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VOLUME 5 — Study of Road User Costs

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PREFACE

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

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

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

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

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

VOLUMES IN THIS REPORT

VOLUME 1 - SUMMARY OF THE ICR RESEARCH

VOLUME 2 - METHODS AND ORGANIZATION

VOLUME 3 - INSTRUMENTATION

VOLUME 4 - STATISTICAL GUIDE

VOLUME 5 - STUDY OF ROAD USER COSTS

VOLUME 6 - STUDY OF VEHICLE BEHAVIOR AND PERFORMANCE

VOLUME 7 - STUDY OF PAVEMENT MAINTENANCE AND DETERIORATION

VOLUME 8 - HIGHWAY COSTS MODEL (MICR)

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

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SUMMARY

This Volume records the activities of the PICR User Cost Surveys Group which conducted a large vehicle operating cost survey in Central, Western and Southern Brazil during the period 1975 to 1981. The Group was responsible for the collection and analysis of vehicle maintenance parts and labor costs, tire costs, depreciation and interest charges, and drivers' salaries. In addition, fuel consumption and speed data were collected, the latter when easily available, to serve as consistency checks on the equations derived from experimental data. The Group was also responsible for collecting data on surface roughness, as well as vertical and horizontal geometry characteristics of the routes of those operators registered in the survey.

The primary data collection phase ran from 1975 to 1979 and 26 staff members were employed, comprising 14 field workers, 8 clerical assistants and 4 supervisors. More than two years was spent in developing and testing appropriate methodologies, documentation and data processing systems for the collection, checking, storage and analysis of both operating cost and highway characteristic data. Contact was made with over 300 companies and more than 2500 vehicles were registered for survey membership. Operating cost data were then collected on a regular basis from company records. Many difficulties had to be overcome during this period. A number of companies only had records of a few cost components and, where possible, assistance was given to provide the necessary documentation and training to collect missing items. Some companies dropped out of the survey and data collection in others was discontinued because the route characteristics of their vehicles were found to be redundant to the needs of the PICR. Finally, data on over 1600 vehicles derived from 132 companies were available in 1979 for preliminary analysis.

Highway characteristics were collected using two specially instrumented vehicles. Roughness was measured with a Maysmeter and calibration maintained through a GM Profilometer and Quarter-Car-Simulator which generated a series of profiles for a calibration course of highway sections established near Brasília. Vertical geometry was measured using a linear accelerometer connected to a panel scale capable of recording grade changes of ± 1% to ± 12%. Horizontal measurements were taken from a standard aircraft directional gyro compass, mounted

in the survey vehicles. Over 85,000 km of roughness and geometry data were collected after measuring more than 36,000 km of operators' routes. After editing, these data had then to be combined with the vehicle operating cost data so that a single file comprising both dependent and independent variables could be made available for analysis.

The second PICR Phase covered the period 1980 to 1981. The staff was reduced to 5, who were principally engaged in conducting more detailed analyses. The statistical methods employed were rationalized into distinct groups of techniques and advanced econometric procedures employed. An important technique which provided a number of the equations reported herein was the generalized least squares estimation of the error component model. The latter considers the company specific error term and the vehicle specific error term which jointly form the components of the unknown random error term considered by ordinary least squares techniques. This is one of the first reported application of error components analysis in the field of transportation studies. All the different techniques are detailed in the analysis procedures section of this Volume. The analyst was able to run a selection of these techniques simultaneously on any data set. This made comparison of the results and the choice of recommended equations an easier task.

Vehicle operating cost information presented for analysis cover the full range of vehicles operating on Brazilian highways. These are grouped into cars, utility vehicles, buses, medium trucks and heavy articulated vehicles for analysis purposes. The results of the analyses of fuel consumption, oil and grease consumption, maintenance parts and labor, tire consumption, depreciation and interest charges and vehicle speed are presented. All five vehicles classes are used in the analyses except for speed which is restricted to cars and buses, and tire costs which are analysed by tire size. The equations recommended in this Volume concentrate on estimating roughness, vehicle age, vehicle characteristics (where appropriate) and geometry effects only when these appear unambiguous. A substantial amount of time was spent estimating the effect of geometry on the various operating cost items and details on the progress made are given in both main text and selected appendices. It is clear that more time is needed to resolve this issue. Further small analyses, together with the findings of the operating cost study in India, presently being analysed, may result in the emergence of a more coherent pattern of the geometry effect on user costs.

The PICR User Survey data are the most comprehensive collected to date and are important both to Brazil, where out-of-date cost tables are widely used and the international research community, where they complement the Kenya, Caribbean and India studies. The PICR survey data covers a spectrum of vehicle types and appears to be the only study with a full range of truck classes. The data have now passed through several phases of analysis and the results presented in this Volume, together with the relevant technical memoranda, can be regarded as an interim final form. They are now ready for extensive evaluation in a variety of economic exercises. When they have passed these tests they can be viewed as being in final form for the period ending December 31, 1981.

Comparisons are made between total operating costs predicted from the various equations recommended in this Volume and prevailing transport service rates and tariffs. The results are encouraring and give confidence to the view that the recommended equations will provide better predictions of vehicle operating costs than anything currently used in Brazil. It is recommended that a user cost manual be prepared to allow the results of the PICR survey to be widely disseminated.

CHAPTER 1 - OBJECTIVES, SCOPE AND ORGANIZATION

1.1 INTRODUCTION

The construction, improvement and maintenance of highway infrastructure requires capital, a limited resource for which other sectors of the economy compete. It is important to assess both the costs and benefits of any proposed highway project in order to objectively evaluate its economic implications. Economic analyses have evolved to assist administrators, engineers and planners perform these cost-benefit evaluations. These analyses provide guidance for highway network investment planning and an important component of such economic analyses is the determination of vehicle operating costs. The relationship between these costs and roadway characteristics, particularly for low-volume roads, is not well understood. In Brazil, the relationships and tables most widely used to calculate vehicle operating costs are based on North American data, some of it derived from research carried out in the 1940's. For this reason, one of the main objectives of the PICR is the establishment of relationships between road user costs, road geometric standards and surface conditions for rural roads in Brazil. A detailed background on the PICR is given in Volume 2 of this report series.

Two different procedures were used to develop improved vehicle operating cost predictions. One involved defining a series of controlled experiments that were designed to generate data to be used to derive predictions of vehicle speed and fuel consumption. The analysis and results of that Group's activities are given in Volume 6 of this report series. In the second procedure, a survey of road users was implemented as the only practical method of obtaining vehicle operating costs for maintenance parts and labor, tires, oil, depreciation, interest and drivers' salaries. It is this Group's activities which are reported in the present volume. This Chapter provides a brief summary of the methods and data so that the reader may better understand the results and analyses in the subsequent Chapters. The organization of the Group and the methodologies employed are given in detail in Chapter 3 of Volume 2 of this report series.

1.2 *OBJECTIVES*

Establishing the full range of vehicle operating costs for feasibility studies and model building relies on a program of data collection within the road transport industry, normally using company cost records as the basic data source. Survey techniques play a prominent role in this program. The wide range of procedures and skills necessary for the efficient collection and analysis of vehicle operating data from company records required the formation of a specific team, the User Cost Surveys Group, within the structure of the PICR study.

The broad objectives of this Group were to establish relationships between the various components of vehicle operating costs and road characteristics, essentially for low volume rural roads. These objectives required that operating cost data be associated with quantifiable road characteristics so that cost differentials, attributable to changes in highway characteristics, could be determined. The inference space, or that set of vehicle and route characteristics to which the results can be inferred, had to cover the widest possible range of operating conditions available in Brazil. Furthermore, confidence intervals had to be placed on the predictions so that the potential user could make an intelligent assessment of the reliability of the estimated relationships.

Vehicle operating cost data collected from road transport companies can be assigned to routes. The characteristics of these routes have then to be quantified before operating data can be analized. The Group was given the responsibility for collecting data on route characteristics, in addition to information on operating costs, because it was considered that management of both data sets would yield the best opportunity for determining the cost differentials.

1.3 *ORGANIZATION*

The organization of the User Cost Surveys Group reflected the need to perform the collection of vehicle cost data and the measurement of route characteristics. These tasks were different in terms of methodologies, techniques, equipment, management and personnel. However, in order to achieve the Group's primary objectives, the activities were closely coordinated from the stage of initial data collection until final analyses. Vehicle operating cost data collection activities were grouped into two geographical areas:

1) The Federal District, Southern Goiás, Espírito Santo, Triângulo Mineiro, Mato Grosso and Mato Grosso do Sul, Rio Grande do Sul and São Paulo, with researchers based in Brasília and Goiânia; and
2) Minas Gerais, (except the Triângulo) with researchers based at the DER-MG (the State's Highway Department) headquarters in Belo Horizonte.

There were 23 main centers of data collection activity within both areas, where visits were made at least once a month and these are shown on the map indicating the geographic scope of the surveys (Figure 1.1).

The User Cost Surveys Group initially concentrated their efforts in the States of Minas Gerais, Goiás and the Federal District, and the major proportion of vehicles recruited for survey membership derived from these regions. It became necessary, however, to supplement these vehicles with others from States with different geographic characteristics in order to ensure that the greatest possible range of highway variables were covered for analysis. Accordingly vehicle data were sought in Mato Grosso, Mato Grosso do Sul, Rio Grande do Sul and São Paulo.

The route survey team measured approximately 36,000 km of operating routes located within the survey area and collected 85,000 km of data on highway characteristics. Route data were recorded using two specially designed survey vehicles (Linder, Visser and Zaniewski, 08/07/1977) which were instrumented, serviced and based at the GEIPOT garage and workshop. There was no field capability to repair or calibrate survey vehicles and any serious problems forced them to return to Brasilia. A range of procedures were developed, the most important being vehicle preparation and instrument calibration, to minimize the risk of failure in the field. These activities played an important part in enabling the team to successfully measure routes in the distant regions of Mato Grosso, Mato Grosso do Sul and Rio Grande do Sul.

The PICR User Survey has gone through two distinct phases in terms of organization. The first phase covered the period 1975 to 1979 and 26 staff members were employed to conduct pre-pilot and pilot studies, develop office procedures, collect data and process it for analysis, assist in the various analyses and finally write up the preliminary results in a technical report (GEIPOT, 1980). Staffing was reduced to 5 in the second phase of the PICR covering the period 1980 and 1981.

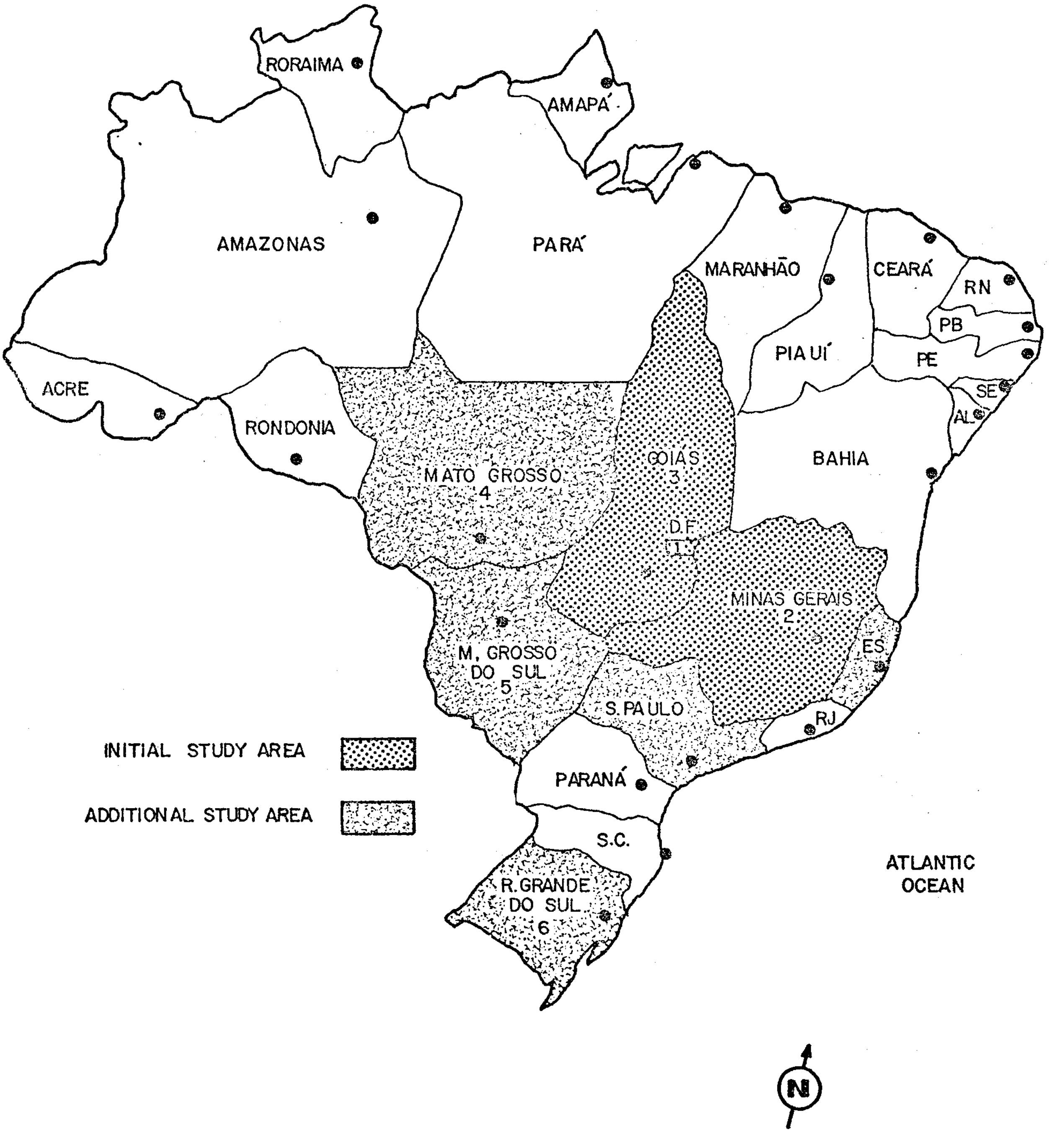

FIGURE 1.1 - THE USER COSTS SURVEY AREA

Some additional data were collected to supplement the main body of information but the major emphasis was on conducting further analyses. The results reported in this volume largely derive from the analyses conducted in this phase of the research.

1.4 VEHICLE OPERATING COST COMPONENTS

Data items which would establish and corroborate the relationships between vehicle operating costs and highway characteristics were determined with relative ease. Previous investigations into vehicle operating costs in Kenya (Hide, *et al*, 1975) provided an adequate basis for identifying, with confidence, those data items likely to be available from the road transport industry and useful for analyses, even though the most suitable survey design for Brazil was unknown in the initial stages of the project. Data items were therefore listed and grouped to enable the survey team to develop an appropriate strategy for their collection and to allocate resources accordingly. These data are specified in Table 1.1 which lists each item, gives its survey number and identifies the general analytical category to which it was assigned. Each data item collected by the User Cost Surveys Group is identified by a combination of prefix and number. The prefix specifies the survey responsible for its collection and the number locates it within the activities of the specific survey. The prefixes are given below.

1.4.1 MS - *Main Survey*

When a transport company had been interviewed and considered suitable for inclusion into the User Survey, a number of details were recorded which thereafter were not checked on a regular basis. Vehicle specifications, for example, were considered fixed for the duration of the survey. Such data were, however, subject to cross checks by senior staff from time to time.

1.4.2 MSC - *Main Survey Continuous*

These are vehicle operating cost components which require col-

TABLE 1.1 - USER COST SURVEYS DATA

Data Item	Survey No.	Category
Fuel	MSC 1	Dependent Variables
Oil and Grease	MSC 2	
Tire Life	MSC 3 SS 2	
Maintenance Parts	MSC 4	
Maintenance Labor	MSC 5	
Accident Costs	MSC 6	
Crew Time	MSC 7	
Depreciation	MSC 8 SS 7	
Utilization	MSC 9	
Age	MS 2	Independent Variables: Vehicle
Payloads, Freight, Passengers	MSC 10	
Distance Travelled	MSC 10	
Time Spent on Route	SS 5 SS 6	
Number of Stops, Loading and Unloading	SS 5 SS 6	
Vehicle Speed	SS 5 SS 6	
Vehicle Specifications	MS 3	
Pavement Type	RS 1	Independent Variables: Route
Roughness	RS 2	
Vertical Geometry	RS 3	
Horizontal Geometry	RS 4	
Pavement Width	RS 5	
Land Use	RS 6	
Traffic	SS 4	
Labor Hours	SS 1	Supplementary Information
Utilization of Heavy Trucks	SS 3	
Vehicle Valuations, Financing Charges	SS 6	
Inflation Indices	SS 7	
Taxes and Duties	SS 8	
Tachograph Studies	SS 9	

lection on a regular basis, typically consumption data like fuel and parts which vary with highway characteristics, fixed vehicle characteristics age and utilization levels. The normal contact cycle was one month, but where companies maintained good records a longer period was sometimes adopted.

1.4.3 *RS - Route Survey*

These data were generated directly by the survey vehicles as they measured operator routes. Emphasis was placed on pavement condition, or roughness, and on geometry since these were believed to have a significant influence on vehicle operating costs. The geographical dispersion of the route network put a heavy workload on the survey vehicles but it was decided that all routes should be measured at least once for roughness and geometry. Thereafter geometry was assumed to remain constant throughout the duration of the survey. Roughness was known to vary significantly on unpaved roads and a program of replication was undertaken to measure this effect.

1.4.4 *SS - Supplementary Surveys*

It was recognized that there would be a need to collect additional information to strengthen or corroborate data from the main areas of the survey. Supplementary surveys, sometimes referred to as satellite studies, were judged to be the most appropriate form for this type of activity. The relevance of this group of data increased after the preliminary analyses when important gaps were revealed and it provided the survey team with an efficient and flexible data collection facility.

A good range of survey data on highway characteristics was required if the cost differentials were to be well determined. It was recognized that extremes would play an important role in the study since they would be difficult and costly to measure but essential to achieve an effective analysis of the data. It was also clear that some time would elapse from the beginning of the study before the route surveys team could generate quantified descriptions of any route identified as being potentially useful. At the same time, the team responsible for collecting data from operators' records had to gain experience thought pre-pilot and pilot studies, together with additional technical assistance from survey economists and statisticians. All aspects of surveys work were covered in this period, from the identification of suitable data to its processing in the Brasília office. In addition, staff training had to be incorporated into these activities. This important stage in the project took more than a year to complete and is documented in detail in the Inception Report (GEIPOT, 1976) and Midterm Report (GEIPOT, 1977). Data collection and processing systems were thereafter tested and ready for operation by the end of 1976. The vehicle operating cost data collection period reported in this Volume spanned the four year period 1977-1980, although in many cases data for 1976 were obtained from old company records or pilot study material.

1.5 VEHICLE OPERATING COST METHODOLOGY

Initial discussions on the most appropriate design for the User Survey were dominated by the need to determine vehicle cost differentials relative to highway characteristics, rather than the measurement of vehicle operating costs for the Brazilian vehicle population. In particular, random sampling was thought expensive and inappropriate for the determination of the cost differentials. A number of designs were evaluated before a stratified sampling approach was adopted for the Main Survey, whose factors consisted of three levels of roughness and vertical geometry, together with two levels of horizontal geometry. The User Cost team was required to recruit companies whose vehicles could be positioned in specific stratum of the sample. The team then collected cost data on a regular basis.

Therefore, a central feature of the Survey's methodology was the use of a sample stratified by homogeneous route characteristics. The sample design could not depend on equal numbers of respondents per cell being recruited since it was known that it would be very difficult to fill some cells with certain vehicle types. Companies were interviewed which were believed to operate vehicles on specific route types. If the interview was satisfactory, data were obtained on selected vehicles within the company. This was repeated in an attempt to cover the sample inference space. Thus, embedded in the stratified sample design, where strata are defined by predetermined route characteristics, there is a cluster sample with companies forming the clusters and vehicles the observations within the clusters. The companies formed the sampling units and their vehicles the observation units. This point is important and will be elaborated in the following Chapter.

1.6 VEHICLE OPERATING COST DATA COLLECTION AND PROCESSING

The procedures for the collection and processing of operating cost data are detailed in a PICR document (Harrison, 11/1979) which also gives examples of all collection forms. The monthly vehicle record form, designed for keypunching and incorporating all the data items specified as continuous in Table 1.1, was the key document in the Main Survey. All field data had to be transformed to this document and all subsequent data processing procedures incorporating cost data either directly accessed it or used if for cross-referencing.

Two basic approaches to data collection were implemented, although some modification for each survey participant was necessary in almost all cases. The first was designed to make maximum use of company records and required that these be tabulated or photocopied so that transformation could take place in the research office where senior staff assistance was readily available. The second approach involved self-administered questionnaires or other PICR documentation like tire cards, designed to generate data where records were inadequate or non-existent.

A range of documents and associated collection techniques evolved so that an appropriate mix of procedures could be developed to meet the specific needs of each operator. There was no single data collection method for the surveys and the need to match collection procedures to the circumstances of the operator gives an indication of why a survey of this type required a significant introductory period.

The User Survey data processing system was the most complex and inter-dependent one in the PICR and required over two years of development before it became fully operational. The basic structure of the system incorporated three major file stages:

- Candidate - where new data entered the system and was checked by automatic editing procedures.
- Master - which consisted of screened candidate data.
- Analysis - where data were passed for analysis after the checking of both dependent and independent data sets was completed.

The system was designed to facilitate the changes or manipulations required for data management or analysis, while protecting the basic field data on candidate file. Reports generated at the candidate and master stages allowed the team to identify problems and take corrective action. Data were therefore only passed for analysis when they were considered to be of a suitable quality.

