REPÚBLICA FEDERATIVA DO BRASIL
UNITED NATIONS DEVELOPMENT PROGRAM (UNDP)

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

REPORT I · Inception Report · Research Concepts and Procedures · April 1976

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PREFACE

This document is the first in a series of reports which will derive from the research project entitled "Research on the Interrelationships between Costs of Highway Construction, Maintenance and Utilization," lately shortened to "Research on the Interrelationships of Highway Costs."

This project is the result of an agreement signed in January 1975 between the Government of Brazil and the United Nations Development Program (UNDP). According to this agreement the Ministry of Transport of Brazil is the Government Cooperating Agency through "Empresa Brasileira de Planejamento de Transportes - GEIPOT," and the International Bank for Reconstruction and Development (IBRD) is the executing agency for UNDP.

GEIPOT is working in close cooperation with the "Departamento Nacional de Estradas de Rodagem" (DNER), through its "Instituto de Pesquisas Rodoviárias" (IPR), and both have received grants from the "Instituto de Planejamento Econômico e Social" (IPEA) and from the "Secretaria de Cooperação Econômica e Técnica Internacional" (SUBIN), respectively.

The IBRD has contracted with the Texas Research and Development Foundation (TRDF) to provide the expatriate staff for the project, which includes professionals on loan from the University of Texas and various other institutions. The expatriate staff includes professionals from the United States of America, Ecuador, Australia, Grat-Britain and South Africa.

Previous publications issued since 1969 by IBRD and since 1972 by GEIPOT defining the feasibility of this Research are listed in the bibliographical references. This report is the result of the first six months of research and presents the concepts and methodology to be applied during the following phases of data collection and analysis. Future reports will deal mainly with the partial and final results of the Research as well as with meaningful features of the Research as they occur. All reports will be written and published in Portuguese and in

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English. Project offices are in Brasilia, Brazil at GEIPOT
headquarters. Authorship of this report is entirely the work
of the senior staff of the project, listed elsewhere in this
document, and does not at this time imply the approval of or
acceptance by any of the sponsors.

As the agency assigned by Brazil's Ministry of Transpor-
tation to conduct such an imposing project, which has from its
inception attracted international interest, GEIPOT is thankful
for the support received from all sponsors as well as from so
many other Brazilian and international entities, such as the
"Departamento de Estradas de Rodagem de Goiás," the "Transport
and Road Research Laboratory" of Great-Britain and the Govern-
ment of Australia, which are so closely cooperating with the
Research, and without which this report and the activities that
have preceded it and will follow it would be impossible.

JOSÉ MENEZES SENNA
President

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ABSTRACT

A research project is underway in Brazil to develop mathematical models for highway planning. Cost models will be developed relating highway construction, maintenance and utilization. The 42-month project began in September 1975. This initial project report describes the background and previous work in the areas as well as the concepts and proposed methodology for the research.

Three basic activities are proposed and described: 1) a series of road user costs surveys to determine operating costs in Brazil, 2) road user and traffic experiments to relate speed and fuel consumption and 3) pavement performance and maintenance experiments. All of these studies will relate construction, maintenance and utilization costs to road construction and design standards, and pavement performance and maintenance.

Analysis of results will incorporate previous work sponsored by the World Bank and results of a Transportation Road Research Laboratory study in Kenya. The first results of the current study are expected in 1977. The project is sponsored by the Brazilian Ministry of Transport and the United Nations Development Program.

SENIOR PROJECT STAFF

Jair L. de Siqueira	General Director	GEIPOT
W. Ronald Hudson	International Technical Director	TRDF and the Univ. of Texas
Theodoro de C. Lustosa	Deputy Project Director	GEIPOT
Bertell C. Butler, Jr.	Deputy Techn. Director	TRDF
Flávio M. Borralho	Deputy Project Director	GEIPOT
Russ L. Kaesehagen	Traffic & Planning Engineer	TRDF (*)
Douglas Plautz	Traffic Engineer	DNER
Alex Theo Visser	Pavement Engineer	TRDF
César A. V. de Queiroz	Pavement Engineer	DNER
Richard John Wyatt	User Cost Specialist	TRDF
Odilon P. Cronemberger	User Cost Engineer	DNER
Barry Kurt Moser	Research Statistician	TRDF
Hugo E. Orellana	Computer Specialist	TRDF
Antonio da Cruz Costa	Civil Engineer	GEIPOT (**)
Stephen L. Linder	Electronic Engineer	TRDF
Stanley Harry Buller	Electronic Engineer	GEIPOT
Lourival Caixeta	Mechanical Engineer	GEIPOT (**)

(*) On loan from the Western Australia Government

(**) On loan from Departamento de Estradas de Rodagem de Goiás

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CHAPTER 1 - INTRODUCTION

NEED FOR HIGHWAY PLANNING MODELS

Highways serve national and public needs by providing trans-
portation links which reduce the cost of moving people and
goods. This reduction in transportation costs encourages the
use of highways, stimulates economic growth and the development
of natural resources. New or better roads and expansion of
rural road systems are needed for accessing these untapped
reserves. Because resources are always limited and many groups
compete for them, objective procedures are needed to establish
warrants for the allocation of such resources.

In the highway transportation sector, there is direct compe-
tition for funds to 1) reduce traffic congestion in cities, 2)
improve road links connecting major population areas and 3)
create an effective rural road system. An objective economic
analysis procedure is needed to assist administrators in deter-
mining an investment policy which will optimize the use of such
funds. These procedures can be quantified in planning models.

Recent experiences have shown that objective planning
models can be designed to effectively help in the economic-
engineering analysis of project alternatives for a given link
or for the road network of a country or region. This project
is concerned with such models for primarily rural roads.

FUNCTIONS PERFORMED BY A HIGHWAY COST MODEL

A planning model is a tool which is designed to assist
administrators in making decisions. As such it augments
professional judgement in the establishment of policy, but never
replaces it.

A highway model can simulate real world relationships
between highway construction and maintenance standards, vehicle
user costs and the condition of a given designed highway in a
known environment. Alternate policies for design standards and
maintenance quality can be examined and blended to minimize

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total transportation cost for a specific project. A model can
also be used to examine a variety of maintenance strategies
for a fixed design standard or the implications of different
designs holding maintenance constant or even eliminating it.
In general, a planning model predicts construction, mainte-
nance and user costs. Ideally, it should quantify user impact
in terms of safety, comfort and convenience. However, these
latter indexes are difficult to quantify in cost terms.

BACKGROUND

    The use of economic analysis for highway project planning
has received limited acceptance historically. Most highway
projects have been based on travel demand, engineering
judgement as to standards and the assumption that a road would
be maintained during its life in its as-built condition.

    Technical papers on vehicle running costs started appear-
ing in the early 20's in the United States, but until the
AASHTO Red Book (Road User Benefit Analysis for Highway
Improvements) (Ref. 1) was published in 1952, little use was
made of economic analysis for planning highways. Even then,
only selected highway agencies used economic analysis and that
primarily to determine least costs between alternate routes.
In Brazil, GEIPOT was responsible for the introduction of
economic analysis of highway projects in 1966.

    The AASHTO Red Book was updated in 1960 and subsequent
publications by Winfrey, de Weille, Lock and Delaney, et al,
Bonney and Stevens, Curry and Anderson, and Claffey(Ref. 2-7)
were directed toward improving the analysis procedures and
developing current empirical data to support these analyses.
This information came into wider use, but still was used
primarily for comparing or selecting between alternate routes.

    The need to establish quantitative warrants for actually
building roads was finally recognized in the early 60's by
the World Bank and other groups in the United States, United
Kingdom, Australia and France. Use of the existing economic
procedures, particularly for-low volume roads were considered

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inadequate. Further, there was little primary empirical data
and most of it was out of date. Furthermore, the applicability
of such information in Brazil was not known.

EXISTING MODELS

In 1968 the World Bank initiated a research contract with
a group at MIT to develop a rational analysis of economic
consequences of alternative design, construction and mainte-
nance policies for low-volume roads (Ref. 8). The conceptual
framework developed included models for road deterioration.
Further, attempts were made to relate road conditions to the
cost and benefits derived from the road. The MIT model was
based on information available from existing literature.
Therefore, the hypothesized 1) patterns of deterioration for
different road types, 2) design standards, 3) surface condi-
tions and 4) road user costs could not be verified with
empirical data. However, the study did show that a model
could be used to optimize total highway transportation cost.

The highway cost model developed at MIT includes modules
to compute construction, maintenance and road user costs as a
function of road design, condition and maintenance policy.
Although operational, it has limited use as developed, because
its empirical base is inadequate.

Because the MIT model was deficient in the sound empirical
relationship needed to predict reliable cost, the Transportation
and Road Research Laboratory, in cooperation with the IBRD,
undertook field studies to develop empirical data in Kenya
(Refs. 9-12) These studies were designed to measure the road
deterioration process of low volume roads and to establish road
user costs on the road as they deteriorated. The results were
used to produce a model directly with data collected in the
field. The Kenya study was to establish a set of relationships
between vehicle operating costs, vehicle type, physical
operating conditions and operator characteristics. Both
experimental investigation into vehicle speeds and fuel
consumption and a user survey on vehicle operating costs were
used to develop the data.

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A second part of the study was concerned with the character of the road, in particular, how a given road design performed in a particular environment when subjected to a given traffic loading. The impact of different maintenance policies also was addressed in this portion of the study.

The models generated by the Kenya study established many empirical relationships which need to be verified under broader conditions. Further, the transferability of the Kenya results to other countries and regions having different conditions needs to be established. Finally, only limited attention and data were developed for certain user cost elements, such as depreciation, and only a limited range of extreme conditions of road roughness and geometry were investigated. However, the model will aid decision making for project selection based on minimizing the sum of construction, maintenance and road user costs over the "life" of the alternative road designs examined.

THE MODULE CONCEPT

For the highway cost model to be an effective decision tool it must be capable of making rapid investigations of many alternate geometric standards, pavement designs and maintenance strategies. To do this economically, the model must be designed for use with a computer. Further, the simulation routines and iterative nature of the analysis process is not practical outside of a computer environment.

The highway cost model will consist of a number of separate sub-systems or modules which are structured to interact with one another through instructions from a main program. These modules can include the following:
1) Main program module
2) Input module
3) Construction quantities module
4) Road deterioration module
5) Maintenance module
6) Vehicle performance module
7) Cost module
8) Output module

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Input Module

In general, the following parameters will be input to the highway planning cost model although some might be generated in the program to facilitate the use of the model in very general situations or for sensitivity testing of various module elements of the model.

a) Environment
   Terrain
   Traffic
   Weather
   Geological Conditions

b) Design
   Pavement
   Speed
   Geometry

c) Unit Costs
   Construction
   Maintenance
   Road User

d) Maintenance
   Policy
   Technology

Construction Quantities Module

For given environmental and design constraints, the construction quantities required to produce the road project will be determined. Further, this module will calculate quantities for stage constructions projects.

Road Deterioration Module

Each year of the analysis, a road in a given condition state is subjected to traffic and the natural environment. It envolves to a second condition state, depending in part on maintenance inputs. This module will predict these roadway conditions in terms of rougness, rut depth, cracking and other quantifiable measures of the condition of the road.

Maintenance Module

Each year of the analysis, the road is in a given condi tion state. Depending on maintenance policy inputs, the condition is translated into maintenance workload. This, in turn,

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is converted to maintenance quantities using maintenance
activity standards which describe the labor, equipment and
material requirements for the workload.

Vehicle Performance Module

Each year of the analysis, vehicle operation is simulated
on a road having 1) given geometric characteristics,
2) surface qualities related to the road condition state, and
3) within a traffic stream of predicted volume and composi-
tion. This simulation process yields quantities of vehicle
consumption, i.e., fuel, oil, tires, etc.

Cost Module

Unit cost inputs to the module are applied to quantities
of construction, maintenance and vehicle user consumption to
produce total annual highway costs. This cost is appropriately
discounted and accumulated over the analysis period being
studied.

Output Module

The principal output of the module is a total transpor-
tation cost value for a given design standard and maintenance
strategy. Any interim costs for major or minor elements of
the system also can be generated by the program. However,
default output will be limited to that information needed to
permit an overall assessment of the analysis. When details in
any area of the analysis are desired, they will be required
to be requested by the user.

A system flow diagram for the highway cost model
developed by MIT for the World Bank is shown in Figure 1.

The highway cost model will be developed to accomodate
a wide range of users, including both governmental and
financial agencies. Further, it will be structured to permit
analysis at various study levels. This includes pre-feasibili-
ty, feasibility and actual project appraisals.   To
permit this maximum interface with users for a variety of
purposes, the input requirements can be varied widely. The
inclusion of extensive default routines to generate needed

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DIAGRAM OF THE MODEL FOR HIGH WAY TRANSPORT COST
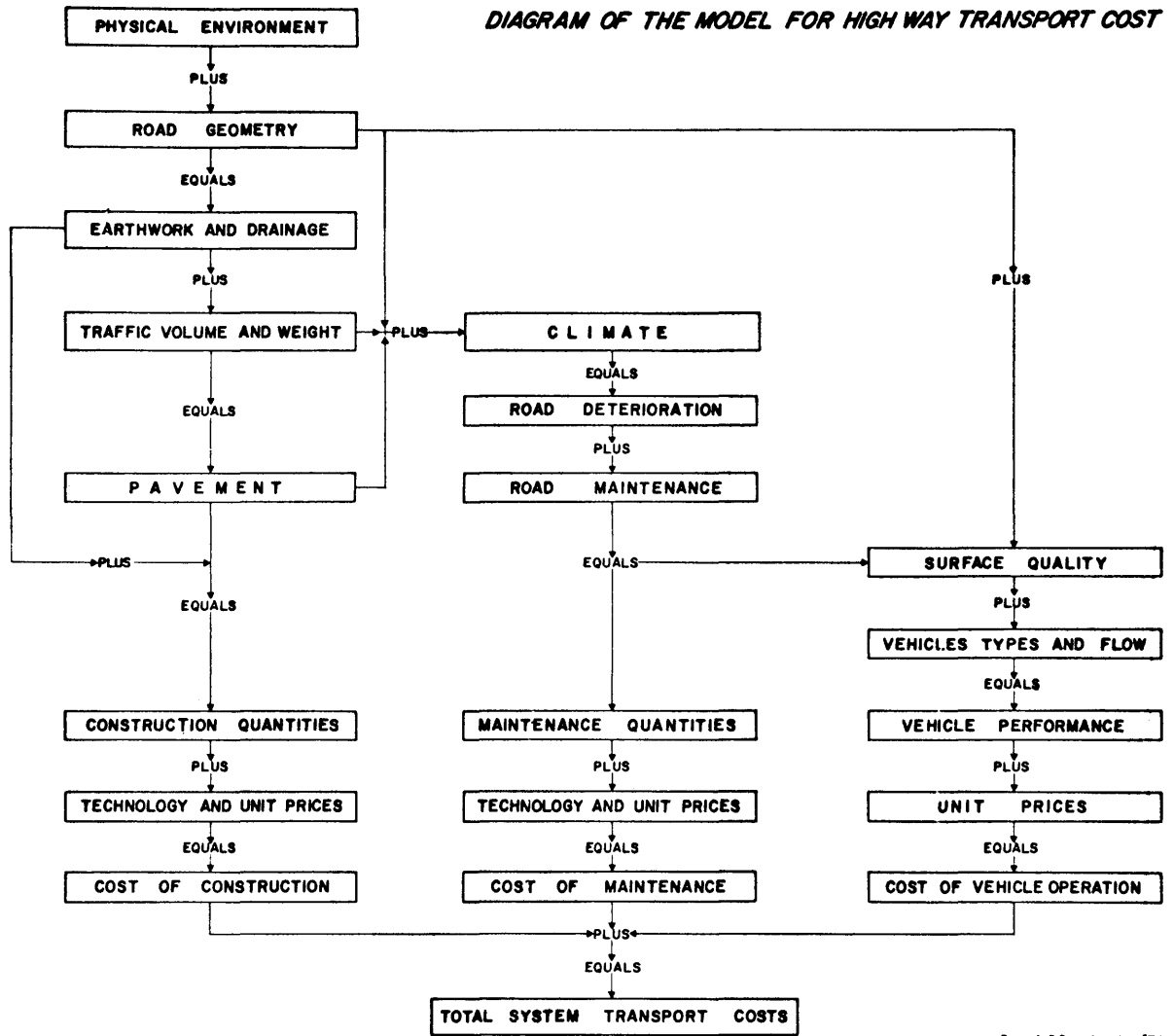
Figure 1   Flow Chart for Highway Cost Model Developed in the
MIT Study (Ref 8)

data when it is not otherwise readily available will maximize
the ease with which the program can be run.

The model also should permit users to modify when needed
many of the relationships defined within the model. This
relaxing of manipulative rigidities can be accomodated
through optional input parameters requiring definitive
action on the part of the user.

The model must be structured so that it is readily
updatable, otherwise it will quickly become obsolete. This
is accomodated in part by the modular structure envisioned
for the model. It also is important that quantities of
materials and user consumption rather than costs be the
predicted output of the relationships established. Using a
unit costing concept facilitates this approach. Finally, in
structuring the actual program, the empirical relationships
used in predicting the various quantities and user consumption
will be clearly delineated and labeled.

ELEMENTS REQUIRING MAJOR ATTENTION

Prior to the Kenya study, no research had been directed
towards understanding the relationships between maintenance
policies, roadway conditions and total highway and user costs.
Considerable study still is required in this area.

More verification between experimental results relating
user costs to roadway geometrics and conditions are needed.
This is particularly true related to tirewear, vehicle
maintenance and depreciation. Also, user relationships need
to embrace a wider range of vehicle classes than was used in
the Kenya study.

Additionally, the effect of vehicle congestion on vehi-
cle speed should be accomodated in the model.

BRAZILIAN MODEL REQUIREMENTS

The majority of the Brazilian road transport network
involves rural highways with less than 5,000 average daily
traffic.

Although new roads are needed to open underdeveloped

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areas in Brazil, major investment decisions involving the maintenance and the existing system will also need to be made in the future. Reliable quantitative planning tools to make these decisions are non-existent. For this reason the Brazilian Government has undertaken with two of its major transport planning agencies research directed towards the development of interrelationships between the cost of construc tion, maintenance and utilization of the highways. This inte- rest is based on a need to have an objective highway planning tool for use in Brazil, and also on the reluctance to use relationships developed for areas unlike Brazil and therefore of questionable vailidity here.

The wide range of traffic, climate and geography encompassed by the road network in Brazil needs to be covered in the study. The scope of these conditions for the country is shown in Appendix 1.2.

Secondary Model Requirements

Recent rises in world petroleum prices and the dependancy of Brazil on oil imports (only about 1/3 produced locally) has created critical problems in the balance of payments with deep reflection on the economy and in the transport industry. To cope with the problem the government is taking several steps in a general fuel-saving policy outlined in several government documents.

The main objectives of the research are related to high- way planning. However, the data collected during research can provide primary input to evaluate many of the steps tried for saving fuel.

The research team is not committed to undertake economic studies that will lead to recommendations to the government on the fuel-saving policies. Nevertheless the output of the rese- arch can be part of the input needed to answer related questions.

1. What would be savings in fuel if the limit of speeds in all federal and state highways were reduced to the optimum level for fuel saving of the average traffic need?
2. How much expenses could be justified to enforce the reduced speed?

CHAPTER 2 - GENERAL STUDY ORGANIZATION

OBJECTIVES OF THE PROJECT

The long-range objective of this Project is both to assist the Government of Brazil in minimizing the total cost of their highway transport system and to provide the results to other countries to achieve the same benefits on a world-wide basis.

This will be accomplished by better defining the interrelationships between the three components affecting road transportation costs: 1) construction, 2) maintenance and 3) road user costs. The individual relationships for these three costs may be used separately in road analysis and/or may be combined in a mathematical model. Using such a model, it will be possible to indicate construction and maintenance strategies leading to the minimization of the sum of these three cost components, i.e., minimum total road transport costs.

The objective will be accomplished through four immediate sub-objectives which are:

(1) to establish the relationships between a) road user costs, b) road geometric standards and c) surface conditions for rural roads;

(2) to measure the relationship of road deterioration and maintenance costs as a function of pavement and geometric design standards and traffic for rural roads and climatic conditions typical of Brazil;

(3) to develop mathematical models or modify and adapt those existing for Brazilian use with parameters developed in (1) and (2) above, and

(4) to establish a capability for continuing applied highway research in Brazil.

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SCOPE OF THE STUDY

A project to accomplish the desired objectives could be undertaken at many levels. The scope of the present study is the largest yet undertaken in the field to define highway cost relationships. Funding will total approximately eight million equivalent US dollars.

Scientific and Analytical Scope

The project will develop primary data which can be used to determine the required cost relationships. These data will be obtained both by controlled experimentation, measurements, and through a well organized and documented survey procedure. Sound experimental design and survey design techniques will be established for the separate studies. This is to insure that in so far as possible, quantitative statements of accuracy can be made about the resulting models and coefficients.

Geographic Scope

The basic research will be conducted on rural highways in central Brazil, in the states of Minas Gerais and Goiás and the Federal District with sufficient satellite studies in other areas of Brazil as needed and economically feasible to provide full coverage of the factor space and variables involved. Where possible, the data and results will be presented in terms of basic variables which can be defined for and translated to rural highways anywhere in the world.

Scope of Application

The primary data, the direct analysis and the resulting models will have direct and immediate applicability in Brazil. In addition every attempt will be made to combine the results of this study with those of previous studies as indicated in

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objective 3. The models will have primary applicability in the pre-feasibility and feasibility studies of rural highway development in Brazil and many developing countries.

The data itself will be recorded and preserved in such a fashion that it can be made available to others for further analysis, testing of models or other useful applications.

Time Scope

Following three years of planning, the project began on 1 July with an initiation phase of 6 months. The primary data collection and preliminary analysis phase will last 30 months, and 6 months have been designated for final analysis and reporting. Continuation of many of the studies on road user costs and road deterioration is desirable and will improve them significantly. The project structure and equipment will be adequate to continue, and it is hoped that a means can be developed to extend certain of the data observations and reanalysis to 1982, in accordance with objective 4. At present no firm plans exist to continue past 1 March 1979.

RESEARCH APPROACH

A study of this magnitude could be approached in many ways. Our approach has been 1) to take full advantage of background information and work done by others particularly the study in Kenya, and 2) to obtain valid primary data on those important areas which need further study.

The basic research approach will be to develop and conduct an integrated research project covering relevant aspects of the highway cost interrelationships problem. Basically these involve the relationships between road user costs, pavement performance, road geometric characteristics, and pavement maintenance. Past experience and current study of the problem have shown that a judicious combination of experimental measurements and "survey" techniques will be required to

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obtain the required relationships. Measurements alone are inadequate. Certain variables such as depreciation, driver behavior and realistic costs of vehicles in actual operation do not yield to direct measurements. Yet these must be related to characteristics of the road and the pavement which are variable and measurable. Pavement performance and the effect of various maintenance strategies are measurable if care is taken and proper instrumentation is available.

All of the major factors to be determined in this study are functions of time. Thus great attention must be given to the time stability of measurements on the study such as pavement roughness or serviceability and pavement maintenance. Likewise, road user costs must be collected over a period of time and these data records must be kept in a uniform fashion for a period of 2 or 3 years.

To accomplish these tasks effectively within the project resources the user costs survey problem is being critically examined. Needed is an effective survey design which is as economical as possible in terms of resources expended per unit of information. Statisticians, experimental designers and survey economists have been called in as consultants to assist in this phase of the Project.

In terms of measurable variables we have undertaken to cover the factor space effectively and economically by using experimental design techniques which provide economical use of sample distribution and experimental units. The analysis of these statistical experiments will be complicated and require effective statistical help and computer support.

The magnitude of the study and the large number of data items generates a need for effective data management techniques. These data processing needs together with the complex statistical analysis requirements, the obvious need for computer modeling and the presentation of the final results dictate the need for strong computer support on the project.

In order to perform the measurements needed and to maintain the equipment effectively, a qualified instrumen-

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tation group is required on the project staff. They will be
active in mechanical as well as electrical instrumentation
and must develop instrumentation on the job as needed.

Research Flow Chart

Figure 2 was developed to summarize a picture of the pro-
posed research approach to the Project.

First, the general project objectives are defined. Then ,
the basic model needs, to be addressed during the project, are
identified. These include major sub-component areas of the pro
ject planning model 1) construction, 2) maintenance and 3)
road user modules. The principal variables to be addressed in
each module are also identified.

Based on these basic modules and variables a general re -
search methodology has been developed. This results in three
branches, one for road construction and maintenance costs ,
another for road user costs and a third indicating the need to
interface with and improve the existing state of the art models.

Under road construction and maintenance two functions are
shown. The maintenance expenditure information will be collected
from existing studies in Brazil. The major pavement studies will
be experimental as shown. Under road user costs two major fun -
tions are also shown: user costs surveys and user costs experi-
ments and traffic studies.

Finally, all the results from the Project will be brought
together to produce a project planning model which will then be
tested and refined to produce the best model possible. The dash
ed lines are proposed extensions of the work by the Brazil re -
search team, to be carried on if possible after the end of the
current study.

Literature Review

Initially, background literature was drawn from surveys

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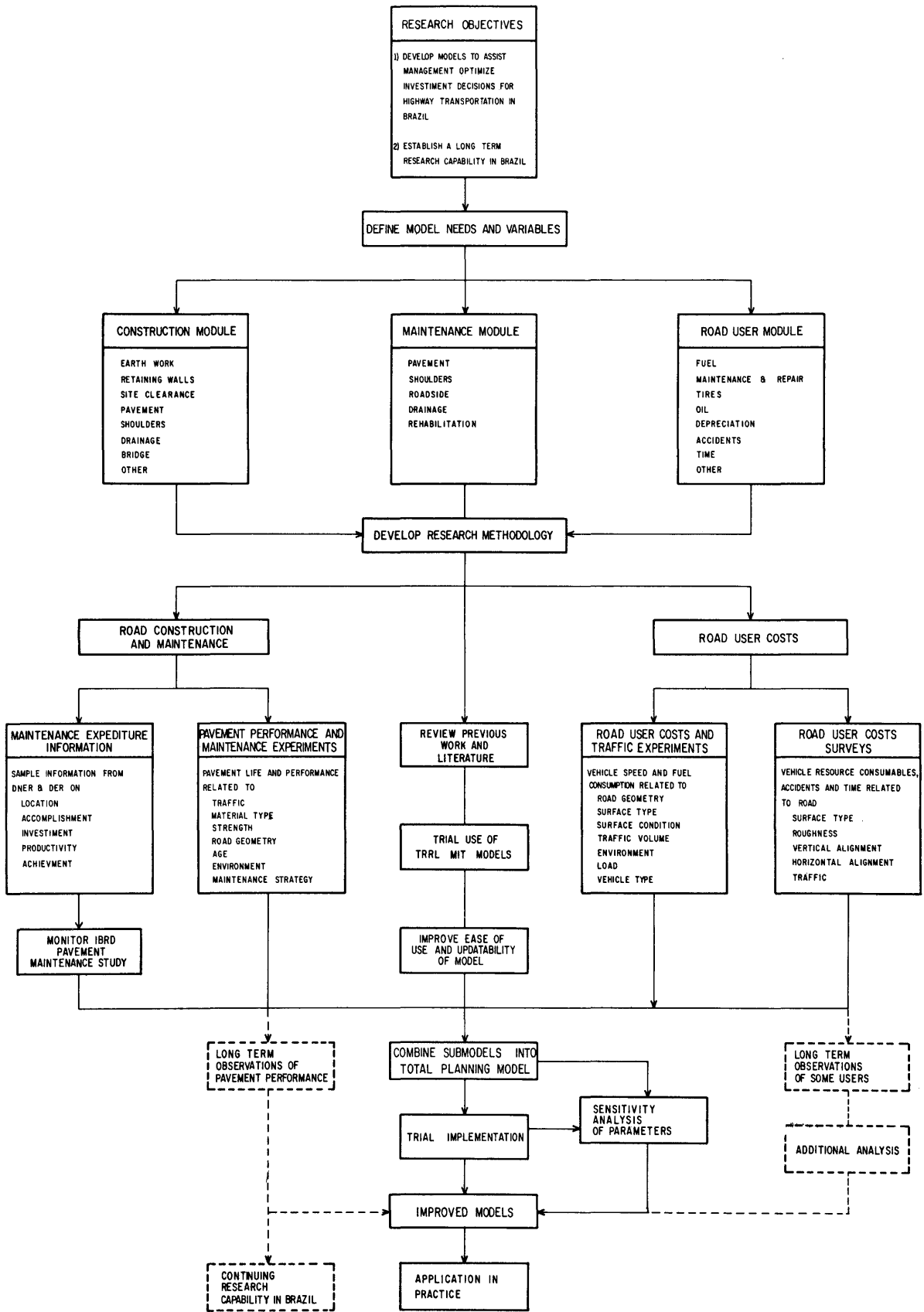
Figure 2 System Flow of the Organization of Research for the Project

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done by the World Bank, the MIT Group, and by TRRL in the Kenya Study. References to this work are presented where appropriate herein. The basic history of these developments has been presented in Chapter 1. Finally a large number of related references have been obtained also from the British Transportation and Road Research Laboratory. Likewise, a thorough search has been made through the Highway Research Information Service and up-to-date information on related topics from this source is still being received. In future project reports a complete bibliography of relevant documents will be listed for permanent reference.

