REPÚBLICA FEDERATIVA DO BRASIL

MINISTÉRIO DOS TRANSPORTES

United Nations Development Programme (UNDP)

Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization

Final Report - 1981

VOLUME 8 – HIGHWAY COSTS MODEL (MICR)

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VOLUME 8 – HIGHWAY COSTS MODEL (MICR)

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PREFACE

This research project was funded through an agreement signed in January, 1975 by the Brazilian Government and the United Nations Development Programme (UNDP). The Ministry of Transportation, acting through the Brazilian Transportation Planning Agency (GEIPOT), assumed the responsibility for the project on behalf of the Brazilian Government, and the International Bank for Reconstruction and Development (IBRD) acted as the executing agency for UNDP.

The research was carried out by GEIPOT and the National Highway Department (DNER), acting through its Road Research Institute (IPR). Funding from the Brazilian Government was channeled through the Institute for Economic and Social Planning (IPEA) and the Secretariat for International Economic and Technical Cooperation (SUBIN), along with the Ministry of Transportation.

The World Bank contracted the Texas Research and Development Foundation (TRDF) to organize the international technical staff and to select and purchase the imported equipment needed for the research. The participation of the TRDF continued until December of 1979.

This report is comprised of twelve volumes (each edited in both English and Portuguese) which summarize the concepts, methods and results obtained by December, 1981 by the project entitled "Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization (PICR)". It includes a documentary index volume which will aid researchers in locating topics discussed in this report and in numerous other documents of the PICR. This report contains much detailed analysis which is being presented for the first time, and also incorporates relevant parts of earlier reports and documents produced under the 1975 Agreement, updating them through the inclusion of new results and findings.

A special mention is due the Highway Departments of the States of Minas Gerais and Goiás, the Universities of Aston, Birmingham, Juiz de Fora, Minas Gerais and Texas, and the Western Australia Main Roads Department, which placed some of their best and most experienced personnel at the service of this project to fill many key positions on the research staff.

Finally, thanks are due the Transport and Road Research Laboratory for its assistance during the initial stages of the project, along with specialists from various countries who periodically visited Brazil to discuss the work being done in the PICR and to assist the permanent research staff in conducting analyses.

JOSÉ MENEZES SENNA
President

*VOLUMES IN THIS REPORT**

VOLUME 1 - SUMMARY OF THE ICR RESEARCH

VOLUME 2 - METHODS AND ORGANIZATION

VOLUME 3 - INSTRUMENTATION

VOLUME 4 - STATISTICAL GUIDE

VOLUME 5 - STUDY OF ROAD USER COSTS

VOLUME 6 - STUDY OF VEHICLE BEHAVIOR AND PERFORMANCE

VOLUME 7 - STUDY OF PAVEMENT MAINTENANCE AND DETERIORATION

VOLUME 8 - HIGHWAY COSTS MODEL (MICR)

VOLUME 9 - MODEL OF TIME AND FUEL CONSUMPTION (MTC)

VOLUME 10- MODEL FOR SIMULATING TRAFFIC (MST)

VOLUME 11- FUNDAMENTAL EQUATIONS

VOLUME 12- INDEX TO PICR DOCUMENTS

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* Volume 1 contains a brief description of the contents of each volume, while Volume 12 provides a subject index to this report and all other PICR documents, including technical memoranda and working documents.

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SUMMARY

This volume describes the major characteristics of the Highway Costs Model (MICR), one of the products of the Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization, carried out in Brazil.

Chapter 1 presents the background of the MICR, in order to inform the reader about its development. There is also a brief discussion of the beginning, objectives and development of the PICR studies.

Chapter 2 describes the objectives and major characteristics of the Model. Finally, Chapter 3 contains a number of considerations regarding the Model, describing its limitations, analysing its fundamental variables, suggesting improvements and commenting on the validity of its potential application by Brazilian highway authorities.

The MICR User's Manual is bound separately and is available in a limited number of copies. Information regarding the computational program is available in Portuguese.

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

One of the precursors of the Highway Costs Model (MICR) was the *Road Analysis Model* (RAM). The RAM was conceived by Louis Y. Pouliquen to be utilized by the World Bank as an instrument for economic evaluation of highway projects. A preliminary version of the RAM was concluded in 1969 and, after being applied in the evaluation of more than 20 projects, the model was reworked by Pedro N. Taborga, of the Department of Transportation and Urban Projects of the World Bank. The new version not only improved the numerical calculations and the results, but also incorporated the experience gained in the applications of the model, together with a number of suggestions offered by its early users.

The RAM focused on the advantages of a new highway project in relation to an already existent project, both designed for the same area. Basically, the model determined the traffic that would be transferred to the planned road, together with the benefits that would be generated by this traffic. Utilizing the project investment costs supplied by the user, the model calculated the internal rate of return on the investment in question, the optimum year for the investment, and its current net value, based on a given annual rate of discount.

The major functions of the RAM were as follows:

- to effect all the calculations associated with the economic evaluation of projects;
- to permit easy and direct communication between the user and the computer;
- to make it possible to obtain reports on the results selected by the user;
- to present a cost-benefit summary compatible with the CBPACK (*Cost Benefit Package*) program, so as to permit analysis of risk;
- to permit additions to the model with minimum efforts in terms of programming.