The processing system is fully described in a PICR Document (Swait, 07/1979). The system was complex because it handled both operating cost data from the Main Survey and highway characteristics from the Route Survey. These files had then to go through various editing and transformation procedures before they were assembled to form the dependent and independent data sets for analysis. The system generated the analytical files on fuel, parts consumption, utilization and tires.

In addition, information collected by supplementary surveys needed preparation for analysis. The processing system was much simpler and this type of data was placed on cards before being manipulated by the S.A.S. package of computer programs (Barr *et al*, 1976). This allowed the analysts to make rapid combinations of data sets and hence strengthened the role of supplementary survey material in the final analyses.

Supplementary Surveys began early in the project and initially embraced economic activities not covered by main survey activities. A methodology for calculating constant prices was developed to take out the effect of inflation on costs, for example, as well as the collection of data on taxes and duties within the transport industry. The real benefit from supplementary surveys was realized after the vehicle operating cost files were examined and preliminary analyses performed. It became clear that most operators' records were not generating a sufficient quantity and quality of data for certain components, particularly tires and labor hours. This was expected given the complexity of many operators' cost systems and the need for the field researcher to record many different cost components at one sitting, rarely getting the opportunity to throughly investigate data quality associated with one particular item. In addition, operators' records themselves often did not include items like labor hours.

This called for corrective action and supplementary surveys were used. These allowed senior staff to design collection documents which concentrated entirely on a specific item. Knowledge of companies, gained from main survey activities, allowed them to direct field researchers to operators known to have potentially useful information. Alternatively, field staff were instructed to search for new survey participants in their area who possessed certain characteristics. Finally, it enabled the field researcher himself to concentrate on a single item and gain a good knowledge of company behavior in that area.

The combination of these factors made the use of supplementary surveys a successful ancillary procedure to main survey activities. Although the main survey did not produce data in all areas, it provided the basis for the effective use of supplementary surveys. These surveys covered such issues as labor hours, tire data, tachographs, route operating hours details and information on the utilization of heavy trucks.

1.7 *ROUTE DATA COLLECTION AND PROCESSING*

The detailed work involved in collecting and processing user survey route data for analysis purposes is fully described in another PICR Document (Harrison and Caixeta, 11/1979). Essentially, routes used by vehicles of participants in the Main Survey had to be described in terms of highway characteristics, especially those of surface condition, vertical and horizontal alignment. These characteristics were calculated from data collected in a route inventory program specially designed for the needs of the research. Survey vehicles capable of measuring route characteristics had to be designed and tested, together with hiring and training of crews to operate them and a data processing system to permit the data to be efficiently analyzed. The group responsible for conducting the route measurement program comprised two office staff members and two survey vehicles, each having a driver and an observer.

The route network rapidly grew as members of the field staff travelled further from Brasília in an attempt to identify participants for all areas of the stratified sample design.

Field staff responsible for the collection of user cost data completed a form which identified the main features of each route used by a potential participant. Each route was then allocated a unique number. When routes were shown to be important to the project, they were located on regional maps based on the latest available state pu -

blications. This involved following each route from origin to destination and describing the configuration in terms of nodes, which represented specific geographic locations easily identified by field crews. Thus all routes could be identified by their assigned route number and a sequence of nodes describing their location. This route number and node sequence formed the basis of the Master Route File. This file had an important role in the analysis of survey data since no user cost data were accepted for analysis unless the route(s) identified on the field collection forms were defined on the Master Route File. A road section beginning at one node and ending with another was termed a link and the measurement of links, rather than specific routes, formed the basis of the route inventory program.

Two Chevrolet Caravan station wagons, each having a four cylinder engine and automatic transmission, were selected to carry the measurement instruments. This model was selected to make it easier to maintain the constant speeds required while measurements were being taken (See Chapter 3 of Volume 2 for details). Crews followed instructions given at the beginning of each program without being directly supervised in the field. Therefore, careful staff selection had to be made to obtain personnel who could work efficiently without direction. Once selection was completed, staff had to be trained to operate the instruments, accurately record the measurement data and learn to drive at constant speeds while data were being collected. Training personnel, together with instrument manufacture and testing, took over six months and the measurement program began in January 1977.

The project roughness measurement system consisted of a GM Profilometer and Quarter-Car-Simulator, a Mays-Ride-Meter (Maysmeter) and an accurate Odometer, the D.M.I. (Linder *et al*, 07/1978). These instruments combined to form the system which generated road surface roughness data and which is detailed in Volume 3 of this report series and in Visser and Queiroz, (11/1979). The Maysmeter produced a count for each 320 m, when in operation. These counts were digitally displayed to the observer who recorded them on a field form. Readings were sensitive to the vehicle condition so the entire vehicle was the measuring instrument. The Maysmeter therefore needed to be maintained in strict calibration with an established roughness base and this was provided by the Profilometer and Quarter-Car-Simulator.

A calibration course of paved highway sections had been established in the vicinity of Brasília and each survey vehicle ran over these sections at regular intervals. The full course was used when calibrating the Maysmeter and five sections for verifying calibration at the beginning and completion of a work program. Each vehicle was calibrated by correlating the Maysmeter output with roughness statistics produced by the Quarter-Car-Simulator running over section profiles produced by the Profilometer when travelling over the course. This correlation produced roughness values in units of QI* counts per km.

The geometry instrument consisted of a carefully positioned linear accelerometer capable of measuring a ± 1g range of accelerations. This output was then transformed to operate a panel scale designed to display grade measurements up to ± 12%. The instrument was sensitive to speed changes, so accelerations and decelerations had to be avoided. Therefore, vehicle drivers were trained to maintain constant speeds on grades and tests demonstrated that the device provided suitable vertical data for the analysis of user survey routes.

Horizontal measurements were taken from a standard aircraft type directional gyro compass, mounted in the survey vehicle. This measured the directional azimuth of the roadway at the beginning and end of each horizontal curve. The start and finish of the curve was identified by the driver and the directional readings and length of the curve were noted by the operator.

Survey vehicles produced a flow of data for each route on roughness and geometry characteristics which had to be reduced to a single roughness value and single measures for both horizontal and vertical geometry for analysis. The objective of this transformation was to produce a single value for each of the three data groups which possessed a suitable range for analysis purposes yet preserved key characteristics within each variable.

Maysmeter measurements were converted to units of QI* counts per km by referencing the survey vehicle number, its measurement speed, the date of measurement and the relevant calibration correlation. The QI* values were grouped into homogeneous bands within the link. Means were then calculated for each link and consisted of the QI* value for each band, weighted by its length. Where link roughness was homogeneous, the band and link were equal. Links were then combined to form routes weighted by their length and the analysis of survey data used this weighted roughness value to represent aggregate route roughness (Moser, 03/1978).

A program of repeat roughness measurements was undertaken to examine the change in roughness over time, in order to determine if the single value calculated for analysis reflected the average surface condition of the route for the period spent collecting the dependent data. This was particularly important for unpaved routes where the variation in roughness was expected to be considerable. No such adjustments were needed for the final analyses as evidence suggested that such variations would not significantly alter the results. The data, however, were collected and stored on file and further work seems warranted to examine this issue.

A number of different geometry statistics were calculated for inclusion in the final analyses. One statistic reflected the interaction between the vehicle and the geometric characteristics of the road at any point along the route. The performance of a vehicle at any point along a route section was considered to be dependent on the characteristics of the previous sections as well as those at that specific point. The technique adopted for calculating the statistic defined a function that related the immediate geometric conditions and then weighted it in relation to the effect of the previous geometric conditions. The weights themselves were based on speed changes, derived from work on the fuel-speed experimental data. The speed change on a vertical profile was a function of entry speed, grade, sign and grade length. The speed change on the horizontal profile was based on curve length, curve radius, entry speed and speed on the curve

The geometry statistics used in the TRRL Kenya project (Hide *et al*, 1975) were also included in the analysis set. Values for rise and fall, in meters per km, and average degrees of curvature, in number of degrees per km, were calculated from field data on file. Calculation of these statistics was considered important so that comparisons between the results of both research projects could be made. Finally, the DNER procedure for measuring vertical geometry in feasibility studies was slightly modified and the results included in the analysis set. Grades were grouped according to whether they were positive or negative and whether they fell into the groups 0 to 3, 3 to 5, 5 to 7 and 7 plus, in per cent. Thus eight groups representing the distribution of grades over the route were placed on the analysis files.

1.8 ANALYSIS FILES

The monthly vehicle operating cost file was originally designed to record all cost items but ultimately only recorded data suitable for the analysis of fuel, parts costs, maintenance labor costs and utilization. The maintenance labor costs could not be taken directly off this file for analysis and had to be systematically checked and transformed to a special analysis file separate from the analysis file derived from the monthly record cost file. This latter file has 54,000 records on 2,506 vehicles and this number of vehicles was considerably reduced for analytical purposes because of the following reasons:

- Vehicles were not included for analysis if they had few months of data assigned to them on main file, in general, a 6 months data minimum rule was followed;
- Vehicles were excluded that engaged in operations considered to be extraordinary and not reflecting normal highway operations; and
- Vehicles were excluded which operated predominantly in urban conditions and not those specified in the PICR terms of reference.

This action reduced the number of vehicles in the analysis file to 1,675, collected from 147 companies (including 75 owner-drivers). The tire file contains records on 20,820 tire changes, representing 6,886 tire lives. Mention has been made of a special analysis file for maintenance labor costs, and other such special files include car speed from timetable data, bus speed from tachograph records and private car utilization derived from a supplementary survey of 5,280 car owners.

The specific number of vehicle records for each cost component depended on the restrictions placed on the data by the analyst. One example of this is whether the analyst accepts parts data only from vehicles with more than 12 months records or whether this figure is smaller. Therefore, the size of each data file is stated in the relevant section of this report and correlation matrices and other tables are available for scrutiny in the technical memoranda associated with the analysis of each operating cost component.

Vehicles were grouped into five classes and these are given in Table 1.2, accompanied by a brief description of some technical characteristics of the representative vehicles in each class. Fortunately, there was a degree of homogeneity in all but the utility class which encompassed a diverse group of vehicles, varying from small pick-ups to

TABLE 1.2 - REPRESENTATION VEHICLE DESCRIPTION FOR USER SURVEY DATA SET

User Survey Vehicle Type	User Survey Vehicle Class	Representative Vehicle Characteristics
Car	1	Gross weight: 1 tonne Engine: 46 bhp.(DIN)34kW Gasoline, 4 cylinder, rear mounted
Utility Pick-up	2	Gross weight: 2.7 to 3.3 tonnes Load: 1.2-2.2 tonnes Engine: 58-133 bhp.(DIN)43-98kW smaller engine is rear mounted. Gasoline, 4 cylinder
Utility Light Truck	2	Gross weight: 6 tonnes Load: 4 tonnes Engine: 85 bhp.(DIN) 63kW Diesel, 4 cylinder
Bus	3	Gross weight: 11 to 13 tonnes Load: 4 to 5 tonnes Engine: 130 bhp.(DIN)96kW Diesel, 6 cylinder Monocoque on paved routes Chassis on unpaved routes Monocoque has two further engine options: 192 bhp.(DIN) 141kW or 210 bhp.(DIN)154kW
Medium Truck	4	Gross weight: 15 tonnes Load: 8 to 10 tonnes, and with 3 axles Gross weight: 18 to 22 tonnes Load: 12 to 15 tonnes Engine: 130 bhp.(DIN)96kW Diesel, 6 cylinder
Heavy Truck	5	Gross weight: 40 to 45 tonnes Load: 24-29 tonnes Engine: 285 bhp.(DIN)210kW Diesel, 6 cylinder turbocharged Tractor 2 axles, semi-trailer 3 axles

6 tonne light trucks. Despite the difficulty of analysing this vehicle class, attempts were made and the results reported in this volume. Therefore, five vehicle class results appear for each cost component , unless the analyses were confined to specific vehicle classes for particular reasons. Details of the various statistical and econometric methods employed to analyse the data are given in Chapter 2.

CHAPTER 2 - ANALYSIS PROCEDURES

2 ANALYSIS PROCEDURES

2.1 SURVEY DESIGN

The basic sampling frame used by the surveys team to recruit vehicles into the research has been described in Chapter 1 of this Volume and in Volume 2 of this Report, Chapter 3. Ideally the sampling frame would have contained companies with vehicles operating on a wide variety of homogeneous routes so that in each company, representation of all combinations of route characteristics was available. No such companies were located in Brazil. Companies whose vehicles operate on homogeneous routes tend to work in distinct geographical regions so that the ranges and combinations of route characteristics available in any one company are limited. Consequently the sampling frame contains many companies whose vehicles exhibit limited ranges of route characteristics. When a company was considered suitable for recruitment into the survey, operating cost data were collected from selected vehicles in its fleet on a regular basis. The company's routes were then measured and the characteristics of its fleet noted so that analysis data sets, comprised of both dependent and independent variables, could be assembled. The structure of these data sets was like that of a cluster sample, the companies forming the clusters and the vehicles forming the observations within each cluster. It was not clear how best to analyse data derived from such a sample and a number of difficult econometric problems had to be addressed before the analyses could be undertaken with confidence. These are fully discussed in another project document (Chesher, 04/81) and only a selection of the more important issues relating to the choice of analytical procedures is presented below.

2.2 BASIC MODELS

It is useful to specify a basic model to demonstrate some of the features which are pertinent to any selection of analytical techniques. Let y denote a dependent user cost variable, such as parts consumption or some transformation of this, like ln(parts consumption). The index i represents companies and the index t stands for vehicles within companies, such that y_{it} denotes the dependent variable associated with vehicle number t in company number i. Let x denote the independent variables and assume that in the basic model there are k of these, indexed by j so that x_{itj} denotes the j^{th} independent variable for the t^{th} vehicle within the i^{th} company. The variable x_{itj} could be some measure of the highways over which the vehicle operates, for example, average route roughness.

The easiest way to proceed with the analysis is to specify a linear model relating the x_{itj} to the y_{it}. Since the linear relationship is in general unknown and will not hold exactly, it is necessary to express it as a stochastic relationship introducing the unobservable random error ε_{it} and the k unknown parameters β_j, j=1...k. Thus:

$$y_{it} = \beta_1 x_{itj} + \beta_2 x_{it2} \dots + \beta_k x_{itk} + \varepsilon_{it} \tag{2.1}$$

or

$$y_{it} = \sum_{j=1}^{k} \beta_j x_{itj} + \varepsilon_{it} \tag{2.2}$$

Data on N companies are available so that i takes values from 1 to N . Within the i^{th} company there are data on T_i vehicles. A feature of the data collected by the User Cost Surveys Group is that T_i varies substantially between companies. A principal objective of the analysis is to estimate the coefficients $\beta_1 \dots \beta_j$ and to have some idea as to the accuracy of the estimators and of the likely performance of predictions derived from them.

2.3 USER COST VARIABILITY AND COMPANY EFFECTS

Consider the unknown random error ε_{it}. When ε_{it} is large and positive, the t^{th} vehicle in the i^{th} company has higher than average costs, given its route characteristics. When ε_{it} is large and negative it has lower than average costs, given its route characteristics.

The error ε_{it} can expected to be positive for some vehicles and negative for others. Some vehicles give trouble while others are trouble-free. In some years maintenance expenditures for a vehicle seem to follow quickly one on another and then the vehicle may have a period where there are no maintenance requirements at all.

Therefore, user cost equations estimated from highway and vehicle characteristics alone can leave unexplained a substantial proportion of the variation in user costs. Even the vehicle owners and the management staff of companies cannot predict maintenance requirements particularly accurately for specific vehicles in their fleet. The analyst knows far less about the vehicles and companies than do the owners or management staff. Consequently user cost equations can be expected to have quite low values for measures of goodness of fit like R^2 and reported equations with a high associated R^2 value should be carefully evaluated. R^2 values do not play such a significant role in the selection of 'good, robust, user cost equations as they do in other research areas, like the analysis of experimental fuel data. Although predictions for individual vehicles may be inaccurate, quite satisfactory predictions of average vehicle user costs can be produced from equations with low R^2 values, and the average values form the main focus of interest in evaluating the interrelationships between highway costs.

A survey of the type conducted by the user cost team cannot hold certain factors constant while observing one specific variable, as is possible with an experimental design. The survey observations arise under realistic user conditions and measure features of the economic behavior of companies and vehicle owners in their efforts to control costs, make a profit and stay in business. Vehicle users can make a wide range of decisions covering such diverse areas as cost control systems, workshop practices, driver control and loading policies. Some run efficient operations so that in time they grow in size. Others are less efficient and perhaps in time they will have disappeared, been bankrupted or sold out to more successful competitors. These company decisions have an impact on the user cost items which is quite independent of the type of highways travelled by the vehicles. When sampling from the population of companies in existence at the date of sampling, it is likely that long lived, stable companies will be over represented. Such companies are likely to be relatively efficient and to be well adjusted to the characteristics of the routes over which their vehicles travel (Chesher, 04/79). Accordingly cost values will tend to be derived from the more efficient type of company. Nevertheless, data in the survey will exhibit variations, sometimes large, that occur because of differences between the operating policies of owners. The analysis procedures must address this feature.

In order to allow for company specific variation in costs, the error term ε_{it} is written as the sum of a company specific error, u_i, and a vehicle specific error w_{it}. Thus:

$$\varepsilon_{it} = u_i + w_{it} \tag{2.3}$$

The term u_i is common to all vehicles in company i. A low cost company will have a small value for u_i and, consequently, relatively low costs for all its vehicles. Variations within companies in the vehicle specific error w_{it}, together with variations in route characteristics, give rise to the variations in costs within companies that are observed. Writing the error term as in (2.3) gives the equation for user cost, (2.4)

$$y_{it} = \sum_{j=1}^{k} \beta_j x_{itj} + u_i + w_{it} \qquad (2.4)$$

Given the error structure in (2.4), how can the coefficient β_j be estimated? Even under the strictest assumptions concerning the error terms, the widely used ordinary least squares technique gives inefficient estimators of the β_j's.

Two distinct approaches to estimating the β_j's are available. In one approach the error terms u_i are estimated. In the other approach the u_i's are not estimated. Instead the u_i's are regarded as a sample from some population of possible company specific errors, and the variance of the u_i's in this population is estimated. Both of these procedures have drawbacks.

If the u_i's are estimated, the number of coefficients in the model (2.4) can be large and the result may be some inaccuracy in the estimates of the coefficients of interest - the β_j's. When the u_i's are estimated a separate intercept is fitted for each company. With this approach only within company variation in costs and route characteristics is exploited to estimate the β_j's, the between company variations being reserved for the estimation of the company intercepts. If there is no great variation within companies in the explanatory variables, x_{itj}, then inaccurate estimates of the β_j's may arise. However the estimates produced via this approach do have the great advantage that they are robust to alternative assumptions concerning the error terms in (2.4).

In order to estimate using the second approach (in which the variance of the u_i's is estimated), distributional assumptions concerning the error terms in (2.4) are required. The standard assumptions are that the u_i's are mutually independently distributed with mean zero and constant variance, that the u_i's are distributed independently of the w_{it} and that the u_i's are distributed independently of the x_{itj}. It is this last assumption that causes most difficulty in practice. It requires that efficient companies are evenly distributed over different route types. Consider a situation in which this assumption will not hold. In this situation efficient companies are underrepresented on poor quality routes because on such routes, which are typically low volume, imperfect markets prevail. Inefficient companies tend to survive longer on such routes. In this situation u_i is correlated with x_{itj}. Procedures which regard the u_i's as satisfying the standard assumptions will, in this situation, produce biased estimates of the β_j's. However, the procedure described earlier in which the u_i's are estimated, will produce unbiased estimates.

If the standard assumptions do apply, then the second approach will produce unbiased estimates of the β_j's which are efficient relative to those obtained by the first method. The choice between the two approaches depends on the likely magnitudes of the correlations between the company specific errors, u_i's, and the explanatory variables, x_{itj}.

2.4 *VEHICLE CHARACTERISTICS*

If user cost data are regressed on highway characteristics alone, relatively large variations in the error term values are produced, whatever statistical procedure is used. Highway characteristics have only a partial effect on user costs, as previously discussed. In Kenya (Hide *et al*, 1975) it was found that the inclusion of vehicle characteristics strengthened the equations because of the strong effect certain characteristics apparently had on costs. Vehicle age in kilometers was found to be particularly potent. Specifically, in Kenya, as vehicle age in kilometers doubles for cars and trucks up to a limit of 160,000 and 400,000 km respectively, so do maintenance expenditures per km. For buses, doubling vehicle age causes maintenance costs to rise by over 40% up to a limit of 1.100.000 km. These increases in maintenance costs apply to each successive doubling of vehicle age.

In the PICR Phase 1 report, selected vehicle characteristics were used in the analysis of user cost data. These included number of carburettors (for cars), tachograph fitted (for buses), engine size in cc, location of engine and so on. It should be recognized that any procedure that introduces vehicle characteristics into a regression analysis may result in estimates that suffer from simultaneous equations bias unless independent variables are chosen which affect vehicle characteristics and not costs. This problem is probably unlikely to occur in the PICR data because it is believed that vehicle characteristics are chosen by operators with long run average costs in mind and the survey obviously only observes a single vehicle's costs for a relatively short period in its life. So vehicle characteristics are not determined by the costs that are observed but by a long run average in which the costs collected by the survey and subsequently passed to analysis play only a small part.

There are several arguments which favor the inclusion of vehicle characteristics in user cost equations. The most significant are:

- the estimated equations often show better fit and possess higher R^2 values. In addition, the inclusion of vehicle characteristics helps avoid the problem of model misspecification which can cause the resulting coefficients to be biased;
- equations with vehicle characteristics give rise to a better understanding of how vehicle characteristics affect operating costs. It is known that operators select from the technical options available for each model so that the overall vehicle specification best suits the operating conditions it will face. Accordingly, inclusion of such options should enable the analyst to more thoroughly evaluate the operating cost data collected from company records; and
- equations with vehicle characteristics may be more robust and transfer more readily to other regions. There will, of course, be applications where the required data on vehicle characteristics are not available. In this case, average values of the characteristics used in estimating the equations can be used as default values.

