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TRANSPORT NOTES

ROADS AND RURAL TRANSPORT THEMATIC GROUP

THE WORLD BANK, WASHINGTON, DC Transport Note No. TRN-2 November 2004

Economically Justified Levels of Road Works Expenditures on Unpaved Roads

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Unpaved roads require periodic road works to maintain a certain road condition over time, comprising typically of routine maintenance, grading, spot regravelling, and regravelling activities, which require planning and economic justification. A main concern in developing counties is defining a proper level of investments and quality of maintenance on unpaved roads. This technical note, targeted to road sector professionals, presents a methodology for an analytical study done to access economically justified levels of road works expenditures on unpaved roads with different traffic levels. The results presented in this technical note should be considered no more than a first approximation of country specific results. To obtain country specific results, the methodology should be replicated and adapted with refined country data.

INTRODUCTION

An economic evaluation measures the economic worth of alternative investment and maintenance choices (project-alternatives) in order to ensure an optimal allocation of resources. It quantifies the economic benefits and costs of each project-alternative compared to a "without project-alternative," which represents a do-minimum scenario. For each project-alternative, road agency and road user costs are computed for a defined analysis period, and the resulting flow of net benefits, compared to the without project-alternative, is discounted at a given discount rate. The economic comparison of project-alternatives is done analyzing their net present value of benefits (NPV). Most measured benefits are reduction on vehicle operating, passenger time and road accident costs. A simplified economic evaluation not normally includes measurement of social impacts, such as health benefits of all-year access, or environmental impacts, such as dust emissions. These impacts are important; therefore, could be considered during the final decision making process.

An economic evaluation is more relevant for roads that serve an economic function and have established traffic, rather than for roads that serve a social function (i.e., provide access to rural populations), which are typically very low volume roads with traffic less than 50 vehicles per day, for which a cost effectiveness analysis or multi-criteria analysis is recommended.[1] An economic evaluation of project-alternatives can be done using a road investment model such as:

- The Highway Development and Management Model (HDM-4),[2] which estimates over time the annual deterioration of paved and unpaved roads and the resulting road agency and road user costs, or
- The Roads Economic Decision Model (RED),[3] which does not estimate over time the annual deterioration of paved or unpaved roads, but is customized for the economic evaluation of unpaved roads by estimating: (i) road user costs, characterized by road roughness or vehicles speeds, at the dry and wet seasons, and (ii) generated traffic as a function of a user-defined price elasticity of demand for transport.

This technical note presents the methodology and sample results obtained applying RED version 3.1 for the evaluation of roads with traffic between 10 and 100 motorized average annual daily traffic (AADT), excluding motorcycles. The methodology consists of defining road quality levels, estimating road agency and user costs, and performing the economic evaluation and sensitivity analysis.

ROAD QUALITY LEVELS

The first step is to define possible road quality levels provided by a road, which is characterized by surface type, road access quality and ride quality. Ride quality is measured by road roughness that is the irregularity of the road surface; it affects the dynamics of moving vehicles, wear of vehicle parts, and the handling of a vehicle. It is difficult to characterize roughness of unpaved roads because it is (i) difficult to measure with equipment; (ii) changes quickly over time, and (iii) depends on the path taken. A subjective assessment[4][5] is, therefore, needed. The table below presents the road quality levels for unpaved and paved roads defined for this study, which considers the entire range of roughness values. The roughness values to be associated with each road quality level varies by country due to different road surface materials, climate and maintenance practices; therefore, they should be adapted to the characteristics of a particular country.

Unpaved Unreliable Access represents roads that do not provide all-year access due to periods when motorized traffic is interrupted. The other road quality levels provide all-year access. Note that although the roughness of some unpaved and paved quality levels is similar, the roughness similarity should not undermine other differences between paved and unpaved surfaces, such as dust and other environmental impacts.

