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

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This Note presents a consumer surplus model to help evaluate investments in roads with traffic volumes between 50 and 200 vehicles per day, so prevalent in Africa. The model is implemented in a series of Excel workbooks that estimate vehicle operating costs and speeds, perform an economic comparison of investments and maintenance options, and perform switch-off values and stochastic risk analysis. Model software is now being tested for debugging, and a pilot empirical validation is planned for Chad. A user manual for the model is under preparation.

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The decision-making process for the development and maintenance of low-volume rural roads suffers from the lack of a customized economic evaluation tool. The World Bank's Highway Design and Maintenance Standards Model (HDM-III) (1) and the forthcoming Highway Development and Management Model (HDM-4), being developed by the International Study of Highway Development and Management Tools, present a good framework for the economic evaluation of road investments and maintenance but are not particularly customized for low-volume roads (traffic less than 200 vehicles per day), do not capture all the benefits associated with rural road investments, and require a series of inputs which are impractical to collect for low traffic levels. Hence, the need for a simplified economic evaluation model to fulfill the planning and programming needs of highway agencies in charge of low-volume roads, without demanding input parameters that may be unrealistic and costly to collect while presenting the results in a practical and effective manner.

This note presents the Roads Economic Decision Model (RED) that performs an economic evaluation of road investments and maintenance options customized to the characteristics of low-volume roads such as:

- high uncertainty of the assessment of traffic, road condition, and future maintenance of unpaved roads;
- periods during a year with disrupted passability;
- levels of service and corresponding road user costs defined not only through roughness;
- high potential to influence economic development; and
- beneficiaries other than motorized road users.

The Model

The model computes benefits accruing to normal, generated, and diverted traffic, as a function of a reduction in vehicle operating and time costs. It also computes safety benefits, and model users can add other benefits (or costs) to the analysis, such as those related to non-motorized traffic, social service delivery and environmental impacts. The model is presented in a series of Excel 5.0 workbooks that collect all user inputs, present the results in a user-friendly manner and perform sensitivity, switching values and stochastic risk analyses.

RED adopts the consumer surplus approach which measures the benefits to road users and consumers of reduced transport costs. This approach was preferred to the producer surplus (2) approach, 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 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:

- reduce the input requirements for low-volume roads;
- take into account the higher uncertainty related to the input requirements;
- clearly state the assumptions made, particularly on the road condition assessment and the economic development forecast;
- compute internally the generated traffic due to decrease in transport costs based on a defined price elasticity of demand;
- quantify the economic costs associated with the days per year when the passage of vehicles is further disrupted by a highly deteriorated road condition;
- use alternative parameters to road roughness to define the level of service of low-volume roads;
- allow for the consideration in the analysis of road safety improvements;
- include in the analysis other benefits (or costs) such as those related to non-motorized traffic, social service delivery and environmental impacts;
- raise questions in different 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;
- present the results with the capability for sensitivity,

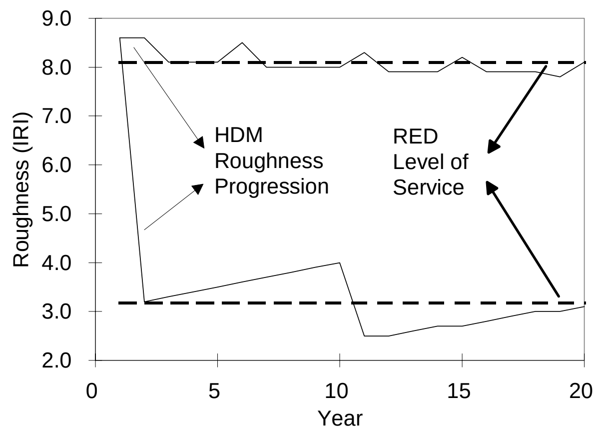

Figure 1. Level of Service with and without Project

- 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.

RED evaluates one road at a time comparing three project alternatives against the without-project case, yielding the investment efficiency indicators needed to select the more desirable alternative and to quantify its economic benefits. RED considers an average constant level of service, for the with- and without-project cases, over a twenty year analysis period (see Figure 1). Road deterioration equations, such as the ones contained on the HDM models, in which the roughness of a given road varies over time as function of condition, traffic and maintenance characteristics are not implemented in RED. Rather RED uses the concept of average levels of service, which is considered reasonable for low volume roads due to the following main reasons:

- convenience in defining levels of service for low-volume roads with parameters other than average annual roughness and gravel thickness;
- difficulty in measuring or estimating the roughness of unpaved roads and determining the grading frequency to be applied to unpaved roads;
- seasonal change in road condition and passability; and
- cyclical nature of the road deterioration under a proper maintenance policy.