Despite these strong arguments in favor of including vehicle characteristics, some problems emerge. The inclusion of some vehicle characteristics is complex and costly because of the non-linear effect some of these characteristics have and because of the difficulty in specifying the way in which they might interact with highway characteristics. Furthermore, it is possible that the effects of vehicle characteristics on operating costs may change over time with technical development. However, development in vehicle technology is likely to be evolutionary in nature and should not be a cause for concern when applying these cost equations over the next decade. It should be remembered that many of the cost tables currently used in Brazil and other countries are based on some data over forty years old.

The analysis of the PICR user cost data has estimated the influence of vehicle characteristics as one of its statistical procedures. In the technical memoranda describing the analyses of the various user cost items, tables will be found both with and without vehicle characteristics. The user can therefore examine in detail the effect of such characteristics. The results reported in this volume include equations with vehicle characteristics where these were found to be significant and improved the prediction of the dependent variable. However, it should be borne in mind that the PICR survey was not designed to estimate the effects of vehicle characteristics on operating costs.

2.5 STATISTICAL PROCEDURES

Four basic statistical methods have been used to analyse the vehicle operating cost data on the PICR project. These are:

- Least squares applied to company cell means

All the within company variations in costs are averaged out so that the statistical estimation relies entirely on between company variations. This method was adopted in the Kenya study and for selected cost components in Phase I of the PICR. This is a useful procedure when there is little variation within companies in user costs , perhaps because of companies' identical treatment of the vehicles in their fleets. This procedure does not address the company effects/error components issue discussed in Section 2.3.

- Least squares applied to individual vehicle data

This procedure does not address the company effects issue either. It is appropriate when the company specific error (u_i in Equation 2.4) is small in magnitude relative to the vehicle specific error (w_{it} in Equation 2.4). The technique was widely used during exploratory work with the data and a few of the results reported later were obtained using this method at an early state in the research.

In the analysis of Phase I, least squares applied to individual vehicle data and to company means were used extensively. The two procedures generally produced similar results (GEIPOT, 1980, p. 167). The subsequent analysis has proceeded within the framework of the error components model described in Section 2.3. As noted in that section, two approaches are available:

- Least squares applied to individual vehicle data with company effects estimated

The technique applies least squares to Equation 2.4, estimating a separate intercept for each company. This is equivalent to estimation after expressing all data as deviations about company means. Thus only within company variation is exploited to estimate the effects of the explanatory variables on costs. In order to obtain equations that predict levels of costs as well as the differences in costs associated with different route types, it is necessary to average the estimated company intercepts. Weighted averages have been calculated using numbers of vehicles per company as weights. Standard errors associated with the intercepts thus produced have been calculated to allow for this averaging process. On occasions companies have been formed into homogeneous groups to give more than one reported intercept. This gives the equations greater flexibility. The procedure described in this subsection is appropriate when correlations between company effects and route characteristics are likely and when there exists within company variation in the data.

- Generalized least squares estimation of the error components model

The company specific error, u_i, is regarded as a random error whose variance is to be estimated. The generalized least squares procedure described in Fuller and Battese (1973) is applied. The procedure is appropriate when the company specific error u_i is negligibly correlated with the explanatory variables. When the company error is zero the procedure produces the same estimates as ordinary least squares applied to individual vehicle data. When the vehicle specific error is zero it produces the same estimates as weighted least squares applied to company means.

The error components model has played a useful role in the analysis since 1980, so the company-cell means method has not been used in this period. The other three methods have all been used, with and without vehicle age and a selection of vehicle characteristics. The output from these analyses was considerable, running to many hundreds of different equations for each user cost component. Naturally, only a selection of equations can be presented here and references will be made at the appropriate time to the relevant technical memoranda where equation choice is dealt with in greater detail.

In the presentation of the results the company means method is identified by "CM"; least squares applied to individual vehicle data is identified by "OLS"; least squares estimating company effects is identified by "OLSCE"; and generalized least squares estimation of the error components model is termed "EC".

Reported coefficients are accompanied by t-statistics written in parentheses below the coefficients. These are ratios of coefficients to their standard errors. They have been calculated using methods appropriate to the technique used to produce the coefficients. In the few cases in which estimates are calculated by least squares applied to individual vehicle data (OLS) the t-statistics are biased if the company specific error u_i has non-negligible magnitude. No attempt has been made to correct for the bias in these t-statistics. Experience of comparing many hundreds of OLS, OLSCE and EC estimations suggests that for the user cost survey data sets the bias is such that t-statistics from OLS estimations are overstated by about 30%. In the EC estimations the t-statistics have a large sample justification only. Accordingly, they should be referred to tables of the normal distribution. Except in the case of the EC estimations, the squared coefficient of multiple correlation is reported. For EC estimations, one of the goodness-of-fit statistics G and H (described in Appendix IX) are reported. These can be interpreted like R^2, values close to one indicate small scatter about the fitted line, values close to zero, the converse. As noted earlier, goodness of fit statistics are not particularly relevant. The quality of the predictions is more important. Reported equations are also accompanied by estimate(s) of the standard deviation of the error term. In the OLSCE estimations, these (s_w) refer to the vehicle specific error w_{it}. In the EC estimations two standard deviations are reported, one (s_w) relating to w_{it}, the other (s_u) to the company specific error u_i.

Equations estimated during the period 1981/82 are accompanied by prediction intervals. For selected levels of the explanatory variables (including the mean levels in the data set) predicted user costs or ln(user costs), as appropriate, are provided. These are presented with upper and lower limits which with probability 0.95 contain average user costs at the levels of the explanatory variables being used.

These intervals provide probabilistic bounds on the prediction error to be expected when using the reported equations. In the case of EC estimations the intervals have a large sample justification only. The intervals are narrowest at the mean of the explanatory variables for the data set. As infrequently observed combinations of the explanatory variables are approached, the prediction intervals widen. Thus the intervals give an indication of the decreasing accuracy of predictions associated with more extreme values of the independent variables.

The prediction intervals also serve another useful purpose. It will be seen that, even though for some equations goodness-of-fit statistics are small relative to those obtained in experimental studies, prediction intervals for average costs are still quite narrow. So, even though the individual vehicle data are quite scattered around the user cost relationships, the modelling and estimation procedures adopted, together with the relatively large numbers of observations, allow quite precise prediction of average costs. This is quite normal and arises in many areas of scientific research. Much useful information can be derived from widely dispersed data as long as sufficient observations are available and care is taken over modelling and estimation.

Statistical analysis was performed using the statistical analysis package SAS (Barr *et al*, 1976). In exploratory data analysis considerable use was made of graphical output. When evaluating these graphs, great care was taken to ensure that observations lying off trend lines were not treated as bad data and excluded from subsequent analyses. Outliers were intensively checked by examining the basic data files and whenever possible retained for analysis. Ordinary and weighted least squares were performed using the SAS procedure GLM. The generalized least squares estimations were calculated using specially written computer programs relying heavily on the SAS procedure MATRIX.

Selected equations are now reported. Note that all logarithms are calculated to base "e", that is natural logarithms are used throughout. Equations estimated in log form or incorporating independent variables in the log form are identified by the designation of 'ln' before the relevant variable. Where cruzeiro costs are being predicted, the equations give values in terms of December 1981 prices.

CHAPTER 3 - ANALYSIS RESULTS

3 ANALYSIS RESULTS

The results are presented first by user cost component and then by vehicle class. All major components have been examined at least twice since 1979 and these analyses have been reported in the form of technical memoranda. The results given below are taken from those sources and it is recommended that they be examined if more details are required. The technical memoranda are referenced in the appropriate sections. Finally oil and grease consumption were not reanalysed as the effort required was disproportionately large in relation to the importance of these items in the vehicle operating cost hierarchy. Accordingly they are presented here in the same form that they appeared in the PICR Phase I report. Definitions of all the dependent and independent variables reported in the following sections are given in Appendix 1.

3.1 FUEL CONSUMPTION

3.1.1 *Introduction*

The collection of fuel consumption data was an important activity of the User Cost Surveys Group and one considered complementary to the extensive experimental work on fuel and speed carried out concurrently within the PICR. Not only did the user data on fuel consumption serve as a consistency check on other cost items, like utilization, but it provided evidence on fuel consumption under the actual conditions faced by the Brazilian vehicle operator and could be used to evaluate the aggregate results derived from the experimental work.

In principle, fuel data from a user survey should be informative. These data should be reasonably consistent since fuel is often the item most closely monitored by the vehicle owner. It is consumed continuously when the vehicle is used and a relatively short period of observation (6 to 9 months) should give a good estimate of a vehicle's fuel consumption. Many unobserved characteristics of vehicles and drivers affect fuel consumption. Consequently low R^2 values are generally obtained when fuel consumption is related to highway characteristics using User Survey data. It is possible to obtain good estimates of the relationship between average fuel consumption and highway characteristics, even when data are widely dispersed and average fuel consumption for the various classes that comprise the vehicle population is the objective of the PICR predictions.

Despite the previous work on fuel consumption in Kenya and the U.S.A., it was not clear a priori what sort of relationship to expect between fuel consumption and highway characteristics under actual operating conditions. This is largely because of the effect of speed changes on fuel consumption. As road curvature increases, for example, average speed may fall and fuel consumption may also fall, in a linear or nonlinear way, even though curvature increases resistance. Thus it is not immediately obvious what the form of the equation or the signs of the coefficients should be. In this report, linear and log-linear models have been fitted using the OLS and EC methods, with and without vehicle characteristics. The independent variables for highway design are road roughness, rise plus fall and average degrees of curvature.

The data were first graphed by vehicle class and a general increase in fuel consumption with increasing roughness was noted, although it was difficult to detect effects for geometry. There is considerable dispersion at times in the data but this is to be expected. Vehicles carry different loads, travel at different speeds and are driven by different drivers in different ways. The vehicles are not always identical within each class and receive different qualities of maintenance. All these factors affect fuel consumption and are a feature of vehicle operation.

3.1.2 Fuel Consumption Equations

The fuel analysis was structured so that predictions from the User Survey data could be compared with results from the Experimental Fuel and Speed Group. This comparison is examined in the next section. To facilitate this only one extra vehicle class, light diesel truck had to be created out of the utility survey data set. These classes are defined in Table 3.1. Linear and log-linear forms were tried and estimations made using OLS, OLSCE and EC methods. The recommended fuel equations reported in this volume are estimated using the EC method which seems better suited to take account of the company and vehicle variations inherent in fuel consumption data. Different variables were found to be significant for different vehicle classes. This may be due

TABLE 3.1 - FUEL CLASSES, SURVEY AND EXPERIMENTAL EQUIVALENTS

Survey Class	Experimental(MTC) Class	Power/ Weight Ratio
Cars	1	-
Utilities	3	-
Buses	2	-
Light Diesel Trucks	6	24
Medium Diesel Trucks	7	17
Heavy Diesel Trucks	8	13

NOTE: Power/weight is BHP (SAE)/tonne

to real differences in the models for fuel consumption or to correlations among the independent variables which obscure the true relationships. Given that there may be different speed and load responses for different vehicles, it is quite possible that distinct models do exist for each vehicle class. These results are based on previous PICR technical memoranda (Chesher, 02/09/1980) and (Lima, P. R., 02/12/81) and more details, for example, on correlation matrices, are contained in these documents.

3.1.2.1 *Car Fuel Consumption*

It was not possible to determine a vertical geometry effect for these vehicles. However, deteriorating horizontal geometry was found to significantly increase fuel consumption. A 100 degree per km increase in average degrees of curvature is predicted to raise fuel consumption by 14 percent. The log-linear equation, estimated by the EC method (t statistics in parentheses) is:

$$\ln(\text{Fuel}) = \underset{(110.54)}{4.425} + \underset{(2.10)}{0.0008QI^*} + \underset{(5.57)}{0.00135ADC} - \underset{(-2.22)}{0.0972CARB} \tag{3.1}$$

$$G = 0.10 \qquad S_u = .070 \qquad S_w = .102$$

Where

Fuel = liters per 1000 km

CARB = 1 if vehicle has twin carburettors
0 otherwise

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (fuel).

CARB	0					
ADC	10		54[1]		250	
QI*	40	100	40	100	40	100
Upper Limit	4.535	4.586	4.594	4.640	4.915	4.949
Prediction	4.470	4.519	4.530	4.578	4.794	4.842
Lower Limit	4.406	4.451	4.465	4.516	4.672	4.735

[1] Data set mean value.

The prediction and prediction intervals demonstrate that equation 3.1 has tight prediction intervals despite a low goodness of fit statistic and illustrates why an equation should not be judged solely on goodness of fit. The equations presented in this Volume are primarily selected for their robustness and ability to give good cost predictions for average vehicles in each vehicle class. The prediction intervals are an important check on the quality of the equations and should be regarded as a most important item in the reporting format of the equations. The equation is based on 243 observations derived from 6 companies. Twin carburettor cars were found to be slightly more economical but since a user of this equation will generally not know what proportion of the car stream has such a feature, it is recommended that the user survey average 0,025 is substituted for the variable CARB which removes the CARB variable and changes the intercept value to 4.423.

3.1.2.2 Utility Vehicles' Fuel Consumption

These vehicles can be broadly grouped into rear engined gasoline and front engined diesel types. The former were analysed first and comprised 33 vehicles derived from 6 companies. A log-linear form similar to cars was found to fit the best but the size of the roughness effect was larger than for cars. This is expected because, although they share similar design features, the load factor will generally cause highway characteristics to have a greater impact on operating costs. The log-linear equation, estimated by the EC method (t statistics in parentheses) is:

$$\ln(\text{Fuel}) = \underset{(56.55)}{4.957} + \underset{(2.16)}{0.00141QI^{*}} + \underset{(2.36)}{0.00142ADC} \tag{3.2}$$

$$G=0.15 \qquad S_u=.141 \qquad S_w=.090$$

Fuel is again measured in liters per 1000 km.

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (fuel).

ADC	47[1]			250		
QI*	30	74[1]	120	30	74[1]	120
Upper Limit	5.207	5.253	5.327	5.623	5.665	5.720
Prediction	5.067	5.128	5.193	5.355	5.417	5.482
Lower Limit	4.926	5.004	5.059	5.088	5.170	5.243

[1] Data set mean value.

Vertical geometry was not found to be significant in the log-linear form but did become significant when fuel was estimated in the linear form. The linear equation, estimated by the EC method (t statistics in parentheses) is:

$$\text{Fuel} = \underset{(6.06)}{111.92} + \underset{(2.81)}{0.271QI^{*}} + \underset{(1.83)}{0.256ADC} + \underset{(2.82)}{1.095RF} \tag{3.3}$$

$$G=0.54 \qquad S_u=17.394 \qquad S_w=13.464$$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for fuel.

ADC	47[1]					
RF	20[1]			40		
QI*	30	74[1]	120	30	74[1]	120
Upper Limit	174	183	196	200	211	226
Prediction	154	166	178	176	188	200
Lower Limit	134	149	161	151	164	174

[1] The mean value for this variable in the data set

3.1.2.3 *Light Diesel Truck Fuel Consumption*

This vehicle class was created from the user survey utility class data set and comprised 49 vehicles, principally engaged in newspaper delivery and milk collection activities. The correlations amongst the independent variables for this set are high and make it difficult to estimate the effects of highway characteristics. No accurate estimation of the effect of vertical geometry was found. Curvature was found to be significant but an interaction term with roughness has the effect of nulifying any influence of roughness at relatively low values of curvature. Accordingly, no regression equation for this vehicle class can be presently reported. Instead, average fuel consumption for paved and unpaved roads, based on individual data on basic file is given. This appears in Table 3.2.

TABLE 3.2 - LIGHT DIESEL TRUCK FUEL CONSUMPTION

	Fuel	Average Route Characteristics QI*	RF	ADC
Paved	184	39	27	39
Unpaved	193	119	30	59

NOTE: Fuel is in units of liters per 1000 km.

3.1.2.4 *Bus Fuel Consumption*

This data set is the most comprehensive. The highway characteristics are weakly correlated with each other and the set contains 462 diesel engined vehicles. Therefore, accurate estimates should be obtained for the effects of roughness, vertical geometry and curvature.

Deteriorations in any of these are found to increase fuel consumption but the size of the coefficients is at times surprising. The effect of vertical geometry is small and generally not significant. A 30 meters/ km change, which is large, only increases fuel consumption by 4 percent. This might be seen as a cause for concern since the experimental results show this variable to exert a significant effect, as does some of the user survey data itself as shown in equation (3.3). On examining the experimental methodology, it can be seen that an identical vehicle is run over highway sections exhibiting different design and maintenance characteristics. Survey utility vehicles yielding data for equation (3.3) were also identical. Buses, however, were not. A tendency was observed for operators to choose technical options for their buses in an effort to reduce operating costs. In the PICR survey, operators normally use large engined buses on hilly routes. The power and torque characteristics of these engines produce, amongst other things, better fuel consumption on such routes than smaller engines which have to work harder. So the influence of vertical geometry is greatly reduced and causes this variable to drop out of many equation forms. This is a good example of where the actual user data differs from experimental analyses and produces unexpected results. The reported log-linear equation, estimated by the EC method (t statistics in parentheses) is:

$$\begin{array}{ll} \ln(\text{Fuel}) = & 5.641 + 0.00061QI^* + 0.0004ADC - 0.0518SM \\ & (291.76) \quad (4.90) \qquad (2.21) \qquad (-2.08) \end{array} \qquad (3.4)$$

$$G = 0.16 \qquad S_u = .050 \qquad S_w = .071$$

Where

SM = 1 if standard of maintenance is high
0 otherwise

The equation is estimated from data on 462 vehicles derived from 21 companies. Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (fuel).

SM	0					
ADC	43[1]			200		
QI*	40	83[1]	160	40	83[1]	160
Upper Limit	5.715	5.739	5.790	5.810	5.832	5.876
Prediction	5.683	5.709	5.756	5.745	5.772	5.819
Lower Limit	5.651	5.680	5.722	5.680	5.711	5.761

[1] Indicates the mean value for this variable in the data set.

As was the case with car fuel predictions, equation 3.4 is shown to have tight prediction intervals even though the goodness of fit is weak. This increases confidence in this equation and indicates that it will produce good predictions for average vehicles in this class.

An equation including the variable SM is reported since good maintenance procedures help reduce fuel consumption. However, the Experimental Fuel and Speed Group was not able to quantify this effect and little information is available on the subject. The results from the PICR survey bus data set, where standard of maintenance was assessed subjectively and through a questionnaire, show that a well maintained bus consumes 5% less fuel than a bus receiving average maintenance. This interesting result demonstrates the savings that can follow if an owner maintains his vehicle in good condition. Where users cannot measure this variable, however, it is recommended that the user survey average value (0.5) is substituted which removes the SM variable and reduces the intercept to 5.613. The equation gives satisfactory predictions over the range in the data set, where the maximum values of roughness and curvature are 214QI* and 208^{o}/km, respectively.

3.1.2.5 Medium Truck Fuel Consumption

This data set, containing 215 vehicles, exhibits some correlations between highway characteristics which complicate the analysis. Equations with significant vertical and horizontal geometry effects could not be estimated separately. The reported log-linear equation for road roughness, estimated by the EC method (t statistics in parentheses) is:

$$\ln\ (\text{Fuel}) = \underset{(118.56)}{5.735} + \underset{(1.99)}{0.00108QI^*} \qquad (3.5)$$

$$G = 0.38 \qquad S_u = .144 \qquad S_w = .106$$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (fuel).

QI*	40	68[1]	150
Upper Limit	5.849	5.875	6.010
Prediction	5.778	5.808	5.897
Lower Limit	5.707	5.742	5.783

[1] Data set mean value.

This equation is considered to give good predictions of fuel consumption for this vehicle class, particularly for the most numerous type, the 3 axle rigid variety. This can be considered the representative medium truck for the Brazilian national fleet and so it is important to have good estimates of its fuel consumption. The equation is considered to give satisfactory estimates up to 200 QI*, and, furthermore, seems to extrapolate fairly well beyond this value.

3.1.2.6 *Heavy Truck Fuel Consumption*

The typical vehicle for this class is articulated and comprises a two axled tractor pulling a three axle semi-trailer. Such trucks are seldom operated on unpaved roads, except for special applications like timber and sugar cane haulage where gross vehicle weights are around 55 tonnes. The data set therefore contains information on fuel consumption only for paved roads. Correlations between certain highway characteristics are high and cause problems in the analysis. In order to obtain a significant geometry main effect, an interaction term between that variable and road roughness had to be estimated.

However, this equation only fitted a narrow range of data and once hilly routes are encountered, increases in roughness are predicted to reduce fuel consumption. More data need to be collected to correct this anomaly. Instead, the average fuel consumption on an undulating, relatively straight road and a more hilly, curvy route are given. These are shown in Table 3.3 and are based on individual vehicle data on file.

TABLE 3.3 - HEAVY ARTICULATED TRUCK FUEL CONSUMPTION

		Average Route Characteristics		
	Fuel	QI*	RF	ADC
Undulating	559	29	29	11
Hilly	737	43	37	78

NOTE: Fuel is in units of liters per 1000 km.

The equations and tables reported above represent the best fuel estimations, based on User Survey data, available at this time. Some vehicle class equations would benefit from further analysis and this is discussed in the relevant section of this report. The bulk of the analyses were conducted in 1980 and estimations using the more sophisticated error components method had to be done quickly. Further analysis and scrutiny of the fuel data on basic file might bring improvements. However, sufficient data presently exist to make an evaluation between survey and experimental results and this is discussed in the following section.