Table 1. Analytical Road Quality Levels for Unpaved and Paved Roads

Road Quality Level	Road Access Quality				Ride Quality	
	Dry Season		Wet Season		Roughness	
	4 Wheel-Drive	2 Wheel Drive	4 Wheel Drive	2 Wheel Drive	Dry Season	Wet Season
Unpaved Unreliable Access	Unreliable	Unreliable	Unreliable	Unreliable	NA	NA
Unpaved Very Poor	Normal	Difficult	Difficult	Difficult	22.0	25.0
Unpaved Poor	Normal	Normal	Difficult	Difficult	17.0	25.0
Unpaved Fair	Normal	Normal	Normal	Difficult	13.0	22.0
Unpaved Good	Normal	Normal	Normal	Normal	10.0	10.0
Unpaved Very Good	Normal	Normal	Normal	Normal	7.0	7.0
Paved Very Poor	Normal	Normal	Normal	Normal	12.0	12.0
Paved Poor	Normal	Normal	Normal	Normal	8.0	8.0
Paved Fair	Normal	Normal	Normal	Normal	4.0	4.0
Paved Good	Normal	Normal	Normal	Normal	3.0	3.0
Paved Very Good	Normal	Normal	Normal	Normal	2.0	2.0
NA = Not Applicable						

ROAD USERS AND ROAD AGENCY COSTS

The second step is to compute unit road user cost and road agency costs. The table below presents the car speeds and vehicle fleet vehicle operating costs (VOC), value of time costs (VOT), and road user costs (RUC), which were computed for this study, with the HDM-4 VOC module of RED version 3.1, based on medium values of data collected worldwide on vehicle unit costs. The fleet costs are based on a typical vehicle fleet composition comprising 40 percent cars and pickups, 20 percent buses, and 40 percent trucks.

Table 2: Car Speeds and Unit Road User Costs per Season

Road Quality Level	Dry season				Wet Season			
	Car Speed (km/hr)	Fleet VOC ($/v-km)	Fleet VOT ($/v-km)	Fleet RUC ($/v-km)	Car Speed (km/hr)	Fleet VOC ($/v-km)	Fleet VOT ($/v-km)	Fleet RUC ($/v-km)
Unpaved Very Poor	28	0.515	0.109	0.624	25	0.560	0.124	0.684
Unpaved Poor	37	0.439	0.085	0.523	25	0.560	0.124	0.684
Unpaved Fair	48	0.375	0.065	0.441	28	0.515	0.109	0.624
Unpaved Good	61	0.330	0.051	0.381	61	0.330	0.051	0.381
Unpaved Very Good	78	0.288	0.040	0.328	78	0.288	0.040	0.328
Paved Very Poor	52	0.360	0.060	0.420	52	0.360	0.060	0.420
Paved Poor	72	0.301	0.043	0.345	72	0.301	0.043	0.345
Paved Fair	84	0.247	0.037	0.284	84	0.247	0.037	0.284
Paved Good	85	0.234	0.037	0.271	85	0.234	0.037	0.271
Paved Very Good	85	0.230	0.037	0.267	85	0.230	0.037	0.267

Considering ninety days as the extent of the wet season, the Figure 1 presents the corresponding average annual road roughness and Figure 2 the vehicle fleet unit road user costs, in $ per vehicle-km.

Figure 1. Average Annual Roughness (IRI)