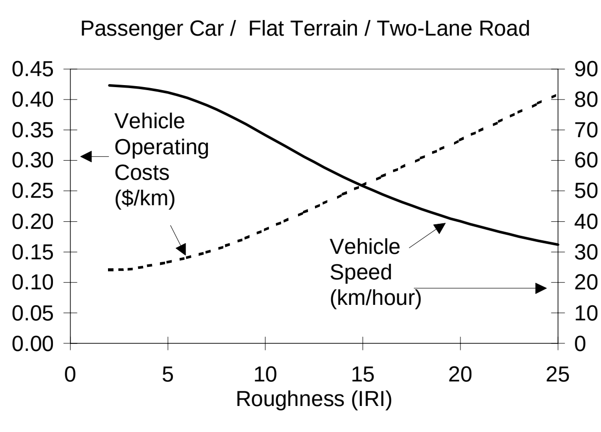

Figure 2. Typical VOC and Speed Relationships

To calculate vehicle operating costs and speeds for a given level of service, the relationships between vehicle operating costs and speeds to road roughness have to be defined, using cubic polynomials, for up to nine vehicle types; three terrain types; and three road types (see Figure 2 for one such relationship).

To estimate road roughness as a function of the speed of a reference vehicle, similar cubic polynomials also need to be defined for the reference vehicle. These relationships can be defined by any means or easily calculated using the RED Vehicle Operating Costs Module that computes, for particular country conditions, vehicle operating costs and speeds as a function of roughness. This module implements the HDM-III vehicle operating costs equations (4), requires the same inputs as HDM-III, and automatically computes the coefficients of the cubic polynomials relating vehicle operating costs and speeds to roughness.

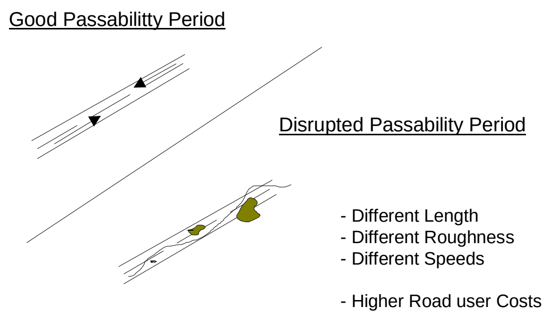

Figure 3. Passability Periods during a Year

To define an average yearly level of service, road condition is defined for the following two possible seasonal periods during a year (see Figure 3):

- period with good passability (dry season); and
- period when the passability is disrupted by a highly deteriorated road condition (wet season); in this case, 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.

For each yearly period, model users have the following three choices with reference to the parameters to be used to define the road condition:

- enter the road roughness; in this case, vehicle operating costs and vehicles speeds are estimated as a function of the inputted roughness, using the previously defined relationships;
- enter the speed of a reference vehicle; in this case, RED estimates the road roughness based on the speed of the reference vehicle (using a model user-defined relationship) and then it estimates vehicle operating costs and speeds of all other vehicles using the estimated roughness; and
- 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.

The second option is appropriate for level and rolling terrain where vehicle speeds are essentially a function of roughness. The last option is indicated for hilly and mountainous terrain where vehicle speeds are less a function of roughness than of road geometry (vertical and horizontal alignments).

To compute safety benefits, model users may enter accident rates and average costs per accident broken down, data allowing, in accidents with fatalities, accidents with injuries, and accidents with damage only.

RED evaluates benefits accruing to the following traffic types:

- normal traffic, i.e. traffic passing along the road in the absence of any new investment;
- diverted traffic, i.e., traffic that diverts to the project road from an alternative road while keeping the same origin and destination.
- generated traffic due to a decrease in transport costs, i.e. traffic associated with existing users driving more frequently or driving further than before, or with new trips undertaken; and
- generated traffic (induced traffic) diverted 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.