3.1.3 *Experimental and Survey Fuel Consumption*

3.1.3.1 *Introduction*

As was noted before, user survey fuel data are important since they provide information on the fuel costs actually incurred by vehicle operators. Such data reflect their responses to road conditions and relative prices. These responses include the selection of operating speeds, vehicle loads and maintenance quality and quantity. However, another valuable source of data on fuel consumption and its sensitivity to road characteristics is the time and fuel algorithm (MTC), produced by the Experimental Fuel and Speed Group in the PICR. MTC uses actual vehicle speed derived from roadside radar observations and from the experimental measurement of fuel consumption. The MTC is essentially a micro model where each grade and curve change can be entered, so in this form it is not very suitable for comparisons with survey data where routes have to be described by a single variable for each characteristic. Therefore, aggregate equations were produced from MTC data (Moser, 19/05/1980) and these are suitable for comparing with survey results. An exercise to compare these equations was carried out soon after as the aggregate equation became available (Chesher, 04/09/1980) and the results are reported below. Before appraising these results some of the discrepancies that might be expected are discussed.

3.1.3.2 *Potential Discrepancies*

The survey data on fuel consumption are quite widely dispersed, for reasons already noted. In addition, vehicles from the survey are not identical even when grouped into the MTC vehicle classes. MTC aggregate predictions give a single figure for any given combination of highway characteristics and consequently when these are compared with survey data, a considerable dispersion must be expected in the latter source. However, MTC is designed only to predict average fuel consumption so this should not, on its own, be a cause of concern.

Although MTC employs observations on actual vehicle speeds, it also uses data obtained from experiments performed with a fleet of test vehicles. Since each vehicle differs to some extent in its fuel consumption, as do drivers in their driving habits, a part of the MTC results derive from what is essentially a single observation on the vehicle population and a small sample of drivers. If MTC were estimated from different drivers and vehicles, then different equations would result. MTC is not, therefore, an absolute standard to judge survey equations.

The MTC aggregate equation is non-linear with respect to highway characteristics and the equations are difficult to apply to vehicles which do not travel homogeneous routes. The problem is that if a vehicle travels on, for example, two routes which are different in their characteristics, the mean of the MTC predictions for each route will not equal the MTC prediction for the mean route. Evidence already available suggests that fuel consumption relationships are non - linear with respect to highway characteristics so this difficulty cannot be removed. Its effect is lessened because the MTC aggregate equation was estimated using a selection of user survey routes which presumably are themselves non-homogeneous in highway characteristics. However, there still must be some difficulty arising from the non-linearity of the MTC equation which will give rise to some non-correspondence between MTC predictions and survey observations.

Finally, there may not be good correspondence in all vehicle classes between MTC speeds and survey speeds, since speed has already been identified as an important operator and driver response. Cars are of particular concern since in the survey they are commercially operated and higher speeds than average roadside observations may be expected.

3.1.3.3 *Method and Results of the Comparison*

First the user survey fuel data was grouped into the MTC classes required for the aggregate equation, as defined in Table 3.1 . The complete form of the MTC aggregate equation is given in Appendix V. To compare the MTC aggregate predicted fuel consumptions and those observed in the user survey, the predictions were graphed against the user survey observations and two sets of regression estimations were performed. In one, survey fuel consumption was regressed on the MTC aggregate predictions which should give a general impression of the degree of under or over prediction. In the other, the differences between the predicted and observed fuel consumptions were regressed on highway characteristics. This should give a sense for the extent to which, as far as this user survey data set was concerned, the MTC aggregate equation was failing to pick up the effects of highway characteristics . Comparisons were made for each MTC vehicle class reasonably represented in the survey data and the regression results are presented in Tables 3.4 and 3.5.

TABLE 3.4 - REGRESSION OF USER SURVEY FUEL ON MTC PREDICTION - INDIVIDUAL DATA (OLS)

Class	Intercept	MTC	R^2	S	n
1	56.25 (2.98)	.404 (2.03)	.03	13.24	154
2	219.55 (9.79)	.367 (3.63)	.03	40.65	490
3	-331.33 (-5.10)	3.377 (7.52)	.75	19.03	20
6	143.17 (3.09)	.266 (1.10)	.03	30.15	39
7	-281.70 (-2.25)	1.847 (4.80)	.64	43.72	141
8	777.62 (13.26)	-.333 (-3.39)	.09	152.34	113

NOTE: See Table 3.1 for class definitions.

The number of vehicles in each class given in n. MTC equals the MTC fuel prediction from the aggregate equation and is measured in liters per 1000 km. Estimation was by weighted least squares with the weight proportional to the number of observations per cell. Figures in parentheses are t-ratios.

TABLE 3.5 - REGRESSION OF MTC FUEL PREDICTION MINUS USER SURVEY FUEL ON HIGHWAY CHARACTERISTICS - INDIVIDUAL DATA (OLS)

Class	Intercept	ADC	RF	QI*	R^2	S	n
1	-11.17 (-1.09)	-.103 (-3.92)	.478 (2.60)	.049 (1.33)	.12	12.87	154
2	-121.24 (-16.34)	-.140 (-3.73)	2.280 (8.82)	-.106 (-3.26)	.18	38.36	490
3	18.21 (1.70)	-.298 (-5.03)	.693 (1.29)	-.430 (-6.20)	.88	10.77	20
6	-14.88 (-.61)	.301 (1.94)	.585 (.55)	-.239 (-1.81)	.14	32.01	34
7	88.97 (3.27)	-.023 (-.31)	-2.285 (-2.65)	-.186 (-1.46)	.08	42.93	141
8	486.45 (2.74)	4.426 (5.46)	-18.208 (-3.62)	-3.989 (-2.96)	.50	176.62	113

NOTE: Refer to Table 3.4 for more details.

The results of the comparisons are uniformly disappointing. In none of the six classes are the predictions produced by MTC close to the fuel consumption observed in the user survey. The correlations between MTC aggregate predictions and the observed fuel consumptions are small except for the sparsely populated utility vehicle class. The predictions' errors are significantly related to rise plus fall, average degrees of curvature and road roughness. The nature of these relationships alters from class to class and is difficult to explain. For cars, buses and utilities, the MTC aggregate equation tends to under-predict fuel consumption, more so on curved routes. For heavy trucks, it tends to over-predict.

Since the MTC aggregate equation is designed to predict average fuel consumption, it was decided to reanalyse the data after it had been averaged across cells defined by ranges of vertical and horizontal geometry and road roughness. In these comparisons average MTC aggregate predictions for broadly defined ranges of highway characteristics were contrasted with the average user survey fuel consumptions over the same ranges. The correlations obtained should give a fairer view of the strength of the relationship between MTC aggregate predictions and the user survey data. Regression results together with a definition of the cells are given in Table 3.6.

The results are similar to those obtained with the raw data. As expected, the correlations between MTC aggregate predictions and survey observations uniformly rise upon averaging but still, except for the utility class, remain small. The discrepancies between the MTC aggregate predictions and survey data require examination. The aggregate equation is not an absolute standard and both it and survey data are prone to error. The error in the survey data may well be larger than the MTC data but the MTC aggregate predictions may suffer from errors or approximations in modelling. It is recommended that more work be carried out in this area and, in particular, the MTC aggregate equation be reestimated.

3.2 ENGINE OIL AND GREASE CONSUMPTION

These items typically comprise around one percent of total vehicle operating costs and are therefore relatively unimportant compared with the other cost components. Nevertheless, some analyses were

TABLE 3.6 - REGRESSION OF USER SURVEY FUEL ON MTC PREDICTION. DATA AVERAGED BY CELLS DEFINED BY VERTICAL AND HORIZONTAL GEOMETRY AND BY ROUGHNESS

Class	Intercept	MTC	R^2	S	n
1	54.67 (4.41)	.421 (3.22)	.06	8.42	20
2	244.78 (18.23)	.342 (6.18)	.07	19.91	25
3	-339.94 (-5.69)	3.437 (8.31)	.78	17.36	7
6	131.79 (4.92)	.326 (2.32)	.12	16.04	12
7	-272.95 (-3.26)	1.820 (7.08)	.26	27.26	14
8	779.40 (16.11)	-.336 (-4.15)	.13	125.55	12

NOTE: Definitions of cells for averaging data are given by:

Level	ADC	RF	QI*
0	$0 \leq ADC < 25$	$0 \leq RF < 22$	$0 \leq QI^* < 50$
1	$25 \leq ADC < 80$	$22 \leq RF < 32$	$50 \leq QI^* < 90$
2	$80 \leq ADC$	$32 \leq RF$	$90 \leq QI^*$

carried out on oil and grease data in 1979 and these are presented in Tables 3.7 and 3.8. They were estimated by applying least squares to company cell means.

TABLE 3.7 - OIL CONSUMPTION

Vehicle Class	Intercept	QI*	XOIL	R^2	S	OBS	Company Means
Cars	.271 (7.89)	.0062 (11.46)	5 (6.94)	.88	.25	264	27
Buses	3.55 (20.75)	.0085 (5.06)	22.07 (3.77)	.42	2.18	500	58

NOTE: The dependent variable is liters per 1000 km. The variable XOIL is the frequency of oil changes per 1000 km. The regressions were estimated by the CM method.

No regression equations with highway characteristics were derived for medium and heavy trucks. The mean oil consumption of the medium class was 4.11 liters/1000 km, which included operations on unpaved, dusty roads where consumption can be high. The average for the heavy class was 5 liters/1000 km for operation on paved highways.

TABLE 3.8 - GREASE CONSUMPTION

Vehicle Class	Intercept	QI*	R^2	S	OBS	Company Means
Cars	.086 (2.24)	.0037 (6.16)	.66	.285	264	28
Buses	.712 (3.80)	.00389 (2.11)	.06	2.58	590	66
Medium/ Heavy Trucks	.337 (2.84)	-0033 (2.26)	.08	1.04	298	61

NOTE: The dependent variable is frequency of greasing/1000 km and can be converted to kg/1000 km by referencing the listing in the text. The regressions were estimated by the CM method.

Engine oil consumption includes regular oil changes and replenishing that oil burnt or blown out by the engine. As expected , frequency of oil changes is the main reason for variations in consumption. The policy adopted by the vehicle owner with respect to oil change policy is influenced by considerations other than route roughness. For trucks, no relationship was derived either because vehicle owners had become efficient in their oil change policy or had vehicles adapted to cope with the conditions. One such option sometimes seen on survey trucks was a large external oil cleaner to counteract the dusty conditions encountered on rough roads.

As with oil, grease consumption depends primarily on the policy adopted by the vehicle owner. Data on the frequency of greasings per 1000 km were analysed. From enquiries made with vehicle operators, the following average quantities of grease consumed at each greasing was derived: car, 0.5 kg; bus, 0.8 kg; medium truck, 2.0 kg and heavy truck, 3.0 kg. Consumption for each vehicle class can be calculated in terms of kg/1000 km by applying these quantities to the greasing frequencies derived from the analyses. Insufficient data were collected for analysing utilities as a separate class. What data exist on file have been checked and it is recommended that the car equation be used and converted to kg of grease/1000 km by multiplying the frequency derived by 0.75 kg.

3.3 *MAINTENANCE PARTS CONSUMPTION*

3.3.1 *Introduction*

This component has received considerable emphasis in the analyses conducted since 1979 and a large number of technical memoranda detail the findings of these enquiries. The equations include roughness, geometry, vehicle age and other vehicle characteristics and the parts consumption is expressed in Cr$/1000 km at December 1981 Brazil prices. The latter form takes out the effects of inflation from the vehicle cost streams collected in different years and the index used to accomplish this is described in the methodology of the user survey (Chapter 3 of Vol. 2 of this Report) and in Appendix XII.

In the PICR data, despite the efforts to find extreme operating conditions, severe geometric effects are rarely found in the route networks and the disposition of vehicles by highway type reflects this feature. Much of the geometric variation present at the link level disappears when the link geometry is averaged to produce the route geometry and this is compounded when vehicles operate on more than one route. Measures of geometry and roughness tend to be correlated in many of the data sets presented for analysis. Furthermore, geometry effects may well be weakened by operators' and drivers' speed responses to various qualities of geometric design (Chesher, 08/1980). However, it is believed that road geometry affects parts consumption in some way although the relationship is complex and not yet well understood. The speed of the vehicle influences the way in which roughness damages or wears out the vehicle and speed is partly determined by road geometry. Therefore, interactions between geometry and roughness are to be expected although when these have been modelled in the analyses, interactions can cause reversals of the expected signs for some independent variables. Non-linear estimations have not been attempted yet, as they are time consuming and difficult, particularly if the error components issue is addressed.

It may be that the parts data produced by a survey of operators' records are not sufficiently precise to pick up geometry effects. The evidence from Kenya and the Caribbean (Hide, 1980) suggests that this is possible and it is recognized that the attempts to relate geometry effects to parts consumption may not be successful. It is recommended that, at the moment, only parts equations with roughness and age are used. Further efforts to determine the effect of geometry should bring about a better understanding of the effects in order to enable the results to be disseminated with confidence. A summary of work done to date is reported in Appendix II and reference should be made to this by those who wish to consider geometric effects.

3.3.2 *Models*

In the analyses, linear, piecewise linear, log-linear and piecewise log-linear functional forms have been tried. In the equations roughness, measures of geometry, vehicle age and other vehicle and company characteristics have been tried. In the piecewise functional form the roughness variable is entered as Q40 defined as QI* for $QI^* > 40$, defined as equal to 40 for $QI^* \leq 40$. This form was tried because it was felt that user survey data yielded rather little information about the effect of roughness on parts consumption for routes with QI* less than 40, that is, smooth paved roads.

When the four functional forms were compared there was rarely any convincing statistical evidence in favour of any one particular form. The parts data are quite scattered and, within the ranges of highway characteristics observed, the various forms fitted almost equally well. Standard statistical procedures for testing hypotheses concerning appropriate functional forms did not give any clear indications as to the form to use. The alternative forms extrapolate rather differently and the choice of functional form depends on which extrapolation is considered more reasonable, given the needs of the PICR.

Log-linear forms tend to predict an unreasonably large roughness-parts response on rough roads, especially given the speed reductions which generally occur on badly surfaced roads. If log-linear forms are used then they should be linearized over the roughness range corresponding to these rougher unpaved roads. Log-linear equations do have a substantial advantage in that they allow the introduction of vehicle age in a multiplicative form. If this is done, new vehicles will be predicted to have zero parts consumption.

Linear forms tend to predict unreasonably large roughness-parts responses on smooth roads and should be used with cut-offs imposed at some lower roughness boundary. In cost-benefit analyses it is dangerous to overstate the effect of roughness changes on parts costs for smooth roads. Such roads may have high traffic volumes so that small benefits per vehicle yield large aggregate benefits for the total traffic flow. The benefits may be sufficiently large to outweigh the high cost of reducing roughness levels on already smooth roads and this may adversely affect planning decisions.

The piecewise linear form helps to avoid this. After very considerable amounts of exploratory analysis, the log-linear form was chosen although it was realized that this form would require modifications after estimating, prior to use in producing predictions. The data indicate some curvature in the relationship of parts cost to roughness, which suggests that linear forms are not appropriate. As noted earlier, adopting the log-linear form allows vehicle age to appear in the equations to be estimated, in a tractable and intuitively reasonable way. The chosen equations are presented with linear extensions over the smoothest and roughest roads to avoid unrealistic predictions on extrapolation.

The estimated equations have the forms:

$$\ln \text{(parts cost)} = a + bQI^* \qquad (3.6)$$

or

$$\ln \text{(parts cost)} = a + bQI^* + (c)\ln(K) \qquad (3.7)$$

Where

K is vehicle age measured in thousand of kilometers and parts cost are measured in December, 1981 cruzeiros per thousand kilometers.

Rewriting (3.7) as:

$$\text{parts cost} = e^{a+bQI^*}\ K^{c} \qquad (3.8)$$

it can be seen that, with c positive, as age approaches zero, parts costs also approach zero. The coefficient c indicates the time path of parts cost as a vehicle ages. With c positive parts costs increase with age. If c is less than one then the increase in parts costs occurs at a decreasing rate and if c is greater than one, at an increasing rate. The evidence from Kenya (Hide *et al*, 1975) suggests that, except for buses, c is about one, implying that parts costs increase linearly with age. For old vehicles this can result in very high parts cost predictions. As will be seen when the results of the PICR analyses are presented below, the evidence from Brazil is rather different.

The reported log-linear equations are presented with a range of roughness (specific to vehicle class) outside which they should not be used for prediction. For extrapolation over rough routes a linear extension is calculated so that at the upper limit of roughness recommended for the log-linear equation (B in Figure 3.1) the log-linear and linear forms predict the same parts costs and have the same slopes. For extrapolation over smooth routes a linear extension is chosen. Therefore at the lower limit of roughness recommended for the log-linear equation (A in Figure 3.1) the linear and log-linear forms give the same predictions while at QI*=10 the prediction from the linear extension is the arithmetic mean of the log-linear predictions at QI*=10 and QI*=A.

3.3.3 *Maintenance Parts Equations*

The effects of road geometry on parts consumption, as was noted earlier, are difficult to determine and it is therefore recom -

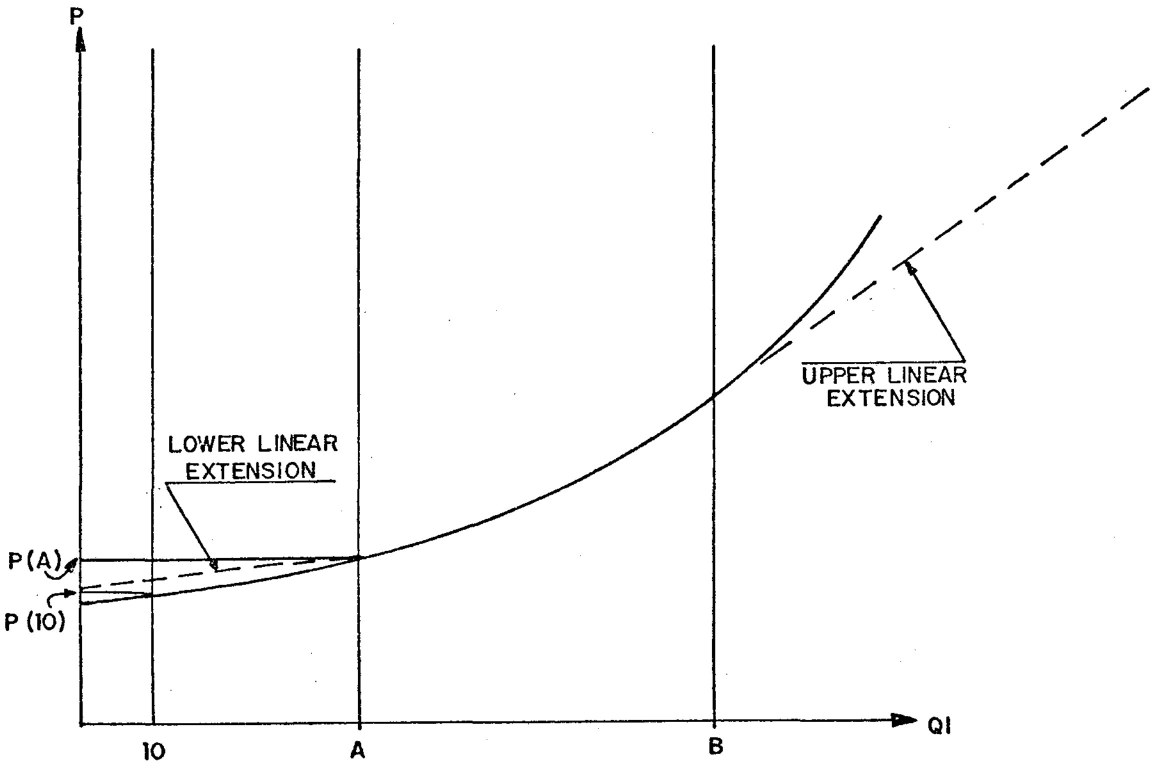

FIGURE 3.1 - EQUATION SHOWING FITTED LINEAR EXTENSIONS

mended that equations utilizing road roughness should be used, with or without vehicle age . The analyses and preliminary modelling of the effects of geometry on parts costs have been reported in a PICR technical memorandum (Chesher and Harrison, 09/1980) and are summarized in Appendix II. The form of the reported equations below is log-linear and the equations are estimated by generalized least squares applied to the error components model (EC).

3.3.3.1 *Car Parts Consumption*

This data set shows limited ranges for highway characteristics and some high correlations between them. The roughness-parts equation can be reported with some confidence. When the log-linear form was used similar roughness effects were estimated, whether or not vehicle age was included. The equations as originally estimated appear in Table 3.9. The car parts data set comprised vehicles with at least 12 months data on file and details of the parts analyses recently completed are available in a PICR technical memorandum (Chesher and Harrison, 08/ /1981).

The recommended car parts equation estimated by the EC method is presented below.

Estimated equation:

$$\ln \text{(parts cost)} = \underset{(3.67)}{4.790} + \underset{(4.40)}{.0128QI^*} + \underset{(3.38)}{.303 \ln(K)} \qquad (3.9)$$

$$G = 0.122 \quad S_u = .571 \quad S_w = .452$$

Recommended equations for prediction:

$QI^* < 40$: parts cost $= K^{.303}(158.14 + 1.068QI^*)$

$40 \leq QI^* < 120$: parts cost $= K^{.303}\exp(4.790 + .0128QI^*)$

$120 \leq QI^*$: parts cost $= K^{.303}(-299.68 + 7.153QI^*)$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (parts costs).

ln(K)	4.74		
QI*	40	67[1]	120
Upper Limit	7.20	7.50	8.23
Prediction	6.74	7.08	7.76
Lower Limit	6.28	6.66	7.29

[1] Data set mean value.

