New TRRL Road Investment Model for Developing Countries

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A computer model is described that is designed to aid investment decisions within the roads sector in developing countries. The model calculates the construction cost of a road and predicts the conditions of the road as time passes and vehicles travel over it. Having predicted the condition of the road, the model estimates the costs of road maintenance and the cost of vehicle operation for each year. All of these costs are then discounted back to the base year and summed over the life of the road to obtain the total cost. All estimates are made in terms of physical quantities, and costs are obtained by applying unit rates to these quantities. The results of a study in Kenya were used to calibrate a prototype version of the model that was tested extensively for the appraisal of road projects in developing countries. As a result of this experience, the model has now been reprogrammed to make it easier to use and to fit onto smaller computers. The opportunity has also been taken to include in the model the results of the latest research in this field carried out in developing countries by the Transport and Road Research Laboratory. The relations built into the model allow it to be used to study interrelations among road design and construction standards, road maintenance policy, vehicle characteristics, traffic flow and growth rates, the environment, and road deterioration. The model can be used to study various aspects of a road investment project such as the optimum maintenance standards for the road; the effects of providing an earth, gravel, or bituminous pavement; and the different benefits that can be obtained by adopting various stage construction options. The model also allows the planner to study the consequences of uncertainties in traffic forecasts or in the discount rate.

In developing countries, investment in rural and interurban roads continues to represent a large part of national development programs. It is therefore important that decisions about such investments be made on the basis of the best possible information. The economic consequences of building roads to particular geometric and structural standards have in the past rarely been adequately investigated at the project appraisal stage largely because knowledge of the interaction between the various factors involved is very limited. A set of geometric and structural standards for a road has often been adopted arbitrarily, and little attention has been given to the effect that alternative design standards would have on vehicle operating costs.

In planning a road investment, the main objective will commonly be to minimize the total cost of transportation to the community. This generally means minimizing the sum of construction, maintenance, and vehicle operating costs. To achieve this objective, it is necessary to know how these costs are affected by the interrelations among the environment, construction standards, maintenance standards, geometric standards, and the operating costs of vehicles using the road (see Figure 1).

PROTOTYPE TRRL MODEL

Model Development

The need to evaluate and quantify the interaction between the factors shown in Figure 1 led the Overseas Unit of the Transport and Road Research Laboratory (TRRL) to undertake a major field study in Kenya. The object of this field study, which extended over a period of three years, was to investigate the deterioration of paved and unpaved roads and factors affecting vehicle operating costs.

The performance of more than ninety 1-km-long test sections of road was monitored at regular intervals over a period of two years. The condition of paved roads was quantified in terms of surface roughness, depth of ruts, amount of cracking, deflections, California bearing ratio (CBR), and moisture content of the various pavement layers. Deterioration was related to the number of passes of an equivalent standard axle and to the strength of the pavement. For unpaved roads, deterioration was related to the gravel type and the number of vehicle passes and was measured in terms of surface roughness, depth of ruts, depth of loose surface material, and depth of the gravel surfacing layer itself.

An experimental study was carried out to measure vehicle speeds and fuel consumption over the same test sections. In addition, data were collected from many commercial vehicle operators on such items as the consumption of lubricating oil by vehicles, maintenance requirements of vehicles, tire wear, and vehicle depreciation. Relations were then developed to relate these factors directly to physical operating conditions.

The results of this study (1,2) were used to calibrate a prototype computer model [the Road Transport Investment Model (RTIM)] (3) for evaluating the costs of construction, maintenance, and vehicle operation for a road investment project in a developing country. An outline flow diagram of the model is shown in Figure 2. The model calculates the construction cost of a road and predicts the condition of the road as time passes and vehicles travel over it. Having predicted the condition of the road, the model estimates the costs of road maintenance and the cost of vehicle operation for each year. All of these costs are then discounted back to the base year and summed over the life of the road to obtain the total cost. All estimates are made in terms of physical quantities, and costs are obtained by applying unit rates to these quantities.

Experience of Use

The prototype version of the model was tested extensively by TRRL and has been used by the World Bank, government departments, consultants, and other organizations. Although the model was relatively complex, it was nonetheless easy to use when reasonably efficient computer facilities were available, and its application and data requirements were well within the capabilities of potential users. The

Figure 1. Interrelations among factors that affect vehicle operating costs.