The study international Director visited several relevant research laboratories all over the world in March 1975 to discuss the study, related on going research and potential personnel for the project staff. These contacts have yielded considerable literature and information for the project.

Instrumentation and Equipment

To support the research effort, available instrumentation has been studied and $ 500,000 worth of the latest and best equipment available has been purchased to carry out the required measurements programs. It was also necessary that a complete instrument development and repair shop be created to maintain the equipment. A separate chapter in this report treats the available instrumentation in detail.

In order to accomplish the measurements of road user cost variables a fleet of 8 test vehicles varying from a Volkswagen 1300 automobile to a 27-ton Scania Vabis truck has been purchased. These are discussed in detail in chapter 4.

RESEARCH ORGANIZATION

The Project is being conducted directly by a team involving input from several groups: 1) sponsors, 2) Brazilian staff, 3) expatriate staff, 4) Expert Working Group, 5) spe-

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cial consultants, and 6) cooperating international agencies.

All of these groups are important to the project and each contributes in a special way.

The Sponsors

This project is the result of an agreement signed in January'75 between the Government of Brazil and the United Nations Development Program (UNDP).

According to this agreement the Ministry of Transport of Brazil is the Government Cooperating Agency through "Empresa Brasileira de Planejamento de Transportes - GEIPOT," and the International Bank for Reconstruction and Development (IBRD) is the executing agency for UNDP.

GEIPOT is cooperating with the "Departamento Nacional de Estradas de Rodagem" (DNER) through its "Instituto de Pesquisas Rodoviárias" (IPR), and both have received grants from the "Instituto de Planejamento Econômico e Social" (IPEA) and from the "Secretaria de Cooperação Econômica e Técnica Internacional" (SUBIN), respectively. The other sponsors include the United Nations Development Program (UNDP) and the International Bank for Reconstruction and Development (IBRD). This sponsorship includes financial, physical and technological support.

Brazilian Staff

The Brazilian staff consists of professional, technical, clerical and administrative employees drawn from several government agencies and state highway departments in Brazil. They are being assembled and organized in GEIPOT offices in Brasilia under the leadership of Messrs. Jair Lage de Siqueira and Theodoro C. Lustosa. The members of the Brazilian staff are shown in Appendix 2.1

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Expatriate Staff

The non-Brazilian project staff was formed by the Texas Research and Development Foundation (TRDF) under the leadership of Dr. W. R. Hudson, technical director of the Project. The team will include ten professionals drawn from all over the world, whose talents fill a special need on the Project. Staffing details are covered later in this chapter and in Appendix 2.2 The team serves under contract to the World Bank, the executing agency for the UDNP portion of the Project. World Bank contact representatives for the Project are Drs. Clell Harral and Per Fossberg.

Expert Working Group and Special Consultants

To provide advice to the Project in technical areas of special concern we established a working group of expert advisors in statistics, economics, pavement performance, pavement maintenance and rehabilitation, vehicle operating costs, and low-cost roads. This group has met twice and is expected to meet as needed once or twice annually throughout the Project. Special consultants including both individual members of the EWG and other experts will be retained as needed to provide assistance in any Project study area.

Cooperating International Agencies

A large group of research agencies around the world have expressed interest in this research project. At present the project staff is corresponding informally with this group to keep them apprised of the project research efforts. Of primary importance of course is the TRRL group who conducted the work in Kenya, led by Henry Hide and S. W. Abaynayaka. These two men have worked with the staff on preliminary visits to the project offices in November, 1975. There have been

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several suggestions that this group be organized into an international project committee to correspond with the project staff and exchange publications, ideas and information relative to the research activity. Such a group could also be an excellent mechanism for early and rapid implementation of the results of the Project.

Project Coordination

An important part of a large complex research project such as this is coordinating it among all the agencies involved. In particular we will be dealing with existing highways which involve several Brazilian state highway departments (DER) and several districts of the federal highway department (DNER). Other government planning agencies in Brazilian and international agencies will be involved in the research and additional coordination will be required here also.

STRUCTURE OF THE PROJECT STAFF

The study approach and background dictate a staff organization which can function in three major research areas with several support functions. This basic organization was set forth by GEIPOT, UNDP and the World Bank in the original Project documents (Ref 13-15) and has been clarified further during the first 90 days of work on the project.

Three basic research units have been set up to deal functionally with the major areas of concern (figure 3).

1. Road user costs surveys group
2. Road user costs and traffic experiments group
3. Pavement performance and maintenance group

These research groups are assisted by five support functions

1. Project management and coordination group
2. Statistics and analysis group
3. Computer and data management group

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4. Instrumentation and equipment group
5. Administrative support group

For each of these eight functions, leadership is shared by the expatriate staff and the Brazilian team except in the administrative support unit which is totally Brazilian and supplied by GEIPOT.

Professional Disciplines

In assembling the research team careful attention was given to the selection of the disciplines and skills required. Ten senior professional slots were specified in the UNDP expatriate budget. These ten persons and their Brazilian counterparts must be carefully selected. Additional supporting professional staff is available through the Brazilian staff group.

Disciplines deemed essential to the study are as follows:

1. Technical Director   - Civil engineer or economist with transport research experience on large multidisciplinary projects.

2. Asst Technical Director   - Same general qualifications as Director.

3. Vehicle Operating Cost   - Transport experience preferably with operating companies.
   Specialist

4. Statistician   - Training in experimental design.

5. Pavement Engineer   - Research experience on pavement maintenance and performance.

6. Traffic Engineer   - Experience on vehicle flow and traffic studies.

7. Transport Economist   - Advanced degree with research experience.

8. Computer Specialist   - Experience in data management and program adaptation.

9. Instrumentation Engineer   - Electronic Engineer with both digital and mechanical experience.

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10. Analyst - Model Builder - Advanced degree in Statis-
tics with training or expe-
rience in computer and/or
Economics.

Each of these jobs is filled by two persons, an expatriate
and Brazilian counterpart. In this way input is made from
both sides of the team and leadership is provided to the
Project supporting staff which is all Brazilian.

Supporting Staff

To support the senior staff and to carry out the detailed
research program a group of younger professionals, technical
assistants, computer programmers, secretaries and clerical
assistants are available. It is expected that this support
group will total approximately 150 persons at the maximum
research effort.

Some of these personnel such as civil engineers, computer
programmers, and soils technicians are available. Many of the
personnel however must be hired and carefully trained to carry
out their particular job on the project. This is particularly
true of technicians to measure speed fuel consumption, and traf
fic flow, and the clerks required to carry out field surveys
of vehicle operating costs and other user costs.

We feel that an important part of this research as out-
lined in objective 4 and as emphasized in the Project docu-
ment signed by the Brazilian Government, the UNDP, and the
World Bank is to develop a trained pool of research manpower
which can continue this type of research work in Brazil in the
future. All staffing efforts will be carried out with this in
mind.

Functional Organization

As a result of the studies and requirements outlined a-
bove an organization has been set up as shown in Figure 3. The
detailed organization chart is shown in Figure 4 as of March

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PROJECT MANAGEMENT

Q.	FUNCTION / POST
1	GENERAL COORDINATOR
1	TECHNICAL DIRECTOR - UNDP
1	ASSISTANT TECHNICAL DIRECTOR-UNDP
1	SECTOR COORDINATOR (UCS)
1	SECTOR COORDINATOR (UCE)
1	SECTOR COORDINATOR (PAV)
6	

RELATIONSHIP WITH DERs (DERs)

Q.	FUNCTION / POST
1	DER/GO REPRESENTATIVE
1	DER/MG REPRESENTATIVE
1	DER/DF REPRESENTATIVE
3	

ADMINISTRATIVE SUPPORT

Q	FUNCTION / POST
2	EXECUTIVE SECRETARY
2	BILINGUAL SECRETARY
2	SECRETARY IN PORTUGUESE
1	EDITOR
2	TRANSLATOR
2	INTERPRETER
1	ADMINISTRATIVE CLERK
3	TRAINEES
7	DRIVER
22	

ROAD USER COSTS SURVEY (UCS)

Q	FUNCTION / POST
1	ROAD TRANSPORT ENGINEER
1	ROAD TRANSPORT ENGINEER - UNDP
1	TRANSPORT ECONOMIST
1	TRANSPORT ECONOMIST - UNDP
1	MECHANICAL ENGINEER
1	ACCOUNTIST
12	COST SURVEY TECHNICIAN
1	ADMINISTRATIVE CLERK
19	

ROAD USER COSTS AND TRAFFIC EXPERIMENTS (UCE)

Q	FUNCTION / POST
4	TRAFFIC ENGINEER
1	TRAFFIC ENGINEER- UNDP
1	MECHANICAL ENGINEER
1	MECHANIC
1	DRAFSTMAN
1	ADMINISTRATIVE CLERK
7	INSTRUMENTATION TECHNICIAN
2	TOPOGRAFER
4	TECHNICAL ASSISTANT
13	RECORDER
1	PHOTOGRAFER
14	DRIVER
50	

PAVEMENT PERFORMANCE AND MAINTENANCE STUDIES -(PAV)

Q	FUNCTION / POST
4	PAVEMENT ENGINEER
1	PAVEMENT ENGINEER - UNDP
1	ENGINEER ASSISTANT
1	DRAFSTMAN
1	ADMINISTRATIVE CLERK
2	LAB CHIEF
3	LAB TECHNICIAN
4	LAB ASSISTANT
17	INSTRUMENTATION TECHNICIAN
4	DRIVER
3	WORKER
41	

STATISTICS AND ANALYSIS

Q	FUNCTION / POST
1	STATISTICIAN
1	STATISTICIAN - UNDP
1	ANALYST
1	ANALYST-UNDP
1	MATHEMATICIAN
5	

COMPUTER AND DATA MANAGEMENT

Q	FUNCTION / POST
1	ANALYST
1	ANALYST - UNDP
2	PROGRAMMER
2	PERFORATING MACHINE OPERATOR
6	

INSTRUMENTATION AND EQUIPMENT

Q	FUNCTION / POST
2	ELECTRONICS ENGINEER
1	ELECTRONICS ENGINEER UNDP
3	ELECTRONICS TECHNICIAN
1	STOREKEEPER
1	DRIVER
1	MECHANIC
2	WORKERS
11	

Figure 4   Detail Organization Chart Showing Number and Title of Personnel Required for Project

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1976. This will of necessity be modified from time to time as the actual progress of the work dictates. A total of ten expatriate professionals, 18 Brazilian professionals and approximately 120 other technical staff and workers will be involved in the Project. The senior professionals are shown in Figure 5. Eight expatriates, 13 Brazilian professionals and 40 staff are on the job as of March 1976.

Road User Costs Surveys

This group will carry out one of the major functions of the Project. Their objective will be to develop realistic and analytically sound surveys for determining vehicle operating costs for all types of vehicles on a variety of Brazilian roads. They will analyse the resulting survey data for input into the overall project cost model. This work will be closely coordinated with the user costs experimental studies. The details of this work are discussed in Chapter 3.

Road User Costs and Traffic Experiments

This group will design, carry out and analyse experiments related to vehicle operating costs, speed and road characteristics. This will include operation and experimentation with the 9 test vehicles previously discussed. Tests will be conducted to determine parameters and costs for calibration and correlation with the user costs survey data, thus close coordination will be required with the user survey group. The details of this part of the Project are discussed in Chapter 4 of this report.

Pavement Performance and Maintenance Experiments

The pavement studies are aimed at determining the pavement design requirements and the construction costs for various traffic flow and load conditions. The related effects and

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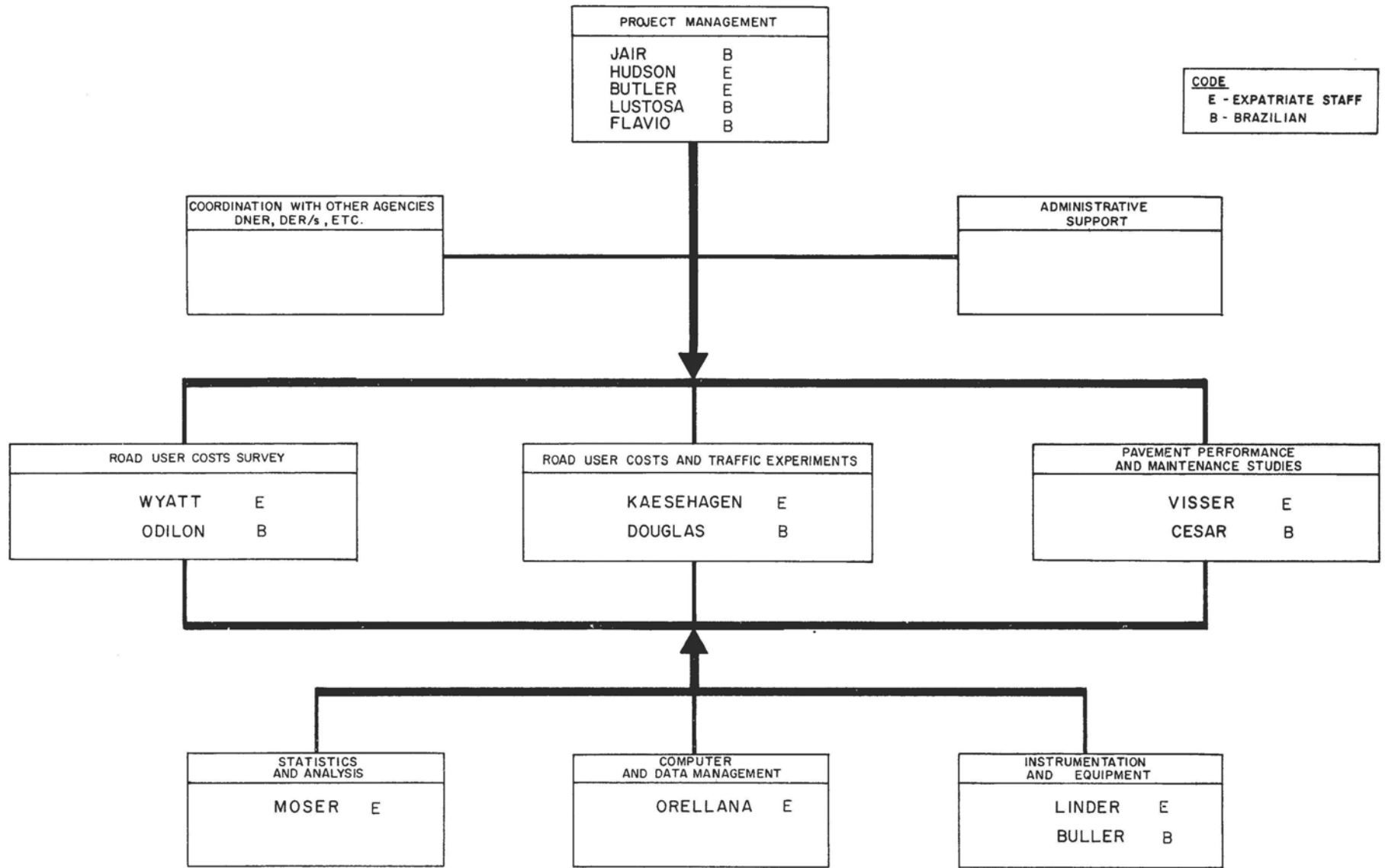
Figure 5   Senior Personnel Assignments for the Research Project

costs of maintenance and rehabilitation will also be studied
to obtain relationships and inputs into the overall highway
cost models. Instrumentation related to pavement measurements
will also be used to measure pavement inputs for the user costs
surveys and user cost experiments. The details of these
pavement studies are presented in Chapter 5.

Support Functions

In chapter 6 are discussed the support functions, particu-
larly instrumentation, computer, and statistics-analysis group.
Little additional attention will be given to the management and
administrative group which will be structured as required to
keep the Project functioning effectively. The coordination
group is made up of engineer representatives of the DNER and
the state highway departments in the States of Minas Gerais,
Goiás and the Federal District, the primary study area of the
Project. These men will assist in coordination of the research
with field units of their respective states.

GENERAL WORK PLAN

It is difficult to consolidate a specific work plan for a
project of this size which does not become long and tedious.
However, it is valuable for understanding of the overall
Project to present a summary plan of the work to be accom-
plished. This gives a general impression of the major work
items to be accomplished and their relationships to each other.
Detailed work plans for the major studies are presented in
their respective chapters with detailed time schedules and
associated information. Table 1 presents a summary work plan
which conveys the overall aspects of the work in a functional
way. No time schedule is shown there but the overall time flow
is indicated in the arrangement and statement of the work items.
A general work flow diagram is presented in Figure 6 to
convey the approximate time phasing of the Project.

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Figure 6 - General Project Work Flow Diagram and Schedule

Timeline header (top): 1975 | 1976 | 1977 | 1978 | 1979
J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F

Project Schedule

RESEARCH ON THE INTERRELATIONSHIPS

BETWEEN COSTS OF HIGHWAY CONSTRUCTION

MAINTENANCE AND UTILIZATION

March, 1976

Activities:

PREMOBILIZATION STUDIES

Setup EXPERT WORKING GROUP

Mobilize EXPATRIATE STAFF in Brazil

Coordinate the mobilization of the BRAZIL STAFF

Conduct background REFERENCE studies and set up project LIBRARY

Develop and test PRELIMINARY DESIGNS for user costs experiments and pavement studies

Identify, order, receive and check all EQUIPMENT

Set up an INSTRUMENTATION SHOP

Select TEST VEHICLES, procure and instrument

Set up a control SOILS LABORATORY

Establish COMPUTER REQUIREMENTS and arrange for COMPUTER SERVICES

Develop BACKGROUND INFORMATION on vehicle user population from records and interviews

Develop SURVEY DESIGN

Conduct survey PRE-PILOT studies

Conduct survey PILOT, analyse and report

Gather INFORMATION on possible PAVEMENT TEST SECTIONS

Select PAVEMENT TEST SECTIONS

Conduct PAVEMENT PILOT STUDIES analyze and report

Gather INFORMATION on road geometrics for USER COST EXPERIMENTS

Select USER COST EXPERIMENTS TESTS SECTIONS

Conduct PILOT STUDIES of user cost EXPERIMENTS, analyze and report

Establish COORDINATION DNER, DER'S etc.

Test and adapt TRRL/MIT highway cost MODELS

EWG draft inception report

Inception report

Pilot study report

Instrumentation report

Mid term report

Draft final report

Final report

PREPARE and EDIT reports

Collect, key punch, verify, and store project data for EDP and ANALYSIS

Begin PAVEMENT PERFORMANCE and MAINTENANCE studies, collect data, preanalyze, analyze

Begin USER COST SURVEY collect data, process, preanalyze, analyze

Begin USER COST EXPERIMENTS, collect data, process, preanalyze, analyze

Obtain periodic MEASUREMENTS on all test sections

Develop data on CALIBRATION SECTIONS to validate user cost models

Timeline footer (bottom):
J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F
1975 | 1976 | 1977 | 1978 | 1979

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TABLE 1 - SUMMARY WORK PLAN PROJECT ON INTERRELATIONSHIPS OF HIGHWAY COSTS

A - <u>MANAGEMENT AND ADMINISTRATION GROUP</u>

1. Mobilize expatriate staff in Brazil
2. Set up Expert Working Group and consultants
3. Mobilize Brazilian staff
4. Coordinate among the research and support groups
5. Provide liaison with sponsors and visitors
6. Administrate budgeting, hiring, purchasing, etc.
7. Prepare and publish reports
8. Coordinate Project in Brazil with transport agencies
9. Supervise final analysis, reporting and implementation

B - <u>ROAD USER COSTS SURVEYS GROUP</u>

1. Gather background information

    a) On national vehicle population
    b) On vehicle operators
    c) From vehicle manufacturers
    d) Develop good will and interest from vehicle-operators

2. Conduct pilot studies

    a) Conduct pre-pilot study
    b) Select pilot sample of vehicle operators, prepare
       forms and collect data

3. Set up final survey design

    a) 300-500 vehicles from
       10-30 individuals
       10-30 companies
        1-3 visits each per month
       15-25 data items
       Total 10-37,000 items per month
    b) 100-300 separate routes
       Measure roughness, geometry, traffic flow
    c) Match vehicle to route

4. Coordinate with user costs experiments

5. Process data

    a) Collect, check and compare
    b) Key punch, verify, computer process

6. Analyse data

    a) Pre-analyse data during the study
    b) Make internal checks for accuracy

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      c) Test Kenya - TRRL data
      d) Final analysis

  7. Prepare reports as required

C - <u>ROAD USER COSTS AND TRAFFIC EXPERIMENTS</u>

   1. Study available roads for test sections
   2. Establish the preliminary experimental designs
   3. Select 100-150 test sections on plans
   4. Mark & survey test sections in the field
   5. Conduct pilot studies to establish procedures
   6. Analyse results and prepare report
   7. Conduct speed studies (500-600,000 measurements)
   8. Conduct acceleration tests (3-5,000 measurements)
   9. Measure free speed (200 sites, 100,000 measurements)
  10. Conduct fuel consumption study

      a) Buy test vehicles
      b) Design loads and arrange for loading/unloading
         equipment
      c) Measure fuel consumption and speed (6-7,000 runs)
  11. Conduct traffic surveys at 144 sites
  12. Classify vehicles at 144 sites
  13. Check and computer process all data
  14. Pre-analyse data during testing
  15. Test MIT-TRRL models
  16. Conduct final analysis and build models
  17. Prepare reports as required

D - <u>PAVEMENT PERFORMANCE AND MAINTENANCE STUDIES GROUP</u>

   1. Gather information on existing roads (paved, gravel, and earth)
   2. Determine maintenance policy and design standards
   3. Design experiments (pavement, gravel & earth, maintenance overlays)
   4. Conduct pilot studies, analyse and prepare report
   5. Set up calibration course for roughness equipment
   6. Assist with instrument calibration as needed
   7. Set up control soils laboratory
   8. Study road maintenance policies and procedures
   9. Set up final experiment designs (150-250 sections)
  10. Select and mark test sections in field
  11. For each section define or measure

      a) Material properties
      b) Traffic data and loads
      c) Roughness and serviceability
      d) Deflections
      e) Distress surveys
  12. Process, ckeck and pre-analyse all data
  13. Test MIT and TRRL - Kenya Models

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14. Conduct final analysis and build models
15. Prepare reports as required

E - STATISTICS AND ANALYSIS GROUP

1. Select statistical analysis programs for computer
2. Develop preliminary designs for all major experiments (about 20)
3. Test each design with dummy data
4. Set up pilot and pilot experimental designs
5. Advise total project on statistics
6. Assist with pre-analysis
7. Lead final analysis and model building

   a) User costs surveys (4-8 studies)
   b) User costs experiments (10-14 experiments)
   c) Pavement performance and maintenance (6-10 experiments)

F - COMPUTER AND DATA PROCESSING GROUP

1. Study computer needs for the Project
2. Determine computer availability
3. Arrange for computer services and facilities
4. Hire and train personnel for data processing
5. Adapt computer statistics library for use
6. Adapt pavement analysis program for use
7. Set up data system for profilometer
8. Develop computer programs as required for project
9. Set up data management system for project
10. Check and process data for all project activities
11. Provide computer support for pre-analysis, analysis and model building

G - INSTRUMENTATION GROUP

1. Create an instrument shop and soils laboratory
2. Purchase all equipment listed

   a) Surface dynamics road profilometer system
   b) Mays road roughness meters (4 each)
   c) Road geometric survey vehicles (2 each)
   d) Dynamic scales
   e) Static scales (2 each)
   f) Traffic counters (25 manual and 10 automatic)
   g) Fuel consumption meters (5 each)
   h) Tachographs (20 each)
   i) Vehicle speed meters (4 each)
   j) Lapsed time Cameras (2 each)
   k) Dynaflect deflection device
   l) Benkelman deflection beams (6 each)
   m) Rain gauges (10 each)

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n) Stop watches (several types - 50 total)
o) Resilient modulus repeated load test machine
p) Splitting tensile test machine
q) Soils laboratory
3. Set up, test, and calibrate all equipment
4. Hire and train crews to operate equipment
5. Repair and operate equipment during 3-year study
6. Select and operate 8 dynamic scales weighing locations
7. Develop and modify equipment as required
8. Establish permanent instrumentation group for Brazil

BUDGET TABLE

     Table 2 shows the distribution of resources planned for each of eight project activities. The man/months shown reflect the total commitments of GEIPOT, UNDP and DNER. The percent total budget is based on a four-to-one professional-support ratio.

TABLE 2 — BUDGET ALLOCATION FOR BRAZIL RESEARCH ON THE INTERRELATIONSHIP BETWEEN COST OF HIGHWAY CONSTRUCTION, MAINTENANCE AND UTILIZATION

Activity Description	Professional Man/Months	Support Man/Months	Equipment US Dollars	Percent Total Budget
Administrative Coordination	189	-	-	8
Administrative Services	-	729	-	8
Computer Services	72	132	-	5
Analysis Services	172	-	-	8
Instrumentation	99	245	-	7
User Costs Surveys	239	590	208,000	19
User Costs and Traffic Experiments	227	1,172	382,000	25
Pavement & Maintenance	197	897	292,000	20

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CHAPTER 3 - ROAD USER COSTS SURVEYS

INTRODUCTION

Road user costs are of primary importance in this study, and a major portion of the total study resources will be directed towards determining these costs. Some elements of user costs can best be determined by experiment as discussed in Chapter 4. However, major effort must go into surveys of real operating costs since some factors can only be developed from real world operating conditions.