TABLE 3.9 - VEHICLE MAINTENANCE PARTS CONSUMPTION

Class	Intercept	TIP	ST	Ax2	QI*	ln(K)	σu^2	σw^2
Car	6.210				0.0126 (4.25)		0.259	0.231
Car	4.790				0.0128 (4.40)	0.303 (3.38)	0.327	0.204
Util	6.497				0.00426 (2.18)	0.302 (3.97)	0.240	0.204
Bus	5.703				0.00323 (4.09)	0.483 (16.00)	0.166	0.188
Truck	8.212	-.327 (-1.53)	.335 (1.80)	.251 (-1.05)	0.0139 (5.94)		.135	.147
Truck	6.083	-.251 (-1.4)	.365 (2.21)	-.072 (-.34)	0.016 (7.68)	0.374 (6.74)	.091	.122

NOTE: The equations are in log-linear form and derived from the error component (EC) method.

In the truck equations the ST variable should not be estimated for QI* > 100 and no truck costs estimated for QI* > 120.

A piecewise linear form is recommended and reported in the section dealing with truck parts costs.

3.3.3.2 *Utility Vehicles' Parts Consumption*

The utilities comprise a rather heterogeneous group of vehicles and are relatively few in number. It was found necessary to include vehicle age in the estimating equation because of the dispositions of vehicles by age and roughness. The data set comprises vehicles with at least 6 months of data on file. The recommended utility vehicles' parts equation, estimated by the EC method, is presented below.

Estimated equation:

$$\ln(\text{parts cost}) = \underset{(7.22)}{6.497} + \underset{(2.18)}{0.00426QI^*} + \underset{(3.97)}{0.302\ln(K)} \qquad (3.10)$$

$$H=0.15 \quad S_u=.490 \quad S_w=.452$$

Recommended equations for prediction:

$$QI^* < 40 \quad : \text{parts cost} = K^{0.302}(660.35+3.155\,QI^*)$$

$$40 \leq QI^* < 180: \text{parts cost} = K^{0.302}\exp(6.497+0.00426QI^*)$$

$$180 \leq QI^* \quad : \text{parts cost} = K^{0.302}(331.74+6.088QI^*)$$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below.

ln(K)	5.5		
QI*	40	76[1]	180
Upper Limit	8.70	8.85	9.53
Prediction	8.33	8.48	8.92
Lower Limit	7.96	8.11	8.32

[1] Data set mean value.

In the data set rear engined gasoline fueled vehicles had costs about 29% lower than the predictions derived from (3.10) above. Front engined, six tonne, diesel vehicles had costs about 10% higher although the effects for both vehicle types were poorly determined. The analysis of parts data for utility vehicles is docummented in a PICR technical memorandum (Chesher and Harrison, 08/1981).

3.3.3.3 *Bus Parts Consumption*

The bus parts data set is the largest in the user survey and the one in which correlations amongst highway characteristics are lowest and ranges of characteristics greatest. Analyses reveal geometry effects and these are found both within companies and between vehicles and companies. As with other vehicle classes, the equations are reported in Appendix II.

A wide range of bus types is available for operators to purchase in Brazil. They can buy a chassis, platform or full monocoque vehicle. Various types of body with fiberglass, steel or aluminium materials can be purchased for the first two vehicle types. Operators can choose a front or rear engine location for the chassis vehicle and a small or large engine for platform or monocoque. The combination of these features produces a diverse range from which the operator can select the type of vehicle that minimises his total operating costs. Different highway characteristics provide incentives for selecting vehicles with specific characteristics. The vehicle characteristics can partially cancel the highway factors and this can cause difficulties for the analyst. The full range of equations generated in the 1981 analyses of bus parts is given in a PICR technical memorandum (Chesher and Harrison, 08/1981) and here age is the only vehicle characteristic included. The recommended bus parts equation, estimated by the EC method, is presented below.

Estimated equation:

$$\ln(\text{parts cost}) = \underset{(12.97)}{5.703} + \underset{(4.09)}{0.00323\,QI^*} + \underset{(16.00)}{0.483\ln(K)} \qquad (3.11)$$

$$G=0.506 \qquad S_u=.407 \qquad S_w=.434$$

Recommended equations for prediction:

$QI^* < 40$: parts cost = $K^{0.483}(320.04+0.525\ QI^*)$

$40 \leq QI^* < 190$: parts cost = $K^{0.483}\exp(5.703+0.00323QI^*)$

$190 \leq QI^*$: parts cost = $K^{0.483}(9.401+0.0787\ QI^*)$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for ln (parts costs).

ln(K)	5.65[1]			
QI*	40	108	140	190
Upper Limit	8.77	8.98	9.09	9.29
Prediction	8.56	8.78	8.88	9.04
Lower Limit	8.34	8.57	8.66	8.79

[1] Data set mean value.

It is noted that vehicles with tachographs and/or high power to weight ratios (large engines) typically have lower costs than the predictions given by equation (3.11). However, both these effects are difficult to disentangle from the roughness effect because their adoption by operators is more common on higher quality road surfaces in the survey.

3.3.3.4 *Truck Parts Consumption*

The analysis of truck parts data has been already reported in a PICR technical memorandum (Chesher and Harrison, 07/1981). Equations without vehicle characteristics are reported although the QI* coefficient alters little as these and vehicle age are included into the regression analyses. The log-linear equation with age, estimated by the EC method is:

$$\ln\text{ (parts cost)} = \underset{(8.38)}{6.083} - \underset{(-1.4)}{0.251}\,TIP + \underset{(2.21)}{0.365}\,ST - \underset{(-.34)}{0.072}\,Ax2 \qquad (3.12)$$

$$+ \underset{(7.68)}{0.016}\,QI^{*} + \underset{(6.74)}{0.374}\ln(K)$$

$$G=0.572 \qquad S_u=.302 \qquad S_w=.349$$

This equation performs satisfactorily over the range of roughness observed for the majority of trucks in the survey. It has been included to maintain continuity with the form of the equations reported for the other vehicle classes and to show the estimated age coefficient. This is well determined and lies above utilities but below buses, as expected. However, this equation does not extrapolate well and it is recommended that predictions be limited to an upper QI* limit of 120.

The user of these equations will want a better range of roughness, so a piecewise linear form was estimated, using the EC method, and it is recommended instead of the log-linear form.

Recommended equation:

$$\text{Parts costs} = \underset{(1.59)}{2865} - \underset{(-1.18)}{2198}\,TIP + \underset{(2.27)}{3537}\,ST - \underset{(-1.09)}{2560}\,Ax2 \qquad (3.13)$$

$$+ \underset{(4.54)}{105.17}\,Q40$$

$$G=0.410 \qquad S_u = 3.022 \qquad S_w = 4.066$$

Where

$Q40 = 40,\ QI^{*} \leq 40;$

$Q40 = QI^{*},\ QI^{*} > 40;$

TIP = 1 if vehicle is tipper, 0 otherwise

ST = 1 if vehicle is heavy tractor, 0 otherwise

Ax2 = 1 if vehicle is 2 axle rigid, 0 otherwise

Intercept = 3 axle rigid vehicle.

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variable are given below for each of the truck types (parts costs in December, 1981 cruzeiros).

Truck Type	Ax2			TIP		
QI*	40	58	120	40	58	120
Upper Limit	9044	10888	18287	7510	9266	17087
Prediction	4511	6405	12925	4874	6767	13287
Lower Limit	0	1933	7555	2244	4244	9488

Truck Type	3 Axle Rigid			ST		
QI*	40	58	120	40	58	80
Upper Limit	9799	11688	19642	13279	15045	17492
Prediction	7072	8965	15485	10609	12502	14816
Lower Limit	4333	6244	11310	7937	9810	11789

The above equation relates to a vehicle age of 204,000 km (user survey average). To obtain estimates for trucks of different ages the predictions from (3.13) should be multiplied by (actual km in units of 1000 km/204)$^{0.374}$. Heavy tractors of the type used to pull large semi-trailers are rarely found on public unpaved roads and predictions for them should be limited to 100QI*. Semi-trailer costs have not been analysed since they generally move from vehicle to vehicle and route to route in the typical Brazilian company. The average trailer costs for 34 units in the survey was Cr$ 5196 per 1000 km at December, 1981 prices, and this should be used to derive the total parts costs for a heavy tractor and semi-trailer unit.

3.4 *MAINTENANCE LABOR COSTS*

Maintenance Labor Costs data are difficult to collect and assign correctly to vehicles and route types. The Kenya and Caribbean studies collected little labor data which could be regressed against highway characteristics. The Indian study has adopted a labor hours method where standard times are assigned to maintenance tasks. This method was first proposed in the PICR pilot study phase (Harrison, 09/ /1976) but not adopted because of a shortage of clerical staff capable of administering the system.

Labor costs data were collected in the user survey when the opportunity arose although it was not an easy task to supervise, since labor recording practices differ widely from company to company. It was decided to create a new labor-parts data set based on the data recorded on main file. This enabled the data to be carefully scrutinized so that only those companies and vehicles which the data collectors felt provided accurate labor cost data were retained in the new data set. Every effort was made to achieve a data set which contained accurate labor and parts information. The parts costs have been checked to ensure that they arise in the same time period in which the labor costs were incured. Since many vehicle parts data do not have corresponding labor data on the maintenance parts file, a substantial reduction in vehicle numbers resulted. A breakdown of company and vehicle numbers by vehicle class is given in Table 3.10. The data were used to estimate relationships between labor costs and parts costs. In this way the results already estimated between parts costs and highway characteristics are utilized and what emerges is a relationship between total maintenance costs and highway characteristics. The following results are taken from a more detailed technical memorandum (Chesher, 07/1981).

TABLE 3.10 - LABOR/PARTS DATA SET

Vehicle Class	Number of Companies	Number of Vehicles
Cars	4	48
Utilities	8	33
Buses	5	81
Trucks	13	150
Total	30	312

3.4.1 *Labor Maintenance Cost Results*

A series of regression equations for predicting labor costs are presented in Appendix X. The equations are by vehicle class and relate to estimations by OLS and OLSCE methods. The latter appears to be a more appropriate method for estimating labor costs because the relatively small labor data set makes it more likely that company specific variations may be incorrectly attributed to changes in highway characteristics. Furthermore, the small number of companies makes it difficult to estimate the variance of the company effect. However, both OLS and OLSCE results were evaluated before arriving at a final choice of a labor cost equation by vehicle class and this process is described in the following sections.

3.4.1.1 Car Maintenance Labor Costs

A coefficient of 0.713 is obtained when ln(labor cost) is regressed on ln(parts cost) using individual vehicle data. When within company variation is used this coefficient falls to 0.547. However, the latter statistical method is inherently more robust than regressing on individual vehicle data, and the coefficient is of similar magnitude to other vehicle class coefficients obtained when company effects are estimated. It seems likely that the estimates obtained using individual vehicle data are substantially influenced by company effects which may not appear in the same way in future applications. Accordingly the within company equation is recommended. No effect could be found for road roughness. Labor cost for all equations is given in cruzeiros at December, 1981 prices. The equation for car labor costs, estimated by OLSCE is:

$$\ln(\text{labor cost}) = \underset{(2.12)}{2.520} + \underset{(4.24)}{0.547}\ \ln(\text{parts cost}) \qquad (3.14)$$

$$R^2 = 0.29 \qquad S_w = 0.500$$

Predictions and asymptotic 95 percent prediction intervals for ln(labor costs) are given below in January, 1976 cruzeiros.

ln (parts cost)	6.3	7.32[1]	7.8
Upper Limit	6.27	6.66	6.99
Prediction	5.98	6.52	6.80
Lower Limit	5.69	6.38	6.61

[1] Data set mean.

3.4.1.2 Utility Maintenance Labor Costs

When ln(labor costs) is regressed on ln(parts) using individual vehicle data, a large coefficient of 0.983 is obtained. It is believed that this is strongly influenced by company effects, and the coefficient is only slightly reduced upon introducing vehicle and company characteristics. When the within company method is used, coefficients are obtained which are similar to those of other vehicle classes as long as the vehicle characteristic which denotes type of fuel is included. This characteristic is important because it distinguishes between two quite different vehicles in the utility class. If road roughness is included the parts coefficient falls to 0.547 and roughness takes a statistically significant positive coefficient of 0.0043.

This predicts an increase in labor costs of 17% for each 40QI* rise and indicates that, as roughness increases, maintenance becomes more labor intensive. The equation for utility labor costs, estimated by OLSCE is:

$$\begin{array}{l} \ln(\text{labor cost}) = \underset{(2.06)}{2.698} + \underset{(3.96)}{0.632}TF + \underset{(4.64)}{0.548}\ \ln(\text{parts cost}) \quad (3.15) \\ \qquad + \underset{(2.73)}{0.00403}QI^{*} \\ R^{2} = 0.70 \qquad S_{w} = 0.228 \end{array}$$

Where

TF = 1 if gasoline, 0 otherwise

Predictions and asymptotic 95 percent prediction intervals for ln(labor costs) are given below in December, 1981 cruzeiros.

Type of Fuel	Gasoline (TF=1)			Diesel (TF=0)		
ln(parts cost)	7.10	8.35[1]	9.10	7.10	8.35[1]	9.10
Upper Limit	7.88	8.51	9.03	7.27	7.73	8.21
Prediction	7.57	8.26	8.67	6.94	7.63	8.04
Lower Limit	7.27	8.00	8.31	6.61	7.52	7.86

[1] Data set mean.

Reducing QI* by 100, with fixed parts costs, reduces labor costs by 35%. In fact, if such a reduction in road roughness takes place, then parts costs themselves will be reduced. Halving parts costs leads to a 32% reduction in labor costs.

3.4.1.3 *Bus Maintenance Labor Costs*

As with the previous vehicle classes, different results are obtained using individual vehicle data (OLS) and within company variation. Using the OLS method coefficient of 0.346 is obtained when ln (labor costs) regressed on ln(parts costs). This increases to 0.659 on introducing vehicle and company characteristics, but falls to 0.613 on including roughness.

Such variation is explained by the fact that substantial company effects are present in this data set. In one extreme case where the company records show low parts costs but high labor costs, the vehicles were treated separately from the rest and given their own variable (U248). The large coefficient for roughness could be attributed to the company specific treatment of bus cleaning costs. Cleaning costs are included in labor costs when done by hand but omitted when done by machine. These effects disappear upon looking at within company variations in costs since in any given company all vehicles are treated alike with regard to cleaning.

If within company variation is used and ln(labor costs) regressed on ln(parts costs), a coefficient of 0.515 is obtained. The introduction of vehicle characteristics hardly changes this value and a significant positive coefficient is found for road roughness, similar in magnitude to that for utilities. The equation for bus labor costs, estimated by OLSCE is:

$$\ln(\text{labor cost}) = \underset{(5.54)}{3.231} + \underset{(8.40)}{0.516}\ \ln(\text{parts cost}) + \underset{(2.23)}{0.00514}QI^* \qquad (3.16)$$

$$R^2 = 0.50 \qquad S_w = 0.241$$

Predictions and asymptotic 95 percent prediction intervals for ln(labor cost) are given below in December, 1981 cruzeiros. Two levels of roughness are used to represent paved and unpaved operations.

Roughness (QI*)	45			100		
ln(parts cost)	6.9	7.84[1]	9.1	6.9	7.84[1]	9.1
Upper Limit	7.15	7.55	8.33	7.59	8.04	8.74
Prediction	7.03	7.51	8.17	7.32	7.79	8.45
Lower Limit	6.91	7.47	8.01	7.04	7.54	8.16

[1] Data set mean.

If road roughness is reduced by 100QI*, with fixed parts costs, then labor costs are reduced by 41%. Halving parts costs is predicted to reduce labor costs by 30%, which is consistent with the utility vehicle class.

3.4.1.4 *Truck Maintenance Labor Costs*

Trucks are treated as one class, using three zero-one variables to indicate whether the vehicle is a tipper, a heavy tractor, a 2 or a 3 axle rigid type. In this class quite similar results are obtained with both statistical methods, but within company variation is preferred because it is inherently more robust and also maintains consistency with the other vehicle classes.

Regressing ln(labor costs) on ln(parts costs) and estimating company effects produces a coefficient of 0.519, which is similar to coefficients obtained for other vehicle classes. This coefficient is little altered by introducing vehicle and company characteristics or roughness. No significant effect for roughness was found. Since there is virtually no within company variation in the variables AX2, ST and TIP, which distinguish truck types, the estimated equations gave a common intercept for some of the truck types. This was unsatisfactory and to obtain intercepts specific to truck types the estimated company intercepts were averaged as described in Section 2.5 of this Volume. Account was taken of the limited within company variation in the variable AX2 which distinguishes 2 axle rigid trucks. In this way, truck type specific intercepts were obtained. The equation for truck labor costs , for each of the four truck types, estimated by OLSCE are:

2-Axle rigid vehicle

$$\ln(\text{labor cost}) = \underset{(6.74)}{3.396} + \underset{(11.84)}{0.519} \ln(\text{parts cost}) \tag{3.17}$$

3-Axle rigid vehicle

$$\ln(\text{labor cost}) = \underset{(8.27)}{3.511} + \underset{(11.84)}{0.519} \ln(\text{parts cost}) \tag{3.18}$$

Tipping vehicles

$$\ln(\text{labor cost}) = \underset{(6.88)}{3.163} + \underset{(11.84)}{0.519} \ln(\text{parts cost}) \tag{3.19}$$

Heavy tractors

$$\ln(\text{labor cost}) = \underset{(8.82)}{3.944} + \underset{(11.84)}{0.519} \ln(\text{parts cost}) \tag{3.20}$$

$$R^2 = 0.50 \qquad S_w = 0.264$$

Here R^2 gives the proportion of within company variation in ln(labor costs) explainable in terms of within company variation in ln(parts costs). In applications users will find that the truck type specific intercept provides additional explanatory power.

Predictions and asymptotic 95 percent prediction intervals for ln(labor cost) are given below in December, 1981 cruzeiros.

Truck Type	2 axle rigid			3 axle rigid		
ln(parts cost)	7.6	8.56[1]	9.6	7.6	8.56[1]	9.6
Upper Limit	7.65	8.14	8.69	7.57	8.03	8.61
Prediction	7.34	7.84	8.38	7.46	7.95	8.41
Lower Limit	7.03	7.54	8.07	7.34	7.88	8.38

[1] Data set mean value.

Truck Type	Tippers			Heavy Tractors		
ln(parts cost)	7.06	8.56[1]	9.6	7.6	8.56[1]	9.6
Upper Limit	7.24	7.72	8.29	8.48	8.89	9.25
Prediction	7.11	7.61	8.15	8.38	8.84	9.17
Lower Limit	6.97	7.50	8.00	8.29	8.78	9.09

[1] Data set mean value.

The operating costs of semi-trailers of the type hauled by the heavy tractors were not collected in sufficient quantity for analysis and the reasons for this are discussed in the section on maintenance parts results. Since an average cost figure is reported for semi-trailer maintenance parts costs, however, it is necessary to recommend an estimate of labor costs. Accordingly the data files have been examined and it has been found that trailer labor costs constitute around a third of parts costs. This is given in Cr$ December 1981 per 1000 km and should be used when calculating the total labor costs for a heavy tractor and semi-trailer unit operating on paved roads.

The non-linearity between labor and parts in these equations represents a considerable advance in the estimation of the parts and labor component of vehicle operating costs. A striking feature of the labor cost results is the similarity of the ln(labor cost) on ln(parts cost) coefficients for the four vehicle classes when the within company variation method is used. In all classes coefficients of around 0.5 are obtained, indicating that a 100% increase in parts costs results in a 40% increase in labor costs. This result seems more credible that the prorating method used in some previous vehicle operating cost studies where a 100% increase in parts costs results in a 100% increase in labor cost. Preventative maintenance, for example, requires a labor input which sometimes has no parts costs associated with it. Major component changes have a high parts to labor cost ratio, bodywork often a low ratio and so on. Prorating cannot capture these effects.

Depending on the form of the model utilized to explain maintenance costs, there is a risk of incurring a simultaneous equations bias if labor costs are regressed directly on parts costs Some limited estimations have been carried out using the instrumental variables techniques - two stage least squares, after modifications to allow for the error components issue. Measures of roughness, route geometry and vehicle age together with company effects are used as instruments for parts costs. The evidence available now suggests that the likely magnitude of any bias is small. The two stage least squares estimates are subject to considerable sampling error and are not themselves useful in generating predictions.

3.5 *TIRE CONSUMPTION*

An operator with a fleet of vehicles typically switches tires from one wheel position to another and from vehicle to vehicle. It is not efficient to keep tires on one vehicle for all their lives and operators generally utilize a tire pool into which repaired and recapped tires are placed before being assigned to vehicles. Company policies with regard to tire recapping and scrapping, vehicle loads, speed of operation and driver bonuses may be expected to affect tire lives and to vary between companies. Tire lives themselves are very variable, even within companies. Due to severe punctures or defects in manufacture, a tire can fail completely after only a short time in operation, whereas other tires, operating under apparently similar conditions, achieve high kilometrages. Similarly the incidence of a recap failure is variable: one recap tire can strip its tread after a few kilometers while another gives many thousand kilometers of good service before it needs recapping again. This inherent variability in tire data causes difficulty for the analyst.

A further complexity arises because of the nature of user survey tire data, particularly in the way it is collected. Originally two methods were proposed. One involved the determination of tread wear on a selection of vehicles (Harrison, 10/1976) and the second was a more conventional survey of company tire records. Unfortunately, the tread method could not be implemented, despite promising pilot results, because of a shortage of trained staff. It was, however, subsequently adopted by the Indian study. The source of data in the PICR study was company records. Since good tire recording systems were not in operation in many companies, the bulk of the tire data comes from few companies, specifically, 90% of the bus and truck data come from 11 companies.