The characteristics of the RAM which differentiated it from the other models were its modularity and its capacity to permit a dialogue between the user and the computer during evaluations.

In the course of 1969, the Massachusetts Institute of Technology (MIT), with the sponsorship of the World Bank, initiated the development of a model to be used in the economic evaluation of investments in roads with low traffic volumes, and more specifically in the evaluation of construction projects and alternative maintenance standards. Directed by Fred Moavenzadeh, the program was concluded in 1971 and resulted in an integrated structure which related the costs of highway construction, maintenance and utilization involving construction projects and alternative maintenance standards proposed by the user.

Phase 1 of the World Bank/MIT Study was dominated by this part of the task, and produced the *Highway Cost Model* (HCM). This model differed from the others by including real correlations of road deterioration, a phenomenon presented in terms of the costs and benefits of the road in question, permitting the user to specify a number of maintenance policies. However, the most important conclusion of the study was that existing empirical data were insufficient to confirm the interrelationships among the characteristics of the construction project, the quality of the road surface and the operating costs of the vehicles utilizing it. These results encouraged the World Bank to enter into an agreement with the British Transport and Road Research Laboratory (TRRL) in order to correct this deficiency and develop the interrelationships deemed necessary.

The TRRL set up a team in Kenya to produce a model based on real data collected in the field. The locality was considered to be adequate for the research, since the government of Kenya had demonstrated considerable interest in it, and the TRRL possessed vast experience in that country - a fact that would facilitate the planning and execution of the field work. The team began working in April 1971, with the specific objective of measuring the characteristics of deterioration of some roads and the operating costs of the vehicles that used them. The studies included:

- measurements of speed and fuel consumption of different types of vehicles on roads possessing varying design standards and surface qualities;
- survey inventory of some transportation companies and gathering information on their fleets, in order to permit estimation of tire consumption, maintenance expenditures and depreciation costs; and
- measurements of the riding surface deterioration of gravel roads and of roads with surface treatment, with differing traffic conditions and maintenance policies.

The work was completed in 1974 and a computational model, the *Road Transport Investment Model* (RTIM), was produced in 1975. This model calculated the total cost of a road and predicted surface conditions and traffic volume over time. With information on the surface conditions in a given period of analysis, the RTIM estimated the costs of vehicle operation and maintenance for each year. All costs were discounted to the base year and added together to obtain the total cost. However, the RTIM had the following limitations:

a) Data from Kenya

The great majority of the interrelationships were obtained during the field work in Kenya. To utilize the model in different localities, it would be necessary to examine the available data to ensure that they would not be used in extrapolations, in order to ensure application of the model within the intervals determined by the Kenya study.

For example, if only flexible paved roads were studied, it would never be possible to apply the model to a rigid road. Similarly, if roads possessing good to excellent surface conditions were the only ones studied, it would be unwarranted to apply the model to highly deterioration roads;

b) Study of Networks

The RTIM made simulations and cost calculations in relation to links. Therefore, it was not possible to use it to study a highway network, unless the network could be broken down into various links and the effects of each link added together to reflect the effects of the network as a whole; and

c) Prediction of Traffic Growth

The RTIM demanded that the user supply the rates and periods of traffic growth, and also estimate the volume of additional traffic (induced or generated traffic) which would utilize the road as a consequence of the improvement made.

Later on, MIT, sponsored by the Agency for International Development (AID), established four objectives specifically related to the RTIM:

- to develop an updated version of the model, incorporating the results obtained in the extensive field work carried out by the TRRL;
- to corroborate the model, utilizing it in the evaluation of investments in recently concluded projects;
- to ensure use of the model as a normal practice by the highway authority of some developing country; and
- to expand the model to include the effects of a highway network.

In June 1976, an agreement was signed among the World Bank, MIT and the TRRL, with the objective of producing a single model that would combine the HCM and the RTIM, while avoiding the imperfections of both. Another version then came into being, designated the *Road Investment Analysis Model* (*RIAM*), which utilized the structure developed during Phase 1 of the Study and incorporated the results of the research carried out by the TRRL in Kenya, together with the results of other technical studies in the area of highway engineering carried out since 1970.

The equations which estimated the costs of highway utilization were based on the Kenya results, and included only vehicles in free traffic conditions, without forecasting the effects of congestion, and reflected only those types of vehicles that are representative of the western region of Africa.

The equations which correlated the effects of highway deterioration and maintenance were based on tests carried out by the American Association of State Highway Officials (AASHO), as well as on the results of the Kenya research. The application of these equations was restricted to surfaces of asphaltic concrete and bituminous treatment, with a stabilized cement base, and subject to limited conditions of traffic and maintenance. The equations of deterioration of unpaved roads were based on the results of the TRRL, and included only well-maintained gravel roads.

The World Bank acquired some experience testing the RIAM in a number of evaluations of Bank projects, and later decided to modify and expand the model. The Bank designated the modified RIAM as the *Highway Design and Maintenance Standards Model* (*HDM*). A second version of the HDM was produced in October 1979 and still another in April 1981.

