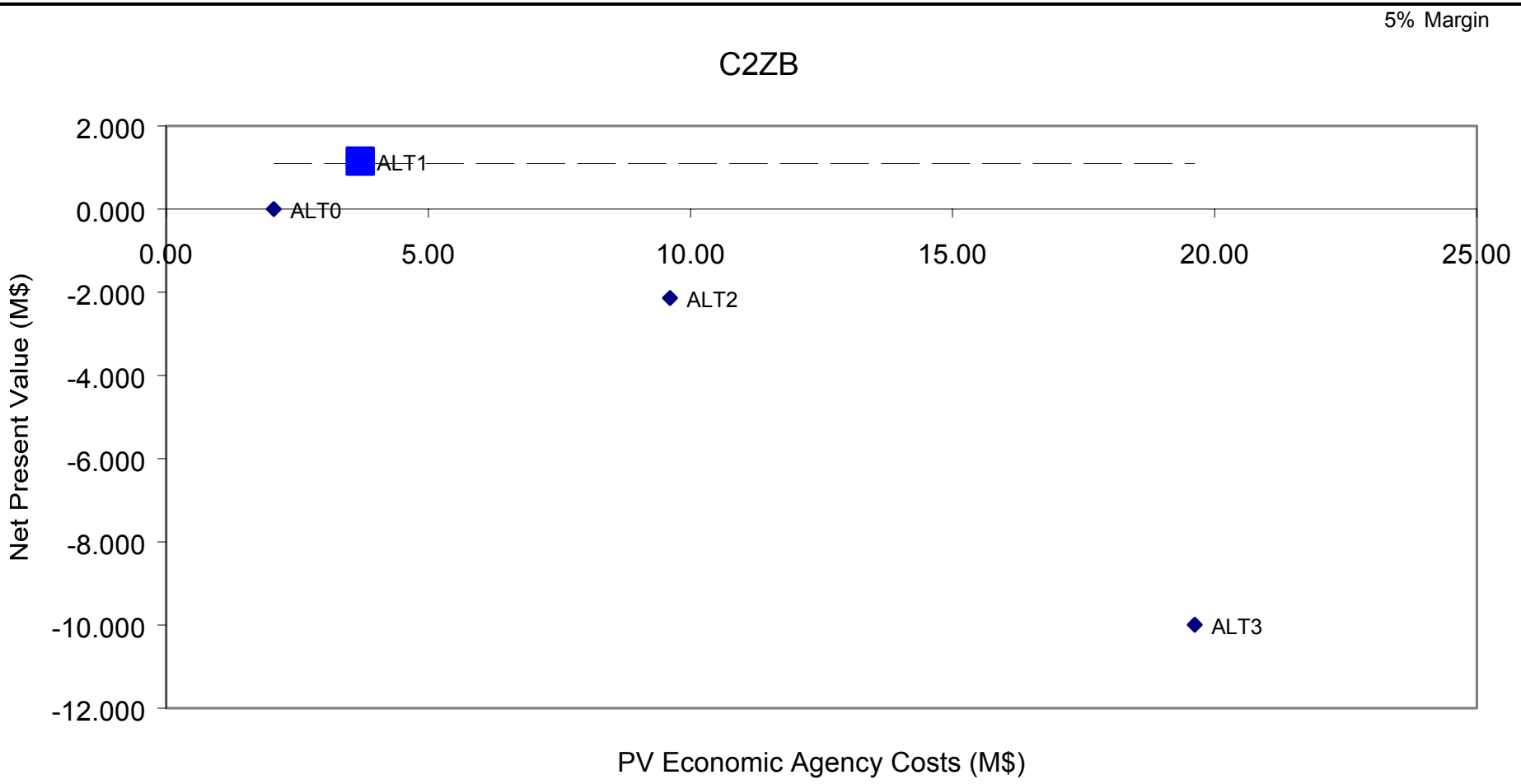
Total	355.7

Economic Evaluation of Each Road Class



	Alternative	Net Present Value (M$)	Internal Rate of Return (%)	Equivalent Annual Benefits ($/km)	Modified Internal Rate of Return (%)	PV of Economic Agency Costs (%)	Financial Investment Cost (M$)	NPV per PV Agency (#)	NPV per Investment (#)
0	Manter Estado Mau	0.000	#N/A	0	#N/A	3.81	0.00	0.00	0.00
1	Manter Estado Razoavel	22.779	#DIV/0!	1148502	#DIV/0!	6.87	0.00	3.31	#DIV/0!
2	Manter Estado Bom	34.872	87%	1758283	28%	17.85	6.64	1.95	5.25
3	Melhorar TS	42.419	38%	2138795	21%	36.43	26.00	1.16	1.63

Economic Evaluation of Each Road Class



	Alternative	Net Present Value (M$)	Internal Rate of Return (%)	Equivalent Annual Benefits ($/km)	Modified Internal Rate of Return (%)	PV of Economic Agency Costs (%)	Financial Investment Cost (M$)	NPV per PV Agency (#)	NPV per Investment (#)
0	Manter Estado Mau	0.000	#N/A	0	#N/A	2.05	0.00	0.00	0.00
1	Manter Estado Razoavel	1.154	#DIV/0!	108048	#DIV/0!	3.70	0.00	0.31	#DIV/0!
2	Manter Estado Bom	-2.141	-1%	-200466	4%	9.61	3.58	-0.22	-0.60
3	Melhorar TS	-9.990	-7%	-935447	0%	19.62	14.00	-0.51	-0.71

Network Solution with Highest NPV

		Geometry and Condition								
		Level			Hilly			Mountainous		
Pavement	Traffic	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Cobblestone	1 - de 0 - 50								Poor	
	2 - de 50 - 150	Good	Fair		Good	Fair	Poor	Fair	Fair	
	3 - de 150 - 300							Good		
	4 - de 300 - 600		S.T.		Good					
	5 - > 600	Good		A.C.	Good	Good			Good	Good
Natural Stone	1 - de 0 - 50		Poor	Poor		Poor	Poor			
	2 - de 50 - 150					Fair	Poor			Poor
	3 - de 150 - 300									
	4 - de 300 - 600					S.T.				
	5 - > 600									
Earth	1 - de 0 - 50			Poor			Poor			Poor
	2 - de 50 - 150									
	3 - de 150 - 300									
	4 - de 300 - 600									
	5 - > 600									

For alternatives with highest NPV or selected alternatives, we obtain: For each road and for the network: NPV, IRR, MIRR, investment costs, maintenance costs, NPV/investment ratio, average roughness, etc.

What is Next for RED

- Release and worldwide dissemination of RED Version 2.0, due in March 2001
- Further dissemination within the Bank (half day hands-on training course?)
- Development of Applications Guide presenting case studies describing real RED applications (Nicaragua, Cape Verde, etc.)
- Development of a new stand alone module to compute road user costs following the HDM-4 relationships
- Incorporating a budget constraint optimization method
- Dealing with social benefits and population served