3.5.1 *Estimating Procedures*

The concentration of tire data within a few companies means there is a danger of incorrectly estimating the effects of highway characteristics if 'by chance' companies with low tire cost tend to operate on routes of a particular type. Effects might then be incorrectly ascribed to highway characteristics and would not be found in a new sample of companies. In order to avoid this problem the analysis has concentrated on the within company variation method (OLSCE), taking variations in tire route characteristics within a company and using them to explain the within company variations in tire lives. These analyses are more completely treated in a PICR technical memorandum (Chesher and Harrison, 07/1981). Another problem faced when estimating equations for tire costs are the high inter-correlations among the route characteristics for the PICR data set. This problem was particularly severe in the data set analysed in 1980 (Chesher, 09/1980) and more data were collected in an effort to reduce these effects.

The problems outlined above combine to make the estimation of tire cost equations extremely difficult and attempts to reduce these difficulties were made before estimation began. First, tires that had spent 20% or more of their lives on survey vehicles were permitted to enter the data set for analysis. In earlier analyses the corresponding figure was 90% and weakening this restriction increased the size of the data set by about 25%. By doing this, less reliable data are introduced,but the analysis gains by obtaining a better representation of route characteristics and having more data to utilize. Secondly, new data have been incorporated which were collected after the 1980 analyses and which turn out to be valuable in obtaining better estimates of the effects of route characteristics on tire costs. Finally, within company variations are used which removes the company policy effects from the data.

While some of the problems related to estimating tire cost equations are addressed, there remain many difficulties with modelling these relationships. Time constraints have prevented any substantial modelling exercise, but it is believed that in the future such an effort would be worthwhile.

3.5.2 *Analysis and Results*

The tire analysis set is the most complex of the PICR data sets presented for analysis. Average route characteristics are calculated by taking a kilometer weighted average of the route characteristics for each stage of a tire's life. Where these characteristics are unknown, the average company characteristics are assigned to the tire for that period of its life. Tires that were sold before the end of their lives were eliminated from the data set. The results in this report are derived from data on 245 car tires, size 500x15, and from 3536 bus and truck tires. Three tire sizes were found in the bus and truck set; 900x20, 1000x20 and 1100x22 (subsequently referred to as A, B and C) . These sizes comprised 67%, 16% and 17%, respectively, of the data set. The tires are of conventional design because in Brazil radial tires are most frequently used only on cars operating on paved roads. Steel belted radials will be available for commercial vehicles in 1982 and it is expected that some companies will quickly change to this tire type. Those companies on unpaved routes, however, may stay with conventional designs because radial tires are prone to sidewall damage and so there will still be a future need to predict wear of conventional tire types. Radials may have to be the subject of a separate, future study.

For each tire on the analysis file, the total number of kilometers travelled through the different stages of its life was calculated. This value appears as TK in the equation below and was measured in units of 10,000 kilometers. The number of recaps put on each tire during its life was also calculated and this appears as RC. The dependent variable used in the reported equations is KPT and can be regarded as measuring kilometers per equivalent new tire. The estimated equation is:

$$KPT = \frac{TK}{1 + RC/6.6} \tag{3.21}$$

The denominator gives the total tire cost when multiplied by the price of a new tire since the cost of recapping is 1/6.6 times the new tire cost in the PICR data. Therefore, KPT divided by tire price gives distance travelled per cruzeiro. Although other measures of tire cost were tried, KPT gave the best results and it is further enhanced because its inverse, multiplied by new tire price, gives tire costs in cruzeiros per 10,000 kilometers.

3.5.2.1 *Car and Utility Tire Results*

All the data on car tires come from one company and relate to narrow ranges of roughness, rise plus fall and curvature. All but two of the 251 tires were used on vehicles in the User Survey for at least 90% of their lives. The inter-correlations amongst the highway characteristics and the narrow ranges over which the data are observed combine to make reliable estimates of the effects of geometry on car tire costs impossible to obtain. The linear equation for car tire life estimated by OLS is:

$$\begin{aligned} KPT &= \underset{(12.90)}{6.508} - \underset{(-3.92)}{0.0389QI^{*}} \\ R^2 &= .83 \qquad S = 2.125 \end{aligned} \tag{3.22}$$

Where

KPT is kilometers per equivalent new tire in units of 10,000 kilometers.

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for KPT.

QI*	35	48[1]	75
Upper Limit	5.522	4.902	4.160
Prediction	5.145	4.638	3.587
Lower Limit	4.767	4.375	3.014

[1] Data set mean value.

The linear form of equation (3.22) fitted better than log-linear forms and produced more reasonable predictions upon extrapolation. Other measures of tire cost were tried but better results were not obtained. The roughness effect in equation (3.22) is quite substantial and it is possible that the roughness measure is picking up some effects due to rise plus fall, which is positively correlated with roughness in this data set. The maximum QI* value for the car tire data set was 87 and the equation does not extrapolate well beyond 120 QI*. Therefore, it is recommended that this equation not be used to predict tires costs for roads in excess of 120 QI* or, if such estimation is necessary, that the tire consumption be held at the estimate derived from 120 QI*.

Some data for utility tires exist on file but it was not possible to estimate the effects of highway characteristics on tire costs for this vehicle class. The difficulty is that there is virtually no variation in highway characteristics over tires for this class. However, an equation to predict tire wear is essential if total vehicle operating costs for utilities are to be calculated. Accordingly the data on file for this class were examined and the mean paved (40QI*) total kilometrage was found to be 59,100 while the mean unpaved (140 QI*) total kilometrage dropped to 32,600. These points were linearized to give the following equation:

$$KPT = 6.970 - 0.0265QI^* \qquad (3.23)$$

The predictions seem to agree quite well with other sources and it is thought that the equation may be used for roads up to 150QI*. If predictions are required in excess of this figure, the predictions should either be held at QI*150 or the results checked with other sources if the equation is used freely.

3.5.2.2 *Bus and Truck Tire Results*

The bus and truck tire data were analysed in a variety of ways. Linear and log-linear relationships were estimated between KPT and roughness, rise plus fall and average degrees of curvature, first making no distinction between companies, vehicle classes, vehicle loads, or tire sizes, and then introducing variables which capture these distinctions, one by one. As this is done, the estimates of roughness effects become smaller in magnitude. In fact, roughness coefficients halve between estimating with individual tire data to estimating using deviations about company means.

When across company variation in tire costs and route characteristics is used, geometry effects appear to be significant, but the signs of the rise plus fall and curvature effects conflict. Thus rise plus fall increases are predicted to increase tire life but curvature increases are predicted to decrease tire life. The effects are quite substantial and are believed to be largely caused by differences in tire costs at the company level and the disposition of the companies over route types. The effects of geometry are different when each company is allowed to have its own intercept in the fitted equations, i.e. when the estimation of highway effects exploits only within company variations. Then increases in roughness, rise plus fall or curvature lead to increases in tire costs, though the effect of curvature is small. The linear equation for bus and truck tire life, estimated by OLSCE is given below.

$$\begin{aligned} KPT &= \underset{(15.59)}{5.756A} + \underset{(10.30)}{6.004B} + \underset{(24.23)}{9.450C} - \underset{(-3.44)}{.00951QI^*} - \underset{(-3.82)}{.0424RF} \\ &\quad - \underset{(-0.58)}{.00127ADC} \\ R^2 &= 0.87 \qquad S = 1.820 \end{aligned} \tag{3.24}$$

Where

A = 1 if tire size is 900x20, 0 otherwise

B = 1 if tire size is 1000x20, 0 otherwise

C = 1 if tire size is 1100x20, 0 otherwise

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for tire life.

ADC	65[1]							
RF	29[1]							
Tire Type	A			B			C	
QI*	40	84[1]	140	40	84[1]	140	40	84[1]
Upper Limit	4.438	3.826	3.358	4.934	4.616	4.261	7.962	7.630
Prediction	4.064	3.645	3.112	4.312	3.893	3.360	7.758	7.339
Lower Limit	3.690	3.464	2.867	3.659	3.170	2.460	7.553	7.048

[1] Data set mean value for this variable.

Separate intercepts are reported for each of the three tire sizes, A, B, and C. These were calculated by taking weighted averages of company intercepts, noting that any given company provided data on only one of the three tire sizes. These intercepts must be regarded as being influenced by company effects but they are quite reasonable, the largest size C tires having much longer lives, though costing more to purchase. The curvature coefficient is not as well determined as the roughness and rise plus fall coefficients. The lack of significance of the curvature coefficient is due primarily to its small magnitude which may be due to speed reductions that arise on increasing route curvature.

Each 40QI* reduction in roughness is predicted to increase kilometers per equivalent new tire by 3800 km, each 10 m/km reduction in rise plus fall is predicted to increase kilometers per equivalent new tire by 4240 km and each 20^o/km reduction in average degrees of curvature is predicted to increase kilometers per equivalent new tire by 254 km. Kilometers per equivalent new tire is 36,940 km higher for the large size C tires than for size A tires. Typically size C tires are found on large articulated vehicles with as many as 18 tires per unit, so that loads per tire are generally smaller than for size A tires.

Further work can be done on the tire data and some recommendations are made in the conclusions of this report. The analysis of tire costs has been difficult, as the factors affecting tire wear are diverse and complex. Nevertheless these equations are believed to reflect the features of the PICR data set and stand as adequate predictors of tire performance in Brazil over the survey period. As was noted earlier, new technologies are being introduced shortly in the Brazilian tire industry and this will require further data collection and analysis in the future.

3.6 DEPRECIATION AND INTEREST COSTS

Vehicle depreciation and interest costs are a major component of total vehicle operating costs and it was therefore essential to derive good estimates of these items in the PICR. Two complementary approaches were developed to provide changes in depreciation and interest charges over different highway characteristics (Harrison, 07/ /1977) and are detailed in Chapter 3 of Volume 2 of this report series. One examines the change in vehicle market values over time and the other estimates vehicle utilization. The first provides annual vehicle depreciation and the latter annual kilometrage travelled. The two are combined to determine the average depreciation and hence interest cost per kilometer.

This approach is basically similar to that reported in the Kenya study, except for one important feature. No utilization equations were derived from the Kenya user survey data and these items had to be modelled in other ways. Therefore, the utilization equations from the PICR analyses constitute an improvement on the basic methodology and enable Brazilian vehicle depreciation and interest costs per kilometer to be directly estimated from highway characteristics.

3.6.1 *Average Market Value*

Lifetime depreciation is defined as the change in the market's valuation of the flow of services provided by the vehicle over its life. For a certain period in a vehicle's life, such as its third year of operation, the annual depreciation charge would be the change in value between the end of the second and the end of the third year. To cover all requirements, valuations at different years in a vehicle's life were needed and a survey to collect such data was conducted in 1978. Data were collected for each vehicle class which represented the average market value for each year of the vehicle's life. They were then expressed as a percentage of the new vehicle price (less tires) and exponential curves fitted to the data, except commercial cars for which a linear form was more appropriate. These equations have been checked with new data collected in late 1981.

Cars and utilities seem to fit the new data well so the original equations are left unchanged. Buses and heavy trucks are different but there is reason to prefer the original forms. In 1981, completely new models were introduced in both these classes and the associated higher prices have biased the data and predicted very large depreciation changes in the early years. These are believed to be short term effects which will smooth out fairly quickly and hence the original equations are retained. The new data for medium trucks has been checked and values over a wide range of vehicle age have altered. This represents a basic change in the market and the medium truck vehicle class has therefore been given an equation based on the 1981 data. All these equations are presented in Table 3.11 where the dependent variable is the value of the average vehicle aged A years on the second hand market, expressed as a proportion of the new vehicle price, less tires. It is recommended that these equations are used with a cut off and a constant value, V_A, used after this point. This constant value can be thought of as representing the residual value of the vehicle and these cut off values are:

Commercial Cars	Age > 5 years, V_A is 0.14
Private Cars	Age > 12 years, V_A is 0.13
Utilities	Age > 15 years, V_A is 0.11
Buses	Age > 12 years, V_A is 0.12
Medium Trucks	Age > 12 years, V_A is 0.10
Heavy Trucks	Age > 12 years, V_A is 0.12

3.6.2 *Vehicle Utilization*

Vehicle utilization has always proved difficult to analyse because it is strongly influenced by factors other than highway characteristics. It was decided to reexamine this item with the 1981 data base, in part to determine whether addressing the error components issue resolved any of the problems encountered in previous analyses. The effects of geometry on vehicle utilization were considered because it was expected that these, acting through speed changes, would have a significant effect on vehicle utilization levels. The geometry effects are reported in Appendix III to maintain consistency with the analysis of parts expenditures and to permit the user who requires an equation with geometry to better access the results. The equations reported below are taken from a PICR technical memorandum (Chesher and Harrison, 10/1981) and refer to the effects of roughness, vehicle age and route

TABLE [illegible] - AVERAGE MARKET VALUES BY VEHICLE CLASS

Class	Equation	R^2
Commercial Cars	V_A = 0.859 - 0.143A	.98
Private Cars	V_A = exp(0.063-0.173A)	.98
Utilities	V_A = exp(-0.294-0.124A)	.99
Buses	V_A = exp(-0.053-0.169A)	.99
Medium Trucks	V_A = exp(-0.185-0.175A)	.92
Heavy Trucks	V_A = exp(-0.174-0.160A)	.94

Where

V_A = value of vehicle aged A years on the second hand marked expressed as a proportion of the new vehicle price.

NOTE: It is recommended that cut off points be used for these equations (see text for suggested values) length.

3.6.2.1 *Private Car Utilization*

Cars in the PICR user survey are used for the daily transport of data processing material between towns and their lives tend to be short in years but high in kilometers travelled, when compared with private cars. In order that private car utilization rates could be estimated, a satellite study was undertaken (Harrison, 12/1980). An agreement was reached with the Authorized Brazilian Volkswagen Dealers' Association - ASSOBRAV (Associação Brasileira de Revendedores Autorizados Volkswagen) to survey the entire Volkswagen dealer network, using a postal questionnaire as the survey mode. The data were collected in January 1980, with preliminary analysis done in April and final analysis in October 1980.

The main findings were that private cars are so underutilized that relationships between kilometers travelled and highway characteristics are of no value to highway planners. Rural utilization, for example, is generally higher than utilization in cities, despite higher levels of roughness. The environment of vehicle operation was thought to be a better grouping for analysis and data were grouped into highway, city, rural and highway/city mix. The sample contained 3,691 cars and the four groups comprised 310, 835, 123 and 2423 vehicles, respectively. The highway/city mix was most popular since only a few car owners regularly run between cities for non-commercial reasons, but a number of owners make such trips once a week. It was thought that utilization levels for each group might be predicted from vehicle age and a number of analyses were undertaken. These are reported in detail in (Harrison, 12/1980) and here only two results are reported. First the data were grouped into the four classes, screened again and then means were derived for each class to give monthly kilometrage. This is shown in Table 3.12 and indicates an interesting ranking. Rural utilization is almost as great as the highway class, while city is below the highway/city mix.

Utilization was first calculated by taking the total kilometrage recorded on each car in the survey and dividing by the total age in months so that, more precisely, what was being examined was average monthly utilization since registration. This may not be appropriate for certain modelling applications where some estimate of the rate of

TABLE 3.12 - PRIVATE CAR UTILIZATION. MEANS OF MONTHLY AND ANNUAL KILOMETRAGE

Group	Monthly km	Annual km	Sample
Highway	2061	24732	310
City	1332	15984	835
Rural	1981	23772	123
Highway/City	1704	20448	2423

TABLE 3.13 - PRIVATE CAR UTILIZATION SINCE REGISTRATION BY AGE

Group	Monthly Utilization	R^2	Sample
Highway	2848-20.00M	.90	157
City	1556- 5.84M	.94	732
Rural	2607-14.48M	.85	75
Highway/City	1758- 6.89M	.77	1782

Where M is the age in months since first registration. The sample sizes are smaller because data were adjusted prior to the grouping.

utilization in any month or year in life is required. This was termed differential rates of utilization and the data were used to estimate these rates. This is fully reported in the technical memorandum already referenced. Here only utilization since registration is reported and Table 3.13 gives the results of an analysis to estimate utilization for each class from the vehicle age in months.

The data reflect the private car population sampled during the collection period. They are not time series data applicable to a representative car but rather a cross section of population data for all Brazilian cars. It is recommended that each linear equation in Table 3.13 is cut off at some point and, although somewhat arbitrary, it is suggested that 90 months for highway, 110 months for city, 120 months for rural and highway/city mix be used. The results from this survey represent the a pineering attempt to quantify private car utilization in Brazil and since they are based on the examination of a range of uses from urban to rural, could prove generally useful to highway planners.

3.6.2.2 *Commercial Car Utilization*

The data for this category were analysed with various statistical methods. Within company variation in utilization and highway characteristics is preferred since data are only available for a small number of companies. However, because the data set exhibits small variations in roughness and geometry, the results using this method are disappointing. The recommended commercial car utilization equation, estimated by the EC method, is presented below.

$$\begin{array}{llll} UT = 5.797 & -0.0259QI^{*} & +0.00733RL & +0.00268K \\ \quad (5.13) & (-2.99) & (5.19) & (1.34) \end{array} \qquad (3.25)$$

$$G=0.90 \qquad S_u=1.644 \qquad S_w=2.215$$

The dependent variable UT is utilization per month, expressed in units of 1000 km and the equation was estimated from data on 183 vehicles, derived from 6 companies.

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below for utilization.

K	101[1]					
RL	320[1]			600		
QI*	40	54[1]	100	40	54[1]	100
Upper Limit	8.917	8.517	7.459	11.126	10.773	9.826
Prediction	7.378	7.015	5.824	9.430	9.068	7.877
Lower Limit	5.838	5.513	4.189	7.735	7.364	5.928

[1] Data set mean value for this variable.

Since the age variable K is poorly determined, it is recommended that it be set to the survey average (101,000 km) and only roughness and route length used in equation 3.25. A method of modelling geometry effect is presented in Appendix III.

3.6.2.3 *Utility, Bus and Truck Utilization*

These vehicle classes were grouped together, as with some previous analyses, although many coefficients are class specific in the reported equation. This grouping was done partly to pull together somewhat different but poorly determined coefficients for certain variables, particularly curvature. Utilities, buses and trucks were allowed to have different roughness coefficients. A separate route length coefficient was estimated for buses and a vehicle age coefficient for buses and trucks. The recommended utilization equation for utility vehicles, buses and trucks, estimated by using the EC method, is presented below.

$$\begin{aligned} UT = {} & \underset{(9.80)}{8.172C2} + \underset{(13.83)}{8.542C3} + \underset{(16.19)}{11.143C4} + \underset{(0.16)}{11.268C5} - (\underset{(-6.13)}{0.0407C2} \\ & + \underset{(-6.17)}{0.0159C3} + \underset{(-6.76)}{0.0352(C4+C5)})QI^{*} + (\underset{(5.77)}{0.00147} + \underset{(6.89)}{0.00485C3})RL \\ & - \underset{(10.14)}{0.0030(C3+C4+C5)K} \end{aligned} \qquad (3.26)$$

$$G=0.92 \qquad S_u=1.990 \qquad S_w=1.443$$

Predictions and asymptotic 95 percent prediction intervals at selected values of the explanatory variables are given below.

Vehicle Type	C2-Utility Vehicle			C3-Bus		
K	-			348[1]		
RL	824[1]			340[1]		
QI*	40	65[1]	140	40	96[1]	200
Upper Limit	9.082	8.013	5.264	9.921	8.989	7.487
Prediction	7.757	6.740	3.690	9.013	8.120	6.463
Lower Limit	6.432	5.468	2.116	8.105	7.252	5.439

Vehicle Type	C4-Medium Truck			C5-Heavy Truck		
K	230[1]			322[1]		
RL	912[1]			760[1]		
QI*	40	67[1]	140	30	39[1]	53
Upper Limit	11.398	10.353	7.918	11.750	11.420	10.919
Prediction	10.389	9.439	6.871	10.365	10.048	9.556
Lower Limit	9.379	8.525	5.823	8.980	8.676	8.192

[1] Data set mean value for each vehicle type.

The equation was derived from a data set of 777 vehicles, comprising 51 companies, where all owner-drivers in the utility class were counted as one company. No age effect could be estimated for utilities. This is due to a particular feature of this class in the user survey. Utility owners who collect milk from farms do so every day of the month so their utilization is high. They also tend to have older vehicles which causes the age sign to be contrary to prior reasoning. The estimated coefficient is poorly determined and therefore the utility age effect is not reported. The effect of geometry on the utilization of these vehicle classes is discussed in Appendix III.

3.6.3 *Interest Charges*

Interest charges should be included in vehicle operating cost calculations, at a rate equal to the opportunity cost of capital. This rate obviously changes over time, reflecting factors in the economy , the transport sector and finally the credit-worthiness of each company. The range for the PICR companies during the survey period was from real annual rate of 11 to 15 percent, but the user must collect information each time interest charges are calculated so that the appropriate rate is determined.

3.6.4 *Modelling Depreciation and Interest Costs*

The components of market values, vehicle utilization and interest rates are combined to predict depreciation and interest charges. Though linked, they are normally calculated separately. For an individual vehicle of a given age or for the average aged representative vehicle per vehicle class the calculations are not difficult. An objective of the PICR is the production of a Brazilian model for forecast -

ing, amongst other things, vehicle operating cost streams for vehicles of different classes on various types of highway. Where an average representative vehicle age is not considered sufficiently accurate, then a more precise estimate can be obtained for that vehicle class, given that age distributions per class are known. In this situation, from new to any given age, the average depreciation cost per km is equal to the change in market value divided by utilization during that period, such that:

$$D_{c,j} = \frac{NP_c(1-DC_{c,j})}{\sum_{i=1}^{j} AU_{c,i}} \tag{3.27}$$

Where

j = 1, ..., k

k = maximum vehicle age in years

$D_{c,j}$ = average depreciation cost for class c per km up to age j

NP_c = new vehicle price less tires for class c

$DC_{c,j}$ = values of class c vehicle at age j, as a proportion of new vehicle price

$AU_{c,i}$ = annual utilization in year i for class c vehicle

Utilizing the same components, vehicle class interest charges can be estimated using:

$$IC_{c,j} = \frac{NP_c R_c \sum_{i=1}^{j} DC_{c,i-1/2}}{\sum_{i=1}^{j} AU} \tag{3.28}$$

Where

$IC_{c,j}$ = average interest cost per km up to age j for vehicle class c

R_c = annual interest rate for vehicle class c

Work has been done on more detailed treatments of depreciation costs using differentiation to calculate point estimates and then integrating to the required time period. Predictions of annual depreciation using this technique, however, generally vary only slightly from those obtained from the simpler method reported above.