1.2 THE RESEARCH AND THE ICR MODEL

In January 1975, the Brazilian Government and the United Nations Development Programme (UNDP) signed an agreement to carry out a highway research project in Brazil. The Brazilian Government made the Ministry of Transportation responsible for the project and assigned its execution to the Brazilian Transportation Planning Company (GEIPOT).

The UNDP designated the World Bank as its executive organ and the Texas Research and Development Foundation (TRDF) was contracted to organize a team of foreign technicians to participate in the research, and to select and purchase the equipment of foreign origin required by the project. The participation of the TRDF lasted until December 1979.

The major objectives of this project were: (1) to interrelate the costs of highway construction, maintenance and utilization, with the use of genuinely Brazilian parameters; (2) to develop methods and models with the aim of minimizing the costs of transportation on paved and unpaved Brazilian roads, with low levels of traffic; and (3) to aid Brazilian highway technicians in their technical-economic feasibility studies.

This project, which was designated the *Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization* (*PICR*), carried out its studies through the following three basic work groups:

a) User Costs Survey Group

The object of this group consisted of the costs incurred by users as a result of the operation of their vehicles on non-urban roads (vehicle operating costs). The group's objective was to identify the relations among the various components of vehicle operating costs, and the variables associated to road design and maintenance, such as surface roughness and vertical and horizontal geometry. Only situations characterized by low and medium traffic volumes were considered in the study;

b) Traffic Experiments Group

The primary objective of the traffic surveys and experiments was to generate a data basis to develop mathematical functions for use in a user-costs simulation model, in order to evaluate speed, travel time and fuel consumption of different classes of vehicles operating on intercity highways. The most important experiments were the following:

- survey of free speeds on positive and negative grades;
- survey of free speeds on curves; and
- measurement of fuel consumption at steady-state speed.

c) Pavement-Deterioration Studies Group

The specific objectives of the pavement and maintenance studies were:

- to determine the deterioration of paved roads in terms of roughness, rut depth, cracks and potholes, as a function of maintenance, pavement structure, geometry and traffic, in climatic conditions typical of Brazil;
- to determine the deterioration of unpaved roads in terms of roughness, rut depth, loss of gravel and loose matter as a function of maintenance, geometry, traffic and material characteristics; and
- to obtain information on maintenance techniques, productivity and unit costs, for the calculation of maintenance costs.

One of the products of the PICR was a model to be used in the economic evaluation of highway investments, designated the *Highway Costs Model* (*MICR*). The MICR is the result of incorporating the equations obtained by the PICR study into the structure of the October 1979 version of the HDM.

It was obviously necessary to modify the structure of the HDM somewhat, since the equations developed by the PICR included variables that were different from those originally found in the HDM, which resulted from the TRRL research in Kenya. A number of modifications were also made to correct errors of logic, since the task involved the utilization of a structure that had not been totally checked (this was the case of the October 1979 version which, for this same reason, gave rise to another version in April 1981). Aside from these, other alterations were made in the HDM, as a result of implementing the following procedures:

- simulation of some maintenance operations on paved roads that were different from those originally found in the HDM, such as temporary patching and slurry sealing;
- correction of the calculations of the benefits of the first year; and
- inclusion of the calculations of the cost/benefit relations.

CHAPTER 2
OBJECTIVES AND PRINCIPAL CHARACTERISTICS OF THE MICR

2.1 OBJECTIVES

As was previously stated, the Highway Costs Model (MICR) resulted from the incorporation of the equations which describe the interrelationships found by the PICR in Brazil into the structure of the HDM (October 1979 version), in place of the correlations found in Kenya by the TRRL.

The Model calculates the total costs (construction costs maintenance costs + utilization costs) of two or more roads or road alternatives, and simulates the surface conditions and traffic volumes of each one of them, during a specific period of analysis defined by the user, which can extend for as long as 30 years. Based on knowledge of road conditions, the Model estimates its maintenance costs and the operating costs of the vehicles that utilize the road, for each year of the specified analysis period. All of these costs are discounted to the base year (the Model permits the utilization of as many as five different rates of discount), and then added together to produce the total costs of each one of the highway alternatives analyzed.

The MICR has the major objective of verifying the technical-economic feasibility of one or more improvements applied to one or more existing roads. Thus, the MICR basically simulates and compares the costs of a given basic alternative with the costs of one or more alternatives for improvement which serve the same geographical area. The basic alternative consists of an existing road, with known traffic level and a maintenance policy whose characteristics are described by the user.

The improvement alternatives normally include a construction project that requires an appropriate maintenance policy. Usually, there occurs an increase in traffic as a consequence of improving road conditions. Other sets of costs and benefits may also appear as a consequence of these more favorable conditions.

Aside from economic feasibility, the MICR can also supply the following results:

- costs and quantities of materials required by highway maintenance policies;
- vehicle operating costs incurred by users of these roads;
- average speed and fuel consumption of the different vehicle classes; and

a thorough follow-up of the simulation, which is carried out on different highway segments to learn about the traffic and its growth, the road conditions (deterioration) and the effects of maintenance operations on deterioration.

These results permit the use of the MICR for other objectives, such as:

- testing different maintenance policies for the purpose of selecting the one most suited to the road segments studied; and
- to verify how the alterations in the composition of traffic affect road deterioration, thus aiding in the establishment of norms to govern the setting of highway taxes.