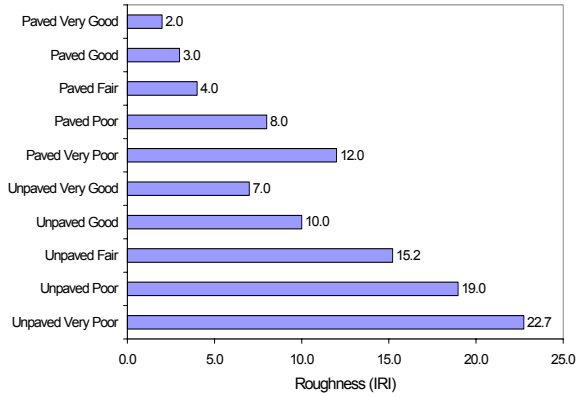


Figure 2. Average Annual Vehicle Fleet Road User Costs

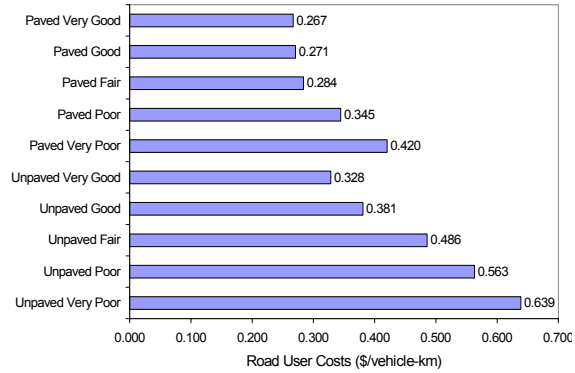
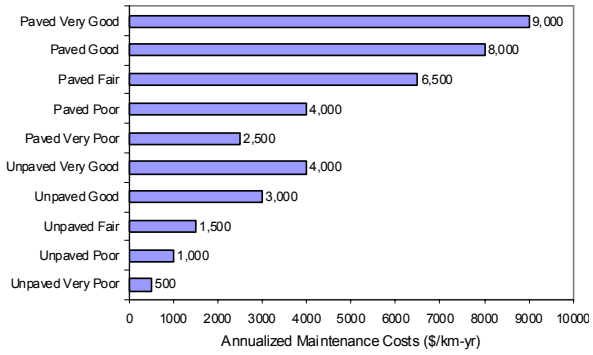


Figure 3. Annualized Road Maintenance Costs Needed to Maintain a Road Quality Level at the Same Road Condition ($/km-year)



Annualized maintenance costs needed to maintain a road quality level over the years are estimated based on country specific data. Annualized maintenance costs consist of recurrent maintenance activities, such as routine maintenance, gradings and spot regravelling, and annualized periodic maintenance activities, such as regravelling or overlays. Figure 3 presents annualized maintenance costs needed to maintain a road quality level of low volume roads, which were estimated based on typical road works unit costs[6]. For example, to keep an unpaved road in good condition, one needs $3,000 per km per year, which is comprised of $700 for routine maintenance and spot regravelling, $300 for gradings, and $2,000 for annualized regravelling ($8,000 regravelling cost divided by four years time interval). A more comprehensive study would estimate different annualized maintenance needs per traffic level.

Investment costs needed to improve the road condition from a road quality level to a better road quality level are estimated based on country specific data. Table 3 presents investments estimated for this study, based on typical worldwide road works costs.[4]

Table 3. Investment Costs Needed to Improve a Road Quality Level (000$/km)

From Road Quality Level	To Road Quality Level					
	Unpaved Poor	Unpaved Fair	Unpaved Good	Unpaved Very Good	Paved Fair	Paved Good
Unpaved Very Poor	5	10	30	95	155	255
Unpaved Poor		5	25	90	150	220
Unpaved Fair			20	85	145	215
Unpaved Good				65	125	195
Unpaved Very Good					60	130
Paved Fair						70

ECONOMIC EVALUATION

A key element for a proper economic evaluation is the definition of without-project alternative, which represents a pragmatic do-minimum scenario and is a function of the traffic and importance of the road. On this study, considering the relatively low traffic ranging from 10 to 100 AADT, the without-project alternative consists of keeping the road in very poor condition, but with reliable access. For roads with higher traffic, a higher road quality level could be considered to represent the do-minimum scenario.

The first evaluation considers a road in very poor. Four project-alternatives are evaluated ranging from improve the road marginally to poor condition to improve the road substantially to very good condition. No paving alternatives are considered due to low traffic. The table below presents the project-alternatives being evaluated.

Table 4 Project Alternatives

Project Alternative	Alternative Description	Investment Cost (000$/km)	Maintenance Cost ($/km-yr)	Average Roughness (IRI)
Without Project-Alternative	Keep Unpaved Very Poor	0	500	22.7
Project-Alternative 1	Improve to Unpaved Poor	5	1,000	19.0
Project-Alternative 2	Improve to Unpaved Fair	10	1,500	15.2
Project-Alternative 3	Improve to Unpaved Good	30	3,000	10.0
Project-Alternative 4	Improve to Unpaved Very Good	95	4,000	7.0

The main economic evaluation assumptions are the following:

- Evaluation period is 15 years and discount rate is 12 percent;
- Traffic composition of cars is 40 percent for traffic less than 50 AADT, and 50 percent for traffic between 50 and 100 AADT, and
- Annual traffic growth rate is 3 percent, and the generated traffic elasticity of demand is 1.0 for all vehicles.

The table below presents the resulting NPV and present value of agency costs for traffic varying from 10 to 100 motorized AADT.