No vehicle cost Survey of this size and complexity has been attempted before. The nearest related study, TRRL's Kenya Study (Ref.9), was fairly limited in extent and in the applicability of its results. Certainly no formal methodology has yet been established for this kind of survey and questions about the methodology outlined here remain to be answered in pilot studies.

Extensive resources have already been allocated to the survey portion of the Project in terms of technical assistance from survey experts, statisticians and economists. They helped in devising and detailing the methodology, and we expect to complete the task of survey design by June 1976 after analysis of pilot survey data.

Within the road users costs surveys, emphasis is also being placed upon depreciation and vehicle maintenance costs. These are the items about which least is presently known and a significant effort in these areas should produce results more valid than the judgemental values historically used.

OBJECTIVES AND SCOPE

The overall objective of the user costs surveys is to establish relationships between various components of vehicle operating costs and road design variables, surface roughness, vertical and horizontal alignment, and for essentially low-volume rural roads. In order to do this it will be necessary

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to determine user costs for measurable road conditions so that cost differentials can be determined.

The components of vehicle operating costs being considered are 1) fuel 2) oil 3) tyres 4) maintenance parts 5) labour and 6) depreciation. Maintenance and depreciation together comprise about 50% of operating costs (see Table 3) and a major task of the Survey is to establish sound relationships for these components. Fuel consumption will be addressed in the user experiments and the results calibrated using survey data. Tyre costs comprise overall an estimated 10% of operating costs, but become a major item in heavy vehicles (see Table 2) and thus an important part of the Survey, particularly for buses and trucks.

In addition to the vehicle operating costs listed above there are several other important costs. These consist of 1) crew costs, 2) interest on capital, 3) insurance, 4) licenses and other fees, and 5) company overheads. These costs cannot be directly related to the primary independent variables of surface type, roughness, and geometry. Although cost items, they will receive only minor attention during the Survey.

Initially the Survey will be conducted in the states of Goiás and Minas Gerais and the Federal District of Brasilia. These areas should satisfy Survey needs in terms of extremes of roughness and geometry. Studies in other states may be required to determine the effects of traffic congestion on gravel roads or to obtain a wider range of depreciation data. Therefore additional satellite studies will be undertaken later to fill any gaps in the Survey as required.

During preliminary evaluations it was established that the cost of data collection must be a primary input to the survey design. Thus an evaluation must be made of the importance, or priority, of all data items, to control costs and maximize benefits. An evaluation of data collection costs will be made during the pilot study (March-June 1976) and by June a fairly objective estimate of the scope of the Survey in terms of numbers of vehicles will be available.

TABLE 3 — IMPACT OF COSTS BY COST ELEMENT AND VEHICLE CLASS, INCLUDING TAXES, ON THE VEHICLE POPULATION OF MINAS GERAIS AND GOIÁS, EXCLUDING VEHICLES IN THE URBAN AREAS OF BELO HORIZONTE AND GOIÂNIA. ANNUAL COSTS IN MILLIONS OF CRUZEIROS, DECEMBER 1975

VEHICLE CLASS	FUEL	OIL	TYRES	MAINTENANCE	DEPRECIATION	TOTAL
CAR	726	58	57	265	468	1574
UTILITY	1045	73	79	564	653	2414
BUS	176	37	69	184	180	646
TRUCK	1040	219	756	1089	792	3896
TOTAL	2987	387	961	2102	2093	8530
PERCENTAGE	35.0	4.5	11.3	24.6	24.5	100

Source - 16,17,18

Note: Figures are rounded.

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TABLE 4 - AVERAGE OPERATING COSTS FOR TYPICAL VEHICLES IN FOUR
MAIN CLASSES, BY COST ELEMENT. COSTS IN CRUZEIROS
PER KILOMETRE INCLUDING TAXES AT DECEMBER 1975

VEHICLE CLASS	FUEL	OIL	TYRES	MAINTENANCE	DEPRECIATION	TOTAL Cr$ PER KM
CAR (4 pass.)	.3102	.0250	.0242	.1135	.2000	0.6729
VW 1300 Sedan	46	4	3.5	17	29.5	100%
UTILITY (LIGHT)	.4653	.0324	.0350	.2510	.2905	1.0742
Chevrolet C 10	43	3	4	23	27	100%
BUS (36 pass.)	.4762	.1004	.1850	.4985	.4861	1.7462
Mercedes 0-362	27	6	10.5	28.5	28	100%
TRUCK - 3 axle	.4762	.1004	.3462	.4985	.3625	1.7838
Mercedes 1113	27	5.5	19.5	28	20	100%

Sources 17,18

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MAJOR COSTS ELEMENTS

Before describing the Survey design being considered for
use in the Project it is appropriate to discuss the various
elements of vehicle operating costs and examine their impact
from information already available. This is done below with
particular attention to Brazil.

Vehicle Depreciation

It seems logical to assume that vehicles which are driven
primarily on rough, unpaved roads will wear out, physically
deteriorate, and therefore depreciate in value more rapidly
than those vehicles used primarily on smooth, paved roads.
Many logical assumptions are wrong, however. If prospective
buyers had perfect information about the vehicles they were
considering for purchase, they might indeed be less willing
to buy vehicles which had been driven on rough roads, thus
forcing a lowering of their prices.

If prospective buyers do not know the history of the
vehicles they consider for purchase, having been driven on
rough roads may not affect the price of these vehicles at all.
It is an empirical question. Since we are working in a market
economy and in general accepting the price (market value) of
each commodity as its value, it would be inconsistent to try
to find some "real" or intrinsic depreciation of these vehi-
cles. We must accept their market value as their true value,
and the reduction in market value as the depreciation.

Thus there are two steps in the process of measuring
depreciation. 1) Obtain a measure of depreciation for each
class of vehicle. 2) Obtain a measure of the difference in
resale value attributable to each vehicle class having been
used under different highway conditions.

For the first item Table 5   shows calculations based on
industry data for used vehicle sales in Rio and São Paulo as
of September, 1975. More data sources are being sought and
similar calculations will be made. In most countries, auto-
mobiles seem to lose a fixed percentage of their current value
each year. In Brazil, inflation complicates these calcula -

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TABLE 5 - PERCENT OF 1975 MODEL VALUE MAINTAINED BY
EARLIER YEAR MODELS, FOR BRAZILIAN AUTOS

	1975	1974	1973	1972	1971	1970	1969	1968
FORD								
Corcel	100	85.2	75.0	63.2	54.4	46.3	39.2	–
Belina	100	85.4	74.4	64.5	55.6	47.1	–	–
Maverick	100	86.4	72.4	–	–	–	–	–
Galaxie 500	100	79.0	65.3	47.2	37.9	30.3	25.0	20.5
Rural	100	82.5	68.5	59.1	51.6	45.9	38.2	33.6
Jeep	100	86.0	75.0	63.8	55.0	47.4	42.0	38.8
CHRYSLER								
Dodge Dart	100	81.8	68.3	54.0	43.7	36.7	30.2	–
Dodge Charger	100	76.9	64.8	49.7	40.7	–	–	–
G.M.								
Opala 4 cyl.	100	83.7	70.8	58.9	50.6	43.1	36.5	–
Opala 6 cyl.	100	78.2	57.4	54.8	57.4	39.5	33.4	–
Veraneio	100	81.7	67.0	57.0	48.8	41.1	35.2	31.6
PUMA								
Puma GTE	100	81.2	71.2	62.6	53.8	48.3	41.8	35.5
V.W.								
Brasília	100	89.3	81.1	–	–	–	–	–
Kombi	100	87.1	77.0	65.3	57.3	50.9	43.7	38.5
VW 1300	100	89.9	79.9	70.6	62.0	55.9	50.3	44.4
VW 1500	100	86.2	74.4	65.3	57.4	50.9	–	–
Average Percentage	100	83.8	71.4	59.9	51.9	44.9	37.8	34.7
15% Depreciation	100	85.0	72.3	61.4	52.2	44.4	37.7	32.1

Data from Quatro Rodas "Automobile Market" report based
on sales prices in São Paulo and Rio de Janeiro. October
1975.

tions, but for automobile models which have been produced for
several years without major design changes, the prices as of
September 1975 have been used to calculate the price on that
date of each preceding model year as a percentage of the 1975
price. The data seem to indicate that autos have a resale
value approximately given by the formula

$$RV = B \ (0.85)^n$$

where   RV = resale value
           B = the base price of the 1975 model in
               September 1975
           n = age of auto in September 1975, in
               years, given by:
           n = (1975 - model year)

Similar data and calculations are needed for trucks and
buses.

The second step in the analysis of depreciation will
involve obtaining information from dealers as to the differ-
ence in resale value of vehicles which have been driven large-
ly on smooth, paved roads. This may be done through the
Delphi process of getting groups of dealers together and seek-
ing a consensus estimate, or it may be done by administering
questionnaires to dealers.

It is proposed to attempt the Delphi method, making
preliminary investigations amongst dealers in Brasilia, before
organization of a wide-spread survey, covering several areas
of Brazil. Information on depreciation will be sought from
the vehicles in the main survey, but it is considered likely,
as in the Kenya study, that relying on these alone for our
sample will yield insufficient data.

Vehicle Maintenance

Vehicle maintenance (parts and labour) is a major compo-
nent of operating costs for all vehicles (see Table 4). It
is necessary to separate the elements of parts and labour
since the relative unit costs of these items varies from time
to time and more importantly, from region to region. The

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ratio of part costs to labour costs also varies for different maintenance operations. This is illustrated in Table 6 for a city bus fleet in Bradford, England.

Maintenance consumption, unlike fuel, oil, and tyres, does not vary uniformly with distance travelled, and this makes measurement more difficult. The numerous different parts must wear out or fail in service and be replaced before consumption can be measured. Thus for study purposes a long period of time is required to measure true consumption rates. These rates vary considerably over the life of the vehicle since different items require replacement or attention at different time or accumulated travel intervals.

Possible relationships between highway characteristics and vehicle maintenance costs follow.

Vertical Geometry - the number and steepness of grades contributes to engine, clutch, gearbox and differential wear. Wear is greatest on up or plus grades but is also affected on down or minus grades. In addition, minus grades affect brake wear.

Horizontal Curvature - affects engine and gearbox wear through required speed changes. Steering gear, springs and shock absorbers are affected by sideways forces.

Surface Type and Roughness - affects every part of the vehicle in some degree, but particularly steering and suspension, electrical parts, chassis and body.

Other related factors contributing to overall mainte - nance costs during the life of the vehicles are a) driver behaviour, b) vehicle use, and c) owner's maintenance policies.

a) driver behaviour - may affect maintenance cost per km much as it does fuel consumption. Excessive speed and acceleration contribute to engine wear, hard braking to brake wear;

b) vehicle use - conditions of use affect maintenance costs. Traffic congestion, frequent loading and unloading for commercial vehicles, causing engine and brake wear, and bodywork damage, respectively.

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TABLE   6   MAINTENANCE AND REPAIRS - LABOUR COST AS A
               PERCENT OF TOTAL COSTS FOR A FLEET OF
               BUSES IN BRADFORD, UK

Item	Labour as a Percent of Total
Painting	94
Bodywork	83
Electrical	71
Chassis and Brakes	67
Engine	60
Transmission	27

Source - R. Travers Morgan and Partners, London "Costing of
         Bus Operations" Interim Report July 1974.

c) <u>maintenance policy</u> - poor maintenance and irregular
   servicing causes premature failure of parts, and
   shortens the vehicle's effective life, thus adding
   to depreciation cost as well as to parts consumption.
   Vehicle "downtime" is an important consideration for
   commercial vehicle operators, and it is often
   difficult to select an optimal maintenance policy.
   Decisions required include 1) when to remove the
   vehicle from operation for inspection and preventive
   maintenance, 2) how frequent should servicing
   intervals be to avoid costly breakdowns, and 3)
   should new or reconditioned spare parts be used
   etc. Operators usually arrive at such decisions by
   trial and error and such policies vary to suit their
   own opinions and peculiar circumstances.

<u>Fuel Consumption</u>

Fuel is a major cost element in all vehicle classes,
and remains so whether considering commercial prices or
economic or shadow prices. It is particularly important for
cars and other gasoline vehicles when considering the
commercial price, since this class (mainly private vehicles),
often subsidizes diesel vehicles (mainly commercial vehicles)
through a higher rate of fuel tax.

From a survey point of view, fuel consumption has the
following characteristics:
1) varies directly with distance travelled
2) is the simplest cost item to measure
3) variation in consumption rates reveal themselves
   quickly
4) can be used to calibrate experimental data
5) most operators keep records
6) can be used to check data on other costs items (in
   fuel consumption data is suspect, so is other data)

<u>Tyres</u>

Highway surface characteristics have a direct and
obvious effect on tyre wear since the vehicles tyres are in
direct contact with the road. Surface roughness on both
paved and unpaved roads is therefore a major factor in tyre
wear. However vertical and horizontal geometry are also

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known to have effects on tyre wear, in association with vehicle speed and direction changes causing abrasion or sloppage. Another factor, particularly important for heavy vehicles, is weight carried per axle.

Oil Consumption

Oil consumption is a relatively minor item of operating cost in all vehicles, usually representing less than 2% of total operating costs. It is probable that engine and gearbox oil consumption is much more directly related to engine wear than conditions of vehicles use.

Other Costs

a) Crew Costs - This information may be derived from operators, organizations such as National Highway Freight Transportation Association (NTC), and official sources. In general, crew costs increase with the size of the vehicle, particularly for freight vehicles but also to some extent for buses.

b) Interest on Capital - In most estimates of vehicle operating costs, an interest or finance charge is included, often lumped together, or hidden within, depreciation costs. In the present study it is hoped to derive reliable estimates for vehicle depreciation and capital on interest charges in each year of vehicle life, and a set of age spectra for each vehicle class.

c) Insurance - In most countries some form of insurance coverage is compulsory and is included as a component of vehicle operating cost. Tariffs issued by insurance companies and amounts paid by vehicle operators usually reflect the claims experience in the preceding year or few years.

d) Licences and Other Fees - Annual vehicle licences for each vehicle class can be calculated easily by reference to TRU (Taxa Rodoviária Única) tables for any year.

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e) <u>Company Overheads</u> - This item covers all other
essential items of expenditure connected with vehicle
operations not already listed above. Overheads
typically include rental costs for offices and work-
shops, clerical and management salaries, insurance
(other than vehicle insurance), accountancy fees,
power light and heat, telephones, stationery and
postage, and may include other items, such as
advertising.

SURVEY DESIGN AND METHODOLOGY

Many questions remain to be answered regarding sample
design and survey methodology. This section summarizes the
current state of the problem and accomplishments. An inten-
sive study of the survey approach and its strengths and
limitations is currently underway as outlined with our
sponsors and the Expert Working Group (EWG) in December.

Preliminary proposals for the survey design for buses,
trucks, utility vehicles and cars are also presented in this
section. These proposals will be refined and revised in the
next three months through the inputs of the experts mentioned
later and the survey group.

To effectively design a survey a wide variety of informa-
tion is required, as follows:

1) the exact objectives of the survey stated in terms of
data inputs

2) data on the vehicle population ,

3) data on route characteristics used by the vehicle
population

4) knowledge of problems likely to be encountered during
data collection.

At the present time three major activities are underway
to gain this required information. These three activities
will assist in developing an effective final survey design
for use in the road user costs surveys.

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1) Gathering background information in pre-pilot studies
2) Consultation with survey design experts
3) Testing survey instruments in "pilot studies."

Background Data Collection Techniques and Sources

In the initial interviews, many items of information will be recorded. Field personnel will first assess the operator's willingness to cooperate and secondly, his ability to do so. The following types of information will be investigated in pilot studies.

Does he keep records?

What items are recorded and how?

What items are missing?

Is information compiled separately for each vehicle?

Are routes and vehicle arrival and departure times noted?

Are tachographs used?

Are loads and passengers recorded for each trip?

Are all invoices, vouchers and receipts kept to support cost control summaries?

Will the field team have access to all supporting documents?

What checks does the operator himself carry out to ensure accurate records?

If formal records are incomplete, can they be compiled from invoices and other documents?

Can the team assist the operator to establish a reliable information system?

Where formal records are not kept, the operator will be encouraged to begin doing so and the team will assist him in setting up a cost control system, monitored by senior project personnel. Original evidence, particularly invoices, will then be checked wherever possible, rather than relying on the summary totals produced by the operator himself. Where records are kept by the operator, data will normally be taken directly from them, but only after checking the recording system for accuracy and reliability.

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Data collection will consist primarily of repeated visits with the operators of sample vehicles. Project personnel will visit each operator at least once per month to complete a set of forms designed to obtain all the information shown in Table 7 for "Interviews - Vehicle Operator's Records."

Often during the regular data collection phase the operator's goodwill will be tested to the utmost by requests for "this document," "that ledger," "those invoices," etc. Tact and patience will be required from the field team to avoid pushing too far on the one hand and to recognize on the other, the appropriate moments to make requests.

In survey terminology the field personnel must be extremely skilled at building and maintaining "rapport" with the operators, since the nature of the data sought, as well as the number of visits required for collection, will require such skills.

In addition to the vehicle operators, information will be sought from a variety of other sources. These include vehicle and tyre distributors, repair shops, NTC (National Highway Freight Transportation Association - Associação Nacional de Empresas de Transporte Rodoviário de Carga), DNER and DER's.

Physical measurements of roughness, and vertical and horizontal geometry, are extremely important to the road user costs surveys and are covered in detail in Chapter 6.

Table 7 summarizes the variables for which data will be collected and identifies for each the sources which the research team will access to obtain the data.

Consultation - Survey Design Experts

Several experts have been contacted to assist the survey team in the design and development of the survey. Presently, Mr. Paul Moore, formerly of Research Triangle Institute (RTI) and now a sampling statistician for USAID with Instituto Brasileiro de Geografia e Estatística (IBGE) in Rio de Janeiro, is contributing time and giving useful ideas under an informal exchange agreements with TRDF.

In late December 1975, Messrs. Wyatt, Odilon, Hudson and

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TABLE 7 - DATA COLLECTION ITEMS AND SOURCES

Item / Source	Independent Variables	Dependent Variables	Other information
Interviews - Vehicle Operator's Records	1. Age of Vehicle 2. Payloads, Freight and Passengers 3. Distance Travelled 4. Time Spent on Route 5. Number of Stops on Route and Time Loading and Unloading 6. Traffic Delays and Congestion 7. Vehicle Speed	Consumption & Cost of - 1. Fuel 2. Oil and Greese 3. Tyres 4. Maintenance Parts 5. Maintenance Labour 6. Accident Costs 7. Crew Time	1. Fleet Size 2. Nature of Business 3. Bus Tariffs 4. Haulage Rates 5. Vehicle Specifications 6. Other backgroung, e. g. growth, 7. Labour Hourly Rates
Physical Measurements Mays Meter Inclinometer Traffic Counters Maps	1. Traffic Volume and Composition 2. Road Surface Type 3. Roughness 4. Vertical Geometry Meters of Rise and Fall by Surface Type 5. Horizontal Geometry Degrees of Curvature by Surface Type		(Continued)

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TABLE 7 - (Continued)

Source \ Item	Independent Variables	Dependent Variables	Other Information
Other Sources - DNER DER's Vehicle Distributors Repair Shops Tyre Distributors IPR NTC	1. Traffic Volume and Composition 2. Bus Passenger Counts	1. Depreciation from Interviews and Delphi Surveys 2. Parts and Labour Costs	1. Blading frequencies for unpaved routes 2. Taxes and Duties on Fuel, Tyres, Spare Parts.

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Moser, of the project staff, and Professor Anderson, consult-
ant, spent four days discussing with Mr. Moore possible
approaches for the survey. Other meeting and telephone
conversations have taken place since that time and additional
working sessions are planned.

In addition, Dr. Wade Clifton joined the staff in early
February and has begun a study of the problems. Dr. Clifton,
a survey research economist from University of Texas, will
remain to assist the staff here until mid-April and can be
available subsequently. Prior to that time, Professors A. A.
Walters and Cheshire, consultants to the World Bank and Dr.
Rob Harrison of the University of Aston in Birmingham, England,
will arrive for discussions in late March 1976 to assist with
finalizing the survey designs.

Pre-Pilot Studies

In order to obtain necessary information for planning the
Surveys, pre-pilot and pilot study activities were planned in
December 1975. A list of the tasks for these studies is given
below. These are followed by the preliminary survey designs
for buses, trucks, utility vehicles, and cars.

Pre-Pilot Study Tasks October 1975 - February 1976

1) Interview fleet owners, NTC, vehicle distributors and
   "autônomos"   unions   to obtain background informa-
   tion on a) vehicle types, b) operating costs, c) the
   structure of the bus and freight industry, and d)
   trends in the industry;

2) Contact others likely to have an interest in the sur-
   vey: IBGE and Instituto de Pesquisas Rodoviárias(IPR);

3) Obtain vehicle population data from various agencies
   including DNER, DER-GO, SUTEG, DER-MG, DER-DF, SERPRO
   headquarters and regional offices, and NTC;

4) Visit DNER, DER-GO, DER-MG and DER-DF for information
   on characteristics of selected routes;

5) Appraise the data collection problems likely to be
   encountered from further interviews with vehicle
   owners;

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6) Design and pre-test the data collection documents.

Tasks 1-5 have been completed except for item 3 where
negotiations are currently in progress with SERPRO to supply
TRU records of vehicle population, fleet sizes and addresses
of owners in Minas Gerais, Goiás and the Federal District.
Task 6, the initial design of the documents has been completed
(see Figures 7, 8, and 9) and pre-testing will commence on 9th
March in a short data collection exercise.

Pilot Studies

The primary objective of the pilot studies as outlined
below is to test the practicality of the survey designs for
efficient selection of vehicles whose routes have the required
discrimination in the independent variables 1) surface type,
2) roughness, 3) vertical geometry and 4) horizontal geometry.
The number of companies and vehicles selected for actual data
collection will be small, probably four or five companies, one
or two "autônomos", and a total of 30 or 40 vehicles. Because
of the short time span, 3 months, the data collected is
unlikely to yield positive results for prediction equations.
However the data collected will be sufficient to fulfill the
second major objective, to provide the team with experience
in data collection, coding and analysis, and evaluation of
data collection costs, as an input to the main survey design.

Pilot Study Tasks March-June 1976
   1) Assemble vehicle population data for buses, trucks,
      utility vehicles and cars and array with corresponding
      available data on route characteristics;
   2) Select pilot-study participant companies in a first-
      stage sample (see below under section "Preliminary
      Survey Designs");
   3) Obtain more detailed information on road characteris-
      tics for the companies' routes;
   4) Select a second-stage sample of participants and
      check routes with the Maysmeter;

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CONTROLE MENSAL DE DESPESAS

MÊS [ ] ANO [ ]

NOME DA EMPRESA

VEÍCULO NÚMERO   MARCA

TIPO DO VEÍCULO   MODELO

PLACA   ANO FABRICAÇÃO

ROTA USADA   CÓDIGO

CONSUMO DE COMBUSTIVEL

VELOCÍMETRO	DIA	CONSUMO		VELOCÍMETRO	DIA	CONSUMO	
		LTS	Cr $			LTS	Cr $
							TOTAIS

ÓLEO DO MOTOR

VELOCÍMETRO	DIA	CONSUMO		VELOCÍMETRO	DIA	CONSUMO	
		LTS	Cr $			LTS	Cr $
							TOTAIS

GRAXAS

VELOCÍMETRO	DIA	CONSUMO	
		KG	Cr $
	TOTAIS		

OBSERVAÇÕES

OUTROS ÓLEOS

ABREV. ÓLEO	VELOCÍMETRO	DIA	CONSUMO	
			LTS	Cr $
			TOTAIS	

Figure 7   Data Collection Document for Fuel, Oil and Grease. Note. Actual Size is 18 x 28 cm.

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CONTROLE DE PNEUS

NOME DA EMPRESA: _____ MÊS: _____ ANO: _____

VEÍCULO Nº: _____ PLACA: _____ MARCA: _____

TIPO DO VEÍCULO: _____ MODELO: _____ ANO FABRICACÃO: _____

ROTA USADA:

| NÚMERO | ESTADO DO PNEU | INSTALAÇÃO | | RETIRADA | | OBSERVAÇÕES |
		VELOCÍMETRO	DATA	VELOCÍMETRO	DATA	

CÓDIGOS:

ESTADO DO PNEU
NOVO
RECAPADO

OBSERVAÇÕES
PARA OUTRO VEÍCULO
PARA RECAPAGEM
INUTILIZADO

Figure 8 Data Collection Document for Tyres Note. Actual size is 21 cm x 26 cm.

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CONTROLE DE SERVIÇO DE OFICINA

NOME DA EMPRESA		MÊS	ANO
VEÍCULO NÚMERO	MARCA	PLACA	
TIPO DO VEÍCULO	MODELO	ANO FABRICAÇÃO	

| ROTA USADA | | CÓDIGO |

VELOCÍMETRO	DIA	CAUSA DO SERVIÇO	CÓDIGO SERVIÇO	REFERÊNCIA	MÃO DE OBRA		VALOR PEÇAS	CUSTO TOTAL
					Nº HORAS	Cr $		

TOTAIS

OBSERVAÇÕES

Figure 9 Data Collection Document for Maintenance Parts and Labour.
Note. Actual Size is 17 x 29 cm.

5) Conduct initial interviews on routes, vehicles and records available;

6) Arrange programme of visits and commence data collection;

7) Code data inputs;

8) Develop specifications for output programmes;

9) Analyze data;

10) Conduct progress checks and monitor data collection costs;

11) Develop pilot study report including final proposals on survey design.

PRELIMINARY SURVEY DESIGNS

The States of Goiás and Minas Gerais together have a population of approximately 3,455 intercity buses, owned by 375 companies and operating on 1,300 lines, totalling about 100,000 kilometers in route length (Ref. DER-GO and DER-MG). The distribution of bus company fleet sizes is shown in Figures 10 and 11. In addition, there are approximately 2,500 buses operating on urban routes which will not be considered for purposes of this study. In these two states there are also 258,000 cars, 98,100 utility vehicles, and 48,500 trucks (Ref. 16).

Given vehicle populations of these sizes, which for all classes represent about 10% of the Brazilian total, we hope to be able to locate sufficient numbers of vehicles operating on extreme route conditions.

Preliminary Survey Design - Buses

There is a probability that if a company has a large number of routes then for operational reasons the buses will change routes quite frequently. In general, the larger the number of routes and buses, the greater the likelihood of frequent route changes for any vehicle. This mixing of the effects of route characteristics will make it difficult to find vehicles operating consistently under extreme route conditions of roughness or geometry during the 30-month data collection period. Therefore companies will be stratified on

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programme of roughness measurements. Additional companies will be selected if the initial sample routes do not adequately cover the expected range of roughness.

A final selection of buses will be made by contacting the companies to request their cooperation in data collection. An initial questionnaire will be completed to check route data, and compile details of each fleet, checking vehicle age spectra. Companies will be oversampled to allow for non-cooperation, or inadequate cost records, and vehicles over-sampled to allow for accidents and vehicle disposals.