It should be emphasized, however, that the Model cannot serve these two purposes directly. To attain then, the user needs to make a number of successive tests or, in other words, to use the Model several times to meet the needs of each case.

2.2 GENERAL CHARACTERISTICS

The criteria used by the MICR to characterize a road and define alternatives are as follows:

i) the road is initially divided into links (each link represents a homogeneous segment as to traffic);

ii) the link can be divided into as many as ten sections and should contain at least one section (each section represents a homogeneous segment in terms of physical characteristics: vertical geometry, horizontal geometry, roughness, suface type, rainfall, road width, deflection and structural number of the pavement, subgrade, CBR, etc.);

iii) the association of a traffic set and a maintenance policy to a *link* constitutes a *link alternative*, which can be called a *basic alternative*;

iv) when one desires to study the feasibility of improving a *link*, it is necessary to associate a construction project to this link, and, should it be the case, a set of other costs and benefits resulting from this improvement. The traffic set is normally changed by adding to the previously existing traffic, the traffic increment due to the improvement. The maintenance policy is also expected to change, in order to better fit the road conditions after completion of the proposed project. This new association constitutes another link alternative, which can be called an *improvement alternative*. Various improvement alternatives can be created, through combinations involving project, traffic, maintenance and other costs and benefits, so that they can be compared one by one with the basic alternative;

v) various *link alternatives* can be brought together to form a *group alternative*. In this way, one can have a basic group alternative and various *group alternatives*, the latter involving improvements. The comparison among these are carried out in the same way as among *link alternatives*; and

vi) a set of *group alternatives* forms a *group* and characterizes a highway system. It is important to note that comparisons can only be made among *group alternatives* that pertain to the same *group* or highway system.

The Model functions at the level of *link alternatives* and the simulation is carried out annually for each section of the *link*. Consequently, for each year of the analysis period, the costs of construction, maintenance and vehicle operation are estimated for the *link alternative* studied. Hence, for each *link alternative* the costs of the highway are structured on an annual basis, either during its existence or during the analysis period. This is illustrated in Figure 2.1, which contains a description of the operations carried out for the survey of the highway costs involving a given *link alternative*. The costs of a *group alternative* are estimated by adding together the costs of its corresponding *link alternatives*.

In each application of the Model, as many as 100 alternatives, including both *link alternatives* and *group alternatives*, can be simulated. In the specification of these alternatives, one can define up to 20 *links*, 50 construction projects, 8 maintenance policies, 20 traffic sets and 20 sets of other costs and benefits.

The MICR also permits comparisons between pairs of *link alternatives* and between pairs of *group alternatives*, provided the total number of comparisons does not exceed 50 in each application. For each comparison made, the Model supplies:

- the flows of estimated economic costs and benefits for the entire analysis period, for each component of the total cost or benefit;
- the total economic costs or benefits discounted to the base year, through the use of up to five rates of discount specified by the user;
- the cost/benefit ratios (totals) and present net values, using the same rates of discount;
- the benefits of the first year, considering all of the non discounted costs and benefits; and
- the internal rate of return.

All the above results refer to the improvement alternative in relation to the basic alternative.