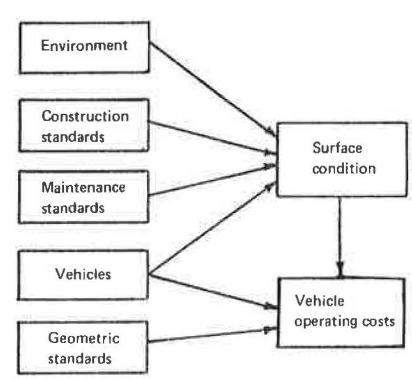
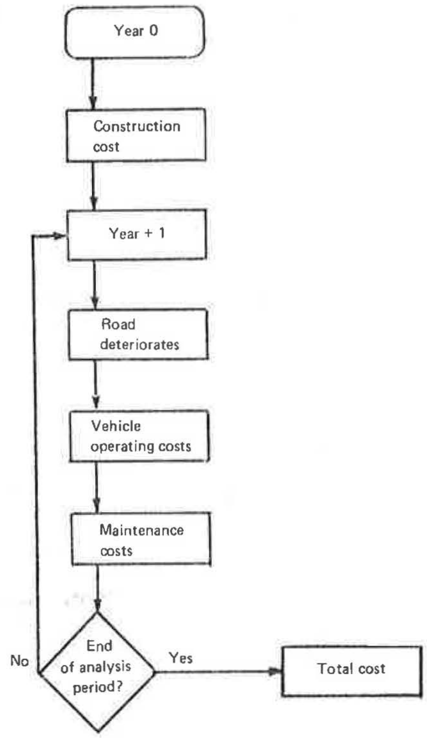


Figure 2. Outline flow diagram of prototype RTIM model.



model represented a significant advance in road planning methodology and has been used in many developing countries.

In 1976, the World Bank instigated further developments of the computer model when it awarded a research contract to the Massachusetts Institute of Technology to produce an extended version of the model that could carry out economic analysis directly, analyze a road link separated into several homogeneous sections, and perform automatic sensitivity analyses of key variables such as discount rate and traffic growth and would require less detailed construction and maintenance input data than the prototype version of the model. This work resulted in the production of the Highway Design and Maintenance Standards model (HDM) (4).

However, experience gained by TRRL in the use of the prototype RTIM suggested that, rather than producing a more complex model, there was also a need for a different approach (5). It was found that in many developing countries adequate computer facilities were either not available at all or were not large enough to run a program of the size of the prototype RTIM or HDM. When sufficiently large computers were available, it was often difficult to gain access to them. Consequently, U.K. consultants who used the model generally preferred to run the program in Britain using data sent from overseas by telex. In addition, potential users in developing countries were often reluctant to use the model because of lack of familiarity with computer methods in general and, when personnel had been trained in the use of the model, staff turnovers often led to the subsequent loss of that expertise.

Some of these difficulties have been overcome by publishing the relations built into the model as a book of tables (6). This enables users in developing countries who do not have access to computers to use the relations in the model in a manual mode. In addition, as a result of experience gained in the use of the prototype in developing countries, the TRRL road investment model has now been reprogrammed to make it easier to use and to fit onto a smaller computer. An ultimate objective is to provide a version of the model for developing countries that will run on a desk-top computer.

In reprogramming the model, the opportunity was also taken to incorporate the results of the latest research on vehicle operating costs carried out by TRRL in the Caribbean (as reported in the paper by Hide elsewhere in this Record). As a result of this study, new relations have been developed for predicting vehicle speed and fuel consumption, spare parts consumption, maintenance labor, tire wear, and vehicle depreciation. Details of all the relations built into the model are included in the report by Parsley and Robinson (7).

As further results become available from other studies, these will also be incorporated into the model.

NEW MODEL

General

A detailed flow diagram of the new model is shown in Figure 3. Operation of the model starts by defining the road alignment. Construction details are then input, and the cost of construction is determined or is specified directly. Road deterioration, road user costs, and road maintenance costs are predicted for each year that the road is open to traffic. Road deterioration is calculated as a function of the construction specification, the maintenance policy, rainfall, and traffic. A vehicle performance submodel uses details of the road geometry and the road surface condition to predict vehicle speed and fuel consumption. Costs of fuel, oil, tires, vehicle maintenance, depreciation, etc., are then determined to give the total vehicle operating costs for the year. An option is available to calculate time costs, and these are based on the values of time that must be input to the model. Road maintenance requirements are found from the condition of the road surface in conjunction with the maintenance policy, and these are used to find the maintenance cost. The model then continues with its year-by-year analysis. The process continues for the selected analysis period and, at the end, the total construction costs, road maintenance costs, and road user costs will be known. These costs can then be discounted at different rates.