RED breaks down the generated traffic into two components: generated traffic due to a decrease in transport costs and generated traffic due to specific local economic development (induced traffic). Model users specify the generated traffic due to decrease in transport costs either by defining it as a percentage of normal traffic or by inputting a price elasticity of demand (3), i.e. the percent increase in traffic per percent decrease in transport costs. The induced traffic and the diverted traffic are entered separately by vehicle type. The benefits accruing to generated traffic are approximated by calculating one-half of the reduction of transport costs for each unit of generated traffic, while the benefits accruing to the diverted traffic are estimated on the basis of the difference between transport costs using the alternative road and using the project road. The traffic growth rate to be inputted in the model is the foreseen increase in traffic due to an overall increase in economic activity, thus affecting equally all traffic types and project-alternatives.

To achieve, and maintain a level of service, an initial investment and annual maintenance costs (fixed and traffic dependent) are specified by the model user, along with other net benefits (or costs), the country / project road and currency names, the evaluation date, the economic to financial costs factor, the discount rate and the initial calendar year. For each project-alternative, RED calculates the following investment efficiency indicators:

- modified rate of return considering the reinvestment rate assumed at the given discount rate;
- net present value per financial investment costs; and
- first-year benefit/cost ratio.

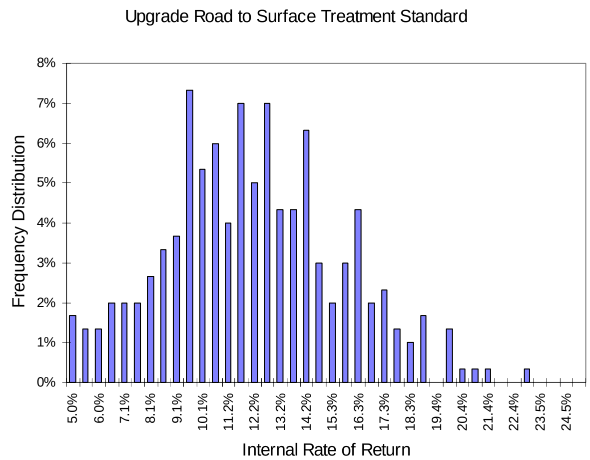

Figure 4 - Typical Risk Analysis Output

RED presents a detailed economic feasibility report for each project-alternative containing all main input assumptions, as well as the computed vehicle speeds, travel times, generated traffic, streams of net benefits, and economic indicators. It also presents a user impacts report presenting the percentage reduction of economic road user costs per vehicle class and the savings in financial annual trip costs in the year after the initial investment is completed. RED does a sensitivity analysis for eighteen main inputs, where model users enter two possible multipliers for each input and the model presents the corresponding investment efficiency indicators. RED also performs a switching values analysis, presenting, in this case, the values of the eighteen main inputs that yield a net present value equal to zero.

The RED Risk Analysis Module performs a risk analysis based on triangular probability distributions for the main eighteen input parameters. Model users define the estimate of an input variable and some measure of the likelihood of occurrence for that estimate taking the form of a triangular probability distribution. The risk analysis module then uses this information to analyze every possible outcome, by executing hundreds of "what-if" scenarios. In each scenario, random inputs following the defined probability distributions are generated, and the resulting frequency distributions presented in graphic form (see Figure 4) together with the following indicators:

- minimum, maximum, average, standard deviation and median rate of return;
- rate of return percentile for three percentile options;
- probability that the rate of return is less than or greater than a certain value.

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 and estimate benefits accruing to motorized road users to which other benefits can be exogenously added. Particular attention was given to the presentation of the results, with a view to highlight all input assumptions and comprehensively integrate them with sensitivity, switching values and stochastic risk analyses. This would assist the analyst in addressing the high variability and uncertainty which normally surrounds the economic analysis of low-volume roads in African countries.

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Road Management Initiative

The RMI was launched in 1988 by the United Nations Economic Commission for Africa (UNECA) and the World Bank, under the auspices of the Sub-Saharan Africa Transport Policy Program (SSATP). The countries taking part in the RMI are Cameroon, Kenya, Madagascar, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe. Others receiving assistance from the program include Angola, Benin, Cape Verde, Djibouti, Ethiopia, Ghana, Guinea, Lesotho, Malawi, Mozambique, and Togo. RMI is administered by the World Bank's Africa Region, and is co-financed with the governments of Denmark, France, Germany, the Netherlands, Sweden, Switzerland, and the European Union. France, Japan and Norway provide senior staff members to work on the Program.