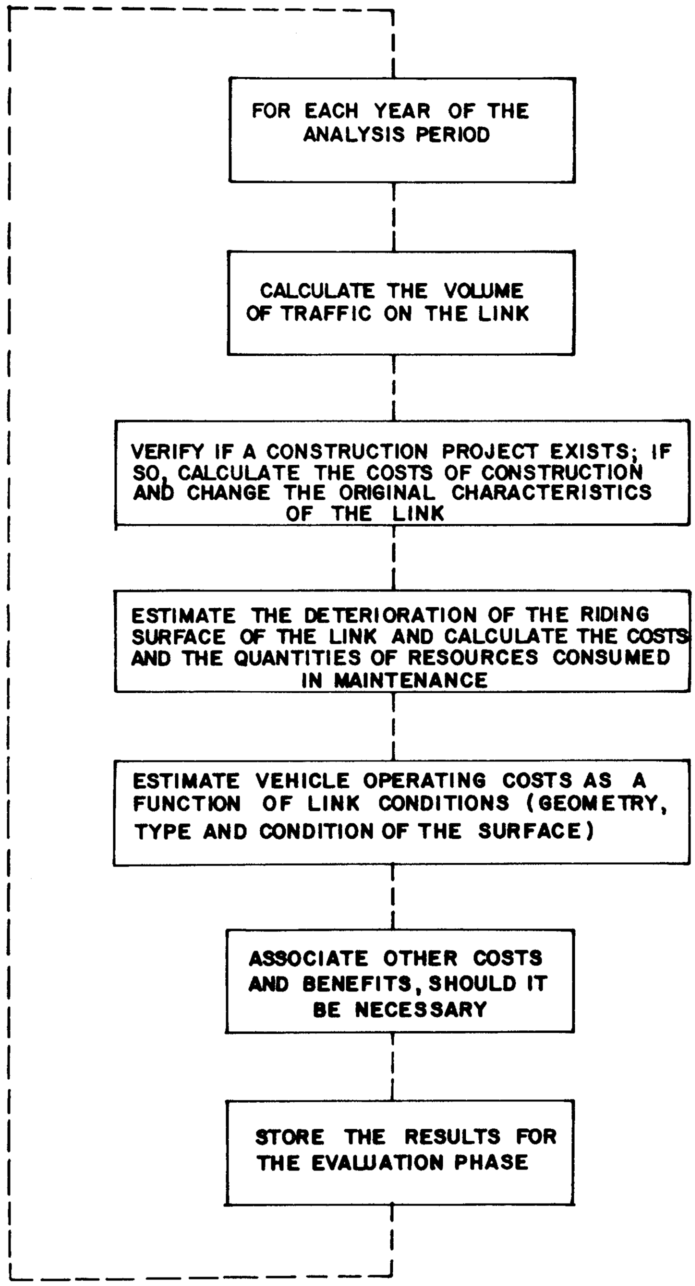


Figure 2.1 - SIMULATION OF A LINK ALTERNATIVE.

In the comparisons among alternatives, the Model user can specify as many as five sensitivity studies. These studies attribute parameters which multiply some or all the components of the total cost of one or of the two alternatives that are being compared. In this way, the user can check the influence of an increase or a decrease in the costs (construction, maintenance, operation, travel time and other costs) on the result of the economic feasibility study, observing that the internal rates of return, the net present values, the benefits of the first year and the benefit/cost ratios were changed.

The MICR requires the following input information:

- characteristics of the existing links;
- specifications of the proposed projects;
- specifications of the maintenance policies and unit costs;
- characteristics and unit costs of the vehicles;
- descriptions of the traffic sets;
- specifications of the sets of other costs and benefits;
- specifications of link alternatives;
- specifications of group alternatives;
- specifications of required output reports;
- specifications of sensitivity studies and of comparisons among alternatives; and
- specifications for control of execution.

More detailed information on the necessary inputs is found in Appendix I, *MICR User's Manual*, Chapter 3 (bound separately in a limited edition).

The output reports supplied by the MICR are as follows:

- a series of reports that arrange and describe in detail all the information submitted as input;
- flows of economic costs for each of the alternatives;
- flows of financial costs for each of the alternatives;
- flows of economic costs and benefits referring to each of the comparisons between pairs of alternatives;
- summary of economic comparisons among the alternatives;
- summary of the total maintenance cost (economic and financial), by link alternative or by group alternative, which can include the entire period of analysis;
- annual maintenance costs by link alternative or group alternative;
- annual situation of the traffic and operating costs of the vehicles, by link alternative; and
- annual situation of road conditions, by link alternative.

More detailed information on the outputs supplied can be found in Appendix I, *MICR User's Manual*, Chapter 4, where the complete application of the Model is exemplified.

2.3 OPERATING CHARACTERISTICS

Basically, the operation of the MICR is divided into three distinct phases. The first phase, or *input phase*, is characterized by the reading and consistency of all the data supplied by the user.

The second phase, called the *simulation phase*, includes all the simulations and cost estimates executed by the Model, involving construction projects, traffic, and road deterioration, maintenance and utilization.

The third phase is the *output phase* or *economic evaluation phase*. It includes all the calculations related to the economic comparisons among alternatives, as well as providing all results.

2.3.1 Input Phase

This phase examines all the input data to verify the existence of possible errors of format, numerical errors and internal inconsistencies.

Tests are carried out to verify the type and content of the information. The first test verifies whether the data supplied is in integers or fractions, depending on the case. The test of content verifies if the information supplied is within an acceptable interval, when numerical, or if the information represents a valid code, when alphabetical. Aside from this, other tests are made to check if the information is consistent or, in other words, if contradictions exist among different bits of information.

Two types of errors can occur during this phase. The first is called "fatal", and when it occurs, an explanatory message is issued and the execution of the two following phases (simulation and output) is halted. Consequently, execution is terminated after completion of the input phase.

The second type is the so-called "non-fatal" error. In this case, a warning message is issued, but there is no interruption in execution after completion of this phase.

After verification of the data, the user is issued several reports which conveniently arrange all of the information supplied by him. These reports are called *input reports* or *echo prints*. By consulting them the user can gain a good overview of the situation he intends to analyze.

2.3.2 *Simulation Phase*

All the simulations required of the Model are executed in this phase. Each of the *link alternatives* specified by the user is accompanied during the entire period of analysis. The construction project, deterioration, maintenance, traffic, operation of the vehicle fleet and the association of other costs and benefits are all controlled.

Figure 2.1 (already presented) shows the sequence of the operations that are executed in the simulation phase of a given *link alternative*.

2.3.2.1 *Traffic*

For each year of the analysis period, the Model calculates the volume of traffic and the number of equivalent standard axles passing over the *link*. The number of equivalent axles is used only to determine the deterioration of paved sections. On unpaved sections, this is done by using the average daily traffic.

The MICR classifies the traffic as *normal traffic* and *generated traffic*. *Normal traffic* is the volume of traffic that originally existed on a *link*. *Generated traffic* is the volume of traffic that is induced or diverted to the *link*, as a consequence of the improvements made on it. According to these definitions, the generated traffic can only be associated to an *improvement alternative*.

Normal and generated traffic are specified by the user in "sets". The manner of specifying the traffic sets is explained in detail in Appendix I of this volume, *MICR User's Manual*, Chapter 3 (bound separately in a limited edition).