3.7 *VEHICLE SPEED*

The PICR Experimental Fuel and Speed Group was responsible for the modelling of speed but, as was noted earlier with fuel, data on both fuel and speed were collected from operators in the user survey when available. Sufficient data on cars and buses were assembled to analyse speed for these vehicle classes and the results are presented below. The MTC algorithm was developed to predict fuel and speed components by vehicle class from a detailed profile of the road and its surface condition. Subsequently, an aggregate speed equation was produced from the MTC (Moser, 05/1980) which was suitable for comparing with the survey data. This comparison is reported after the speed equations are presented.

3.7.1 *Average Commercial Car Speed*

The analysis of car speed data is reported in a PICR technical memorandum (Wyatt and Chesher, 05/1979) and the results reported below are derived from this document. Data on car journey times were collected from 4 companies engaged in collecting bank correspondence on a regular basis from the various branches in different towns or cities. Data on 91 routes were assembled and journey times derived either from official timetables or drivers' journey records. The companies were questioned about unofficial stops on each journey but they were considered to be of minimal duration because of the tight schedules imposed. The best estimate was between 2 to 3 minutes per one way trip, with a maximum of 5 minutes. Stops on the highway were forbidden and unofficial stops ignored in calculating the average speeds. Their effect was thought to be small since adequate rest periods were scheduled between journeys at the driver's home base.

The reported equation, estimated by the OLS method, is:

$$\begin{array}{l} CS = 66.19 - \underset{(-7.83(}{0.192QI^{*}} - \underset{(-2.01)}{0.27RF} + \underset{(3.41)}{7.265T} + \underset{(6.20)}{0.068D} \qquad (3.29) \\ R^2 = 0.65 \qquad S = 7.19 \end{array}$$

Where

CS = is the average running speed (km/h) for the route, mean of both directions

T = is the number of round-trips per day where 1 round-trip = 0 and 2 round-trips = 1

D = is the route distance, in km, one way. The shortest route with 1 trip was 116 km and the largest with 2 trips was 235 km

Increasing roughness by 100 QI* is predicted to reduce speed by 20 km/h on average. Routes with 2 trips per day are travelled about 7 km/h faster than one trip per day routes and increasing route length by 100 km is predicted to increase speed by 7 km/h. These last two effects may offset each other in practice for as route length increases the number of trips per day will often drop from two to one. Each increase in rise plus fall of 10 m/km is predicted to reduce speed by 2.7 km/h. Predictions from equation (3.29) for a variety of roughness and rise plus fall levels are given in Table 3.14.

TABLE 3.14 - PREDICTIONS OF CAR SPEED FROM EQUATION 3.29

	RF			
QI*	10	20	30	40
40	72.8	70.1	67.4	64.7
80	65.1	62.4	59.7	57.0
120	57.4	54.7	52.0	49.3
160	49.8	47.1	44.4	41.7

Where

T = 0 (one trip per day)

D = 250 km

3.7.2 *Average Bus Speed*

Bus speed data were collected on 110 routes from 18 companies in the survey and were derived either from tacograph charts or drivers' trip records. Since the tacograph gives a very accurate record of vehicle speed, it was decided to concentrate solely on data from their charts. The analysis is reported in a PICR memorandum (Wyatt and Lima, 07/1979) and the results reported below are taken from this document .

Tacograph data were obtained from 12 bus companies operating on 52 routes. The average running speed (km/h) for the entire route was calculated by dividing total round trip time, less stops, by route distance. Stops of very short duration, which could not be accurately measured from the chart, were counted as being of 40 seconds each, so that some account was taken of these short stops when they occurred.

The final equations indicated that roughness, horizontal geometry and route distance were significant in explaining the variation in average speeds. One measure of vertical geometry (mean grade) entered at the 15 percent level and all other variables were insignificant. The equation, estimated by the OLS method, excluding mean grade, is reported below.

$$BS = 64.07 - 0.1457QI^* - 0.0616ADC + 0.0182D \qquad (3.30)$$
$$\qquad\qquad (-7.07) \qquad (-3.79) \qquad (5.12)$$
$$R^2 = 0.66 \qquad S = 6.19$$

Where

BS = is bus speed in km/h

D = is the one way route length in km

In equation (3.30) each increase of 10 QI* is predicted to reduce speed by 2.4 percent, while each increase of 10 ADC is predicted to reduce speed by 1 percent. Predictions for equation (3.30) are given in Table 3.15 for different levels of QI* and ADC. These levels reflect the limits of the bus speed data set.

TABLE 3.15 - PREDICTIONS OF BUS SPEED FROM EQUATION 3.30

	ADC			
QI*	10	30	100	200
40	61.3	60.0	55.7	49.6
80	55.4	54.2	49.9	43.7
120	49.6	48.4	44.0	37.9
160	43.8	42.6	38.2	32.1
200	38.0	36.7	32.4	26.3

NOTE: D = 200 km.

3.7.3 *Experimental and Survey Speed Comparisons*

Predictions from the MTC aggregate speed equation were compared with the survey data described in the previous two sections . Some discrepancy must be expected. MTC, in its aggregate form, takes no account of congestion, speed limits or the need to decelerate to and accelerate from stops and these are important factors in predicting bus speeds. The comparison was reported in a PICR technical memorandum (Chesher, 08/1980) and more details are contained in that document.

3.7.3.1 *Car Speed*

Correlations between highway characteristics, MTC speed, survey speed and their difference are presented in Table 3.16. The correlation between MTC and survey speed is 0.45, which is low given that these are simple correlations, presented to show the direction of the relationships. This figure implies that the MTC aggregate speed equation explains about 20 percent of the variance in survey speed. However, variations in individual journey speeds must be expected, particularly as the service provided by the survey cars require high speeds to be maintained. MTC is designed to estimate average speeds and it is

TABLE 3.16 - CORRELATION COEFFICIENTS FOR CAR SPEED

	TC	US	TC-US	QI*	ADC	RF
TC	1	$.45^s$	$.38^s$	$-.61^s$	$-.94^s$	-.00
US		1	$-.66^s$	$-.67^s$	$-.31^s$	-.13
TC-US			1	.19	$-.47^s$	.13
QI*				1	$-.38^s$	.00
ADC					1	-.01
RF						1

NOTE: TC = MTC predicted speed (km/h) from aggregate equation
US = user survey speed (km/h) from timetable records
s = correlation significantly different from zero at better than 5 percent level
The number of observations is 84.

more important that it picks up the effects of highway characteristics correctly.

When the MTC speed versus survey speed data were graphed, the MTC was shown to overpredict, although the graphs of MTC minus survey speed against roughness and rise plus fall suggested that the effects of changes in these variables were reasonably well captured. Finally, the same speed data were graphed against curvature and it appeared that this geometry variable was not being well represented by the MTC as far as these survey data were concerned. Regressions of survey speed on MTC speed and of the difference between MTC and survey speed on roughness, rise plus fall, curvature and route length are presented in Table 3.17. The equation relating survey speed to MTC speed is substantially

TABLE 3.17 - REGRESSIONS OF SURVEY CAR SPEED ON MTC AND OTHER VARIABLES

Eq	Intercept	MTC Speed	Route Length	RF	ADC	QI*	R^2	S
1	25.57 (2.84)	0.55 (4.56)					0.2	10.40
2	10.41 (1.95)		-0.044 (-4.34)	0.275 (1.86)	-0.129 (-8.20)	0.106 (3.35)	0.51	7.99

NOTE: Equation 1 is survey speed on MTC predicted speed and Equation 2 is MTC speed minus survey speed on highway characteristics.

and significantly different from the line of equality. The coefficient on MTC speed is only 0.55 and there is a large positive intercept. The regression of the prediction error on route length and highway characteristics (Table 3.17, equation 2) shows that the effects of average degrees of curvature and roughness are not being captured correctly as far as this survey data set is concerned. Over 50 percent of the variance in the prediction error can be explained in terms of route length, rise plus fall, average degrees of curvature and road roughness.

The coefficients indicate that the MTC under-predicts speeds on longer routes and on routes with bad horizontal geometry. For every 50 degrees increase in ADC, MTC aggregate speed equation under-predicts by 6.5 km/h. MTC tends to over-predict speeds on rougher routes, by 3.3 km/h for each 30 QI* increase in roughness.

3.7.3.2 Bus Speed

Two variable correlations between MTC speed, survey speed, highway characteristics and number of stops per kilometer are given in Table 3.18. The correlation between TF and US is higher for this class, but the difference between MTC and survey speeds is significantly correlated with roughness, curvature and number of stops per kilometer. MTC appears to over-predict to a greater extent as bus routes get rougher and have more stops per kilometer and, to a lesser extent, the more extreme horizontal geometry becomes.

TABLE 3.18 - CORRELATION COEFFICIENTS FOR MTC AND SURVEY BUS SPEED

	TC	US	TC-US	QI*	ADC	RF	NSTOP
TC	1	$.68^s$	.04	$-.63^s$	$-.71^s$	-.02	.09
US		1	$-.71^s$	$-.70^s$	-.23	-.05	-.23
TC-US			1	$.34^s$	$-.37^s$	.04	$.40^s$
QI*				1	-.01	-.21	.07
ADC					1	.05	-.16
RF						1	.05
NSTOP							1

NOTE: TC = MTC predicted speed (km/h) from aggregate equation
US = user survey speed (km/h) from tacograph records
s = correlation significantly different from zero at better than 5 percent level
NSTOP = number of stops/km
The number of observations is 41.

Regression of survey speed on MTC predicted speed (Table 3.19, equation 1) is very close to a 45 degree line, suggesting that, for buses, the MTC predictions agree well with the average bus speeds found in the survey. When the difference between MTC and survey speeds is related to highway characteristics (Table 3.19, equation 2) average degrees of curvature takes a significant negative coefficient and road roughness a significant positive coefficient. For every 50 degrees increase in ADC, MTC under-predicts speed by 3.3 km/h. For every 30 QI* increase in road roughness, MTC over-predicts speed by 1.8 km/h. These effects are small and it can be concluded that for the bus class, the

MTC aggregate equation performs reasonably well. When number of stops per kilometer is introduced, these conclusions are broadly upheld. As number of stops per kilometer increases, MTC increasingly over-predicts speed, as expected.

Therefore, when MTC speed predictions are compared with survey data, moderately good agreement is found for buses but rather poor agreement for cars. As noted earlier, cars in the survey are not typical of cars observed during the MTC data collection since they are commercial cars. Furthermore, the bus data for the survey is likely to be of a higher quality since it is derived from an accurate instrument mounted in each vehicle and not from operating schedules, as was the case for cars. When the prediction error is related to highway characteristics, MTC does not capture the effects of curvature and roughness very well for either classes. MTC tends to under-predict speed more as average degrees of curvature increase and over-predict as road roughness rises. Further work on the MTC aggregate equation is indicated and re-estimation might yield substantial improvements.

TABLE 3.19 - MTC AND SURVEY BUS SPEED REGRESSIONS

Eq	Intercept	TC	RF	ADC	QI*	NSTOP	R^2	S
1	-.5265 (-.49)	0.956					0.46	7.84
2	2.310 (0.40)		0.174 (0.93)	-0.0664 (-2.64)	0.0599 (2.49)		0.26	6.91
3	0.799 (-.14)		0.212 (1.18)	-0.0567 (-2.35)	0.0565 (2.48)	15.433 (2.53)	0.38	6.53

NOTES: Equation 1 is survey bus speed on MTC predicted bus speed (aggregate equation).

Equation 1 is MTC predicted speed minus survey speed on highway characteristics.

Equation 3 is equation 2 plus stops per km added to highway characteristics.

CHAPTER 4 - TOTAL VEHICLE OPERATING COSTS

4 TOTAL VEHICLE OPERATING COSTS

When reporting vehicle operating cost analyses, it is useful to aggregate the individual cost items and to demonstrate how the total cost of vehicle operation varies with respect to changes in highway characteristics. The items typically presented are fuel, oil, maintenance parts, maintenance labor, tires, depreciation, interest and crew salaries. In addition time savings and accident costs are sometimes specified. In the PICR, all these items except the value of time received attention and data were collected either through surveys or controlled experiments. Only operators' accident costs were not analysed due to the complexity of setting up a suitable data file combining vehicle accident costs with highway characteristics.

In this chapter, aggregate vehicle operating costs are presented in both financial and economic terms. The costs are in August 1981 prices, as detailed in Appendix VI. Economic costs are derived from a number of assumptions which have to be made about tax rates , principally those relating to pretroleum based products where taxes are not disclosed. The assumptions are declared in the appropriate section. Comparisons are then made between the 1979 and 1981 results, using identical price data. All these aggregations are based on vehicle operation on paved and unpaved roads where roughness is varied but geometry is held constant. Some geometry effects in the reported equations are then discussed, even though the equations reported in the main text have deliberately concentrated on variables describing road roughness, vehicle age and other vehicle characteristics. A consistency check is then made with data collected on tariffs and rates, and some comparisons are made with results from other studies.

4.1 TOTAL OPERATING COSTS BY VEHICLE CLASS

The recommended equations in Chapter 3 were used to derive a series of tables, by vehicle class, specifying the cost per km for each cost item, the total operating cost per km and the percentage of total cost represented by each cost item. The tables are for a typical 2 year old commercially operated car (Table 4.1), a 3 year old, diesel engined utility vehicle (Table 4.2), a 3 year old bus, monocoque construction on paved roads and chassis type on unpaved (Table 4.3), a 3 year old ,

TABLE 4.1 - FINANCIAL COSTS PER KM - 2 YR OLD COMMERCIAL CAR

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	6,72	55	7,28	42
Oil + Grease	0,26	2	0,39	2
Parts	0,60	6	2,08	12
Labor	0,36	3	0,70	4
Tires	0,24	2	0,68	4
Depreciation	0,53	4	0,81	5
Interest	0,36	3	0,56	3
Salary	3,05	25	4,68	28
Total	12,12	100	17,18	100

NOTES: 1. Roughness 38 QI* paved, 138 QI* unpaved
Rise plus fall 28 m/km, average degrees of curvature 30 degrees/km.

2. Prices in Cr$, August 1981.

3. Utilization, km/month, is 7427 paved, 4837 unpaved.

4. Interest rate 12 percent

5. Age is 101,000 km

6. Route length 320 km

7. Salary is driver's wage plus all social taxes in August, 1981

TABLE 4.2 - FINANCIAL COSTS PER KM - 3 YR OLD UTILITY VEHICLE, DIESEL ENGINE

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	7,73	39	8,11	26
Oil + Grease	0,27	1	0,42	1
Parts	3,58	19	5,34	17
Labor	1,41	7	2,64	8
Tires	0,99	5	1,78	6
Depreciation	1,22	6	2,90	9
Interest	1,19	6	2,80	9
Salary	3,21	17	7,56	24
Total	19,60	100	31,55	100

NOTES:
1. Roughness 38 QI* paved, 138 QI* unpaved
Rise plus fall 28 m/km, average degrees of curvature 30 degrees/km.
2. Prices in Cr$, August 1981.
3. Utilization, km/month, is 7066 paved, 2996 unpaved.
4. Interest rate 12 percent.
5. Age is 284,000 km.
6. Route length 300 km.
7. Vehicle type Mercedes Benz 608D.
8. Salary is driver's wage plus all social taxes in August, 1981.

TABLE 4.3 - FINANCIAL COSTS PER KM - 3 YR OLD BUS

Cost Item	Paved Cr$	Paved %	Unpaved Cr$	Unpaved %
Fuel	11,94	31	12,69	26
Oil + Grease	1,43	4	1,63	3
Parts	4,59	12	6,32	13
Labor	2,14	5	4,22	9
Tires	3,55	9	4,60	10
Depreciation	4,84	12	5,47	11
Interest	3,45	9	3,89	8
Salary	7,25	18	9,52	20
Total	39,19	100	48,34	100

NOTES: 1. Roughness 38 QI* paved, 138 QI* unpaved
Rise plus fall 28 m/km, average degrees of curvature 30 degrees/km.

2. Prices in Cr$, August 1981.

3. Utilization, km/month, is 9036 paved, 6879 unpaved.

4. Interest rate is 12 percent.

5. Age is 348,000 km.

6. Route length 340 km paved, 250 km unpaved.

7. Monocoque operates on paved, chassis type on unpaved.

8. Salary is driver and conductor's wage plus all social taxes in August, 1981.

three axle rigid truck (Table 4.4) and finally a 3 year old heavy articulated truck, for paved roads operation only (Table 4.5). The price data used in the calculations for all vehicle classes is given in Appendix VI with additional notes accompanying each table. Costs are in financial terms and the importance of fuel and crew costs can be seen in all the aggregations.

For utilities, the operating cost breakdown is of interest because it is the first time that this vehicle class has been analysed in such detail. Within this class, parts are an important item in the cost breakdown, along with fuel expenditures.

Buses were treated in a rather special way. In 1979 the same bus type was used for both levels of roughness whereas, in reality, an operator actually selects different bus types for paved and unpaved surfaces. The bus table attempts to replicate this phenomenon. A rear engined monocoque bus is selected to operate on paved roads and a front engined chassis plus body type on unpaved roads. This causes the increase in total cost per km following a move from paved to unpaved operation to be lower than when the same bus operates on both road types, which is precisely why the operators choose different bus types.

For trucks, the three axle medium version was chosen because it is representative of this vehicle class in Brazil's national fleet. Since the majority of these vehicles are driven by their owners, the interest rate for calculating the cost of capital is raised to 15 percent. The heavy class, 40 tonne articulated vehicle shows that even in financial terms the cost of fuel is almost equalled by the maintenance parts plus labor costs for tractor and trailer. Tire costs can also be seen to be a significant cost item in this class and is a contributing reason as to why these vehicles are not frequently observed operating on public unpaved highways. More comparisons between the two truck classes are made in the section on rates and tariffs. The percentage increase in total operating costs resulting from a change from paved to unpaved operations is 42 for commercial cars, 61 for the utility diesel truck, 23 for buses and 49 for medium trucks. The high and low differentials for utility vehicles and buses respectively are partly caused by the utilization differentials which in turn affect the depreciation, interest and salary costs when they are transformed from a fixed to a per km basis. This shows that care has to be taken in the selection of utilization equations when predicting total vehicle operating costs. In addition, the choice of bus types the operator makes

TABLE 4.4 - FINANCIAL COSTS PER KM - 3 YR OLD, 3 AXLE FLAT TRUCK

Cost Item	Paved Cr$	 %	Unpaved Cr$	 %
Fuel	13,54	38	15,09	28
Oil + Grease	0,83	2	0,96	2
Parts	5,39	15	13,26	24
Labor	2,54	7	4,05	8
Tires	6,57	18	8,52	16
Depreciation	2,27	7	3,83	7
Interest	1,95	5	3,26	6
Salary	2,94	8	4,77	9
Total	36,03	100	53,74	100

NOTES:
1. Roughness 38 QI* paved, 138 QI* unpaved Rise plus fall 28 m/km, average degrees of curvature 30 degrees/km.
2. Prices in Cr$, August 1981.
3. Utilization, km/month, is 9415 paved, 5601 unpaved.
4. Interest rate is 15 percent.
5. Age is 375,000 km.
6. Route length 500 km paved, 300 km unpaved.
7. This vehicle type is chosen because it is the most numerous in the medium truck class. Chassis is Mercedes Benz L2013.
8. Salary is driver's wage plus all social taxes in August, 1981.

TABLE 4.5 - FINANCIAL COSTS PER KM - 3 YR OLD HEAVY ARTICULATED TRUCK

Cost Item	Paved Cr$	%
Fuel	23,48	34
Oil + Grease	1,06	1
Parts - Tractor	8,60	13
Trailer	4,12	6
Labor - Tractor	5,14	8
Trailer	1,37	2
Tires	9,61	14
Depreciation	5,41	8
Interest	4,07	6
Salary	5,17	8
Total	68,03	100

NOTES:
1. These vehicles typically only operate on paved roads with average roughness=38 QI , rise plus fall 28m/km, degrees of curvature 30 degrees/km.
2. Prices in Cr$, August 1981.
3. Utilization, km/month, is 10,080.
4. Interest rate is 12 percent.
5. Age is 322,000 km.
6. Route length is 760 km.
7. Vehicle type is Scania T112 M, 40 tonne gross vehicle weight.
8. Salary is driver's wage plus all social taxes in August, 1981.

to reduce total operating costs further reduces the bus differential so that it finally looks small in relation to the other vehicle classes.

Financial costs are of interest to the operator, customer and certain governmental agencies. However, the allocation of resources for road construction and maintenance by cost-benefit techniques usually employs input data net of taxes and social transfers, since these cause distortions. Therefore, a selection of aggregate operating cost tables using economic price data have been derived from the same equations used to calculate the financial tables. The rates of tax deducted from the financial prices are given in the notes under Table 4.6 . The economic prices for diesel fuel, oil and grease are estimated because no published information is available about the prevailing tax rates. Tables are presented for a 3 year old bus, using the same bus type choice between paved and unpaved as before (Table 4.6), a 3 year old three axle rigid truck (Table 4.7) and a heavy articulated (truck (Table 4.8). The tables show some significant differences between economic and financial costs in terms of component per km cost and total operating cost per km, for each class. Fuel costs per km and as a percentage of total operating costs per km fall strongly, as expected. In percentage terms maintenance parts and tire cost rise significantly in economic costs although labor falls, as expected when social taxes are deducted from mechanics salaries. Depreciation and interest rise in economic terms for all classes but particularly strongly for buses . Crew costs fall in terms of cost per km but on a percentage allocation basis remain relatively unchanged for trucks and fall more significantly for buses. The percentage increase in total cost per km from paved to unpaved operations is greater when the operating costs are calculated in economic terms and give a bus figure of 25 (23) percent and a medium truck figure of 58 (49) percent. The figures in parentheses give the financial cost differentials between paved and unpaved operations.