An analysis period of up to 50 years can be considered. This may include up to 4 years for the initial construction to take place.

Traffic

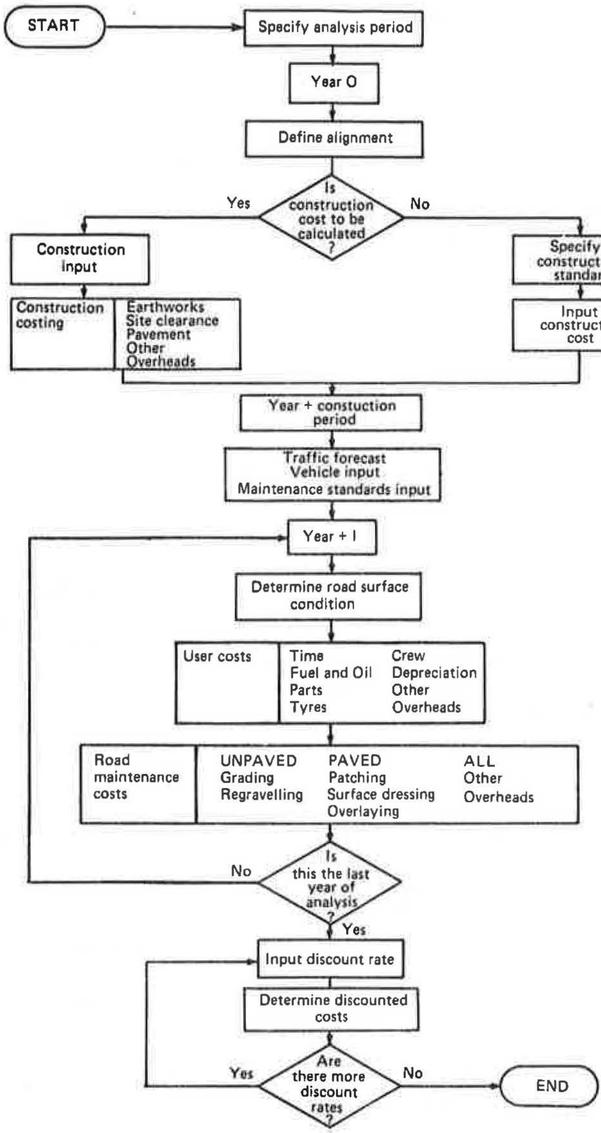
The model can consider separately as many as seven types of vehicles, defined in four classes: passenger cars, light commercial vehicles, buses, and heavy commercial vehicles. Input is required on vehicle price and tire price for all classes and on vehicle load and equivalence factors for heavy vehicles. The loads and equivalence factors can be different for vehicles moving in opposite directions.

Traffic growth forecasts must be made for each vehicle type and can be specified in a variety of ways to allow any type of growth function to be simulated. Because the model uses relations for vehicle speeds that were developed under "free-flow" conditions, it cannot predict the speed reductions caused by traffic congestion.

Road Design

The geometry of the road is defined by its horizontal and vertical alignments and its cross section. The horizontal alignment is specified in terms of

Figure 3. Detailed flow diagram of reprogrammed RTIM model.



the average degree of curvature per kilometer; this is used only in the prediction of vehicle speed. The vertical alignment is specified in terms of the rise and fall and is used in the prediction of vehicle speed and fuel consumption and also in the prediction of the loss of material from gravel roads. The road cross section is defined in terms of carriageway and shoulder width, and this affects vehicle speed, rate of road deterioration, and road maintenance costs. If the model is used to determine construction costs, more detailed information about the vertical alignment and the cross section must be input.

Construction Cost

Often when the model is used, the construction cost will already be known or an existing road will be under examination. However, the model can be used to estimate the earthworks, site clearance, and pavement costs for roads at the feasibility study stage of design.

Road Deterioration

Roads will deteriorate at different rates depending on whether they are earth, gravel, or paved. The deterioration relations used in the model were developed during the Kenya study (2).

Deterioration of earth and gravel roads is defined in terms of roughness, rutting, and looseness of the surface material, which are all functions of traffic volume and type of surface material. For gravel roads, deterioration is also expressed in terms of gravel loss, which is a function of traffic volume, rainfall, and the gradient of the road. Four different types of gravel surface are considered by the model.

Deterioration of paved roads is defined as a function of roughness and cracking. These are functions of pavement strengths (modified structural number) and cumulative axle loading expressed in terms of equivalent standard axles.

The model predicts deterioration of the road surface in each year that the road is trafficked.