Table 5. Economic Comparison of Project-Alternatives

Road Quality Level	PV Agency Costs (000$/km)	Net Present Value (000$/km) Average Daily Traffic (AADT)									
		10	20	30	40	50	60	70	80	90	100
Unpaved Very Poor	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unpaved Poor	11.6	-4.5	-2.0	0.6	3.1	5.7	6.9	9.2	11.6	13.9	16.2
Unpaved Fair	19.9	-8.9	-3.8	1.4	6.6	11.8	14.3	19.1	23.8	28.5	33.3
Unpaved Good	49.9	-30.5	-21.3	-12.2	-3.0	6.1	10.5	18.8	27.2	35.5	43.9
Unpaved Very Good	121.5	-89.2	-78.0	-66.7	-55.4	-44.2	-38.8	-28.5	-18.2	-8.0	2.3

The following graphs present the comparison of the project-alternatives in terms of NPV.

Figure 4. Net Present Value of Alternative Levels of Service (10 to 50 AADT)

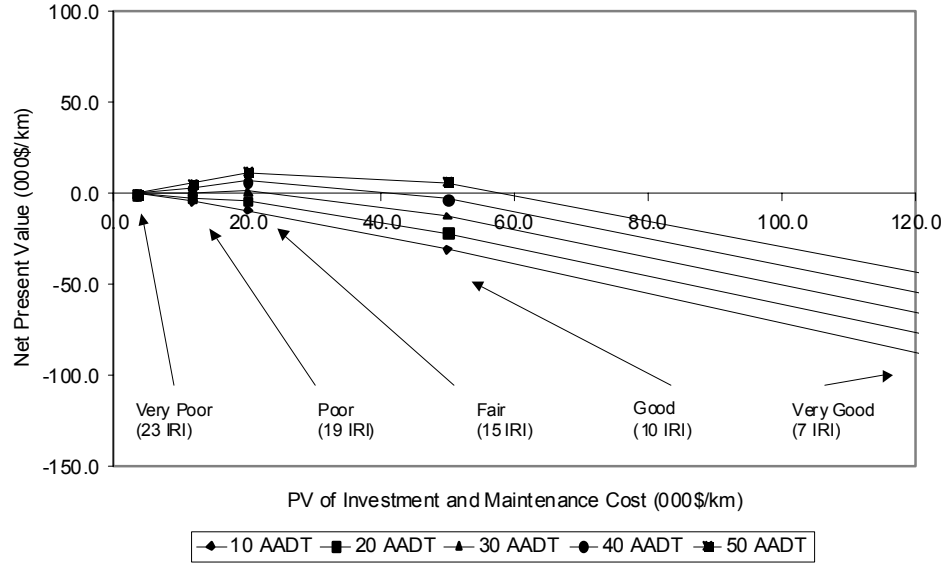
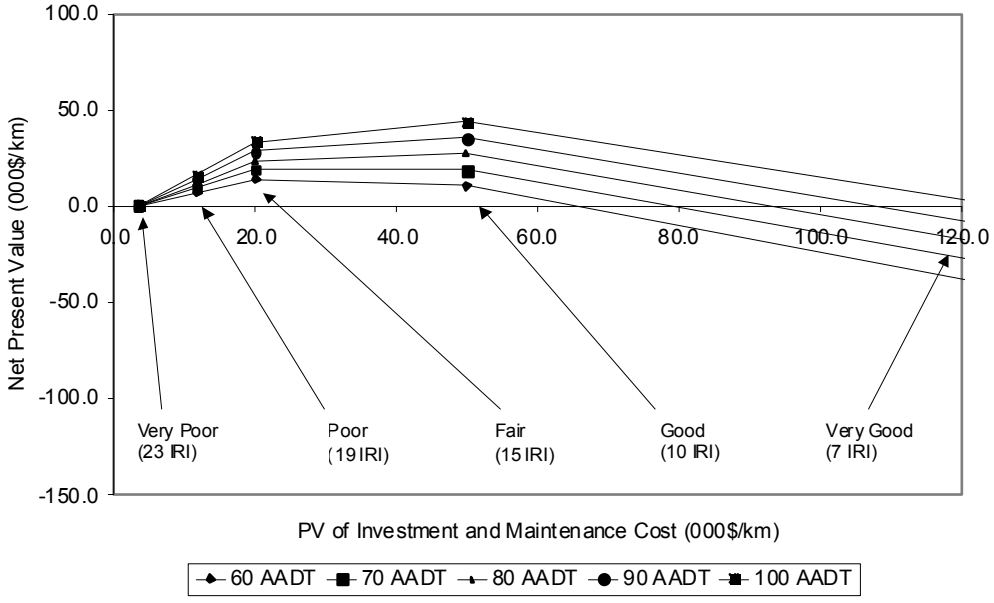