Only one normal traffic set is permitted for each *link alternative*, although various generated traffic sets can be specified.

2.3.2.2 *Construction Projects*

The costs of construction are allocated to the *link* on an annual basis, in financial and economic terms and in foreign currency, during the entire construction period.

After conclusion of construction, the original characteristics of the links are modified according to the project specifications, and the generated traffic sets and sets of other costs and benefits are associated to the link. The following improvements can be specified:

- new construction;
- overlay of road surface;
- reconstruction of the pavement, without altering its geometric conditions;
- widening of the section;
- widening of the section and pavement reconstruction; and
- change in alignment.

The specifications of the construction projects are explained in Appendix I, Chapter 3.

2.3.2.3 *Deterioration and Maintenance*

The simulations of highway deterioration and maintenance play an important function in the interrelationships of highway costs. The deterioration of the highway is the result of the original pavement project, the type of materials, the volume and composition of traffic, and the specified maintenance policy.

For each year of the analysis period, the Model estimates traffic-caused deterioration of the road surface. Once road conditions are known, the Model calculates the quantities of maintenance services required, updates the conditions of the road after these services have been executed, and applies the unit costs to determine the total maintenance costs for that year, corresponding to the *link alternative* being simulated.

The following operations can be specified in the design of a maintenance policy for paved roads:

- temporary patches;
- permanent patches;
- slurry sealing;
- surface treatment;
- overlay with asphaltic concrete; and
- routine maintenance.

The execution of any one of the maintenance operations for paved roads is always considered by the Model as occurring at the end of each year of the analysis.

The computational procedure that involves the simulation of the deterioration and the maintenance of a paved road for each year of the analysis period can be summarized in the following steps:

1) calculation of the annual increase in road surface deterioration, as a function of pavement strength, surface conditions and traffic at the start of the current year;
2) addition of the increase calculated in (1) to the deterioration found at the beginning of the year, to obtain the deterioration of the road at the end of the year;
3) calculation of the costs and quantities of resources consumed in maintenance, by operation, based on the specified standards and surface conditions of the road at the end of the year;
4) calculation of the conditions of deterioration at the beginning of the next year of analysis, based on the conditions at the end of the current year and on the maintenance operations executed during the course of the same year; and
5) calculation and storage of the average values of deterioration in the current year, to be utilized later in the calculation of vehicle operating costs.

The following operations can be specified in the design of a maintenance policy for unpaved roads:

- road blading in the dry season;
- road blading in the rainy season;
- localized regravelling;
- regravelling along the entire course of the road; and
- routine maintenance.

The deterioration of unpaved roads is measured basically in terms of gravel loss and surface roughness.

In Appendix I, MICR *User's Manual*, Chapter 2, item 2.6.10, the statistical equations that simulate and describe the development of roughness on unpaved roads are presented.

Routine maintenance operations, on both paved and unpaved roads, include drainage, control of vegetation, maintenance of shoulders, signs and signals, safety installations and other items that are not entirely simulated by the Model. The Model may consider the cost of these operations, but does not estimate their effects on pavement quality.

The total cost per kilometer and per year should be provided in order to represent the resources consumed by routine maintenance operations. Since the equations that estimate deterioration were developed on the basis of the supposition of adequate drainage conditions, the user should provide at least the drainage cost.

All of the equations that simulate road deterioration and maintenance are presented in Appendix I, Chapter 2.

2.3.2.4 Vehicle Operation

In each year of the analysis period, vehicle operating costs are estimated as a function of the geometric characteristics of the road, type of surface, volume and composition of traffic and surface conditions in the current year. These costs are obtained by multiplying the quantities of resources consumed in vehicle operation, such as fuel and tires, by their respective unit costs.

In the Model, the costs referring to the vehicles are classified under *operating costs* and *travel time costs*. The operating costs take in vehicle maintenance and operation and include fuel, tires, spare parts and labor, depreciation, interest, overhead and crew costs. The travel time costs are the value of the time of the passengers and the cargo in transit.

The MICR allows the user to provide the unit costs in financial and economic terms. Some items can also be provided in terms of foreign currency.

The financial costs represent the costs incurred by transportation operators in order to maintain and operate the vehicles. The economic costs represent the actual costs for the national economy which result from vehicle ownership and operation, where adjustments are made to compensate for distortions in market prices caused by the existence of taxes, exchange restrictions, labor laws, etc. The costs presented in foreign currency can represent financial costs or economic costs, depending on the situation.

It is important to observe that the concepts of financial and economic costs, presented above, are only for illustrative purposes. Therefore, the adoption of these concepts is not essential. When the user has different areas of interest, he can provide the units costs of the vehicles in a manner coherent with them.

Assuming a directional symmetry of the traffic, the Model calculates the resources consumed per kilometer, for five vehicle classes:

- automobiles;
- utilities;
- buses;
- medium trucks; and
- heavy trucks.

Appendix I presents all the characteristics of the vehicles considered in the Model, together with all the statistical equations which estimate the costs.