Preliminary Survey Design - Trucks, Utility Vehicles, and Cars

Unlike buses, where much useful information has been made available from the records of DNER and other agencies, far less initial information is available for trucks, utility vehicles and cars. While most buses, or bus companies, have defined routes, the majority of trucks, utilities, and cars, do not. Furthermore, no published information is available on those who may operate regular trips on defined routes. Thus the task of finding vehicles traversing mostly routes of a homogeneous nature becomes difficult.

Geographic stratification will be used to classify road usage as mostly paved, unpaved or mixed. Centers of population will be classified by size, and grouped in a number of geographic areas according to distance from the main paved road networks. Large population centers are normally closer to paved roads. However a number of towns in northern Minas Gerais have already been noted which are up to 200 km from the nearest paved roads. Four centres of between 5 and 10 thousand people and one between 10 and 50 thousand have been identified.

Estimates based on vehicle ownership (see Table 8) indicate perhaps 500 cars, 250 utilities, 40 buses and 130 trucks as the vehicle universe in this "mostly unpaved" region.

A register of the vehicle universe, at least for the main study area, is considered essential and is being obtained through DNER, from TRU records held by SERPRO on magnetic tapes. From the TRU records, owners names and

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TABLE 8   -   VEHICLE OWNERSHIP

VEHICLE PER 1,000 OF POPULATION					
	GOIÁS	MINAS GERAIS	FEDERAL DISTRICT	BRASIL	KENYA
CARS	12.9	17.0	73.0	31.0	6.4
UTILITIES	5.4	6.4	13.4	8.4	4.1
BUSES	0.25	0.45	1.5	0.55	0.30
TRUCKS	2.1	3.3	3.9	4.8	1.6

Notes:

1) Vehicle figures TRU 1974. Population figures
    for Brazil from the 1970 census plus 10%.

2) Kenya population estimated as 10 million.
    Vehicles figures for 1973 from TRRL
    Report 672.

3) Cars - Compare:

    Western Europe - 1970, 228 per 1000
    U.S.A.   - 1970, 434 per 1000

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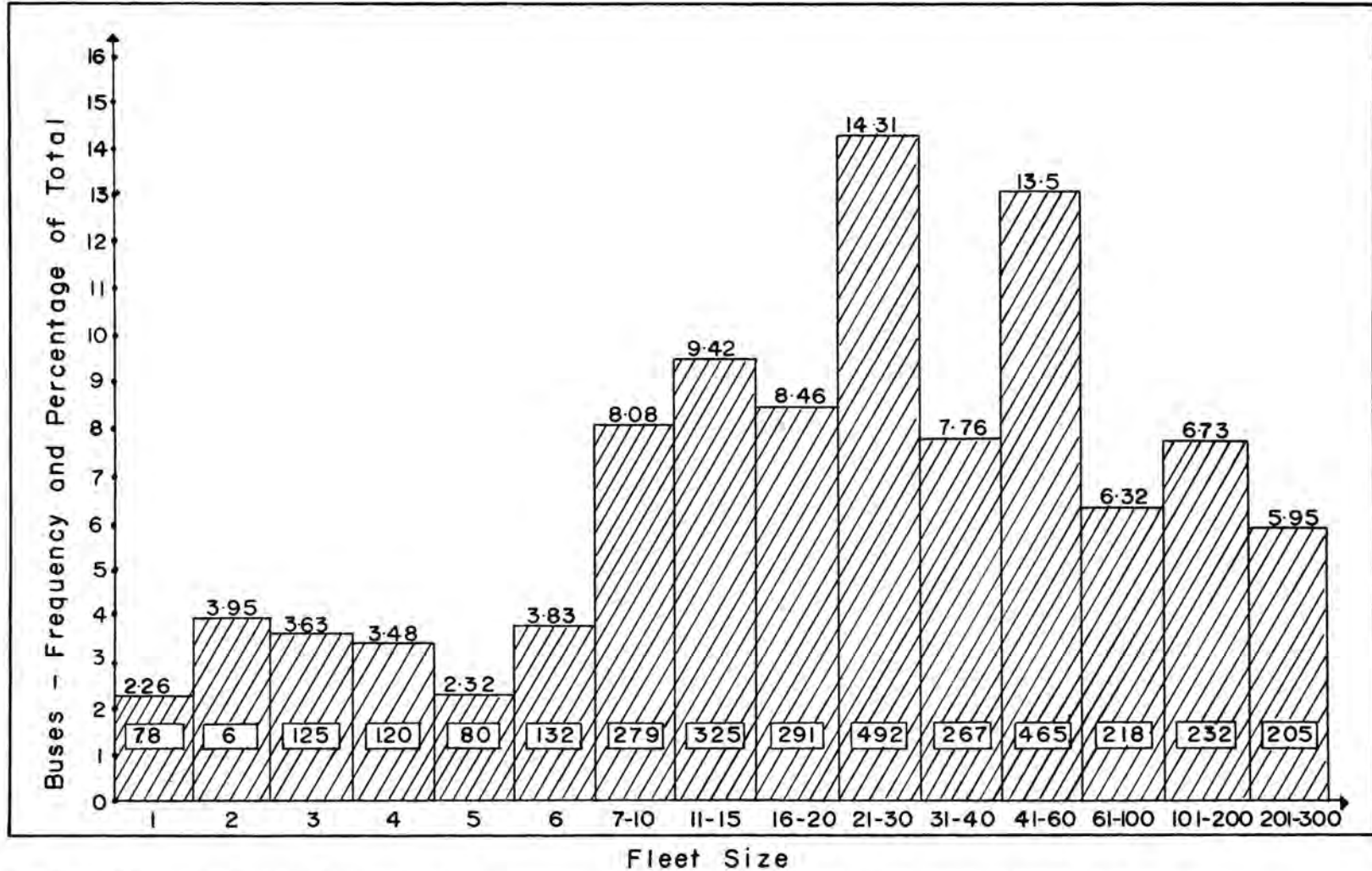
Figure 10 - Percentage and Frequency Distribution of Bus and Fleet Size for Intermunicipal Companies in the States of Goiás and Minas Gerais.

61-100 101-200 201-300

...terminucipal

...nas Gerais,

the basis of whether their routes in general are "mostly paved", "mixed", or "mostly unpaved". The total length of each route will be divided into paved and unpaved. These totals will be summed for all routes and the total route length of each company expressed as total kilometers and percentage unpaved. Paved and unpaved sections of each route will be multiplied by trip frequency (number of buses per week) and the totals of paved and unpaved for all routes summed again. The total vehicle distance travelled will be expressed as total kilometers and percentage unpaved. This may be a more useful figure than total route length since it characterizes the average amounts of paved and unpaved travel for any vehicle. We can now stratify each company into "mostly paved," "mixed" and "mostly unpaved" on the basis of vehicle distance travelled.

The companies will be stratified based on operating locations into geographic regions characterized as mostly hilly or mostly flat, so that the first stage of sampling will have a better chance of including hilly and flat routes. The proposed strata are shown in Figure 12.

From each stratum a sample of companies will be chosen, taking medium or larger companies where possible. This will be done to obtain as many buses as possible on different route types and to reduce the number of companies to be visited during the pilot survey. A higher proportion of companies will be selected from the "mostly paved" and "mostly unpaved" strata since they represent the extreme characteristics of the routes.

The actual hilliness of the routes of each company chosen will be investigated in detail, from road profiles where available or from the 40-metre interval contour maps. The sample companies will then be stratified on the basis of "steep," "medium" or "flat" routes. At this stage a check will be made to ensure that an adequate range of vertical geometry has been obtained. The strata are illustrated in Figure 13. An initial sample of unpaved routes will be measured in different geographic areas using the Maysmeter, prior to the full

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	Mostly Paved		Middle		Mostly Unpaved	
	Companies	Nº of Buses	Companies	Nº of Buses	Companies	Nº of Buses
Mostly Flat						
Middle						
Mostly Hilly						

Geographic Areas

Figure 12 - 1st Stratification of Bus Companies by Vehicle
Miles of Travel and Geographic Area.

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	Mostly paved		Middle		Mostly unpaved	
	Companies	Nº of Buses	Companies	Nº of Buses	Companies	Nº of Buses
Flat						
Medium						
Steep						

Vertical Geometry of Routes

Figure 13 - 2nd Stratification of Bus Companies by Vehicles
Miles of Travel and Measured Vertical-Geometry.

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addresses and vehicle fleet details being stratified into "mostly unpaved," "mostly paved" and "mixed" regions.

Fleet Size Stratification - The maintenance policies and thus total operating costs of the"autônomo" class and large companies ("empresas") may be significantly different regardless of what type of roads they use. Therefore although from previous experience it seems easier to collect data from large companies, for prediction purposes"autônomos" should be included. However, from a sample of about 200 roadside interviews undertaken by DNER in Goiás it appears that the overhelming majority of "autônomos" routes cover very large areas of Brazil and are of such a mixed character as to make them useless for survey purposes. A very small percentage of the sample appeared to operate regularly on the same routes for short periods. It is probable that such operators have sub-contract agreements with large companies and thus information about"autônomos" on regular routes may best be obtained from large companies.

Initially 6 strata will be identified, except for cars, where there is no fleet size distinction.

1. Empresas   -   Mostly Paved
2. Autônomos   -   Mostly Paved
3. Empresas   -   Mixed Routes
4. Autônomos   -   Mixed Routes
5. Empresas   -   Mostly Unpaved
6. Autônomos   -   Mostly Unpaved

From these strata, samples will be chosen. The extremes will be oversampled particularly on "mostly unpaved," where both fleet sizes and the range of vehicle types are likely to be smaller. At this first stage we will ensure that vehicle classes and types are covered.

Direct Contact with Owners - Unlike the bus survey, no information about routes is known. Therefore the sample owners will be interviewd using a questionnaire. They will be asked to give details of vehicles routes and frequency of use, and to give ratings along a scale for roughness, hilli-

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ness, and curviness. The questionnaire will assist in giving owners a feeling that their opinion is worthwhile · and may encourage a willingness to cooperate in the research when subsequent contacts are made for data collection.

Second-State Sample - From the analysis of the questionnaire a second-stage sample will be taken, stratified by route classification. It is likely at this point that some owners may change from the strata in the first-stage, geographic stratification. This is more likely for long distance operators. In any event long distance routes may be dropped because of measurement difficulties and because they are far less likely to be of a homogeneous nature.

Final Sample - Based on the previous stratification and the questionnaire results, final sampling would proceed in the same way as for buses. Many trucks may have routes in common with buses so that information from route measurements with the Maysmeter may be available, together with additional measurements taken as required.

SAMPLE DESIGN - DISCUSSION OF ALTERNATIVE SAMPLING APPROACHES

Any survey effort consists of five sequential phases: 1) sampling selection; 2) questionnaire design; 3) field work; 4) coding; 5) analysis. This effort is still on phases 1 & 2. Decisions made at each phase limit the options at all future phases, so the analysis required must be anticipated before making decisions about any previous phase. This is now being done on this Project. Presently a choice must be made between alternative sampling techniques, and the choice has serious implications for future analysis plans. Although many sample designs are possible, preliminary calculations and discussions have focused attention on three alternatives: 1) a probability sample of vehicles; 2) a quota sample of vehicle-route patterns; 3) a combination of these two. Below is a cursory discussion of each with the major attendant implications described briefly.

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However, one central point needs to be understood. There is no such thing as one "best" sampling design unless the study has one single objective. If the study has multiple objectives, as most do, then value judgements must be made about what weight to attach to each objective. The design effect (DEFF) is a measure of the increase in sampling error obtained in a particular type of sample over and above that obtained from a simple random sample (SRS) of equal size. Simple random samples set the standard for excellence in samples, but they are almost always too expensive to conduct. Clustered samples, are vastly more economical to draw and to use.

It is possible to calculate, post hoc, the sampling error (and hence the DEFF) for any variable obtained in a probabilistic sample. Such DEFFs have been known to range from 1.04 (very good) to 18.0 (very bad) for different variables within the same study. In this case, the first variable was the most important variable in the study, and the sample was designed to minimize its variance. It succeeded, but obviously at the expense of some of the other variables. The point of this discussion is to give some content to the statement that there is no such thing as one "best" sample design unless the study has a single objective.

What is needed in this study, then, is the establishment of a hierarchy of objectives. The overall objectives of the road user cost survey are given and discussed in the second section of this chapter under OBJECTIVES AND SCOPE. They are multiple. One class of objectives - those involving the estimation or validation of costs for such items as fuel, oil, tyres, etc.-is in conflict with another, establishing the relationships of the various components of vehicle operating costs to the main road design variables.

It is in this context that the following alternatives should be reviewed and considered.

Probability Sample of Vehicles

A probability sample of vehicles is the most conventional

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approach. A sampling frame is available from Serviço de Proces-
samento de Dados (SERPRO) in the form of a computer tape list-
ing all vehicles which have paid their Road Tax (Taxa Rodoviá-
ria Única - TRU) for 1975. There are uncertainties concerning
physical access to the tapes and processing them, but these
problems can be resolved. This type of information provides
an excellent sampling frame permitting stratification of the
vehicles by age or type of vehicle, geographic area, number of
vehicles owned by the potential respondent, etc.

If a sample of vehicles were drawn from this frame and
interviews taken with their owners, it would yield a
representative sample of all the vehicles registered in any
state. To increase the efficiency of the data collection
effort, owners of multiple vehicles could be oversampled;
or buses and trucks could be oversampled; or clusters of
vehicles could be selected from a geographically-ordered list
to prevent their being thinly spread all over the 2-state
area.

Such a sample would provide excellent population
estimates of all variables measured with easily calculated
confidence intervals. It is not clear whether it would
provide a very useful estimation of the impact of road types
on vehicle operating costs, however. This depends upon the
distribution of vehicle travel among road types. If the
sample vehicles are fairly similarly distributed in their
travel over all the different road types, then little can be
learned from them about the impact of road type on operating
costs. For example, if all vehicles did half their travel on
flat, smooth, straight, paved roads, then one could never
learn anything about the impact of such roads on vehicle
operating costs. If some spent a great deal more and others
a great deal less on such roads, then there is a good chance
of relating variations in their operating costs to variation
in the types of roads they operate on.

A major problem with using such a sample is the unknown
but probably unsurmountable difficulty of sending project
measurement vehicles over all the routes that a representa-

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tive sample of vehicles would travel. Measures of roughness, horizontal and vertical geometry are needed, and surface type for all roads travelled on by all vehicles in the sample if these road characteristics are to be used to explain varia - tions in vehicle operating costs.

A sampling approach seems ideal for providing estimates of vehicle operating costs. It is not attractive for estimating the impact of road characteristics on vehicle operating costs.

Quota Sample of Vehicles

A quota sample of vehicles with fixed, homogeneous routes is the most efficient way to estimate the impact of road characteristics on vehicle operating costs. Before defining the cells, each of which will be assigned a quota of vehicle owners, it will be helpful to review the condition under which quota samples can be useful. If enough is known about the dependent variable of interest to specify all its major determinants and if one knows how these determinants are distributed throughout the population and can classify a potential respondent readily on these major determinants, then quota sampling may be useful. It can only be useful in terms of predicting the dependent variable, and never allows one to put confidence intervals around his·predicted value for that variable. Since not every element in the population being "represented" by the sample has known, non-zero proba- bility of selection, the quota sample doesn't even meet the minimum requirements for a probability sample. One searches until he fills his quota for a cell, then accepts no more respondents in that cell Order of encounter determines probability of selection, and that probability drops from 1 to zero when the cell is filled.

Quota sampling is normally used only in political polling and marketing research but it provides a way here of filling the cells of an experimental design which was developed to estimate the impact of road characteristics on vehicle operating costs, and yields the additional benefit

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of allowing us to accept into our sample only those vehicles which operate on fixed as well as homogeneous routes. This option to exclude vehicles which run all over the country virtually guarantees the ability to send project survey vehicles to measure all the roads used by sample vehicles, thus ensuring a full complement of the major independent variables whose effects on operating costs are the purpose of the user costs survey.

By giving up legitimate probabilistic estimates of the population characteristics, one gains the kind and quantity of data he must have to use the experimental design developed to test the impact of road characteristics on vehicle operating costs. Essentially, while enough may not be known to satisfy all the criteria for using a quota sample, if the assumption that vehicle operating costs depend upon road characteristics is not borne out by the data collected to measure the nature of this dependency, then we know the assumption was wrong. If the data do show a dependency, then measures of how much and in what way each road character istics determines user costs will emerge from the analysis which shows the dependency.

The cells will be defined by the intersection of five vehicle types with sixteen road types. Eighty cells will be defined by such intersections, but some of these cells may not exist in the real world. If no vehicles can be found operating on mainly "rough-paved-straight-hilly" routes, then that cell's allocation of sample cases will be redistributed among the other cells.

Before moving on to the third alternative, it should be emphasized that we do not now know enough about how vehicle travel is distributed across all the road types to apply weights to the vehicle operating cost estimates obtained from all the cells and obtain a weighted estimate of the population mean for vehicle operating costs. We do not know enough about our study population to follow the lead of the political pollsters in this technique. Using a quota sample means giving up good estimates of the mean vehicle operating

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costs in favor of better estimates of the impact of road characteristics on these costs. It is a clear, but not a simple choice.

A Mixed Sample

The third alternative is a mixture of the previous two. Actually, it is simply combining a smaller version of the probability sample and a smaller version of the quota sample. It is an awkward compromise, but if population estimates are necessary and measuring the impact of road characteristics upon vehicle operating costs is vital, then some such compromise may be necessary.

Other Considerations

Quota samples don't provide reliable estimates of population means or distributions. Further, studying only vehicles which operate on fixed homogeneous routes, may bias the findings. Speculation about the nature and direction of such biases can be raised, but without a probability sample, nothing can really be known about them.

Consider driver behaviour. On a very familiar route it's surely different from what it would be on an unfamiliar one. Selecting vehicles operating on fixed routes may minimize the impact of surface roughness on vehicle repair costs if, for example, the driver who makes his route daily learns exactly where major bumps in the road are and avoids them.

Cumulative impact of certain kinds of stress on vehicles, if it exists, will work to bias the results in the opposite direction. One can hypothesize, for example, that the suspension system of a vehicle doesn't begin to suffer from road roughness until the shock absorbers have worn out. For the vehicle subjected to rough roads infrequently, its engine, brakes, drive train and other parts may wear out before its frame suffers any damage from its infrequent encounters with rough roads. For the vehicle which runs every day on rough roads, the suspension system may be the first part of the vehicle to need repairs. Parallel arguments could be made for the impact of other road characteristics on other vehicle parts.

But this may not be misleading. If the model is developed and implemented, the kinds of roads found most efficient in the model will, over time, become more and more common. Thus vehicle exposure to these kinds of roads will grow, and it is probably just as well to start with a measure of impact under conditions of extreme exposure.

In conclusion, the decision between quota sampling and probability sampling must be a value judgement about what the most important goals of the study are. It might be better not to think of quota sampling as sampling at all. Just calling it a process of finding real world examples of vehicle use sufficiently homogeneous to fill cells in an experimental design might be a better description. Quota sampling is a term which is almost pejorative among sampling experts, and it promises more of the benefits of probability sampling than it delivers to the uninitiated. Nevertheless, it is an accurate and brief description of one option.

WORK PLAN AND SCHEDULE

The work plan shown in Figure 14 divides the road user costs surveys into 18 separate activities within the 3 1/2 year period of the project.

In late 1978 a final report will be prepared for this study; however it is proposed that survey activities should continue in some form to provide additional long term verification of the results.

Referring to the schedule, there are some major milestone dates which mark the start or end of key activities.

1) June 1976 marks the end of pre-pilot and pilot studies and finalization of survey design and methodology;
2) In July 1976 the main survey is initiated along with data analysis;
3) In December 1976 the build up to full survey size will be completed;
4) January 1977 marks the completion of initial measurements of vehicle routes and when full definition of the range of route characteristics can be made;
5) July 1978 shows the commencement of final data analysis phase;
6) The Final Report is due in late 1978.

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TASK NUMBER	A C T I V I T Y	1975	1976	1977	1978	79
		S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F
01	Obtain vehicle user information to guide the selection of survey participants and to establish user population statistics		▨▨▨▨▨▨			
02	Interview selected users & identify the vehicles, the amount of travel & vehicle routings for all potential survey participants		▨▨▨▨▨▨▨			
03	Contact vehicle manufacturers to develop replacement frequency information on vehicle parts		▨▨▨▨▨▨▨▨			
04	Establish the information required from the user survey participants, draft & print recording documents		▨▨▨			
05	Select tentative pilot study participants and routes based on surface type travel and check geometry of routes before finalyzing pilot study participants		▨			
06	Draft specifications for computer programs to summarize user survey data		▨▨			
07	Implement the pilot study for the user survey and debug the data collection process during the initial phase		▨			
08	Visit pilot study participants at intervals to collect data		▨▨▨			
09	Identify companies having effective operational cost control and collect their historical data including tachographic data when available for comparison with user survey data		▨▨▨▨			
10	Test procedures for obtaining geometric & roughness information using pilot routes		▨▨			
11	Evaluate and revise user survey procedures based on a review of pilot study procedures, data forms, computer summaries & the results of the factorial analysis on the pilot data		▨▨			
12	Establish the final user survey design & develop an implementation schedule		▨			
13	Contact user survey participants & initiate data collection process		▨▨▨▨			
14	Data collection and follow up throughout the study period		▨▨▨▨▨	▨▨▨▨▨▨▨▨▨	▨▨▨▨	
15	Data Processing and Analysis		▨▨▨▨▨	▨▨▨▨▨▨▨▨▨	▨▨▨▨	
16	Develop geometric information on user routes from construction plans and field measurements		▨▨▨▨			
17	Obtain periodic roughness measures on user survey routes using a Mays Meter		▨▨▨▨	▨▨▨▨▨▨▨▨▨	▨▨▨▨	
18	FINAL ANALYSIS & REPORT PREPARATION					▨▨▨▨▨

Figure 14 – Road User Survey Work Plan and Schedule

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CHAPTER 4 - ROAD USER COSTS AND TRAFFIC EXPERIMENTS

INTRODUCTION

Time and fuel savings are two of the more important bene-
fits that accrue to users through road improvements. Time
savings result when road improvements reduce travel distance
and speed changes.

Many factors affect the speed adopted by a driver when
traveling on the road. The more obvious and important ones
are 1) the capacities of the vehicle and driver; 2) the geo-
metric characteristics of the roadway; 3) surface type and
roughness; 4) traffic and 5) climatic conditions.

These factors alone, or in combination, cause vehicles to
accelerate or decelerate to or from a desired cruising speed
causing in turn variations in the rate of fuel consumption.

The objective of the road user costs and traffic experi-
ments is to develop parameters to be used in a computer based
user costs simulation model for estimating the speed (time)
and fuel consumption and hence costs for each vehicle class
traversing any section of the road network.

THE SPEED/FUEL CONSUMPTION MODEL

It is assumed that details of the vertical and horizontal
alignment will be available as input to the model. With this
information it is proposed to develop time and fuel consump-
tion profiles by use of the model for each vehicle type by
working through matrices of the form shown in Table 9.

For each vehicle type four matrices consisting of accelera
tion and deceleration on positive and negative grades would
be used for each road segment for each of wet and dry condi-
tions. A road segment would be defined as being homogeneous
if there was no significant variation in surface type, grade,
width, roughness, etc., within its length. Because of the

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TABLE 9 - TYPICAL SPEED/FUEL CONSUMPTION FOR DECELERATION ON POSITIVE GRADES

GRADE % / LENGTH KM	2			3			4			N GRADE		
	SPEED *	TIME SECS *	FUEL *									
00	75	–	–	75	00		75	00		75	00	
0.1	72	4.9	.016	71			70			68		
0.2	69	10.0	.022									
0.3	66	15.4	.037									
0.4	63	21.0	.051									
0.5	60	26.9	.065									
0.6	56	33.1	.079									
0.7	53	39.8	.092									
0.8	50	47.0	.105									
0.9	48	54.5	.118									
1.0	46	62.3	.131									
1.1	45	70.3	.144									
1.2	44	78.5	.156									
Distance at which steady state speed occurs	34											

* SPEED = the spot speed at the distance shown (km/hour)
  TIME = the time taken to travel the distance shown (secs.)
  FUEL = the fuel consumption over the distance shown (litres)

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sporadic distribution and variation in the design (or safe) speed of horizontal curves, it is proposed to isolate this factor from the speed/fuel matrices. A separate highway speed profile will be developed for the horizontal alignment and this in turn will be used by the model to constrain speeds in the speed matrices for each road section.

To construct these matrices, curves of the forms shown in Figure 15 will need to be developed empirically.

It is proposed to develop the speed/length curves for free speed conditions for each vehicle type operating on any type section of the road network under both wet and dry conditions. To ensure that the speeds measured represent the free speed desired by the driver under the particular set of road conditions and climate only the speeds of isolated vehicles or those leading a platoon of vehicles will be measured.

The hourly traffic volume on any road segment may vary considerably for the 8,760 hours in a year and in general, as the volume varies so does the actual operating speed of the vehicles so that free flow conditions may not exist throughout all hours of the year.

It will therefore be necessary to establish the volume of traffic at which free flow conditions no longer exist and to incorporate a sub-routine within the model which will estimate the reduction in speed of each vehicle class for traffic volumes where free flow conditions do not exist.

In the model the hourly distribution will be specified by a histogram in terms of the number of hours during which traffic volume is, say, in the range of 0-5 per cent of Annual Average Daily Traffic (AADT) 5-10 per cent AADT, 10-15 per cent etc. as shown in a smoothed form in Figure 16. Vehicle speeds, time and fuel consumption and their corresponding costs can then be calculated for each bar of the histogram. The annual costs would thus be obtained by summing over all bars of the complete histogram. Provision would need to be made for different histograms to be specified where different seasonal variations of traffic flow occur.