Figure 5. Net Present Value of Alternative Levels of Service (60 to 100 AADT)



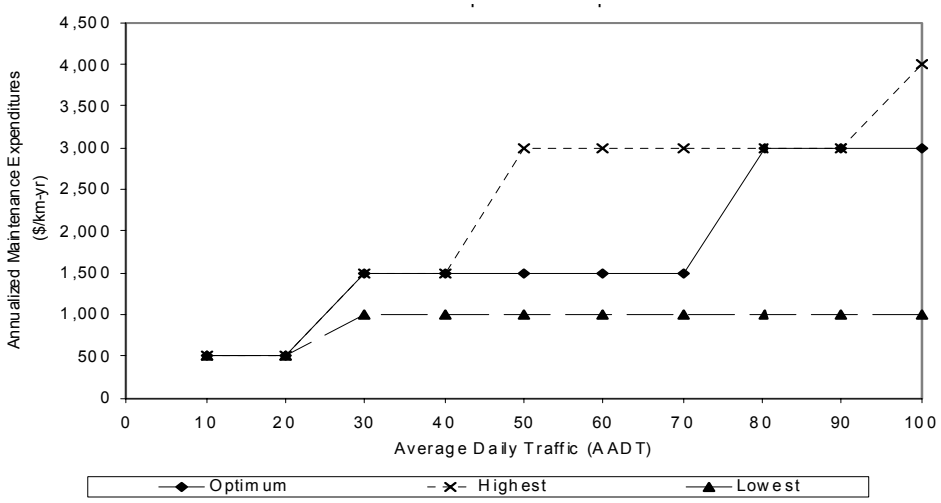
The evaluation determines for a given traffic level: (i) lowest economically justified road quality level, which is the one with lower agency costs yielding a positive NPV; (ii) optimal economically justified road quality level, which is the one with highest NPV, and (iii) highest economically justified road quality level, which is the one with highest agency costs yielding a positive NPV. The table below presents the economic evaluation results.

Table 6. Economic Evaluation Results: Road in Very Poor Condition

Daily Traffic (AADT)	Road Quality Level	Investment Cost (000$/km)	Annualized Maintenance ($/km-yr)	Average Roughness (IRI)
Lowest Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Very Poor	0	500	22.7
30	Unpaved Poor	5	1,000	19.0
40	Unpaved Poor	5	1,000	19.0
50	Unpaved Poor	5	1,000	19.0
60	Unpaved Poor	5	1,000	19.0
70	Unpaved Poor	5	1,000	19.0
80	Unpaved Poor	5	1,000	19.0
90	Unpaved Poor	5	1,000	19.0
100	Unpaved Poor	5	1,000	19.0
Optimal Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Very Poor	0	500	22.7
30	Unpaved Fair	10	1,500	15.2
40	Unpaved Fair	10	1,500	15.2
50	Unpaved Fair	10	1,500	15.2
60	Unpaved Fair	10	1,500	15.2
70	Unpaved Fair	10	1,500	15.2
80	Unpaved Good	30	3,000	10.0
90	Unpaved Good	30	3,000	10.0
100	Unpaved Good	30	3,000	10.0
Highest Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Very Poor	0	500	22.7
30	Unpaved Fair	10	1,500	15.2
40	Unpaved Fair	10	1,500	15.2
50	Unpaved Good	30	3,000	10.0
60	Unpaved Good	30	3,000	10.0
70	Unpaved Good	30	3,000	10.0
80	Unpaved Good	30	3,000	10.0
90	Unpaved Good	30	3,000	10.0
100	Unpaved Very Good	95	4,000	7.0

The graph below presents the lowest, optimal and highest economically justified annualized maintenance costs.

Figure 6. Annualized Maintenance Expenditures per Traffic Level



The second evaluation considers a road that is in fair condition. The table below summarizes the project-alternatives considered, which includes lowering the road quality level to very poor or poor condition.