Road User Costs

Road user costs consist of time costs and vehicle operating costs and are determined for each year that the road is open to traffic. Vehicle costs are determined from relations developed in Kenya (1) and in the Caribbean (see the paper by Hide in this Record). Time costs are found from the product of the value of passengers' time, which may be input to the model, and journey time, which is found from road length and average vehicle speeds.

Vehicle speed is calculated separately for each type of vehicle and for each direction of travel. Speeds are used in conjunction with details of road geometry and surface characteristics and details of the vehicle to predict fuel consumption. Fuel costs are found from this and the prices of petrol and diesel oil. The consumption of lubricating oil is built into the model for different types of vehicles running on paved and unpaved roads. The cost per journey is found from this and the unit cost of the oil. The cost of replacement parts for a journey over the road is related to the new-vehicle price, the distance traveled by the vehicle since it was new, and the roughness of the road surface. Tire costs are related to the roughness of the road and, for heavy vehicles only, to the gross vehicle weight. Depreciation of vehicles has been related to vehicle age in years. An initial age spectrum of vehicles may be input, and this may be modified, if required, each year by vehicle growth and wastage. In addition, the model calculates crew costs and standing costs, all of which are related to journeys over the road being studied.

To calculate these costs, the model requires input on fuel and lubricant prices, tire costs, new-vehicle prices, crew hourly rates, and the value of passengers' time.

Road Maintenance Costs

Maintenance of paved roads is assumed to consist of patching, surface dressing, and overlaying. Maintenance of unpaved roads is assumed to consist of grading and, in the case of gravel roads, regraveling. The model computes the cost of carrying out the maintenance that has been specified by the user. The cost of maintenance overhead, which should include shoulder maintenance and ditch clearing, may also be included if required.

Stage Construction

As part of the maintenance routines, it is possible to study the effects of planned improvements to the standard of the surface of the road. Earth roads can be graveled, gravel roads paved, and paved roads overlaid. Any number of additional layers can be added, but the alignment and the width of the road will remain unchanged. After an upgrading, the maintenance policy may also change.

Stage construction that involves changing the geometry of the road can only be studied by making separate runs of the model.

Costing

All calculations in the model are carried out on a quantity or nondimensional basis, and input unit rates are used to determine costs. Thus, the model can be used with any system of costs or prices and its relations do not become outdated because of the effects of inflation or changing relativities in commodity prices.

Prices should be expressed in either market or economic terms depending on the type of analysis being carried out.

An important aspect of the cost of building roads in developing countries is the foreign exchange requirement. The model has the capability to calculate the foreign exchange requirements for construction, road maintenance, and vehicle operation based on percentages of components such as fuel, construction plant, and materials, which must be bought with foreign exchange.

SUMMARY

An attempt has been made to obtain a better understanding of the interaction between road construction and maintenance standards and the cost of operating vehicles in order to improve the quality of decisions made at the planning stage of road investment projects. The relations derived from various studies have been built into a computer model that can be used to aid investment decisions within the roads sector in developing countries.

The relations in the model allow it to be used to study the interrelations among road design and construction standards, road maintenance policy, vehicle characteristics, traffic flow and growth rate, the environment, and road deterioration. The model can be used to study many aspects of a road investment project, such as the optimum maintenance standards for the road; the choice of an earth, gravel, or bituminous pavement; and the benefits of adopting any number of different stage construction options. The model also allows the planner to study the consequences of uncertainties in traffic forecasts or in the discount rate.

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Traditional Goods and Passenger Movements in Indonesia

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During an economic and engineering evaluation of a prototype rural road program, the study area of Yogyakarta Special Province in Indonesia was found to possess many effective, non-European types of transport methods. These were used for movement of passengers and goods. Counter to most international studies of this type, the consultants approached these transport functions as relevant to the needs of the community rather than discard their existence as novel and unimportant. Measures of productivity and costs of operation were derived by field study. The work suggests that other nations and parties should attempt to better document the benefits and costs of such local transport methods.

International transportation consultants frequently arrive at a host nation with all their conclusions about the transport needs in a state of final draft. Within Asian, African, and South American nations there is paltry documentation of existing types of local transportation and their characteristics. It may be acceptable to have a belief that modern powered transport is the answer to all land-based transport needs, but the specialist should not jump to that conclusion prior to applying professional tools and skills to the problem of nonurban transport activity.

During the Second Highway Development Loan by the International Bank for Reconstruction and Development (IBRD), a pilot project was initiated to assess the needs for local nonurban transport within the