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DECELERATION ON POS GRADES

ACCELERATION ON POS GRADES

ACCELERATION ON NEG GRADES

COULD BE SIMILAR
TO POS GRADES

DECELERATION ON NEG GRADES

FUEL CONSUMPTION
(litres per hour)

SPEED ON POSITIVE GRADES
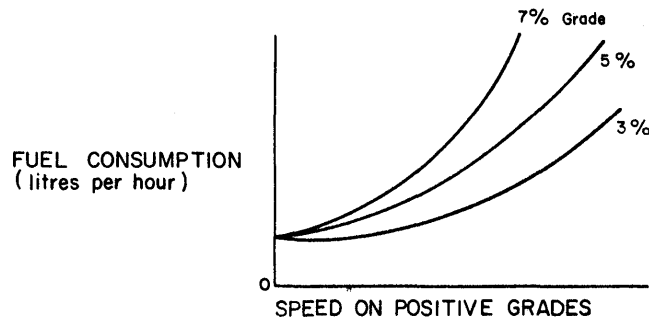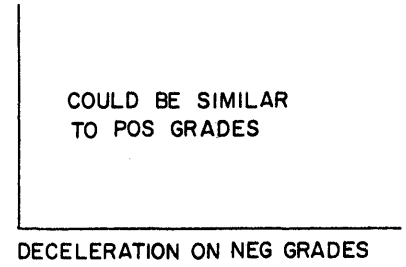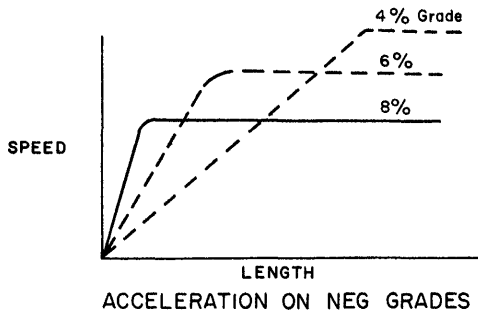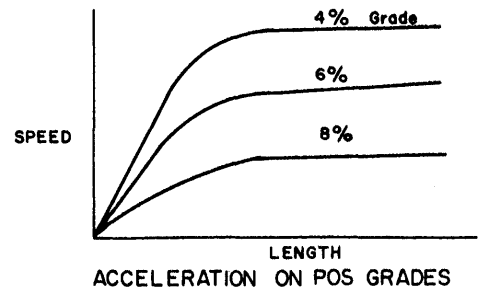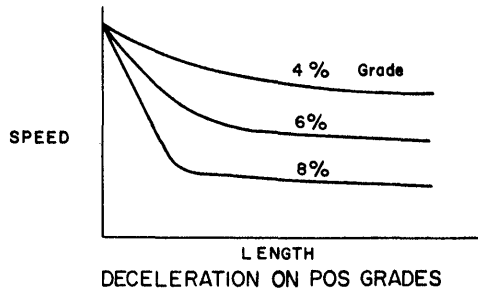
Figure 15 - Speed/length and fuel/speed curves

% AADT

Hours
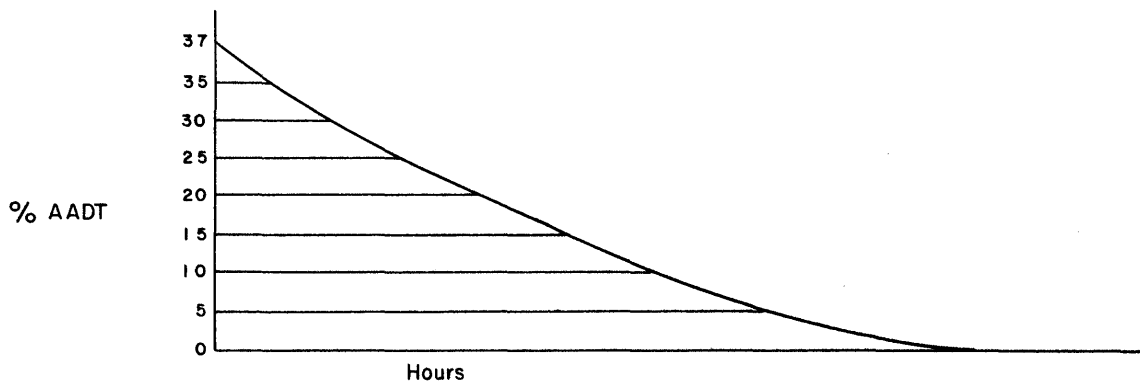
Figure 16 - Traffic Histogram

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THE EXPERIMENTAL DESIGN

As matrices and hence curves of the type shown in Figure 15 will be required for all road geometric and climatic conditions for each vehicle type, the experimental design should include all possible road and climatic parameters.

The following parameters have been identified for possible inclusion in the experiment:

a) Road Geometry

    horizontal curvature (average highway speed)

    vertical alignment (grades)

    roadway width

b) Surface Type

    asphaltic concrete (AC)

    double surface treatment (DST)

    gravel surface

    earth surface

c) Surface Condition

    roughness

    rut depth

    looseness (gravel and earth only)

    moisture content (gravel and earth only)

d) Rainfall

e) Altitude

The results of work in Kenya (Ref. 19) show that speeds are significantly reduced on roads narrower than 5.0 meters. Extensive enquiries with officers of DNER and DER in a number of states indicate that all constructed rural roads in Brazil have a minimum pavement width of about 6.0 meters and a formation or crown width of about 10 meters for unpaved roads. The width parameter has therefore been omitted from the experimental design.

The physical properties of the materials forming the surface of earth roads vary considerably within each kilometer and preclude them from use in the experimental design. However, three different types of gravel roads will be included

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to investigate significant variations in speed caused by the properties of the surface material.

Ideally each of the remaining factors should be considered at three levels in the experimental design as set out below in Table 10. This would require a minimum of 243 test sections without any repeat sections. Observation would be required at three different times on the gravel sections to cover the range of roughness and three times on all sections to obtain measurements at the three-levels of climatic environment.

Preliminary investigations in Brazil make it apparent that test sections conforming to all these conditions can not be located. Technical resources also dictate that the scale of this portion of the study needs to be reduced to a more manageable proportion.

Project Location

In order to achieve this objective it is planned to conduct the major portion of the study in the geographical area around Brasília and extending into the States of Goiás and Minas Gerais. However, to include all of Brazil within the inference space, satellite studies will be undertaken in other geographical areas of Brazil.

The sampling frame selected for the main study is shown in Figure 17.

The number of test sections required for this frame is as follows:

27   Double Surface Treated

27   Asphalt Concrete

 9   Gravel (Laterite)*

<u>10</u>   Repeat Sections

73   Total

A search of the plans and profiles of federal and state roads in D.F. and portion of Goiás indicates that most or all

---

* The same laterite gravel sections will be tested at three different levels of roughness.

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			DOUBLE SURF. TREATMENT			ASPHALT CONCRETE			GRAVEL (LATERITIC)		
			1	2	3	1	2	3	1	2	3
50-70	0-2										
	3-4										
	5-9										
80-90	0-2										
	3-4										
	5-9										
100+	0-2										
	3-4										
	5-9										

SURFACE TYPE
ROUGHNESS
VERT. PROFILE
HORZ CURV.

Figure 17 - The Sampling Frame for Main Study

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TABLE 10   FACTORS AND LEVELS FOR THE IDEAL EXPERIMENTAL DESIGN

FACTORS		LEVELS	
Horizontal curvature (average highway speed)	40-70 km/hr	80-90 km/hr	>100 km/hr
Vertical Alignment (percent grade)	0-2%	3-5%	6% - 10%
Surface Type	Asphaltic Concrete	Double Surface Treatment	Gravel 1 Gravel 2 Gravel 3
Surface Condition	Smooth	Inter.	Rough.
Climatic Condition	Dry	Light Rain	Heavy Rain
Altitude	0-200m	300-500m	700m

Note: The actual sampling frame proposed is shown in Figure 17

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of this sampling frame can be filled. However, the low volumes of traffic on the gravel roads may necessitate locating further gravel sections in the more populated areas in the south of Brazil for observation of existing vehicle speeds.

Wet vs. Dry Conditions

The sporadic distribution and relatively short duration of rain storms in Brazil will also preclude observations of speed being made on all test sections under wet conditions. However, it is intended to study dry versus wet conditions on at least a small number of sections.

Two experimental approaches will be considered. The first is a controlled design where the factor levels are narrowly specified. This is the ideal approach but may be too restrictive because of the difficulty of estimating when it will be raining on the sections. The second approach is less restrictive since the selection of sections is not controlled. Instead data will be collected for wet conditions on as many sections as possible.

A reduced experiment to test wet vs. dry conditions using the first approach would use the following factors and levels.

Factors	Levels		
Surface Type	AC	DST	Gravel (Lat.)
Roughness	Smooth		Rough
Vert. Profile (Grade)	0-2		5-9
Horiz. Curv. (AHS)	<70		>100

To obtain two roughness levels for gravel the same sections will be tested at different times. Therefore, the total number of wet test sections needed is 20.

The sampling frame for this experiment is shown in Figure 18.

The sampling frame proposed for the second approach where the sections are not controlled is shown in Figure 19.

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Figure 18 - Sampling Frame for Testing Wet vs Dry
Specified Sections

		GRAVEL		A.C		D.S.T	
		1	2	1	2	1	2
		WET / DRY					
≥100	5+						
	0-2						
<70	5+						
	0-2						

(Diagonal row labels: SURF. TYPE, ROUGHNESS, VERT. PROFILE, HORZ. CURV.)

Figure 19 - Sampling Frame for Testing Wet vs Dry
Conditions Unspecified Sections

SECTIONS	WET LENGTH			DRY LENGTH		
	2	3	4	2	3	4
1						
2						
⋮						
n *						

Satellite Study for Gravel Roads

In the main experiment the free speed measurements have been restricted to study only one type of gravel, laterite . This has been done since the areas of District Federal and Goias have gravel roads predominantly constructed with late - ritic materials. However, there is a possibility that other gravel types with the same roughness as lateritic will have different effects on free speed. Therefore, the following experiments are proposed for dry conditions only.

The sampling frame proposed is as shown in Figure 20.

DEVELOPMENT OF FREE SPEED PREDICTION CURVES
Steady State Speeds on Positive Grades

Test sections approximately one kilometer long with a transition section of 500 meters at each end of similar cha - racteristics to the test section itself are proposed for use in the development of those portions of the speed/length curves (Figure 15)within the range of speeds recorded for each vehicle type as illustrated in Figure 21.

It is considered that for positive grades most vehicle types will reach a steady state or crawl speed within the latter portion of the test sections for all grades. Speed observations will be made at three stations, entry, exit and mid-point of the test sections by use of radar speed detection meters, (spot speed). In addition space mean speeds will be calculated from the differences in times recorded at each of the three observation points.

In the event that steady state speed has not reached at the exit of the test section, i.e., the difference in speed at the mid-point is say 5 km greater than the exit speed , then the test section for the positive grade will be moved 500 meters uphill by incorporating the departure transition in the test section.

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Figure 20 - Sampling Frame for Satellite Study
for Gravel Roads
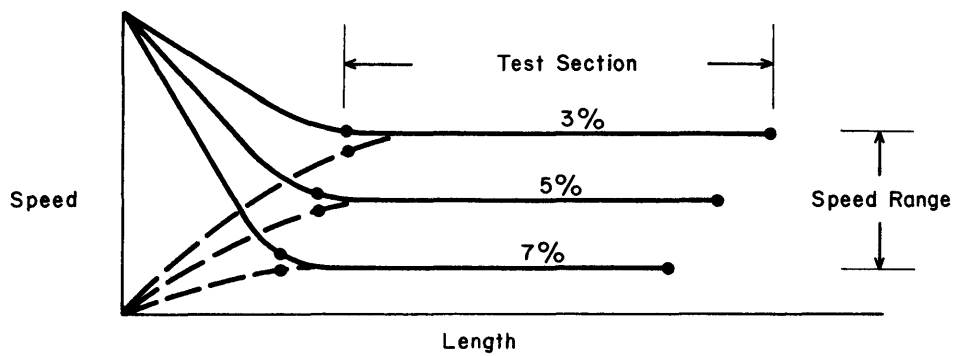
Figure 21 - Typical Speed Length Curves for Positive Grades

Development of the Steady State Speed Prediction Curves

Depending on the magnitude and sign of the grade preceeding the transition zone of the test section vehicles may be in a deceleration or acceleration phase at entry to the test section. Limited spot speed observations to date verify that some vehicle classes are still in a deceleration phase 500 meters above the base of certain grades.

The factorial matrix (Figure 17) will be used for the analysis of steady state speeds. The dependent variables to be investigated in this experiment are 1) spot speeds at each of three stations, 2) space mean speeds between the stations, and 3) the overall space mean speed.

In order to predict the steady state speeds for any vehicle class for the various road characteristics analysis of variance procedures will be used. The dependent variable, spot speed, which is measured at three stations on the test section, start, midpoint and exit will be analyzed by methods described in Appendix 4.1. It will be possible through this analysis to not only predict steady state speeds but also to verify if each of the vehicle classes is on a deceleration of acceleration phase or at its steady state speed.

The factor 'station' has to be analyzed very carefully. Two possible situations can occur. First if 'station' is a non-significant effect then the mean spot speeds are equal at the three stations, that is, the vehicle has maintained steady state speed throughout the test section. The overall mean spot for each vehicle class at these three stations will then be used as the dependent variable in regression analysis. Secondly, if 'station' is a significant effect then the mean spot speeds at each station are not all equal. If this is the case then the mean spot speeds at each station will be analyzed.

The difference will have to occur between the first station and the other two stations since the method of measuring requires steady state speed be maintained over the last subsection. Therefore the average spot speed of the last two

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stations will be used for the prediction equations. Also, if
the first spot speed is less than the second two then the
vehicle is on an acceleration phase, and if greater then the
vehicle is on a deceleration phase. The estimate for steady
state speed developed here can then be checked against the
estimates obtained from space mean speeds. If the vehicle is
on a deceleration phase the first space mean speed estimate
will be greater than the second estimate and if the vehicle
is on an acceleration phase the opposite will be true.

Deceleration on Positive Grades

    For the development of the remainder of the speed/length
curves for deceleration it is proposed to measure spot speeds
at 150-200 meter intervals commencing at the start of the
transition zone and extending within the test section to the
point where steady state speed is reached for all vehicle
classes. However, limited observations have shown that it
may not be possible to locate all test sections of a length
of two kilometers that will permit vehicles to attain maximum
free speed at the entry to the transition zone, as some sec-
tions are preceeded by positive grades of a different magni-
tude or have restricted horizontal geometry.

    It will, therefore, be necessary to locate for these
experiments additional sections of shorter length which are
preceded by negative grades and by horizontal geometry
permitting high speeds.

    The analysis procedure for the development of the speed/
length prediction equations for the deceleration phase on
positive grades will be as set out in Appendix 4.1. The
analysis of variance table there depicts the factors involved,
the only difference being that the levels of the factor 'sta-
tion' will be actual length measurements.

    The dependent variable will be spot speed while the
analysis of variance procedures will identify the significant
independent variables. Various covariates, the levels of
which cannot be controlled will also be included in the
analysis of variance. Regression analysis will then be used

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to develop the prediction equations for speed. Since the steady state speed is known from the previous experiment for any road condition it will be possible to identify the actual distance the vehicle travels on the grade before reaching steady state speed. From these two experiments it will then be possible to develop the entire speed curve for deceleration on positive grades.

Free Speeds in Other Geographical Areas

In addition to the above experiments it is proposed to measure free speeds on level smooth paved roads throughout Brazil to determine whether trip length or purpose affects speed. If there is a significant variation in free speeds at different locations, adjustment will need to be made to the maximum speeds at zero length on the deceleration curves for the various geographical areas. The sampling frame for this experimental design is shown in Figure 22 and the analysis is similar to the one presented in Appendix 1. Since all the vehicle classes are measured at each location this design is also called a split plot design (Ref. 20). The location within each geographical region form the whole plot treatments. The vehicle classes then form the split plot. Since locations within geographical regions are considered chosen at random from an infinite population of locations, the variance estimate for locations will test differences across geographical regions. The interaction of locations by vehicle class will test vehicle classes in the analysis of variance.

Acceleration on Positive Grades

For the development of the remainder of the curves for the acceleration phase two courses of action are open;

a) Stop a sample of vehicles of all classes at the start of the transition zone on all test sections and measure spot speeds in a manner similar to the deceleration measurements, or

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GEOGRAPHIC AREA / LOCATIONS / VEH CLASS	1			2			3			4		
	1	2	3	4	5	6	7	8	9	10	11	12
1												
2												

Figure 22 - Sampling Frame for Free Speeds in Different Geographical Areas

VEHICLE TYPES	1		2		3		4		5		6		7	
VEIHICLES WITHIN TYPES	1	2	3	4	5		6		7		8		9	
LOAD	L U	L U	L U	L U	L	U	L	U	L	U	L	U	L	U
ROAD CHARACTERISTICS 1														
2														
3														
4														
27														

Figure 23 - Design Matrix for Acceleration on Positive Grades

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b) Use the Project test vehicles from a dead stop at the beginning of the transition.

Ideally, the first approach should be used because the prediction equations developed from the analysis will be used to simulate actual road vehicles. However, the logistic pro - blems associated with stopping a large number of vehicles on some of the test sections may preclude this approach. There - fore, the test vehicles will be used for the development of these curves. The procedure to be used for the field measure- ments is described on page 102. Also as a check a few private vehicles will also be stopped for comparison.

For the main acceleration experimental design the following factors will be investigated:

Vehicle Characteristics	Vehicle Types Vehicles within Types Loads
Road Characteristics	Surface Types Roughness Vertical Profile Horizontal Curvature Stations

The levels of the factors are the same as those presented in Appendix 4.2 except that the stations will be identified by the actual distance along the test section. The analysis of variance matrix is shown in Figure 23.

The dependent variable to be analyzed is the space mean speed for each vehicle at the several stations along the grade. The actual analysis of variance procedure follows the methodo- logy set out in Appendix 4.2 except that some of the factors are eliminated. Once the analysis of variance procedure has identified the significant independent variables, regression analysis will be run to develop the prediction equations. It should be noted that although only a small fleet of vehicles is used, vehicles within types is considered a random effect so that the inferences can be taken across all vehicles of the types tested (refer to Appendix 4.2 for more complete explanation).

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Development of the Speed/Length Prediction Curves for Negative Grades

A preliminary study has been conducted to test the hypothesis that the speed selected by drivers on negative grades depends on the length of the grade, its magnitude and the exit conditions e.g. when a negative grade is followed by a positive grade, drivers may take advantage of the later portion of the negative grade to develop maximum momentum, consistent with the prevailing road conditions, to assist in ascending the following positive grade.

At three sites situated at the base of grades ranging in magnitude from 4 to 7% and followed by level or positive grades, continuous observations were made of the speeds of vehicles descending the grade by using a radar speed meter operated in the manual mode. In the manual mode spot speeds are not locked in as in the automatic mode but instead speed changes are instantaneously shown on the readout display.

The observations clearly demonstrated that certain vehicles, particularly loaded trucks, do pass through an acceleration phase near the base of some negative grades. In some cases loaded trucks and semitrailers reached speeds in excess of 100 km/hr from speeds of approximately 70 km/hr in the last 700 meters of the negative grade.

Research carried out in Colombia (Ref. 21) showed that vehicles, particularly loaded trucks, adopt a steady state speed in descending long steep grades, of the same order as adopted for ascending a similar grade. It is therefore important that the simulation model be able to predict when to apply the acceleration phase on negative grades.

It is proposed to conduct a pilot study with the objective of determining the speed patterns on grades up to two kilometers in length. Spot speeds and space mean speeds will be taken at 500 meter intervals along the section. Only paved sections that provide encouraging conditions for acceleration will be used in the pilot study.

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The sampling frame proposed for this experiment is shown in Figure 24.

The analysis proposed for this experiment is set out in Appendix 4.3. Based on the results of the pilot the main study design for acceleration and deceleration on negative grades will be developed.

CALIBRATION OF THE SIMULATION MODEL FOR PREDICTION OF FREE SPEEDS

It is essential that the results of simulation be compared with known real responses to the same inputs in order to verify that the modelling has been satisfactory. Validation is the process of evaluating the simulation model to determinate whether it satisfactorily predicts traffic behaviour.

It is proposed that calibration of the model will be carried out in two ways:

1) Speed observations will be made on relatively short (4-5 km) sections of roads in rolling terrain which can be monitored by observers along the route to record intermediate times and insure that free flow conditions exist throughout the section. The averages of space-mean speeds of each vehicle class will then be compared with the estimates derived from the model. It will be possible to get confidence on the free speed estimates for the whole section if the estimates for the short homogeneous subsections are added and the variances are assumed additive. If the observed average speeds for any of the vehicle classes over the whole route are outside the confidence band of the predicted equations of the model then the intermediate estimates must be investigated in detail and compared with the intermediate observed speeds. The homogeneous subsections, where the estimates are not in agreement with the observed data will then have to be retested so that the prediction equation can be developed more accurately.

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		GRADE															
		1					2					3					
		STATION					STATION					STATION					
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
REPLICATES	1															
		STATION					STATION					STATION					
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	2															

Figure 24 - Sampling Frame for Free Speeds on Negative Grades

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2) Speed profiles will be obtained from tachographs fitted to users vehicles operating on fixed routes of say 50 km in length. The speed profiles from the tachographs will be compared with profiles developed by the model for the particular vehicle class at the extreme values of the confidence band established for each homogeneous subsection.

SPEED/CAPACITY RELATIONSHIPS

Reduction in speed below free speed is in most cases caused by either;

a) delays at junctions where a certain area of carriage-way must be used alternatively by two crossing streams of vehicles; this can lead to queues of waiting vehicles. Variations between speeds of individual vehicles are of secondary importance.

or b) delays on rural roads where the variation in free speeds of various vehicle classes cause queues of vehicles to develop if overtaking is not always possible, either because of lack of overtaking sight distance or inadequate gaps in the opposing traffic stream in the case of single carriage roads.

As this Project is concerned primarily with rural roads the latter condition only will be investigated.

Operating Speed Simulation Model

Free speed profiles will be available for each homogeneous road section from the simulation process previously described. The problem then is to predict;

a) how will vehicles enter each homogeneous road section, that is, e.g. in what order and headway for each level of traffic flow, and

b) given this order, what vehicles will be restricted from travelling at free speed over what portion of the section and to what degree.

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In order to obtain an intuitive feeling for how the traffic system is operating a simulation model will be constructed using as input;

a) the free speed profiles of each vehicle class
b) the visibility profile of the road section
c) flow rate and composition of traffic
d) the directional split of the traffic.

The simulated vehicles will be initially placed in a random array on both carriageways. The vehicles will then be processed through the section using the periodic-scan method while allowing other vehicles to enter the section randomly with headways exponentially distributed.

The model will be run until a sufficiently large sample of all vehicle classes has passed through the section. The average time (speed) of each vehicle class will then be calculated. A comparison of these average speeds with the free flow speeds will indicate the traffic flow at which free speeds no longer exist for the particular road characteristics of that section.

CALIBRATION OF THE OPERATING SPEED MODEL

Field Experiment

Since capacity conditions are seldom found on unsurfaced roads, test sections will be restricted to surfaced roads. One kilometer sections will be located with the following factors and levels:

FACTOR	LEVELS		
Grades	Flat	Inter	Steep
Overtaking sight distance	None		Full
* Traffic Flow	Free flow	Medium	Heavy

* If possible the same test sections can be used by sampling
  in off-peak through to peak conditions.

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The total number of sections required is thus six. However, because of the necessity to provide an estimate of the error terms as outlined in Appendix 4.4 all sections will be duplicated.

Measurement will be taken of spot speeds at entry, midpoint and exit to the sections and space mean speeds will be determined from the differences in travel times recorded at the three observation points. In addition the traffic flow will be measured in the opposing lane using a recording counter.

Data Analysis

The following information will be obtained from these observations:

vehicle speed (spot and space mean)

headway

vehicle classification

estimate of load

traffic flow by unit time in both directions

number of overtaking manoeuvres within each subsection

These data will be analyzed using the procedures set out in Appendices 4.4 and 4.5 and the results compared with the estimates produced by the simulation model.

DEVELOPMENT OF FUEL CONSUMPTION MODELS

Selection of the Test Vehicles

Unlike free speeds where the vehicle population can, for the most part, be sampled to derive free speed prediction curves, fuel consumption curves have to be developed from measurements taken of fuel consumed by test vehicles operating over the test sections used for speed measurements. It is therefore important to select vehicles that are truly representative of the vehicle population.

To be representative the test vehicles selected should fulfill the following objectives:

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1) The range of test vehicles must cover the full range of the vehicle population from the smallest car to the largest truck.

2) As both diesel and gasoline trucks are operating on the road system, the fuel consumption characteristics of these two types should be tested.

3) There should be a sufficient number of vehicles between the smallest and largest vehicle to permit reasonable interpolation between test vehicles to cover all vehicles.

4) The vehicles selected should be representative of the rural vehicle fleet for each particular class.

5) Because of the relatively large number of buses operating on the rural roads, a bus should be included in the test vehicle fleet.

6) At least one of the vehicles should be replicated to allow a random error component to be estimated.

The following vehicles have been selected to satisfy these objectives:

1) Small Car - In order to cover a full range of vehicles it has been proposed to select a small car. There have been trends in other countries towards smaller vehicles because of the economical benefits gained, due to the increasing price of fuel. According to the production figures for Brazil 1957/1973 (Ref. 22) the Volkswagen 1300 is the most produced passenger vehicle on the road. It also has the smallest engine of the popular models.

In August 1975 40% of all passenger vehicles produced in Brazil were VW 1300's. This compares with a figure of 25% in the previous August (Ref. 23). These figures strengthen the feeling that the trend in passenger vehicles is toward the smaller car and that the VW 1300 leads the trend.

The origin - destination survey conducted on 99 road sections in Goiás in 1972-1973 only covered cargo

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vehicles. Therefore, no figures are available for this class of vehicle. It should also be noted that the origin-destination sample taken simply counted vehicles, their age and their present km readings on the odometer. The survey did not produce actual vehicle miles of travel on rural roads. Since the VW 1300 comprises such a large percentage of the population and is operating on the rural road system it has been selected as representative of the small vehicle class.

2) Pickup or Utility Vehicle (2000 kg gross weight) - In order to fill the weight range between passenger vehicles and commercial trucks, a utility vehicle has been selected. This vehicle is used in rural areas mainly for farm-to-market transport by small producers.

The VW Kombi comprises 45% of the vehicles produced in this class from 1957-1973. This trend in production is continuing since the Kombi also represents 41% of the production in August 1974 and 45% in August 1975.

Of the actual users, there are fleets of Kombies operated by small companies in rural areas. It will be possible to collect data from these companies in the road user survey and hence correlate these data with the data collected from the test vehicle.

The origin-destination survey carried out in Minas Gerais and Goiás did not count the Kombies on the road since they are not classified as open-bed cargo vehicles. The Chevrolet was the most representative vehicle of the light cargo class in this survey. However, as the weight range of vehicles in this class was very wide, it did include much heavier cargo vehicles than the VW Kombi. Therefore, when choosing a representative vehicle of this class the origin-destination figures are not directly applicable.

The VW Kombi has been selected as the utility vehicle for this class.

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3) **Light Truck (Gasoline vs. Diesel), (6,000 kg gross weight)** - This is the smallest class of vehicles where both gasoline and diesel trucks are produced. If there is a significant economical saving in the use of diesel fuel vs. gasoline in this class, then a more substantial saving can be realized in the heavy class since their fuel consumption rate is higher. However, if gasoline vs. diesel were tested in a heavier weight class and one fuel type showed economic savings over the other, the results could not be generalized to a lighter vehicle class since the fuel consumption rate is less in the smaller class. For this reason, the light truck class is chosen for testing gasoline vs. diesel.

It is essential that the two vehicles be as identical as possible in all aspects other than the type of fuel used. The Ford F-350 (gas) leads production with 45% of all vehicles of this class (based on 1957-1973 production figures). The two other most popular models in this class are the F-400 (gas) and the F-4000 (diesel). These two vehicles have just been introduced to the market recently, so that comparative production figures are not available. However based on all specifications the F-400 and the F-4000 are most similar, differing only in fuel type and engine type and weight.

Based on these similarities and a probable increased popularity of the F-400 and F-4000 these two vehicles have been selected for the light truck class.

4) **Medium Truck (11,000 kg gross weight) (Replicate Vehicles)** - The production figures for 1957/75 show that the medium truck class Mercedes Benz comprises 85% of the vehicle fleet. The origin-destination survey shows that for 99 sites checked in Minas Gerais and Goiás the Mercedes Benz accounted for over

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50% of the vehicles counted in the 11,000 kg average
gross weight class. The medium class truck will allow
the gap in weight class to be filled between the
light truck (gross vehicle 6000 kg) and the heavy
truck class (gross weight 40,000 kg). With the addi-
tion of a third axle the MBL-1113 will cover a weight
range up to 18,500 kg when fully loaded. This vehi-
cle, therefore offers a great deal of versatility to
represent a large range of weights.