Table 7. Project-Alternatives

Project Alternative	Alternative Description	Investment Cost (000$/km)	Maintenance Cost ($/km-yr)	Average Roughness (IRI)
Without-Project Alternative	Lower Standard to Very Poor	0	500	22.7
Project-Alternative 1	Lower Standard to Unpaved Poor	0	1,000	19.0
Project-Alternative 2	Keep Unpaved Fair	0	1,500	15.2
Project-Alternative 3	Improve to Unpaved Good	20	3,000	10.0
Project-Alternative 4	Improve to Unpaved Very Good	85	4,000	7.0

The table below presents the economic evaluation results.

Table 8. Economic Evaluation Results: Road in Fair Condition

Daily Traffic (AADT)	Road Quality Level	Investment Cost (000$/km)	Annualized Maintenance ($/km-yr)	Average Roughness (IRI)
Lowest Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Poor	0	1,000	19.0
30	Unpaved Poor	0	1,000	19.0
40	Unpaved Poor	0	1,000	19.0
50	Unpaved Poor	0	1,000	19.0
60	Unpaved Poor	0	1,000	19.0
70	Unpaved Poor	0	1,000	19.0
80	Unpaved Poor	0	1,000	19.0
90	Unpaved Poor	0	1,000	19.0
100	Unpaved Poor	0	1,000	19.0
Optimal Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Fair	0	1,500	15.2
30	Unpaved Fair	0	1,500	15.2
40	Unpaved Fair	0	1,500	15.2
50	Unpaved Fair	0	1,500	15.2
60	Unpaved Fair	0	1,500	15.2
70	Unpaved Fair	0	1,500	15.2
80	Unpaved Good	20	3,000	10.0
90	Unpaved Good	20	3,000	10.0
100	Unpaved Good	20	3,000	10.0
Highest Economically Justified Road Quality Level				
10	Unpaved Very Poor	0	500	22.7
20	Unpaved Very Poor	0	500	22.7
30	Unpaved Fair	0	1,500	15.2
40	Unpaved Fair	0	1,500	15.2
50	Unpaved Good	20	3,000	10.0
60	Unpaved Good	20	3,000	10.0
70	Unpaved Good	20	3,000	10.0
80	Unpaved Good	20	3,000	10.0
90	Unpaved Very Good	85	4,000	7.0
100	Unpaved Very Good	85	4,000	7.0

The levels of service found for the road in fair condition are essentially the same as for the road in very poor condition, thus, confirming the annualized maintenance needs per traffic level for the lowest, optimal and highest economically justified road quality level.

SENSITIVITY ANALYSIS

For the road that is in very poor condition, the following table presents a sensitivity analysis varying the traffic annual growth rate from 0 to 6 percent and the generated traffic elasticity of demand from 0.5 to 1.5 for all vehicles.

Table 9. Traffic Growth Rare and Elasticity of Demand Sensitivity Analysis

Optimal Economically Justified Road Quality Level			
Traffic (AADT)	**Growth = 0% Elasticity = 0.5**	**Growth = 3% Elasticity = 0.5**	**Growth = 6% Elasticity = 0.5**
10	Unpaved Very Poor	Unpaved Very Poor	Unpaved Very Poor
20	Unpaved Very Poor	Unpaved Very Poor	Unpaved Very Poor
30	Unpaved Very Poor	Unpaved Fair	Unpaved Fair
40	Unpaved Fair	Unpaved Fair	Unpaved Fair
50	Unpaved Fair	Unpaved Fair	Unpaved Fair
60	Unpaved Fair	Unpaved Fair	Unpaved Fair
70	Unpaved Fair	Unpaved Fair	Unpaved Good
80	Unpaved Fair	Unpaved Good	Unpaved Good
90	Unpaved Fair	Unpaved Good	Unpaved Good
100	Unpaved Good	Unpaved Good	Unpaved Good
Traffic (AADT)	**Growth = 0% Elasticity = 1.0**	**Growth = 3% Elasticity = 1.0**	**Growth = 6% Elasticity = 1.0**
10	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
20	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
30	Unpaved Very Poor	**Unpaved Fair**	Unpaved Fair
40	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
50	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
60	Unpaved Fair	**Unpaved Fair**	Unpaved Good
70	Unpaved Fair	**Unpaved Fair**	Unpaved Good
80	Unpaved Fair	**Unpaved Good**	Unpaved Good
90	Unpaved Good	**Unpaved Good**	Unpaved Good
100	Unpaved Good	**Unpaved Good**	Unpaved Good
Traffic (AADT)	**Growth = 0% Elasticity = 1.5**	**Growth = 3% Elasticity = 1.5**	**Growth = 6% Elasticity = 1.5**
10	Unpaved Very Poor	Unpaved Very Poor	Unpaved Very Poor
20	Unpaved Very Poor	Unpaved Very Poor	Unpaved Very Poor
30	Unpaved Very Poor	Unpaved Fair	Unpaved Fair
40	Unpaved Fair	Unpaved Fair	Unpaved Fair
50	Unpaved Fair	Unpaved Fair	Unpaved Good
60	Unpaved Fair	Unpaved Fair	Unpaved Good
70	Unpaved Fair	Unpaved Good	Unpaved Good
80	Unpaved Good	Unpaved Good	Unpaved Good
90	Unpaved Good	Unpaved Good	Unpaved Good
100	Unpaved Good	Unpaved Good	Unpaved Good