2.3.2.5 *Other Costs and Benefits*

For each year of the analysis period, the Model checks if the user specified any other cost or benefit which should be associated with the link alternative that is being simulated. The user specifies the other costs and benefits in "sets". The reason for the existence of these sets of other costs and benefits is to allow the user to consider costs and benefits other than those simulated by the Model, which occur as a consequence of the improvement effected on the link. Therefore, it can be seen that the specification of a set of other costs and benefits only makes sense if it is associated with an improvement alternative. In Appendix I, an explanation is provided as to how these specifications can be made.

2.3.3 *Output Phase*

This third and final phase of the MICR executes the economic analysis for each link alternative and for each comparison between pairs of alternatives. A number of reports are produced, some of which are generated automatically, while others are generated only when requested by the user.

In the MICR, the procedures required for effecting the economic analyses of the alternatives may be summarized in the following steps:

1) for each link alternative, the Model establishes the annual cost flow, in financial and economic terms and in foreign currency. These cost flows involve investments in construction projects, resources consumed in maintenance, vehicle operation, time of passenger and cargo permanence in transit, and also other costs that may be provided by the user;
2) the annual cost flows established in (1) are added together for each group alternative;
3) for each comparison among pairs of alternatives, the annual cost and benefit flows are calculated for the improvement alternative in relation to the basic alternative. These flows include construction costs, maintenance costs, benefits from the operation and travel time of the vehicles, other benefits, total economic benefits and total costs in foreign currency;
4) the cost and benefit flows calculated in (3) are added together for each comparison between group alternatives;
5) for each pair of link alternatives compared, the Model calculates the current net values and the benefit/cost ratio for five different rates of discount supplied by the user; the rate of return; and the benefits of the first year;
6) step (5) is repeated for each comparison between group alternatives; and
7) steps (5) and (6) are repeated for each sensitivity study specified by the user.

2.4 *COMPUTATIONAL CHARACTERISTICS*

The major characteristics of the computational program of the MICR are described in a separate document containing information on the computational program (currently available only in Portuguese).

CHAPTER 3
CONSIDERATIONS REGARDING THE MODEL

3.1 *INTRODUCTION*

As was stated in Chapter 2, the MICR calculates the total cost of a highway by aggregating the shares relative to road construction cost, maintenance cost and utilization cost.

The construction cost is provided by the user, since the Model does not calculate the quantities of materials and services that would be consumed in the implementation of a proposed project, and does not aid the user in the initial choice of favorable alignments.

The maintenance cost is calculated by the Model through the survey of the quantities of materials consumed in each of the maintenance operations, which are later multiplied by the unit costs provided by the user. The execution of most of the maintenance operations can be specified by the user in a programmed or conditioned manner. The programmed maintenance consists of the execution of the operation at certain time intervals. The conditioned maintenance consists of the execution of the operation when the road surface reaches a certain level of wear considered critical by the user. On paved surfaces, this level is determined by the roughness and by the cracked area, while for unpaved surfaces it is determined only by roughness.

Finally, the MICR calculates the cost of utilization of the highway, by adding together vehicle operating costs and travel time costs. These costs depend principally on the condition of the road surface (represented in the Model by roughness), and by the indices of vertical and horizontal geometry.

The indices of geometry are utilized only in the equations which estimate the average speed and fuel consumption of the vehicles. By affecting speeds, they have an indirect influence on travel time costs and on the calculation of vehicle utilization, which reflect the number of kilometers covered by each type of vehicle in one year.

The equations of speed and fuel consumption that are built into the MICR have their origin in the *aggregation* of the equations of the Model of Time and Fuel Consumption (MTC), described in Volume 9 of this report.

Aside from this, the equations that estimate utilization costs were developed on the basis of the performance of a fleet of vehicles supposedly representative of all Brazilian vehicles. This restricts the application of the Model to situations which involve vehicles with characteristics that are at least similar to the types of vehicles studied, and subjects the Model to the risk of obsolescence as a consequence of future developments in the mechanical characteristics of the vehicles. For more detailed information, see Appendix I, Chapter 2, item 2.8.

3.2 FUNDAMENTAL VARIABLES

From item 3.1, it can be seen that some of numerous variables utilized by the MICR were considered to be more representative than others by the procedures of statistical analysis (i.e., as being those which better explained the interrelationships of the areas researched). These are the fundamental variables and are given as follows, in order of their increasing importance to the Model: the index of horizontal geometry, the index of vertical geometry, and surface roughness.

3.2.1 *Index of Horizontal Geometry*

The index used to represent the horizontal geometry of the roads is based exclusively on the central angles of the curves, and is determined in the following manner:

$$ADC = \frac{\sum_{i=1}^{n} AC_i}{\ell}$$

Where:

ADC = index of horizontal geometry, in degrees per kilometer (average degrees of curvature);

AC_i = central angle of the i-th horizontal curve, in degrees;

ℓ = total length of the section under analysis, in kilometers.

As it was conceived, the ADC utilized by the MICR does not seem to discriminate the horizontal geometry of a road in a totally satisfactory manner. However, it was also found that the horizontal geometry of a road has only a moderate influence on the fuel consumption results and on the majority of the operating cost components.