By replicating the medium class truck it will be
possible to estimate the variation between two vehi-
cles of the same type, for both speed and fuel consump
tion. This variation (called within error) will be
estimated over all the road sections tested. The
differences calculated will be due to the differences
in the two vehicles themselves and will not be
related to the road characteristics. This variation
between vehicles of the same type will then be used
to test the differences due to the various road
characteristics. Dr. Anderson, the statistical
consultant to the project agrees that the replication
of at least one vehicle is necessary for these experi
ments. Since the variation between the two vehicles
of the same type will be used to test all other
effects, it is essential that the estimate be accurate.
However, this estimate variation could be different
if another vehicle, say the VW 1300, were replicated.

It is important, therefore, to have some check
which insures that our estimate of the within error
is the same for all vehicle classes. One way in
which this could be done is to repeat another vehi-
cle type across a few road sections. Preferably
this extra vehicle should be one from a lighter class
since any differences in the within error should be
most significant between the widest range of vehicle
weights. Then, two estimates of within error will be

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available for comparison. If the two are not signifi-
cantly different then the confidence in the first
estimate will be that much stronger. If there is a
significant difference between the two estimates,then
a transformation of the data is necessary to make the
two variances more homogeneous.

If this extra replication is not carried out, it
is possible that the estimated "within error" will not
be correct. In the case where the estimate is smaller
than the true within error, more of the road charac-
teristics will become significant. In the case where
the estimate is larger than the true "within error",
it is possible that some road characteristics that are
truly significant will be called insignificant.

It has been decided to purchase two MBL-1113 trucks
to represent the medium truck class and to provide
replication in this class. A project Kombi for use
for the speed observation crew can be used for repli-
cating in the light commercial class on a limited
number of sections.

5) Heavy Truck (Semi Trailer, 40,000 kgs Gross Vehicle
    Weight) - In order to cover the full range of vehicle
    weights it is necessary to include a heavy truck.
    Production figures from 1957/1975 indicate that the
    FNM has produced 56% of the vehicles in this class
    while Scania has 25%. However, between January and
    October 1975 FNM sales were 55% while Scania sales
    were 45%. The origin-destination study reported that
    68% of the vehicles in this heavy weight class
    (average sampled had gross weight of 40,000 kg) were
    Scania semi trailers. FNM recorded only 14% of the
    total. The difference in these figures is possibly
    due to the fact that the sample was taken on specific
    road sections in Minas Gerais and Goiás for one week
    on each road. The seasonal variation in kilometers of
    travel and the location of the road sections could

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have biassed the results.

Based on the gross vehicle weights of the FNM CM-200 and the Scania L-11038 and other characteristics there is little difference between these vehicles.

It was decided to select the Scania equipped with a triple axle trailer.

6) <u>Bus</u> - The Mercedes Benz represents about 85% of all buses produced in Brazil from 1957-1975. Scania, the next most popular bus is only 5% of production during that period, and current monthly production figures confirm this pattern.

The Mercedes Benz "monobloco" represents 42% of bus sales from January to October 1975 and is used almost exclusively on inter-urban travel. It has been decided to select the 0-362 "monobloco" model to represent the bus population operating on rural roads. Table 11 shows the vehicles purchased and their characteristics.

Vehicle Instrumentation

The test vehicles will be used in three forms of controlled experiments:

a) for the development of speed/length acceleration prediction curves on positive grades and, subject to the result of the pilot study, acceleration on negative grades.

b) for the development of fuel consumption/speed prediction equations for short homogeneous road sections.

c) calibration of fuel consumption with users over reasonably long routes of 50 km in length.

For experiments a) and b) all test vehicles will be equipped with:

1) a distance measuring instrument (DMI) with an accuracy of 1 meter per kilometer.

2) two stop watches.

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TABLE 11   TEST VEHICLE DESCRIPTIONS

VEHICLE TYPE	VEHICLE MAKE	TARE WEIGHT (KG)	GROSS WEIGHT (KG)	BRAKE HORSE POWER	FUEL
Passenger Car	Volkswagen 1300	780	1160	46	Gasoline
Pickup	Volkswagen Kombi	1195	2155	58	Gasoline
Light Truck	Ford 400	2277	6000	163	Gasoline
Light Truck	Ford 4000	2444	6000	98	Diesel
Medium Truck	Mercedes Benz L-1113/42	3685	18500	147	Diesel
Heavy Truck	Scania 110/38 Articulated	13470	40000	285	Diesel
Bus	Mercedes Benz 0-362 Mono-bloco	7500	11500	147	Diesel

3) a fuel gauge of the type used in the Kenya road tran-
sport cost study (Ref. 9). This gauge consists of a
250 millilitre glass measuring cylinder fitted with a
float and needle valve which allows the cylinder to
be filled with a constant quantity of fuel at all
times using an electric fuel pump. The outlet from
the cylinder is connected to a two-way fuel tap which
is, in turn connected to the vehicle fuel tank and the
feed lines feeding the engine. The system is modified
for operating on the diesel engines in order to accom-
modate the spill-over from the diesel engine. In the
case of the heavy vehicles two 500 millilitre cylinders
will be used in tandem.

4) a lapse time camera (one only to be used on all vehi-
cles) for photographing the DMI and stop watch.

For experiment (c), calibration with the road users,
those test vehicles that match the particular user will
be equipped with tachographs and fuel gauges of the
types to be installed in the users' vehicles.

FIELD MEASUREMENTS

Acceleration on Positive Grades - On all the test sections
used for the fuel consumption experiments the test vehicles
will be accelerated from a stopped start at the beginning of
the section to the steady state speed recorded for each vehi-
cle class for the particular section. The lapse time camera
will be used to photograph the distance measuring device and
a stop watch at approximately one-second intervals. The
space mean speeds thus obtained will be used in the analysis
outlined previously on page 88.

Fuel Consumption - In order to include many of the factors
that affect fuel consumption in the controlled experiment, in
particular driver characteristics and condition of the engine,
it is proposed to rotate the drivers on all the test vehicles
and to run the vehicles in both a tuned and untuned condition.

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As fuel consumption will need to be measured at three different speeds in a loaded and unloaded condition, the number of test sections has been reduced to 24 with 3 repeat sections and containning the following factors and levels:

Factors	Levels		
Surface type	Asphaltic conc.	DST	gravel
Roughness	Smooth		Rough
Grade	0-2%		5%+
Average highway speed	<70 km/hr		>100 km/hr

Each test vehicle will be driven over the one-kilometer sections at three nominated speeds to cover the range of speeds possible under the particular road and load condition. As the vehicles must travel at constant speed, two trial runs will be made at each speed to enable the driver to establish the correct gear to maintain constant speed.

At the start of the transition the distance measuring device will be started. At a reading of 500 meter (the start of the test section) the observer in the vehicle will turn on the two-way fuel tap and start the two stop watches. At a reading of 1000 meters one of the watches will be stopped and at 1500 meters the two-way tap will be turned off and the other watch stopped. The space mean speeds for the two 500-meter subsections will be compared to ensure that constant speed has been maintained throughout the section.

Data Analysis

The analysis outlined in Appendix 4.2 will be used for developing prediction equations for fuel consumption using the factors set out above.

Calibration with Road Users

Fuel consumption calibrations will be carried out in a manner similar to the speed calibration by fitting fuel meters in addition to tachographs in user vehicles operating on known routes. In addition, test vehicles which are of the same class

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as the users' will be run over the routes at similar speeds as
recorded on the user tachograph. A comparison can then be
made between the users', test vehicles and the simulation model.

WORK PLAN AND SCHEDULE

Figure 25 shows the ordering of the activities necessary
to complete the speed/fuel consumption experiments.

The table below presents the User Cost and Traffic Work Plan and Schedule as a Gantt chart spanning 1975 to 1979.

	ACTIVITY	1975 S O N D	1976 J F M A M J J A S O N D	1977 J F M A M J J A S O N D	1978 J F M A M J J A S O N D	1979 J F M
1.	Selection of Test Sections	▨	▨▨▨▨			
2.	Mark and Survey Sects.		▨▨▨▨			
3.	Design and Print Data Collection Forms		▨			
4.	Arrange Manufacture of Concrete Blocks		▨			
5.	Arrange Purchase of Test Vehicles		▨			
6.	Install Fuel Meters, DMT's, Tachographs & Camera Support in Test Vehicles		▨			
7.	Install Instrument in Inventory Vehicle		▨			
8.	Conduct Pilot Studies (a) Full Test on Two Sections. Two veh.		▨			
	(b) Acceleration & Deceleration Measurements on Negative Grades		▨			
	(c) Test Recording Equipmen for Capacity Studies		▨			
9.	Complete Inception Report	▨				
10.	Measurement of Free Speed 91 Sections (Dry) and Max. Free Speeds		▨▨▨▨	▨▨▨▨		
11.	Measurement of Free Speed 20 Sections (Wet)			* ▨▨▨ ▨▨▨		
12.	Measurement of Fuel Consumption 27 Sections		▨▨▨▨▨	▨▨▨▨▨▨		
13.	Measurement of Acceleration with vehicles 27 sections		▨▨▨▨▨	▨▨▨▨▨▨▨		
14.	Measurement of Operating Speeds(Capacity) 12 Sections				▨	
15.	Measurement of Free Speeds on Calibration Sections (3-5 kms)			▨▨▨▨▨		
16.	Measurement of Fuel Consumption on Calibration Sections			▨▨▨▨▨		
17.	Measurement of Fuel Consumption on Long Calibration Sections (Matching Speed Profile of Users)			▨▨▨▨▨		
18.	Set up Traffic Counters (Permanent and Coverage)		▨▨▨▨	▨▨▨▨▨	▨▨▨▨▨	
19.	Analysis & Compilation of Main Report		▨▨	▨▨▨▨	▨▨▨▨▨	

| S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F M |

*▨▨▨▨ intermittent

Figure 25 - User Cost and Traffic Work Plan and Schedule

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CHAPTER 5-PAVEMENT PERFORMANCE AND MAINTENANCE STUDIES

INTRODUCTION

In this research project on the interrelationship between cost of highway construction, maintenance and utilization, pavement deterioration plays an integral and important role in the minimization of road transport costs. In fact, some measure of pavement performance is the common denominator linking the three study areas of the Project. That is, pavement performance as measured by roughness is the measure of pavement life and of the effectiveness of pavement maintenance procedures. Likewise roughness affects user costs, speed, and fuel consumption. Thus the condition of the pavement surface describes both figuratively and actually the interface of the project parts or submodels.

Pavements are complex structural systems involving many variables which include various combinations of load, environment, materials, geometric layout of the road, construction and maintenance. These variable influence pavement performance, and consequently overall transportation costs. Besides attempting to determine a pavement deterioration model, a pavement maintenance model and a variety of maintenance policies will be examined to create a capability within the overall model to predict costs for a range of maintenance policies.

The proposed experimental design, and work related to the pavement performance and maintenance study is discussed in this chapter. Indications are given of the pre-pilot and pilot study work which are being carried out before the design can be finalized. Some of the variables discussed could also have an effect on other portions of the study, e.g. road maintenance could also affect road safety, but in this chapter only the effects of the variables on pavement performance and deterioration will be discussed.

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OBJECTIVES

The objectives of the pavement performance and maintenance studies are:

a. To determine a pavement performance relationship as a function of 1) structural variables, 2) materials, 3) age of road surface, 4) traffic, 5) climate, 6) rehabilitation and 7) maintenance. This relationship will be determined for roads which are as-constructed, and also for roads which have been overlayed, since the relationship may be different. The models obtained should be predictive in order that the total transport cost of different decisions can be tested. Such as when to upgrade an earth road to a gravel road, to a double surface treated road, or to asphaltic concrete surface, etc.

b. To determine a maintenance simulation model which will allo different maintenance policies to be examined. Maintenance management systems are being implemented in many areas of the world and the resulting model could be input into one of those systems.

SURFACED ROADS

The study has two main sub-parts involving asphalt surfaced roads and gravel or earth roads. Installation will be given first to the discussion of surfaced roads.

Approach

The approach proposal to the problem of determining a pavement deterioration relationship is to monitor a number of variables describing pavement behaviour, distress and performance on a number of selected test sections. Adjacent test sections will be treated with different maintenance levels. It is envisaged that each observation section will be 300 m in length, with a 100 m transition between the adjacent nil-maintenance and maintenance sections. This means that each experimental location will be 700 m in length. The 300 m length is sufficient to take measurements, and this relatively

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short length will also help reduce the random variability within the section.

Factors in the Experiment

Factors, which are defined as independent variables with specified controlled levels, are selected to cover the range of the variables which are to be studied. The factors have been selected based on 1) general observations of performance of different road sections in Brazil, 2) on the results of previous research in pavement performance and 3) also on the results obtained in the Kenya study (Ref. 10).

The factors shown in Table 12 will be considered at two levels, for which tentative limits have been set. Although ranges have been indicated for the selection of the sections, it should be understood that actual values will be measured and used in the analysis of the data.

Discussion of Factors

a) Surface type   In Brazil only asphaltic concrete and double surface treatments have been used in the recent past for surfacing roads. In general federal roads have an asphaltic concrete surfacing and state roads have a double surface treatment. Single surface treatments are normally only used for paved shoulders. Tests will be carried out on the asphaltic material.

b) Base type   In general three base types are found in Brazil, 1) natural granular material, 2) crushed stone and 3) cement treated bases. Since cement treated bases are generally found primarily in the north-east and the south of Brazil, this base type will be considered in a satellite study. Another fact which will have to be investigated further is that it appears as if crushed stone is only used with an asphaltic concrete surface, and if the surface is a double surface treatment then usually soil is added to the crushed stone. This will not, however, affect the analysis as indicated below.

c) Traffic The present ADT will be used to stratify the sections. The factor levels have been selected to cover the lowest and the highest ADT on both surface types. In addition

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TABLE 12 - FACTORS AND LEVELS PLANNED FOR SURFACED

Factors	Levels	
	1	2
Surface type	Asphaltic concrete	Double surface treatment
Base type	Natural granular material	Crushed stone
Traffic (ADT)	Low (100-500)	High (1000 +)
Vertical Geometry	Flat (0-1,5%)	Steep (4 % +)
State of rehabilitation	As - constructed	Overlayed
Age (years since last new surface)		
As - constructed	New (0-4)	Old (12+)
Overlayed	New (0-2)	Old (6+)
Maintenance	Nil-Maintenance	Maintenance at a level higher than normal

equivalent 80 kN axles will be used as a covariate as discussed below.

d) Vertical geometry   In order to investigate the effect of grades on pavement deterioration, two levels have been selected to cover the extremes of vertical geometry.

e) State of rehabilitation   The pavement deterioration relationship may be different for roads which are as - construc ted and those which are subsequently overlayed. In order to investigate the relationship for these two road states, these factors were included.

f) Age of road surface   Since total traffic or equiva- lent 80 kN axles alone do not describe the deterioration pattern of surfaced roads, the age since the last new surface will also be considered. Since overlays are generally not older than 6 years, different levels have to be used for the two states of rehabilitation.

g) Maintenance   The lower level of maintenance will essentially be a nil-maintenance strategy, and this will only consist of filling potholes with gravel, cleaning the culverts and correcting any bad slope erosion which may occur.

The decision on which standard to use for the other level has caused some problems. Three maintenance residences of the DNER have conducted a study over the last 3 years to set up the methodology for determining maintenance costs. A visit to one of these pilot residences, at Ponta Grossa, indicated that there are problems about applying the information available directly to the Project. Besides budget problems the residence also suffers from a lack of maintenance staff, and this has resulted in minimal maintenance work being carried out especially on the pavement. Only about 25 per cent of the maintenance budget is spent on the pavement where as more than 50 per cent is spent on aspects related directly to road safety. For this reason it has been decided to set a maintenance standard for the level other than nil-mainte- nance at a level which is above what is generally used. If pavement deterioration is related to the maintenance applied, then a rapid difference in performance between the two

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maintenance levels will be obtained. The exact descripton of this standard will be developed during the pilot study phase.

The information required for the maintenance model will also be captured on the test sections by having the highway authority measure the work accomplished and costs by location and then this information will be verified during condition surveys on test sections. Work standards defining the procedures and productivity for maintenance activities can be established from time-and-motion observations. Pavement maintenance activities are confined to the roadway and lend themselves to photographic monitoring with time-lapse equipment. This will be further investigated during the pilot phase.

Covariates to be Measured or Determined

Besides the factors listed above, the following covariates will be measured or determined:

a. Cumulative equivalent 80 kN axles
b. Deflection and curvature
c. Pavement strength, as a structural number.

a. Cumulative equivalent 80 kN axles Weight classification of different vehicle types on different routes will be obtained from axle load surveys and classification counts and from these the cumulative equivalent 80 kN axles on each test section will be determined. In fact four levels of classification will be used:

1) Traffic counts

2) Vehicle classification counts

3) Sampling vehicle weights by loadometer surveys by the Project and by the DNER or DER

4) Sampling vehicle weights with the WIM-IA weigh-in-motion system.

The AASHTO axle load equivalency factors will then be used. There is a problem in that the AASHTO tables do not consider 3 rear axles, but some further work will be carried out to overcome this problem. A further problem is that the historical data is a weak link in the whole analysis of

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pavement deterioration and it will always be so, since very little traffic count data or vehicle weight data is available over the life to date of many of the surfaced roads.

b. Deflection and curvature Most of these measurements will be obtained with the Dynaflect and Benkelman beam but the initial work will be done by Benkelman beam since the Dynaflect will not be available until June 1976. Correlations will also be determined between these instruments to incorporate the local practice of using the Benkelman beam into the study. In addition the deflection will be determined with the Road Rater on a few sections to obtain a correlation. It is envisaged that 10 tests per section per direction will be carried out; the feasibility of this procedure will be tested in the pilot study. There will be at least two tests per year, but on a small sample of roads in the vicinity of Brasilia tests will be conducted at monthly intervals to try to obtain a seasonal weighting factor, since the climatic and geological conditions around Brasilia are representative of those in the central plateau of Brazil. Deflection will be used in this study as the first surrogate for strength, and it can also be used as a fall back for predicting performance.

c. Pavement strength From in-situ measurements of 1) CBR, 2) density, 3) moisture content and 4) layer thicknesses, pavement strength will be determined. This may be in the form of a structural number, or in some other form which will be determined during analysis.

Dependent Variables

As outlined in several references on the subject, particularly the work by Hudson and Finn (Ref. 24,25) we will monitor the following dependent variables which will be used in the analysis:

1) Serviceability - Performance
   Serviceability index by surface dynamics profilometer
   Roughness index.

2) Distress - distress surveys
   Cracking
   Patching
   Rutting
These recordings will continue beyond the 3-year duration

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of the UNDP sponsored project, and therefore results can be
forthcoming over the entire life of many road sections.

Experimental Design

In order to develop pavement performance equations with
statistical accuracy the experimentation will be carried out
in accordance with controlled design procedures. This will
allow more reliable estimates of the results to be made while
at the same time increasing the efficiency of the data collection.

Two maintenance levels are carried out at each location
and these can consequently be accommodated within a split-plot
design and thus six factors with two levels each remain.
Normally a complete factorial is used in analysing an experiment
of this type, and for this case 64 locations would be required.
However, since there are six factors with two levels each the
full inference space can be covered with only half the effort
by statistically selecting only half the blocks of the complete
factorial design. This is termed a half replicate factorial
design. The analysis of the half replicate factorial is dis-
cussed in Appendix 5. Additionally, replicate sections should
be chosen so an error estimate can be calculated.

By having only two levels of each factor only linear
relationships between the factors and variables can be
investigated. Curvature relationships can be investigated by
using star points, which are selected at a level in between
the levels of the factors in the factorial design. The design
for curvature is also discussed in Appendix 5.

Using the designs as described above would require the
following number of locations:

From:	the half replicate factorial	32
	the 10 replicates of 32	10
	the 28 star points	28
	Total	70

If it is not possible to find the same two base types
for the different surface types, then a pseudofactorial can be
used to represent the four levels of surface and base type.
The analysis remains the same as above, but eventually the
results are interpreted in terms of the four levels. The
pseudofactorial design is also discussed in Appendix 5.

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A second major experiment will be conducted for unpaved roads. The general approach for the unpaved roads is the same as for the surfaced road experiment in that two sections of 300 m each will be used for the two maintenance levels, and these will be separated by a 100m transition. The selection of the factors has been based on the results of previous research of pavement performance with major input from the Kenya study (Ref.10).

Factors in Experiment

The following factors will be considered, and tentative limits have been indicated. Although ranges have been indicated for the selection of the sections, actual values will be measured and used in the analysis of the data.

TABLE 13. FACTORS AND LEVELS PLANNED FOR UNPAVED ROADS

Factors	Levels
Type of surface material	
Gravel	Laterite, Granite, Quartzite,
Earth	Clay, Sand
Traffic (ADT)	Low (100) High (400+)
Vertical Geometry	Low (0-1,5%) High (4%+)
Horizontal Geometry	Straight Curved
Maintenance	No blading, blading at 3-month intervals

Discussion of Factors

a) Type of surface material   In Brazil the three gravel types indicated are primarily used for the wearing surface materials on roads which are designed. On undesigned roads the surfacing material frequently does not fall within the DNER specification for surfacing materials, and from observation

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these materials result in rapid pavement deterioration. From
discussions it appears as if the quartzite and granite have a
similar performance, but this will be investigated in the
pilot studies.

   b. Traffic Unpaved roads generally have an ADT less than
700 vehicles per day, and the levels selected should be able
to cover the full range.

   c. Vertical geometry In order to investigate the effect
of grades on pavement deterioration,two levels have been
selected to cover the extremes of vertical geometry. Extremes,
i.e.,grades up to nine percent will be included in the
regression analysis.

   d. Horizontal geometry Pavement deterioration on unpaved
roads is generally worse on horizontal curves, as a result of
shear forces at the surface generating loose material and the
superelevation promoting erosion of the surface.

   e. Maintenance Maintenance on unsurfaced roads generally
only consists of blading when the surfacing layer is thicker
than about 2 cm. Roughness is therefore dependent on the
frequency of blading. On the one maintenance section the
blading frequency will be about once every three months, and
on the other section there will be no maintenance at all.

Covariates to be Measured or Determined

   Since the deterioration relationship of unpaved roads is
relatively unknown a number of associated covariates will be
used. These covariates, listed below are all readily obtainable:

   a. Average daily traffic (ADT)
   b. Percentage heavy vehicles
   c. Total weight passing over the section per day
   d. Passenger-car units (PCU)- the heavy vehicles
      are expressed as equivalent passenger-car units
      to consider pavement deterioration
   e. Number of vehicles that used the road since the
      last blading
   f. Number of days since last blading
   g. Identify which blading period we are in since
      time zero

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  h. Plasticity index (PI) and liquid limit (LL)

  i. Moisture content - to identify wet or dry season

  j. Deflection and curvature

  k. In-situ CBR of subgrade

  l. Wet abrasion test results to classify durability
   of the surfacing material

Dependent Variables

The following dependent variables will be monitored for use in the analysis:

  a. Serviceability index by surface dynamics profi-
   lometer.

  b. Gravel loss i.e. the rate at which the wearing
   course material is lost

  c. Looseness of gravel. Before the surface material
   is lost, it is loosened, and this will particularly
   affect vehicles performance especially on steep
   grades.

  d. Rut depth

Experimental design

Setting up the full factorial - In this case a full factorial will be used, i.e. all the cells in the experimental design will be filled. Although there may be 4 or 5 types of surface material this would not influence the experimental design and it would only change the number of locations from 32 to 40. Maintenance at two levels will be performed at each location and it will be considered a split plot.

Composite factorial, including star points - Since the full factorial will be used, the following locations will be required for the composite factorial analysis. It was suggested that granite and quartzite have the same performance, but until this statement has been verified the two options will be considered separate.

  a. If 5 surface gravel materials are used then the
   following locations would be required:

    40 locations for the factorial part

    35 locations for star points

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<u>10</u> locations for replicates

                          85 locations total

      b. If 4 surface gravel materials are used then the
         following locations would be required:

                          32 locations for the factorial part

                          28 locations for the star points

                          <u>10</u> locations for replicates

                          70 locations total

<u>Incomplete Factorial</u> - If it proves impossible to fill all the
cells within the experimental design, an incomplete factorial
analysis will be carried out similar to that discussed for the
surfaced experiment in Appendix 5.

SATELLITE STUDIES

      There are variables such as climate which play an
important rule in pavement performance. When these variables
are included into the experimental design they increase the
number of locations required by a product of the number of
levels, and generally these variables are also located outside
the main study area. In order to keep the experimental design
to a manageable size, these factors which occur outside the
main study area are investigated as satellite studies. These
satellite studies are independent experiments whose results
are ultimately compared with those of the main study.

<u>Cement-Treated Bases: Surfaced Roads</u>

      Cement-treated bases are generally found near São Paulo
and in the Northeast of Brazil. By eliminating this variable
from the main experiment the number of factors remaining are
of a form suitable for using a half replicate factorial design.
The sections to be selected for this satellite study will be
selected in the same rainfall area as the main experiment, i.e.
the range of 1500 to 2000mm per annum. The following experi-
ment is proposed, and it is imperative that all the cells be
filled for an analysis to be carried out (Figure 26).