The following table presents a sensitivity analysis done for the same road varying the percent of cars and pickups from 40 percent for traffic less than 50 AADT and 50 percent for traffic between 50 and 100 AADT to 20 and 30 percent respectively and 60 percent and 70 percent respectively

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Table 10. Cars and Pickups Composition Sensitivity Analysis

Optimal Economically Justified Road Quality Level			
Traffic (AADT)	**Cars & Pickups 20% to 30%**	**Cars & Pickups 40% to 50%**	**Cars & Pickups 60% to 70%**
10	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
20	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
30	Unpaved Fair	**Unpaved Fair**	Unpaved Very Poor
40	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
50	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
60	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
70	Unpaved Good	**Unpaved Fair**	Unpaved Fair
80	Unpaved Good	**Unpaved Good**	Unpaved Fair
90	Unpaved Good	**Unpaved Good**	Unpaved Good
100	Unpaved Good	**Unpaved Good**	Unpaved Good

Traffic projections in terms of annual traffic growth rate, expected generated traffic, and traffic composition influence the results. Other important factors are road agency and road user costs and the definition of the evaluation period. The table below presents the sensitivity analysis for an evaluation period of 10, 15 and 20 years.

Table 11. Evaluation Period Sensitivity Analysis

Optimal Economically Justified Road Quality Level			
Traffic (AADT)	**10 Years**	**15 Years**	**20 Years**
10	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
20	Unpaved Very Poor	**Unpaved Very Poor**	Unpaved Very Poor
30	Unpaved Very Poor	**Unpaved Fair**	Unpaved Fair
40	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
50	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
60	Unpaved Fair	**Unpaved Fair**	Unpaved Fair
70	Unpaved Fair	**Unpaved Fair**	Unpaved Good
80	Unpaved Fair	**Unpaved Good**	Unpaved Good
90	Unpaved Good	**Unpaved Good**	Unpaved Good
100	Unpaved Good	**Unpaved Good**	Unpaved Good

SUMMARY

The road quality level of roads is characterized by surface type, road access quality and ride quality. The benefits of improving or maintaining a road quality level can be measured by a life-cycle economic evaluation in terms of reduction on road user cost, but the resulting economic indicators not often measure social or environmental impacts. Nevertheless, economic evaluation is a good tool to help define proper levels of road quality of roads that carry an established traffic, typically with traffic greater than 50 vehicles per day.

This note presents a methodology for the evaluation of unpaved roads with traffic between 10 and 100 motorized AADT, using the RED model, and the type of results that are obtained by which a first judgment can be made to determine a proper level of investments and maintenance on unpaved roads. If this screening test for a given unpaved road is "positive" then it is necessary to perform a more rigorous project level economic evaluation.

The key element of an economic evaluation is the definition of the without-project alternative, which should represent a pragmatic do-minimum scenario and should be a function of the traffic and importance of the road. The sensitivity analysis shows that the results are influenced by the traffic projections, road agency and road user costs, and the definition of the evaluation period; therefore, the results presented in this note should be considered no more than a first approximation of country specific results. To obtain country specific results, the methodology should be replicated and adapted with refined country data.

TO LEARN MORE

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Transport Notes are available on-line at:
http://www.worldbank.org/html/fpd/transport/publicat/pub_main.htm

Urban Infrastructure Notes are available on-line at:
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