3.2.2 *Index of Vertical Geometry*

The index of vertical geometry adopted by the PICR for use in the Model was developed on the basis of the TRRL studies. In the Kenya research, two indices were utilized in an attempt to represent the vertical geometry of a road: *Rise* and *Fall* (See Report 764 of the TRRL - *Road Transport Investment Model - RTIM*). Through the utilization of these two indices, interrelationships considered unsatisfactory by the specialists were found. Therefore, the PICR sought to define a single index that would include *Rise* and *Fall*. This new index, designated *Rise plus Fall*, is defined in the following manner:

$$RPF = \frac{\sum_{i=1}^{n} |g_i| \cdot \ell_i}{100 \sum_{i=1}^{n} \ell_i / 1000}$$

Where:

RPF = *Rise plus Fall*, or index of vertical geometry, in meters per kilometer;

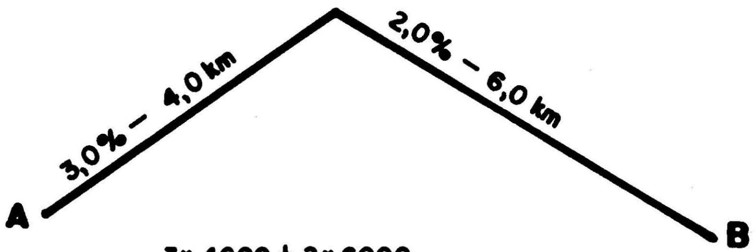
$|g_i|$ = absolute value of i-th grade, in % (5=5%);

ℓ_i = length of i-th grade, in meters.

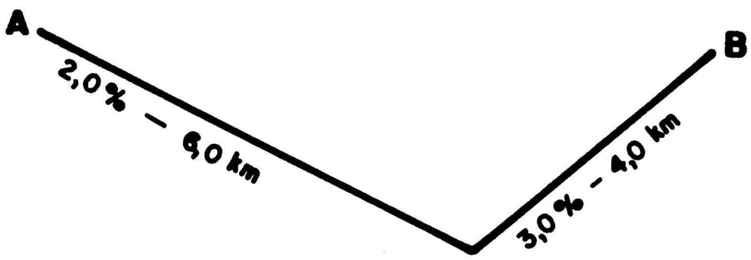
Figure 3.1 presents three different vertical profiles joining points A and B, located at a distance of 10 km from one another. On calculating the RPF in the manner defined above, one obtains the same value (24 m/km) for the three situations. This indicates that the RPF is unable to fully discriminate a given vertical geometry and, for this reason, it does not have the weight or influence that was expected in the equations which estimate vehicle speed and fuel consumption.

3.2.3 *Roughness*

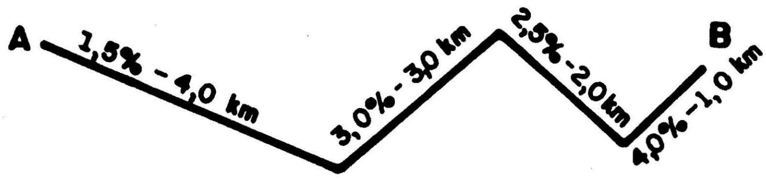
Among the fundamental variables, the roughness index has the greatest influence on the MICR equations. For this reason, it was chosen to be the principal measure of road surface condition. Roughness thus has a decisive influence on vehicle operating costs.



$$RPF_1 = \frac{3 \times 4000 + 2 \times 6000}{100\left(\frac{4000 + 6000}{1000}\right)} = 24\,m/km$$



$$RPF_2 = \frac{2 \times 6000 + 3 \times 4000}{100\left(\frac{6000 + 4000}{1000}\right)} = 24\,m/km$$



$$RPF_3 = \frac{1{,}5 \times 4000 + 3 \times 3000 + 2{,}5 \times 2000 + 4 \times 1000}{100\left(\frac{4000 + 3000 + 2000 + 1000}{1000}\right)} = 24\,m/km$$

Figura 3.1 - CALCULATION OF RISE PLUS FALL FOR DIFFERENT VERTICAL PROFILES.

A study of the validity of the roughness data was carried out by a team composed of PICR researchers. In October 1981, this team produced a conclusive report, explaining the problems relative to conception and measurement involving those data (Alckmin, *et al.*) The study indicates that the roughness measurements are subject to a number of factors that diminish their precision.

In some of the tests carried out, the MICR proved to be extremely sensitive to roughness variations. Consequently, the roughness variable as now present in the MICR equations has an effect on the predicted cost that is much greater than should be expected.

3.3 SUGGESTIONS AND CONCLUSIONS

A careful study of the other basic data on pavement conditions could make a favorable contribution to the development of new equations that would minimize or perhaps even exclude the effects of roughness, exchanging the roughness measure for the effects of cracks, potholes and patches. If feasible, this procedures would considerably improve the equations for operating cost, thus making the Model's estimates for paved roads much more trustworthy.

As for the geometry indices, a study has been started to develop new indices based on the physical characteristics of the roads. If these indices prove to be trustworthy, they could be used to discriminate more precisely the horizontal and vertical geometry of the highway.

Once a good geometric representation of the highways is obtained, it will become possible to improve considerably the Model's estimates of speed, fuel consumption, vehicle utilization and travel time costs.

In conclusion, it can be perceived that, in the light of the present state of the MICR, it would be premature to recommend the model for general use by Brazilian highway planners. However, when employed by duly trained technicians, it can supply indications for the evaluation of the impacts of specific highway construction and maintenance policies.

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