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	TRAFFIC (ADT)			
	LOW		HIGH	
	VERT. GEOM.		VERT. GEOM.	
	FLAT	STEEP	FLAT	STEEP
NEW				
OLD				

AGE

Figure 26. Experiment Design for Cement Treated Bases

The Effect of Annual Rainfall on the Performance of Surfaced Roads

During the discussions with engineers in Brazil it became evident that the surfaced roads in the drier parts of the country, viz the Northeast of Brazil, performed better than in other parts of the country. This difference in performance is attributed to the drier climate. In order to study the effect of low rainfall, i.e. less then 100 mm per annum, a satellite study will be carried out in Bahia. This will consist of finding all the base - surface type combinations used in the main experiment. Only treatment combinations, i.e. levels of factors, that match those in the main part of the investigation will be used. One of these combination will be repeated to compare with the replication of the 10 sections in the main part of the experiment. The analysis of variance would then be:

Source	df
Rainfall (R)	1
Treatment comb. (T)	4
Rainfall x Trt. comb. (RxT)	4

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```
                    Within error from mainstudy (W_1)       10
                    Within error from satellite (W_2)        4
                    Maintenance (M)                          1
                    Maint x Rainf (MxR)                      1
                    Maint x Trt comb (MxT)                   4
                    Maint x Trt comb x Rainf (MxRxT)         4
                    Within error (W_1xM)                    10
                    Within error satellite (W_2xM)           4
```

The Effect of Rainfall Intensity on the Performance of Unpaved Roads

In the report on the Kenya study (Ref.10) it was indicated that rainfall intensity affects the deterioration of unpaved roads, but that a further study of this topic would be required. The effect of rainfall intensity on the deterioration of unpaved roads will be studied in a satellite study which is to be carried out in the same geographical area as the main study using some of the locations of the main study. It is envisaged that initially eight laterite sections in the vicinity of Brasilia will be studied. These sections will consist of two levels of traffic, vertical geometry and horizontal geometry. The rainfall per day, which will be used as a covariate, will be measured by raingauges which will be set up at each location. The dependent variable which will be studied is the serviceability index which will be measured at frequent intervals, possibly daily.

GENERAL EXPERIMENTAL DESIGN CONSIDERATIONS

To fill all the requirements of the experimental design the following locations would be required for the complete analysis of the pavement deterioration study:

a. Surfaced roads

Fractional factorial with star points and replicates 70

Soil cement base satellite study   8

Annual rainfall satellite study   5

b. Unpaved roads

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Full factorial, using 4 surface type materials
with star points and replicates   70
Rainfall intensity satellite study   8
                                                                    _____
                                              Total   140 +   21

Since each location will consist of 2 adjacent test
sections, a maintenance and a nil-maintenance section, it is
considered that these 2 sections are equivalent to the time
and labour requirements of about 1.4 sections which are
geographically separated. Therefore, in the main study there
will be the equivalent of 196 sections. During the planning
of the project it was estimated that resources would be
available for about 200 sections, thus the two figures
correspond reasonably well. The satellite studies are equiva-
lent to about 30 sections, and within the scope of resources
for the pavement study these would be able to be handled.

EQUIPMENT

The equipment which will be used on this project is some
of the most sophisticated of its type in the world at present.
A   list of the main equipment related to the pavement aspects
of the study, and which may also be used in the other study
areas, are given below. Initial activities related to the
calibration of this equipment are discussed in the section
on pilot studies and the scheduling of this work is indicated
on the workplan and schedule.

Surface Dynamics Profilometer - this equipment measures the
wave forms of the road surface, and analyses the road surface
according to wave form theory based on work done at the
University of Texas (Ref. 26.27) to provide a serviceability
index of the pavement or a standard roughness measurement.

Maysmeters - this equipment when fitted into a vehicle
measures the summation of the movement of the vehicle body
relative to the rear axle as the vehicle moves over a road
section. This measure of roughness is correlated against the
profilometer for standardization (Ref. 28).

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Weigh-in-motion system - this system is capable of weighing
vehicles at normal highway speeds. It also takes the
dimensions of the vehicles and its velocity as it passes over
the sensing transducers.

Static wheel weighing scales - four static wheel weighing
scales are also available in addition to the dynamic system.

Dynaflect - measures the deflection and deflection basin of the
pavement under a cyclic dynamic load.

Benkelman beams - this is the standard device for measuring
static deflections of pavements under normal highway loads.
These static deflections will be correlated with the Dynaflect
so that the model of pavement deterioration obtained may have
widespread applicability.

Road rater - this is another instrument which measures the
deflection under a dynamic load, but its load measuring
characteristics differ from the Dynaflect. This equipment is
available from consultants in Brazil, and a correlation will
be obtained with the results of the other two types of
deflection measuring devices.

Control soils laboratory - a laboratory will be set up and
equipped to carry out the standard soil tests under controlled
conditions. In addition, specialized equipment, will be impor-
ted from the United States and will include splitting tensile'
test apparatus and repeated load triaxial equipment.

PRE-PILOT AND PILOT STUDIES

Pre-Pilot Studies

These studies include activities related to procurement
and calibration of equipment and training of personnel which
must be carried out before the equipment can be used in the
pilot studies.

a) Maysmeters - this is the first time that Maysmeters
will be installed in vehicles produced in Brazil, and
since these vehicles are lighter in weight than the
vehicles generally used in the United States, research

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has to be conducted with the local vehicles. This will consist of determining the effect of 1) tyre pressure 2) load 3) variations of time on the roughness results. These tests will be conducted on road sections with the widest range of roughness available.

b) Benkelman beam - at present no temperature correction curve has been developed for deflection by the Benkelman beam for the Brazilian conditions. These correction curves will be developed during the training of personnel phase.

Pilot Studies

The pilot studies are primarily aimed at:

a) Obtaining sections of the quality required for the experimental design in the field, and perfecting the system of section selection;

b) Setting up the procedure for carrying out the field and laboratory tests in the main study;

c) Obtaining realistic dummy data for a pre-analysis of the experimental design. The pilot studies follow basically the same procedure for the surfaced and unpaved experiments. The pilot studies will consist of selecting three locations for the surfaced and three locations for the unpaved experiments. In the case of the unpaved sections initial material tests will be carried out on many possible test sections in DF in order to obtain a full spectrum of materials which are generally used. In the DF there are no specifications for the quality of the wearing surface gravel, and we expect to find a wide range of material properties. The following activities are planned, but these may change during testing.

1) Select possible sections from construction plans and traffic statistics

2) Verify traffic counts

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3) Verify the materials used in the sections by taking samples by coring and augering at one point/location and then analysing these samples in the laboratory

4) Mark and survey the sections if they fill a block in the design

5) Carry out in-situ material tests (3 test pits and 8 core holes per location) and take samples for laboratory analysis

6) Take at least 7-day counts at each location

7) Measure the deflection with the Benkelman beam at 20 points per location per lane

8) Measure the roughness on each section, and determine the frequency of roughness measurements required on the unpaved roads

9) Carry out pavement distress surveys on surfaced section

10) On the unpaved sections carry out a survey for gravel loss determination, and measure the looseness of surface materials.

Another activity during the pilot study phase is to run the weigh-in-motion system, WIM-1A, at a location to debug any problems, to train personnel and to obtain sample data for the pre-analysis.

EXTENDED STUDY CONSIDERATION

Investigating the Roughness of Newly Constructed and Overlayed Roads

In the main part of the study roads of different ages will be used. The roughness of many newly constructed roads will be measured to establish some quantitative measure of the roughness of the study roads when new. This will at the same time give a quantitative measure of the present construction quality.

During the discussions with the maintenance personnel of the different road departments, no clearcut existing policy on when to overlay could be determined. In order to quantify levels of roughness at which roads are currently overlayed, the roughness of roads currently awaiting overlay will be measured before and after overlaying.

All of the results obtained after overlaying will indicate the improvement in riding quality achieved and it will also be

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used as the roughness at time zero in the pavement deterioration model for roads that have been overlayed.

Pavement rating scale

To calibrate the serviceability index obtained by the surface dynamic profilometer with Brazilian conditions a limited rating experiment may be run probably during the second year of the project.

INTERFACE WITH ROAD USER COSTS EXPERIMENTS AND SURVEYS

The measurement of pavement surface properties (roughness, rut depth, etc) will also serve as independent variables in the road user costs experiments and surveys. Thus ultimately the models can be related, and user costs, speed, etc can be predicted as a function of pavement design and maintenance variables.

WORK PLAN AND SCHEDULE

The work plan and schedule for the pavement performance and maintenance study is shown in Figure 27.

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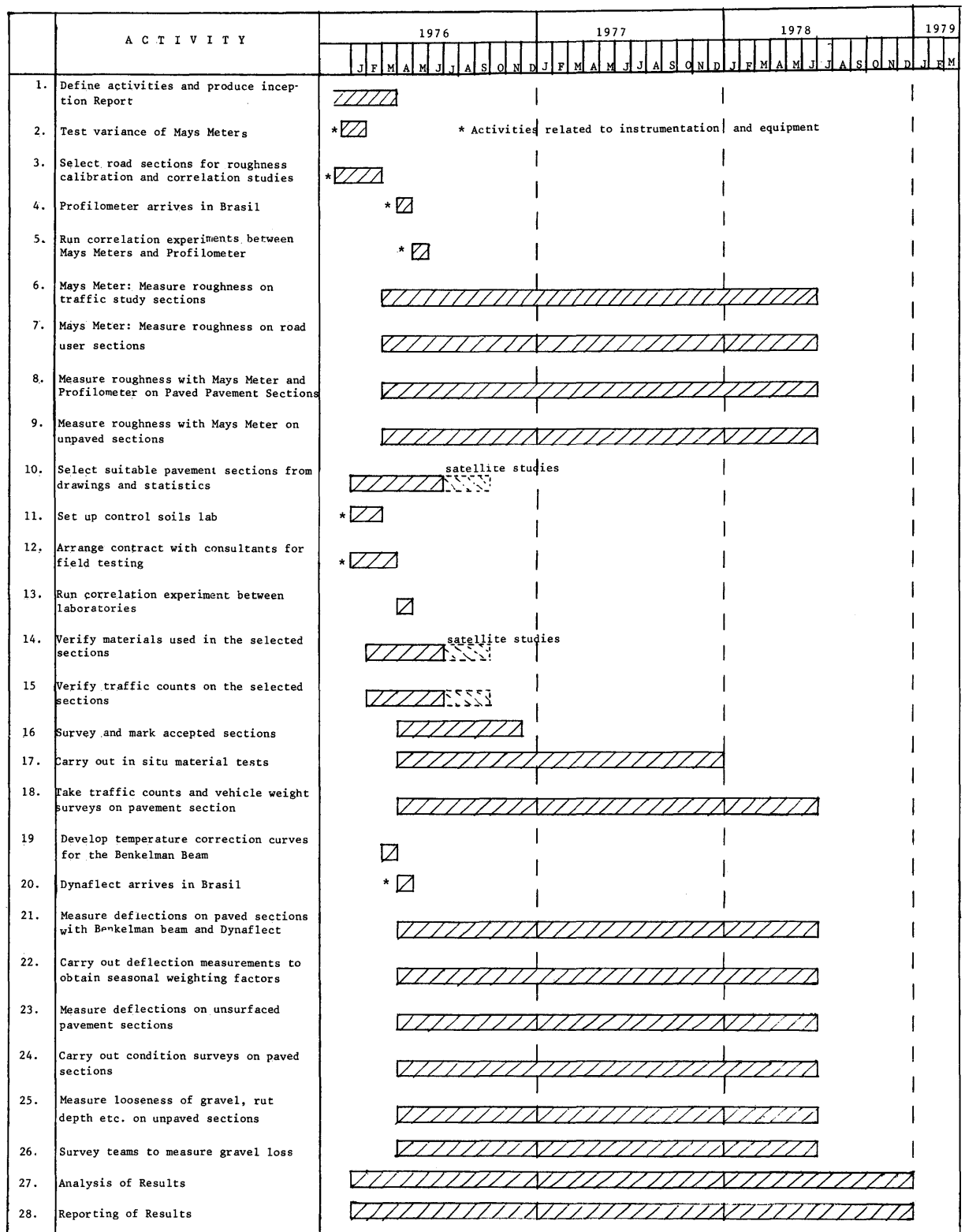|	A C T I V I T Y	1976	1977	1978	1979
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M
1.	Define activities and produce inception Report				
2.	Test variance of Mays Meters		* Activities related to instrumentation and equipment		
3.	Select road sections for roughness calibration and correlation studies				
4.	Profilometer arrives in Brasil				
5.	Run correlation experiments between Mays Meters and Profilometer				
6.	Mays Meter: Measure roughness on traffic study sections				
7.	Mays Meter: Measure roughness on road user sections				
8.	Measure roughness with Mays Meter and Profilometer on Paved Pavement Sections				
9.	Measure roughness with Mays Meter on unpaved sections				
10.	Select suitable pavement sections from drawings and statistics	satellite studies			
11.	Set up control soils lab				
12.	Arrange contract with consultants for field testing				
13.	Run correlation experiment between laboratories				
14.	Verify materials used in the selected sections	satellite studies			
15	Verify traffic counts on the selected sections				
16	Survey and mark accepted sections				
17.	Carry out in situ material tests				
18.	Take traffic counts and vehicle weight surveys on pavement section				
19	Develop temperature correction curves for the Benkelman Beam				
20.	Dynaflect arrives in Brasil				
21.	Measure deflections on paved sections with Benkelman beam and Dynaflect				
22.	Carry out deflection measurements to obtain seasonal weighting factors				
23.	Measure deflections on unsurfaced pavement sections				
24.	Carry out condition surveys on paved sections				
25.	Measure looseness of gravel, rut depth etc. on unpaved sections				
26.	Survey teams to measure gravel loss				
27.	Analysis of Results				
28.	Reporting of Results				

Figure 27. Pavement and Maintenance Work Plan and Schedule

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CHAPTER 6 - SUPPORT ACTIVITIES

INSTRUMENTATION

Equipment Requirements

Measurements are vital in any research effort to determine physical relationships precisely and effectively. The measurement of pavement roughness (serviceability) and road geometry are important variables throughout this study. All of the surveys and experiments involve these variables in one way or another. In the road user costs surveys and traffic experiments, the costs must be related to pavement and road characteristic measures. In the pavement performance and maintenance studies, roughness and serviceability are dependent variables used to define performance and to describe the effect of maintenance. Finally road geometry must be related to observed pavement behavior.

Fuel consumption is another important variable and special attention is needed for these measurements, both on the experimental vehicle studies and in certain of the road user costs surveys for internal checking and model calibration.

A variety of so called traffic measurements are involved in the study: a) vehicle counters, b) vehicle weighing systems, c) speed measurements, and d) tachographs for speed profiles. This equipment records vehicle operating data and traffic volume and weights for all phases of the study requiring measurements as outlined in the detailed chapters.

Another set of important measurements relate to pavements. These include: 1) pavement deflections with both the Dynaflect and Benkelman beam devices, 2) pavement distress measurements such as rut depths, skid resistance, surface looseness, etc. and 3) a variety of material testing ranging from field CBR tests to repeated load stiffness testing. A complete control soils laboratory will be set up to coordinate materials testing for all test sections.

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Finally, there will be miscellaneous tests of various kinds which will be developed as needed. Examples of these include rain-gauges, both volume and intensity and wind measurements to evaluate possible effects of wind resistance on speed and fuel consumption.

For each of the measurements a careful study of available equipment has been made. Where possible and within the budget limits of the project the best or most appropriate equipment available to accomplish the job has been purchased (Table 14). A brief description of each piece of equipment is included below. A later project report will cover instrumentation, equipment and procedures in detail.

1. <u>Surface Dynamic Road Profilometer System</u> - This profilometer, first developed by General Motors Corporation, uses an inertial reference system to insure long term accuracy and stability of the measurements. The measured profile can be 1) analyzed in detail, 2) used to calibrate other roughness devices, and 3) used to evaluate serviceability and performance.

2. <u>Mays Road Roughness Meters</u> - Four of these devices are available for routine measurements. Although inadequate as primary measurements, they can be calibrated regularly and used for the majority of the pavement roughness measurements.

3. <u>Road Geometric Survey Vehicles</u> - Two vehicles will be instrumented to record road geometrics at reasonable vehicle speeds. They will also contain a Maysmeter (Item 2 above) and will be capable of evaluating routes of the user vehicles being surveyed for good correlation.

4. <u>Dynamic Scales</u> - A weighing-in-motion system developed at Texas University is capable of weighing passing traffic at normal highway speeds without stopping the vehicles. Axle spacing, vehicle length, and vehicle speed are also recorded electronically.

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TABLE 14   SUMMARY OF PROJECT EQUIPMENT

1.   Surface Dynamics Road Profilometer System
2.   Mays Road Roughness Meters (4 each)
3.   Road Geometric Survey Vehicles (2 each)
4.   Dynamic Scales (WIMIA)
5.   Static Scales (2 each)
6.   Traffic Counters, Manual and Automatic (25 and 10 each)
7.   Fuel Consumption Meters
8.   Tachographs (20 each)
9.   Vehicle Speed Meters (4 each)
10. Vehicle Distance Odometers (20 each)
11. Lapsed Time Cameras (2 each)
12. Dynaflect Deflection Device
13. Benkelman Deflection Beams (6 each)
14. Rain Gauges (10 each)
15. Wind Measurement Devices (3 each)
16. Stop Watches (Several Types, 50 total)
17. Resilient Modulus Repeat Loads Test Machine
18. Splitting Tensile Test Machine
19. Soils Laboratory

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5. _Static Scales_ - Four standard load-o-meter wheel weight static scales are available for field weight determination and calibration as needed.

6. _Traffic Counters Manual (25 each) and Automatic (10 each)_ - It will be necessary to determine traffic movements for the test sections in both the user costs experiments and the pavement experiments. A system of traffic records will be established.

7. _Fuel Consumption Meters (15 each)_ - Several types of fuel meters are being examined. One type will be used for the controlled experiments. Another simple continuous flow meter will be installed in some of the user vehicles being studied in the survey.

8. _Tachographs (20 each)_ - A tachograph is a device which is equipped with a clock so that it can record the speed of a vehicle continuously on a graph. This will be used to obtain the speed profiles on the user survey vehicles.

9. _Vehicle Speed Meters (4 each)_ - Radar speed meters are necessary for measuring the test vehicle speeds, for sampling the travel speeds of the vehicle population and for developing the acceleration and deceleration curves for different vehicles.

10. _Vehicle Distance Odometers (20 each)_ - Electronic distance measuring devices which can economically be installed in test vehicles or user vehicles being surveyed with minimum trouble and labor.

11. _Lapsed Time Cameras (2 each)_ - 16mm movie cameras are adapted to take single shot photographs at prefixed intervals or when triggered.

12. _Dynaflect Deflection Device_ - Measures the deflection of a pavement under a dynamically oscillating load. This equipment is fully automated and is able to measure deflec-

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tions considerably faster than in the case of the Benkelman beam.

13. Benkelman Deflection Beams (6 each) - This is the standard device used for measuring pavement deflections under a wheel load in Brazil, and these results will be correlated with those of the Dynaflect.

14. Rain Gauges (10 each) - Simple rain gauges will record precipitation at several of the test sections as required throughout the tests.

15. Wind Measurement Devices (3 each) - Wind direction and speed may affect the speed and fuel consumption of test vehicles. It must therefore be determined during test runs.

16. Stop Watches (Several Types - 50 total) - Time will be recorded for speed studies and other research as required.

17. Resilient Modulus Repeat Load Test Machine - The resilient modulus, which is a fundamental pavement design parameter for the subgrade, is determined with the repeated load triaxial apparatus. The confining pressure is variable but constant during a test and the axial load can be varied cyclically.

18. Splitting Tensile Test Machine - When an increasing diametrically opposite knife-edge load is applied to a cylindrical sample, the sample will break in half, and with this equipment the failure forces are measured and then the tensile strength may be calculated.

19. Soils Laboratory - The control soils laboratory has been set up to control the work which will be carried out for the project by other agencies. The laboratory is fully equipped to carry out standard soils laboratory tests such as:

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1. Granulometry
2. Liquid limit and plasticity index
3. Laboratory CBR tests
4. Laboratory density analysis
5. ,Moisture content determinations

Correlation tests will be run to compare the results of the other laboratories with our control laboratory in order that consistent results will be obtained during the work in the various regions.

Calibration

This project will require careful use of equipment through-out the 36 months of measurements. Calibration and testing procedures will be established for each piece of equipment and carefully documented to help insure that uniform measurements will be made during the full term of the Project.

Documentation

For future studies of the data and possibly in future re-search, it will be essential to have good records of data acquisition and instrumentation procedures. A detailed set of data forms and instrument calibration procedures will be established. These will make easier to document the accuracy of the data. At about mid-term of the project a detailed instrumentation report will be prepared to describe equipment and procedures. This will insure accuracy and also record the information for future use.

COMPUTER SUPPORT GROUP

Computer Requirements for the Project

The main tasks of this group are: to develop a computer data bank for storing all data and to provide support for computer analysis and programming for the three study years of the project.

Due to large amounts of data to be processed and the number of analysis to be done, the Project needs to have access to a computer system with certain basic characteristics such as:

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1. Good core capacity (512 K bytes or better), capable of handling a data management system and some large engineering programs;
2. Available basic compilers (FORTRAN IV, ANS COBOL, PL/I, ASSEMBLER);
3. Available statistical and mathematical routines;
4. Available data management system routines;
5. Available system utility programs;
6. Teleprocessing capabilities.

The ideal working condition for this project would be to have a remote job entry terminal (RJET) that could access a large computer system which has these characteristics.

Evaluation of Computer Installations

Since September 1975 we have been searching for a computer installation capable of handling project data processing needs, not only from the machine capacity point of view but also with regard to related data processing services and overall efficiency. After visiting several of the computer installations here in Brasília in late September we agreed that the installations most suitable to the project needs were:

1. The IBM System 370/158 OS/VS used by the Senate Data Processing Center;
2. The Burroughs B 6700 used by the University of Brasília Computer Center.

These systems were recommended because they met the basic characteristics required for our analysis and data processing needs.

GEIPOT has a working agreement with the installations shown in the table below.

Project personnel have been using the facilities at the University to adapt statistical and engineering programs, as well as the TRRL-MIT-IBRD Highway Cost Model System. The services at the University have not been totally satisfactory.

In February 1976, we started using the IBM 370/145 at Companhia Auxiliar de Empresas Elétricas Brasileiras (CAEEB), which is small for the project needs (252 K of memory). It is too early to evaluate their services, but they seem efficient and business oriented.

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We have not had the opportunity to use the facilities at
Companhia Brasileira de Alimentos (COBAL) or at Departamento
Nacional de Estradas de Rodagem (DNER). We do not expect to
have a great amount of work for the COBAL computer center,
but we do expect to use extensively the DNER computer facili-
ties.

To process our data at DNER computer center the data will
be recorded in cassettes and sent by pouch to Rio for proces-
sing. This procedure will go on until we have our computer
terminal in operation.

Mr. Diamant, director of DNER computer center, will be
personally contacted in mid March about establishing proce-
dures to handle the Project data.

Terminal Facilities

During their December 1-5, 1975, meeting in Brasilia the
Expert Working Group (EWG) strongly recommended to GEIPOT
that the Project should have an electronic data processing
capability within our offices in GEIPOT (see Appendix 6.2).

Staff personnel of the project computer group together
with Dr. Grover Cunningham, EWG member, visited the computer
installations with which GEIPOT has agreements. The purpose
of these visits was to make an assessment of their capabili-
ties, experience and support for remote job entry terminals
(RJET). As it turned out none of them had a RJET in operation.
The University of Brasília has been experimenting with RJET
but they do not have any as part of their regular operations.
The installations at the University of Brasilia and DNER have
the equipment to support RJET, but no experienced personnel
in software and teleprocessing to provide terminal technical
support.

In addition to the computer installations we visited two
local banks that are using Olivetti data entry equipment to
record and transmit data to their headquarters in other
cities through the local and long distance telephone lines.

Conversations were also held with personnel from the
telephone companies TELEBRASILIA (local telephone lines) and

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EMBRATEL (long distance lines) to run a check on costs, lead time needed to obtain a line and other technical details regarding data transmission through their lines.

The next step was to get cost information on terminal equipment from different manufacturers, specifically from Burroughs, Olivetti, and IBM that maintain offices in Brasilia. We were able to get some information from Olivetti and IBM, but none from Burroughs.

With this information in hand on Thursday December 11, 1975 project staff personnel together with Dr. Grover Cunningham of TRDF and Dr. Per Fossberg of IBRD, visited the DNER computer facilities in Rio de Janeiro, in particular José Diamant, Director of the DNER computer center. We explained to him the purpose of our visit and our interest in setting up a RJET, and were pleasantly surprised at the enthusiasm he showed for working with us.

Mr. Diamant showed us their computer facilities, and informed us about time available and future plans for expansion including installation of terminals for the DNER district offices. He also indicated that DNER had ordered 32 Olivetti's DE 523 (Data Entry Terminals) and the possibility that the Project could obtain two of these machine on a loan basis.

On January 15 the Brazilian Directors of the Project met with Mr. Diamant, at the Ministry of Transport, here in Brasilia. At that meeting Mr. Diamant agreed to loan one Olivetti DE 523, and it was received on January 22, 1976.

Olivetti was requested to prepare a proposal for peripheral equipment for the DE 523 to function as a RJET. On February 6, 1976 we received the proposal from Olivetti. This proposal was forwarded to the Brazilian project director for appropriate action.

As of this writing the outlook for the prompt installation of a RJET is not promising. All the peripherals needed for the Olivetti DE 523 to function as RJET have to be imported and GEIPOT is experiencing difficulties in obtaining such equipment due to the Government restrictions on importations.

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Other alternatives are being studied to find a solution to this problem. Table 15 summarizes the current facilities.

Computer Programs

The computer programs for statistical analysis brought from the University of Texas have been converted and are operational on the Burroughs B 6700.

The Road Transport Investment Model for Developing Countries (TRRL Program) was compiled and executed with the Yala-Busia test data. On February 9, 1975, from EMBRAPA we obtained a magnetic tape with the BMD statistical package. Currently we are working to have this package operational on the CAEEB, IBM system 370/145 OS/VS. We also hope to have this system in operation in the DNER computer by late March. Programs for analysis of the weight-in-motion (WIM) data as well as programs to analyze the pavement deflections are being revised to have them operational in the IBM System 370/145 OS/VS. The programs relating to analysis of profilo-meter data will have to be modified for the new profilometer, and make them operational in IBM equipment. This task is being undertaken by TRDF in Texas.

Pre-Pilot, Pilot and Full Scale Studies

During the pre-pilot and pilot studies, for the pavement, user costs surveys and experiments, computer support will progress as follows:
a)   develop and design forms for data collection;
b)   keypunch, record, verify and edit data for storage and analysis, and
c)   use of statistical programs for data analysis.

Currently this section is involved in developing the programming needed for route control of bus companies for Goiás, Minas Gerais and Distrito Federal.

For the full scale study the production of input formats and software packages will progress in the same order as the study program.

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Personnel and Supplies

Because Brasília is not a good market to find top qualified personnel, it has been and will continue to be difficult to recruit personnel. In the data processing field a good programmer and keypunch operator are required to complete the staffing requirements of this group.

Another area that will need special attention is the ordering of data processing supplies. In general the suppliers in Brasilia do not carry a good inventory and the lead time for ordering supplies manufactured in Brazil is about ninety days.

TABLE 15   COMPUTER SYSTEMS AVAILABLE*

Computer Installation	Type	Model	Location
University of Brasília	Burroughs	1130	Brasília
University of Brasília	Burroughs	B 6700	Brasília
Companhia Brasileira de Alimentos (COBAL)	Burroughs	B 6700	Brasília
Companhia Auxiliar de Empresas Elétricas Brasileiras (CAEEB)	I B M	370/145	Brasília
Departamento Nacional de Estradas de Rodagem (DNER)	I B M	370/145	Rio de Janeiro

*   GEIPOT was unable to effect a working agreement with the Director of the Senate Computer Center. See Appendix 6.1 for available hardware and software.

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STATISTICS AND ANALYSIS GROUP

The main objective of the Project is to examine the interrelationships between the three components of road transportation: construction, maintenance and road user costs. The actual relationships will then be set into a model which will predict the combination of design and maintenance which produces the minimum total transportation costs for any road section. Therefore, it is of major importance to develop prediction equations with reasonable accuracy that will relate the three components, and do so under a wide variety of conditions.

The final analysis procedure that will be used to develop the many prediction equations will be regression analysis. However, to arrive at the best equation in all situations, analysis of variance approaches will be utilized first.
The functions of the statistics and analysis group are two-fold: 1) to propose designs for the various experiments which will allow the development of prediction equations while at the same time reducing data collection: 2) to analyse the data according to the design procedure set up.

The number of the factors that effect the various dependent variables is in the most cases very large. Simple analysis procedures would require an enormous amount of effort in the field, more than would be possible by this study team. The experimental designs assist in reducing the overall size of each experiment, but in most instances become very complicated to analyse.

A list of the experiments that have been planned is given below. This list is then followed by a short explanation of each experimental design.

Pavement Performance and Maintenance Experiments

1. The development of pavement performance relationships for surfaced roads.
2. The development of pavement performance relationships for unsurfaced roads.
3. The investigation of pavement performance of surfaced roads with soil cement base.
4. The effect of annual rainfall on pavement performance of surfaced roads.

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5. An investigation of the effect of rainfall intensity on the pavement performance of unpaved roads.

Road User Costs Experiments (Traffic Studies)

1. The effect of dry or wet conditions on the acceleration, deceleration, and steady state speeds on negative and positive grades.
2. Investigation of the differences of free speed measurements on various gravel types.
3. Development of free speed, steady state prediction curves on positive grades.
4. Deceleration phase on positive grades.
5. Free speeds in different geographic areas.
6. Acceleration phase on positive grades.
7. Speed/lenght curves for negative grades (pilot).
8. Calibration of simulation model for free speeds.
9. Speed/capacity relationships from field data.
10. Calibration of simulation model for capacity & field data operation.
11. Fuel consumption relationships.
12. Calibration with road users.

Road User Costs Surveys

1. Pilot study to check sampling frames for buses, trucks and cars; 2. Updating of procedures based on pilot study results.

Pavement

The development of the performance relationships for paved roads will be accomplished by analysing a one-half replicate, split plot design with star points and covariates. The use of the one-half replicate minimizes the number of test sections while allowing full analysis to be performed on the major factors. The split plot decreases the number of total test sections by one half since each location is divided (or split) so that two forms of maintenance can be performed on each location. By including star points curvature relationships can be investigated as well as linear effects. Covariates, which are simply measured at each section will add strenght to the prediction equations while not increasing the number of test locations.

In the development of the performance relationships for unpaved roads a full factorial will be utilized. The number of controlled factors is less in this experiment than in the main

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study for paved roads. Thus, a full factorial with star points will most efficiently describe serviceability. By using star points, curvature can be added to the regression equations for the quantitative independent variables.

The investigation of pavement performance of surfaced roads with soil cement base will be carried out in a satellite study. This approach is proposed for two reasons, (1) most soil cement base roads are not in areas near Brasilia and (2) by placing soil cement in a satellite the efficiency of the main study on surfaced roads is greatly increased since it is possible to run a one-half replicate design there. The soil cement sections that are tested in the satellite will be compared to sections with other bases by means of factorial analysis of variance procedures.

In a satellite study a small number of test sections will be tested in Bahia where rainfall is very low. These sections will be compared against identical sections with higher rainfall (from the main study) by means of analysis of variance procedures. Again, a split plot design is used to analyze maintenance.

The effect of rainfall intensity on paved roads will be investigated on a small scale. The testing has been limited to a total of eight sections because of the expense involved in the equipment. Various levels of intensity will then be related to deterioration by means of regression analysis.

Traffic

It is proposed to study dry and wet conditions on a small scale. The same sections will be tested when it is raining and when it is dry. The factorial design is therefore called a split plot. Differences in the speed for each vehicle class will be compared across various road factors and against wet and dry conditions. From this analysis, regression procedures will follow to develop the prediction equations for free speed.

The main study for free speeds will test only one type of

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gravel, lateritic. However, there is a possibility that other
gravel types may have a different effect on speeds. Therefore,
a satellite study is proposed to investigate other gravel
types in Paranã and Minas Gerais. The analysis will follow
factorial procedures, gravel type and roughness with a split
plot for the various vehicle classes. Prediction equations
will then be developed for free speeds by regression analysis.

For the development of free speed steady state speed
curves on positive grades it is proposed to use a full split
plot factorial design, followed by regression analysis. The
split plots decrease the total number of different road sections
that must be tested. This is very important because a complete-
ly randomized design procedure would necessitate the investiga-
tion of too many sections.

In order to develop the full deceleration curve for posi-
tive grades each vehicle class must enter the test section at
their maximum speeds. Therefore, the test sections must be
chosen carefully. A split plot factorial will again be used
for this analysis. In addition, the travelling lenght up the
grade where each vehicle class decelerates to steady state will
be estimated. By joining analysis (3) & (4) it will then be
possible to develop the full deceleration curve for positive
grades.

Trip length purpose in different geographic areas may have
a significant effect on free speeds. Therefore, in a satellite
study various locations with different geographic areas will be
tested. The speeds of all vehicle classes will be measured on
each location. The design is therefore a nested split plot
factorial. Differences in speeds across various geographic
areas which have different trip purposes can then be examined
for each vehicle class.

For the acceleration phase on positive grades the Projects'
fleet of test vehicles will be used. In all of the previous
experiments described above actual road users will be measured.
Using test vehicle alters the design and the inferences. For
the acceleration phase on positive grades, the design is a split
plot with nesting. However, here the vehicles constitute the

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whole plot and all other effects represent the split plots. This is different from previous experiments discussed. The actual prediction equations will be developed by means of regression analysis.

A number of different speed patterns can exist on negative grades depending on the road itself and on the vehicle class. In order to identify clearly some of these speed patterns a pilot study will be carried out first. The design is again a split plot factorial in which actual road users are measured. This pilot will produce information which can then be used to develop a full experimental approach for speeds on negative grades.

Once the free speed curves have been developed for short homogeneous sections they must be tested and calibrated against longer runs over heterogeneous sections. This will be done in two ways (1) by measuring speeds of our own vehicles over 3-5 km heterogeneous sections and comparing their average speeds with the simulated speeds; (2) by measuring speeds of actual road users who have tachographs installed in their vehicles and comparing the measurements to our estimates.

The objective for the analysis of speed/capacity data is to determine the flow/composition combination for any road section where free speeds are reduced to operating speeds. The analysis procedures are based on the split plot design that will organize the study. Regression analysis will be used to predict the speeds of any vehicle class under various flow/composition levels on a variety of road sections.

A simulation model has been proposed for the development of capacity situations on different road sections. These simulated results will be compared through factorial analysis with the capacity data collected in the field. In this way the accuracy of the simulation model can be examined; The fuel consumption relationships will be developed by the use of the project vehicles. As in the experiment on acceleration on positive grades, a split plot design will be used with the test vehicles forming the whole plot. Fuel consumption can be predicted for the vehicle classes at different speeds by means

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of regression techniques.

As with the calibration of free speed with road users, the fuel consumption equations must also be checked against users driving over heterogeneous routes and by the project's fleet driving over similar routes. Data from the users will be accumulated by the survey staff.

Users Survey

Sampling plans have been proposed for the bus, trucks and cars surveys which must be checked in a pilot study for applicability and practicality. If the proposed plans will fulfill the objectives of the survey then the full scale survey will begin. If not, new approaches must be developed.

Based on the outcomes of the pilot studies revisions will be made as needed in the sampling design approach. Presently, Dr. Wade Clifton and Paul Moore are giving assistance in the development of sampling frameworks for the road user costs surveys. Updated versions of the survey procedures will be established after the results for the pilots are analyzed.

WORK PLAN AND SCHEDULE

The work plan and schedule shown in Figure 25, 26 and 27 outlines the activities of the instrumentation, computer and statistics support groups.

TASK NUMBER	A C T I V I T Y	1975	1976	1977	1978	1979
		J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M
1.	Develop an instrument shop and soils laboratory	▨▨▨▨				
2.	Purchase and ship equipment listed	▨▨▨▨▨				
a)	Surface dynamics Road Profilo-meter	▨▨▨				
b)	Mays Road Roughness meters (4 each)	▨				
c)	Road surveys vehicle (2 each)	▨▨				
d)	Dynaflect (deflection measure-ments)	▨▨				
e)	Dynamic scales, WIM-1A	▨				
f)	Static scales (2 sets)	▨				
g)	Fuel meters (15 each)	▨▨				
h)	Misc other equipment	▨▨				
3.	Set, Test & Calibrate Equipment	▨▨▨				
a)	Surface Dynamcis Profilometer	▨▨				
b)	Mays Road Roughness Meters	▨				
c)	Road Survey Vehicles	▨▨				
d)	Dynaflect	▨▨				
e)	Dynamic Scales	▨				
f)	Static Scales	▨				
g)	Fuel Meters	▨▨				
h)	Misc other equipment	▨▨				
4.	Hire and train crews to operate equipment	▨▨▨				
5.	Repair and operate equipment during 3 years study	▨▨▨▨▨▨▨▨▨				
6.	Select & operate 8 Dynamic Scale weighing locations	▨▨▨▨▨▨▨				
7.	Develop and modify equipment as required	▨▨▨▨▨▨▨				
8.	Establish permanent in-strumentation group for Brazil				▨▨	▨

Figure 28. Instrumentation Work Plan and Schedule

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TASK NUMBER	ACTIVITY	1975	1976	1977	1978	79
1.	Establish computer require-ments for project					
2.	Evaluate available computer installations and select system					
3.	Adapt existing statistical and engineering programs					
4.	Evaluate REMOTE JOB ENTRY equipment					
5.	Obtain computer equipment and supplies					
6.	Hire and train data process-ing personnel					
7.	Run sensitivity analysis on Road Transport Investment Model (TRRL) Program					
8.	Review and design data input forms, modify and print					
9.	Check, keypunch, record, verify and store data on computer tapes					
10.	Adapt statistical programs for data analysis					
11.	Establish data management systems and data bank format					
12.	Test, run and process simula-tion models					
13.	Develop, write and debug programming for Highwaw Planning Cost Model					

Figure 29. Computer Support Work Plan and Schedule

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ACTIVITY	1975				1976											1977											1978											79
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D J F

1. Develop preliminary experimental
designs for user experiments
and pavement studies ▓▓▓▓▓

2. Prepare material for inception
report ▓▓▓▓▓

3. Test all experimental designs
using dummy data ▓▓▓▓

4. Study available user population
information and establish a
sample for the user survey ▓▓▓▓▓

5. Develop a formal process for
handling data ▓▓▓▓▓▓▓▓▓

6. Test and demonstrate a capa-
bility to use all packaged
computer software ▓▓▓▓

7. Analyze pilot data, evaluate
samples and experimental
designs, modify as indicated. ▓▓▓▓

8. Prepare computer input for Mays
Meter Calibration ▓▓▓▓

9. Make preliminary analysis of
data and modify experimental
designs and survey samples as
required ▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓

10. Final analysis of data on
completed experiments and
survey ▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓

11. Write material for reports ▓▓▓▓▓▓

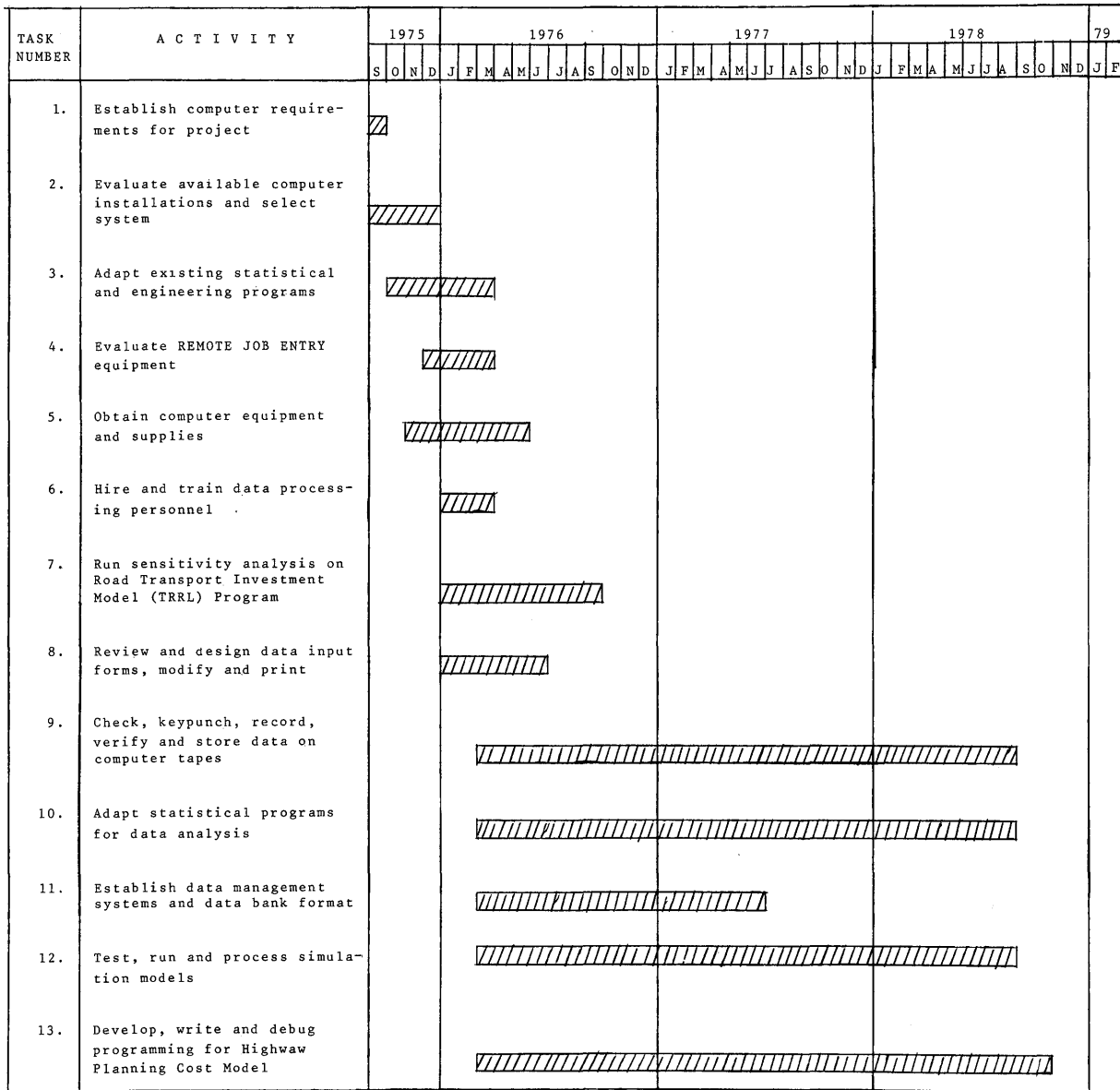| | S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D | |

Figure 30. Analysis Support Work Plan and Schedule

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CHAPTER 7 - SUMMARY AND RECOMMENDATIONS

MODIFIED MODELS

From the work in this Project new empirical data will be available to develop input parameters for highway planning models. The MIT and TRRL models and combinations thereof will be used as the basic framework for the models coming from this Project.

During the first year of the Brazil study, additional analysis of the Kenya data will be undertaken with the help of TRRL and the World Bank. The model will be applied and tested in Brazil under a variety of conditions. As time and manpower permits we will also undertake sensitivity studies of the model to examine parameters in more detail.

The experience gained using and testing the existing models together with the empirical relationships developed during the Brazil Project will all be blended to produce a modified cost model.

The model resulting from this project will satisfy the basic project objectives of providing Brazil with a planning tool to help them optimize highway transport investments. In more specific terms the model

1) Will assist management make investments decisions on highway design and maintenance policies;

2) Permits an evaluation of design standards relating to earth, gravel and paved roads at specific locations over fixed time periods;

3) Permits an evaluation of alternate construction procedures, stage construction and uncertainties in traffic forecast and interest rates;

4) Permits minimization of total transportation costs for available construction and maintenance options over life of alternates investigated;

5) Assists in decisions between alternate routes at

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planning and preliminary design levels;

6) Can be used in network analysis to investigate the impact of vehicle sizes in the establishment of axle load regulations;

7) Permits the examination of fuel conservation policies and their alternate benefits.

Application in Brazil

As pointed out at the beginning of this report our first goal is to develop a model directly applicable to Brazil's roads network. This will be given close attention as the MIT and TRRL models are studied and tested in Brazil. The parameters and data developed here will, of course, be most directly relatable to Brazil. In this regard, users guides and data input guides will relate to Brazil and Brazilian methodology for easy application.

General Application Worldwide

In addition to application in Brazil the Project has some responsibility to generalize the models for worldwide application. The background of the MIT and TRRL models, developed for quite different conditions, suggested that general application models can also be developed without conflict with Brazilian versions.

Flexibility - Updatability

In all cases attention will be given to flexibility in the models. To this extent it is hoped that the Brazil and worldwide models can have the same basic forms with minimum overall changes. Formats for use of the models for computer analysis will be as flexible as possible as attention will also be given to easy updatability.

Using The Models

During 1976, trial applications will be made using the model generated by the Kenya study. Data will be collected in Brazil to be used in evaluating how effectively various sub-models predict quantities for Brazil conditions. The combined

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MIT-Kenya model also will be evaluated when it becomes available.

Implementing both the existing models and the version resulting from this Project is important and early efforts will be made to secure the traffic, maintenance, and construction; quantity, composition, standards and unit costs data need for this purpose. Historical data does not always exist so obtaining vehicle data may prove difficult. Therefore, it will be desirable to collect the required data as soon as practical. The first effort will be initiated in 1976 and will continue through 1977 and 1978.

Data Requirements and Systems Application

A road network and its traffic load constitute a dynamic system that is constantly but sporadically changing. The method of monitoring and analysing the effects of these changes at the various levels of refinement (nationally, statewide, on a regional basis, or on specific routes) is to adopt a system approach. The models developed here can be applied to any link in this network to compute cost-benefit relationships for that link.

This is a first and vital step in the effective economic analysis of any highway system. To apply the model effectively to any link in the system it is necessary to have data on the whole network. This study does not address the networkwide modelling problem but since the data base and the basic model are common, the outline of the data generating system is presented.

A DATA GENERATING SYSTEM DESIGN

The overall system would need to include:
a) a continuously up-dated computer based data bank containing:
   I) All the physical characteristics of the road network and environmental factors influencing the cost of transport;

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II) The present and projected traffic on the network with all the necessary details, including its composition (seasonal, daily and hourly) and occupancy of the vehicles;

III) Unit cost data or (productivity rate, labour, and plant costs) for construction, maintenance, vehicle operation, time and accidents.

b) a series of computer programs for a data storage, manipulation, and retrieval.

c) simulation models to determine the cost of construction, maintenance and road users developed and validated individually as required.

The network flow diagram (Figure 30) summarizes the information system in conceptual form and shows the logical flow of the systems approach to produce model input. Each simulation model should be constructed in such a way that, given the appropriate input data, it can be used as a separate entity. It will, however, act as an integral part of the overall solution process. It is felt that if each model can be used or run independently, output results will be available more readily and variations can be rapidly tested. This point is important when considering the initial sensitivity checks to be carried out on the models.

SENSITIVITY AND USE OF THE MODELS

When complex models are developed, verification and sensitivity should be established prior to using the model. This is true for all types of models, empirical, theoretical or conceptional.

Model Verification

In this Project we are dealing with empirical models determined by experimentation and survey techniques. The models must be verified subsequent to development by comparing results to new measurements or observations not used in developing the equations themselves. In this study, data on different pavement sections, different vehicles and different users will be compared

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with model predictions to provide verifications. Design of verification studies will be given greater attention in subsequent project reports.

Model Sensitivity

After models are developed and verified it is essential to test their sensitivity. Such studies can show the relative importance of each input variable to the model and its effect on the predictions or outputs. Ultimately such sensitivity studies must be more detailed than time and funds will allow. However, initial sensitivity studies will be run on each model and reported. Initial experience will be gained by testing the sensitivity of the TRRL-IBRD models.

Implementation And Use Of The Model

In order to assist with early implementation of the Brazil models every effort will be made to educate potential users early in the study. This can be done by early adaption and use of the TRRL-IBRD models. Furthermore the work will be extended as preliminary results of the Brazil study analysis become available. Early attention will also be given to briefings, meetings and other efforts to educate potential model users to the workings of the Project.

RECOMMENDATIONS FOR UPDATING

Three years is a short time in the history of a highway facility. It is difficult to predict pavement performance accurately from such a short time data base. This Project will yield in Brazil an organization and a set of research experiments which can overcome this time problem relatively inexpensively. It is proposed that consideration be given to continuing data collection on a portion of the user survey vehicles, and a portion of the pavement test sections for an additional 2-4 years to provide better estimates of the model coefficients than will be available at the end of this study.

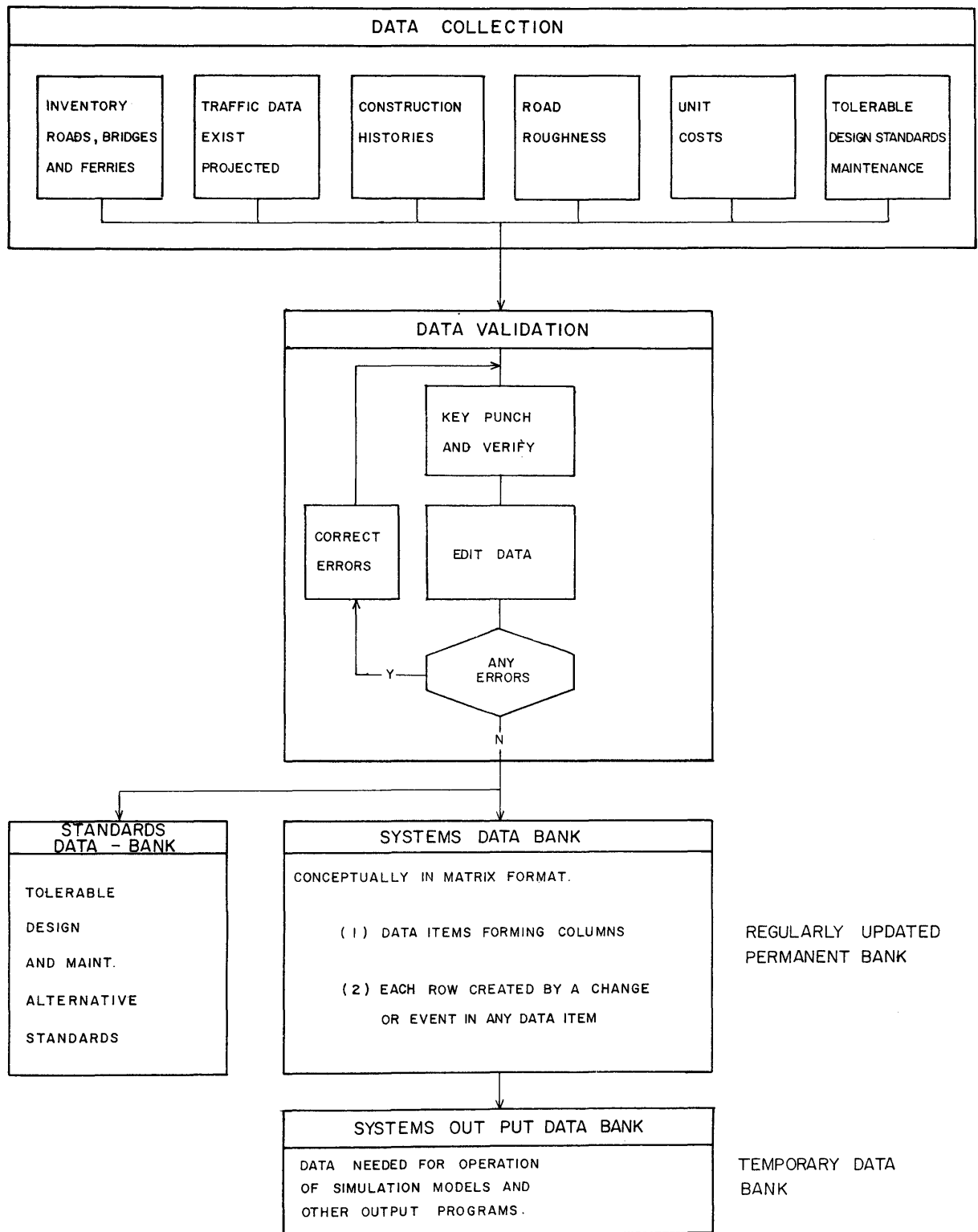Additional updating of the models can be accomplished if

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Figure 31 - Data Generating Network Diagram.

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and when data become available from other sources such as the similar proposed study in India.

Finally some agency such us GEIPOT and/or the World Bank should serve as a central coordination agency for continued use and updating of these models. Without such continued leadership no additional progress will be made.

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LIST OF TERMS AND ABBREVIATIONS USED IN THE REPORT

ACAR — Associação de Crédito Assistencial Rural
(Rural Credit Assistance Association)

CAEEB — Companhia Auxiliar de Empresas Elétricas Brasileiras
(Auxiliary Company of Brazilian Electric Firms)

CAESB — Companhia de Água e Esgotos de Brasília
(Brasilia Water & Sewage Co.)

C I P — Conselho Interministerial de Preços
(Inter-ministry Council for Prices)

COBAL — Companhia Brasileira de Alimentos
(Brazilian Food Company)

DER — Departamento de Estradas de Rodagem
(State Highway Department) — Usually followed by the
appropriate state abbreviation. Example; DER-MG —
Highway Department of Minas Gerais

D M I — Distance measuring instrument

DNER — Departamento Nacional de Estradas de Rodagem
(National Highway Department)

DNMET — Departamento Nacional de Meteorologia
(National Meteorology Department)

EMBRAPA — Empresa Brasileira de Pesquisa Agropecuária
(A research unit of the Brazilian Ministry of
Agriculture)

EMBRATEL — Empresa Brasileira de Telecomunicações
(Brazilian Telecommunications Company)

E W G — Expert Working Group — the group of expert consultants
who advise the project staff.

GEIPOT — Empresa Brasileira de Planejamento de Transportes
(The Brazilian Agency carrying out the research)

I B G E — Instituto Brasileiro de Geografia e Estatística
(The National Census Bureau of Brazil)

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I.P.R.   - Instituto de Pesquisa Rodoviária
(Road Research Institute - a unit of DNER)

M.I.T.   - Massachussets Institute of Technology

N.T.C.   - Associação Nacional das Empresas de Transportes
Rodoviários de Carga (National Highway Freight
Transportation Association)

PESQUISA ICR   - Pesquisa sobre os Inter-relacionamentos dos
Custos Rodoviários (Research on Interrelation-
ships of Highway Costs)

RJET   - Remote job entry terminal - A terminal that
permits someone to use the facilities of a
computer center at distance

SERPRO   - Serviço Federal de Processamento de Dados (Federal
Service of Data Processing)

SUTEG   - Superintendência de Transportes e Terminais de
Goiás (Goias Passenger Transportation and Terminals
Administration)

TELEBRASILIA   - Telecomunicações de Brasília, S.A.
(Brasilia Telephone Company)

Triângulo Mineiro - A geographic region covering Uberaba,Uber-
lândia and Araxá in the state of Minas Ge-
rais

TRRL   - Transport & Road Research Laboratory

T R U   - Taxa Rodoviária Única
(Combined Vehicle Registration Tax)

UnB   - Universidade de Brasília (University of Brasilia)

UNDP   - United Nations Development Programme

APPENDIX

Because of its length the appendix of this report is being published separately as Project Working Document Number 3, entitled Appendix, Project Inception Report - Research Concepts and Procedures. That working document includes the following appendices for this report and should be referred to when needed (Ref. 29):

Appendix Number

1.1 List of Terms and Abbreviations Used In The Report

1.2 Statistical Data On Brazil

2.1 Summary Curriculum Vitae of Brazilian Senior Project Personnel

2.2 Summary Curriculum Vitae of Expatriate Senior Project Personnel

3.1 Road Classification System

4.1 Free Speed Experimental Design for on-the-Road Vehicles

4.2 Free Speed Experimental Design for Test Vehicles

4.3 Analysis of Pilot Study for Traffic Experiments on Negative Grades

4.4 Operating Speed Experiment

4.5 Calibration of Field Data for Capacity and Simulation

5.1 The Statistical Design of the Surfaced Road Experiment

6.1 Available Hardware and Software

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