So far, emphasis in the tables presented has been on determining the differentials between paved and unpaved road operation and geometry characteristics have been held constant using the average values found in the survey. As noted in the various sections on the individual cost component analyses, doubts exist about some of the geometry effects found during analysis. This has resulted in recommending some equations without a geometry effect until those effects that were identified are better understood. Table 4.9 details those reported equations that do have a geometry effect and gives the percentage change in the dependent variable when ADC is raised from 50 to 100^{0}/km or RF raised from 20 to 30m/km for paved road operation.

The effects appear quite reasonable although caution must be

TABLE 4.6 - ECONOMIC COSTS PER KM - 3 YR OLD BUS

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	5,68	21	6,04	18
Oil + Grease	0,72	3	0,82	2
Parts	4,25	17	5,85	18
Labor	1,29	4	2,54	8
Tires	3,09	12	4,00	12
Depreciation	4,17	16	4,71	14
Interest	2,97	11	3,34	10
Salary	4,37	16	5,72	18
Total	26,54	100	33,02	100

NOTES:

1. Prices in August, 1981.
2. Economic cost of diesel fuel is 20 Cr$ per litre.
3. The following items have been adjusted so that their prices are net of tax, the prevailing tax rate is shown next to the item:
   a) tires, 15 percent;
   b) parts, 8 percent ;
   c) new vehicle prices, 16 percent;
   d) labor costs, 66 percent; and
   e) oil and grease, 50 percent.
4. Salary is driver and conductor's wage (bus) and driver only (trucks) less social taxes, in August 1981.

TABLE 4.7 - ECONOMIC COSTSPER KM - 3 YR OLD, 3 AXLE FLAT TRUCK

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	6,44	2	7,18	19
Oil + Grease	0,42	2	0,48	1
Parts	5,00	21	12,29	32
Labor	1,53	6	2,44	6
Tires	5,71	23	7,41	19
Depreciation	1,96	8	3,30	9
Interest	1,68	7	2,82	7
Salary	1,77	7	2,86	7
Total	24 51	100	38,78	100

See Table 4.6 for notes on these data.

TABLE 4.8 - ECONOMIC COSTS PER KM - 3 YR OLD HEAVY ARTICULATED TRUCK

Cost Item		Paved Cr$	%
Fuel		11,18	23
Oil + Grease		0,53	1
Parts -	Tractor	7,96	17
	Trailer	3,81	8
Labor -	Tractor	3,10	7
	Trailer	0,83	2
Tires		8,36	18
Depreciation		4,65	10
Interest		3,50	7
Salary		3,11	7
Total		47,03	100

See Table 4.6 for notes on these data.

TABLE 4.9 - EFFECTS OF GEOMETRY ON THE REPORTED COMPONENT COST EQUATIONS

Vehicle Class	Cost Item	Percent Change on raising ADC from 50 to 100°/km	Percent Change on raising RF from 20 to 30m/km
Car	Fuel	6.98	
	Speed		-4.1
Utility	Fuel:		
	gasoline[1]	7.36	
	gasoline[2]	7.60	
Medium Truck	Tires[3]	1.56	9.79
Bus	Fuel	2.1	
	Tires[4]	1.72	10.6
	Speed	-5.24	
Heavy Truck	Tires[5]	0.92	5.39

NOTE: Fuel is liters/1000 km, tires are cost per km and speed is km/h. Roughness is 40 QI*.

[1] is equation (3.2), [2] is equation (3.3), [3] is tire size 1000x20, [4] is 900x20 and [5] is 1100x22.

exercised when considering the influence of ADC on fuel consumption . It is known from controlled experimental results that the plot of fuel against speed gives a U shaped relationship. Furthermore it has been empirically established that speed varies inversely with ADC. Therefore, an interpretation of this ADC effect on fuel consumption is that as ADC is increased from 0, fuel consumption improves as the vehicle speed falls to the point where the engine is working most efficiently and fuel consumption is minimized. It then worsens as continuing increases in ADC bring about greater speed reductions. From this interpretation it would appear that the survey data lie in the part of the relationship where increasing ADC worsens fuel consumption. It is unlikely that this limitation will affect the overall PICR results, since speed and fuel predictions are derived from experimental data and survey data for these items primarily serve as consistency checks. However, if the survey equations are used, it is recommended that care be exercised when interpreting fuel predictions derived from changes in ADC.

Finally, it was thought useful to compare the results presented in the main text with those similarly reported in the Phase 1 1979 report. First the increases in total per km cost from bus and medium truck paved to unpaved operations were compared. The 1981 percentage differentials, with 1979 in parentheses, are bus 25 (54) and medium truck 58 (77). However, these cost increases are not strictly comparable for a number of reasons. As noted previously, the 1979 costs are based on one bus type (irrespective of surface condition), and on a 2 axle truck. In 1981 each surface has a specific bus type and the truck has 3 axles which affects components like tires, depreciation and interest costs. In addition, input prices have changed significantly since 1979 so to make a fair comparison between both sets of equations, the same vehicle types and unit prices were applied to both sets of equations. The results are given in Tables 4.10 and 4.11 for buses and 3 axle medium trucks, respectively. The bus comparisons are very similar with respect to the component percentage of total cost. Fuel rose sharply in 1981 and maintenance parts plus labor fell, the rest of the items did not change significantly. In Table 4.11, 1981 truck maintenance parts plus labor are significantly greater, tires are less when on unpaved roads and depreciation plus interest less on paved roads. The latter is due to higher utilization levels being predicted using the 1981 equation. The rest of the items are broadly similar between 1979 and 1981. The analyses since 1979 have used a wide variety of econometric techniques in order to capture the effects of high -

TABLE 4.10 - PERCENTAGE COMPARISONS BETWEEN 1979 AND 1981 RESULTS - ECONOMIC COSTS 3 YR OLD BUS

Cost Item	Paved 1979	Paved 1981	Unpaved 1979	Unpaved 1981
Fuel	19	21	14	18
Oil + Grease	2	3	2	2
Parts + Labor	24	21	32	26
Tires	11	12	14	12
Depreciation + Interest	29	27	24	24
Salary	15	16	14	17
Total	100		100	

NOTES: 1. Route characteristics are virtually identical between 1979 and 1981.

2. Both 1979 and 1981 cost items reflect the operation of monocoque vehicles on paved routes and chassis types on unpaved routes.

TABLE 4.11 - PERCENTAGE COMPARISONS BETWEEN 1979 AND 1981 RESULTS-ECONOMIC COSTS 3 AXLE TRUCK

Cost Item	Paved 1979	Paved 1981	Unpaved 1979	Unpaved 1981
Fuel	27	28	19	19
Oil + Grease	2	2	1	1
Parts + Labor	18	27	31	38
Tires	24	23	26	19
Depreciation + Interest	20	15	16	16
Salary	9	7	7	7
Total	100		100	

NOTE: 1. Route characteristics are virtually identical between 1979 and 1981.

way and vehicle characteristics. Additional data were also collected to supplement certain cost component analyses so that the 1981 results are more robust and can be used with greater confidence. It is also encouraging to note a number of similarities between the two series of results and this again increases confidence in the results. The PICR user survey equations are able to provide estimates of total vehicle operating costs in Brazil and yield the differentials between certain road characteristics that are sought by highway planners and transport economists. In this report these differentials are based on roughness, vehicle age and other vehicle characteristics. In addition, some geometry effects are reported for selected items. The issue of geometry and its effect on vehicle operating costs is not yet fully resolved, as shown in Appendices II and III. This should be a priority item in future work programs.

4.2 COMPARISON OF RESULTS WITH TARIFF AND RATES DATA

In any competitive economy, aggregate vehicle operating costs should be related to the average rates charged by vehicle operators. Owners may accept rates which fall below total costs from time to time but, on average, rates must exceed costs or bankruptcy will follow. An important consistency check for any vehicle operating survey is to see how the estimated total costs compare with the prevailing rates in the industry. In Brazil, freight haulage is competitive and therefore a rates study can be used to assess cost predictions. However, the passenger sector is regulated and care must be exercised when making comparisons, since some distortions may be expected. Nevertheless, it was considered that such an exercise using the equations recommended in this report was worthwhile. Therefore, a small tariff and rates survey to collect data for comparing with PICR estimates was conducted in August 1981, after analyses were completed.

The survey was restricted to the States of Goiás and Minas Gerais where it was possible to survey a wide range of highway types quickly and efficiently. Visits were made to a variety of truck companies, some of whom where not members of the User Survey and also to the agencies in Goiás responsible for the regulation of bus passenger fares. At the same time that data on rates and tariffs were collected, details of crew costs were also noted to ensure that the input data for the PICR cost estimates accurately reflected the cost structure of the industry at the time of the rates survey.

It must be emphasized that the tariff and rates data are not an absolute standard for judging the reported results of this study. In the first place, some discrepancy must be expected when trying to estimate the rates for an individual company using equations which are based on mean or median vehicle class data. A very efficient company may fall below the prediction and a less efficient operator lie above it. The objective of the research was to predict costs for a population of vehicles operating on highways of different types and it was not designed to predict accurate estimates for any one vehicle or company.

Secondly, the User Survey concentrated on key components that were considered to vary with highway characteristics so that less emphasis was placed on items that were fixed relative to these variables. Overhead costs like utility costs for workshop and truck yard, office costs and secretarial assistance were thought to vary with company size but not highway characteristics, and this was borne out by the Main Survey. Nevertheless, the items presented in Tables 4.1 through 4.8 have to be supplemented by estimates of overhead costs and profit margins before predictions of rates can be made. The objective of the exercise, however, is not to predict the rates but to compare the aggregate costs with the prevailing rates. The estimated PICR costs do not include any contribution to fixed costs (overheads) or a profit margin and so the PICR total cost for any vehicle class should be less than the prevailing equilibrium average rate or tariff.

Thirdly, a survey carried out in any particular month may be biased because the rates have just changed or are about to change and do not reflect closely the prevailing prices for that month. Possible distortions from this feature have to be remembered when making comparisons between estimated costs and tariffs. Finally the recession in Brazil has badly affected truck operators and the competition for work has forced them to accept very small profit margins. This is particularly true of the owner-driver operations and it should be expected that where a company's fleet is supplemented by hired vehicles, the latter's rates are less than those for trucks owned by the company. The results of the rates and tariffs survey are now presented, trucks first and then bus operations.

4.2.1 *Truck Rates and Tariffs*

Each truck company gave the rates structure for its routes and the route most regularly used was subsequently selected. The characteristics of the route and of the vehicle (principally vehicle age) were then used to predict a PICR estimate of the total vehicle operating costs for the type of vehicle used by the company over the route yielding the tariff. The PICR estimate included the main vehicle operating cost components, including driver's salary but not profit margin or overhead contribution. Details of this exercise are given in Appendix IV and a comparison of total costs per km was then made between the PICR estimates and the tariff data. The results appear in Table 4.12 for companies 1 through 6. The truck data were grouped into the vehicle classes used in Chapter 3 and comprised a two axle, 13-15 tonne gross weight truck (tipper variety), a three axle, 18-22 tonne gross weight rigid vehicle (flat) and a 40 tonne gross weight articulated unit. In all but one case, the earnings per km exceed the PICR cost estimates , as expected. The exception is probably caused by the PICR fuel prediction which is high for this vehicle type and so earnings may actually exceed costs, but not by a substantial amount. Therefore, earnings per km exceed predicted costs by relatively slim margins to cover overhead costs and profit. Averaging all vehicle data gives a differential of 13% return on capital for 2 axles, 14% for 3 axles and 10% for articulated vehicles. These margins are probably acceptable given the recession in the trucking industry. What is more significant, especially to the highway planner, is the comparison of costs per tonne.km. In many cases, earnings per km exceed costs per km only because the operator overloads the vehicle and the asterix in Table 4.12 shows which vehicles are operating above the legal payload. It was therefore decided to standardize the per km costs by dividing them by the maximum legal payload and the results are shown in Table 4.13. This shows that, except for the articulated vehicle, the differentials between costs and earnings fall, reducing the profit and overhead margins or resulting in losses. In spite of the difficulties in comparing rates with cost data in 1981 it would seem that the PICR aggregate costs are not far off the competitive rates, which provides an important consistency check.

TABLE 4.12 - COMPARISONS OF PICR ESTIMATES OF PER Km COSTS COMPANY TARIFF AND RATES DATA (Cr$ AUGUST 1981)

Company	Vehicle Type	PICR Estimate	Company Data	
			Own Vehicles	Hired Vehicles
1	2 Axle Tipper	28.94	35.40	27.63 *
2	2 Axle Tipper	54.48		57.79 *
3	2 Axle Tipper	44.24		48.60
4	2 Axle Tipper	40.06		51.48 *
	3 Axle Flat	37.24		41.15 *
5	3 Axle Flat	36.60		41.67
	Articulated Heavy Truck	75.48	85.03	
6	Tractor for Articulated Heavy Truck	51.11		52.00
7	Bus Chassis Type	48.80	65.85	
8	Bus Monocoque	41.29	47.68	

* Vehicle operates in overloaded condition.

TABLE 4.13 - STANDARDIZED COMPARISONS OF PICR ESTIMATES OF TONNE/KM AND PASSENGER/KM COSTS AND COMPANY TARIFF AND RATES DATA

Company	Vehicle Type	PICR Estimate	Company Data	
			Own Vehicles	Hired Vehicles
1	2 Axle Tipper	2.89	3.52	2.28
2	2 Axle Tipper	5.45		5.03
3	2 Axle Tipper	4.42		4.86
4	2 Axle Tipper	4.01		4.68
	3 Axle Flat	2.66		2.29
5	3 Axle Flat	2.93		3.33
	Articulated Heavy Truck	2.90	3.27	
6	Tractor for Articulated Heavy Truck	1.97		2.00
7	Bus Chassis Type	1.95	2.63	
8	Bus Monocoque	1.53	1.77	

NOTES:

1. The hired vehicles are predominantly driven by their owners;
2. All the trucks types are standardized so that they carry the maximum legal load. The buses have the same occupancy rates.

4.2.2 Bus Tariffs

The road passenger sector is regulated and each State is responsible for fixing cost per passenger.km charges for operations within its boundaries. Visits were made to the regulatory agency in Goiás in order to collect data on how the calculations are made. In Goiás, the agency is SUTEG, Superintendência de Transportes e Terminais de Goiás, and it furnished considerable information on its method of regulating fares (SUTEG, 1981). Although each State varies in some details, the mechanism is basically similar. At periodic intervals data are collected from bus companies to calculate the price increases of the various operating cost components over the review period. In Goiás, vehicle operating costs are related to three pavement types, paved, mixed surfaces and unpaved. Total operating costs per km for the three types of road surface are then calculated and a cost per passenger/km derived by multiplying the number of seats per vehicle by the occupancy rate (70% in Goiás) and dividing into the total per km cost. The prevailing cruzeiro passenger per km rates in Goiás in August 1981 were Cr$1,7657 paved, Cr$2,3104 mixed and Cr$2,6341 unpaved, without taxes. The actual fares include taxes but since these are merely social transfers, it is not appropriate to include them in any comparison with operating costs.

The estimated PICR per km cost and passenger.km cost comparisons with the corresponding rates data for two companies, one operating on unpaved roads (Company 7) and paved (Company 8) are given in Tables 4.12 and 4.13 respectively. It must be recognized that buses are more complicated to manage than the average trucking operation. If a company continually fails to provide good service on its route, it may lose its licence to operate that route and will certainly lose revenue, so vehicle maintenance is a priority management task. In addition, it deals with more crew, has to keep good daily accounts, maintain reserve vehicles and all these require larger overhead cost allocations than trucks. Therefore, it is to be expected that the actual tariffs well exceed the basic list of vehicle operating components presented in Appendix IV. The data for Company 8 in either 4.12 or 4.13 show an 16 percent differential between PICR estimates and estimated earnings (using the same occupancy rate as SUTEG) while that for Company 7 is 35 percent. The former is for paved road operations and seems a reasonable margin for overheads and profit while the latter, for unpaved routes, seems high. Indeed, using SUTEG data unpaved operations are the most profitable whether calculated on a passenger.km/load factor or total annual earnings basis. Because of this, the SUTEG data for unpaved routes were carefully examined. SUTEG data were based on 237 vehicles running on 39 routes and reporting costs while running a total of almost 7 million kilometers. However, only 10 percent of that total was run on unpaved routes, so some biases might arise. Differentials, based on the percentage change in each reported cost item between paved and unpaved operations, were calculated using the SUTEG information and these appear in Table 4.14. If operational costs are first considered, wide variances between the cost differentials are noted, particularly for parts consumption on unpaved roads which is almost three times larger than for paved operations. Maintenance labor is only 27 percent greater, which gives rise to some concern. High parts consumption cannot be explained solely in terms of expensive parts/low labor cost items like engines or gearboxes. Body work costs, for example, which are frequently labor intensive, should be expected to be an important parts/labor item on unpaved road operations. Therefore, the parts and labor differentials appear inconsistent and cannot be judged reliable without further evidence.

Fixed costs vary proportionally with utilization and the SUTEG and PICR utilization figures show a wide variation, especially on paved routes. The SUTEG figures for annual utilization are 132,900 km paved and 61,500 unpaved while the corresponding PICR estimates are 108,400 paved and 82,500 unpaved. The PICR data are derived from 19 companies operating over a wide range of conditions, whereas the SUTEG data are dominated by one company. The PICR utilization differentials look more credible and if used in the SUTEG calculations would result in a significantly lower unpaved per km cost estimate. As a further check, a comparison between the paved and unpaved differentials for the PICR estimates and the SUTEG data is given in Table 4.15. It can be seen that no agreement exists between the two sources of data. Parts and labor have already received comment and oil consumption is a small cost item that can be disregarded in this context. Fuel is important and the unpaved SUTEG figure is based on a consumption of 2.74 km/liter. This is a high average figure for bus operations on unpaved routes and the PICR estimate of 3.31 km/liter seems more credible. The tire differentials cannot be evaluated because of insufficient information on the SUTEG data but it would seem that the PICR differential is due to the paved highway tire life being far below that in the SUTEG data. It may be that the SUTEG data is influenced by the very efficient tire management and recapping policy operated by the main company in the data. Whereas

TABLE 4.14 - PERCENTAGE DIFFERENTIALS BETWEEN PAVED AND UNPAVED ROADS BY OPERATING COST ITEM, IN COST/KM CHANGES, SUTEG DATA

Operating Cost Item	Paved/Unpaved	
	% Increase	Total [1]
1. Operational Costs:		
i) Fuel	11.8	
ii) Oils + Grease	50.8	
iii) Tires	69.9	
iv) Maintenance Parts	185.1	
v) Maintenance Labor	27.1	
vi) Other Labor		
a) drivers	122.6	
b) traffic staff	25.0	
vii) Other Costs	142.2	
Total 1		70.7
2. Depreciation:		
i) Vehicle	116.1	
ii) Equipment	116.1	
Total 2		116.1
3. Interest Charges	55.5	55.5
4. Overhead Costs:		
i) Taxes, Insurance	116.1	
ii) Administration	0	
Total 4		9.2
5. Expansion Allowance	60.3	60.3
Overall Total	69.3	69.3

[1] This column represents the individual cost item differentials weighted by their prices to give the differentials for each group of items.

TABLE 4.15 - PERCENTAGE INCREASES IN BUS COSTS PER KM ON MOVING FROM PAVED TO UNPAVED ROUTE OPERATIONS

Cost Items	PICR	SUTEG
Fuel	6	12
Oil	14	51
Parts	38	185
Labor	97	27
Tires	30	70
Depreciation	13	116
Interest	13	56
Salary	31	123

the PICR tire data encompasses a spectrum of companies, with ranges of efficiency which give rise to lower tire life for paved roads. Also, the depreciation, interest and salary differentials are a result of the different utilization levels predicted by PICR and SUTEG data. This has already received comment. Finally, a percentage breakdown of bus operating costs/km for paved and unpaved routes, based on SUTEG data, are presented in Appendix VIII.

The comparisons between PICR and SUTEG data show that regulated fares on a per km basis exceed the PICR predicted costs per km , as was expected. On paved routes the difference would represent a reasonable overhead and profit margin. Unpaved operations show much less consistency and the SUTEG data exhibit wide variations for the individual item cost per km differentials that require explanation. In general, the aggregate PICR costs seem more credible than the corresponding SUTEG information for unpaved bus operations.

4.3 COMPARISONS WITH OTHER USER SURVEY STUDIES

It is difficult to make accurate comparisons between vehicle operating cost studies. The problems of transferring results from one country to another are large and insufficient work on transferability has been done to permit detailed inter-study comparisons. The comparisons that can be made now can only illustrate differences rather than indicate whether results are correct or even reasonable. In addition, few vehicle operating cost studies have been conducted. The Kenya Study was the most comprehensive before the PICR but, even so, great difficulties emerge in trying to make comparisons. Brazil has a large vehicle component and assembly production sector while Kenya imports vehicles or assembles kits produced in other countries. There is likely to be large variations in labor rates, vehicle prices, parts costs and utilization levels between Kenya and Brazil. In addition, the Kenya study did not analyse survey data on the operating costs of utility vehicles and heavy trucks, so the vehicle class comparisons are limited to cars, medium trucks and buses. The equations are often dissimilar in form and roughness was measured differently in each study. Work is proceeding on relating the roughness measures and at the moment the conversions between the two units are approximate. Nevertheless, some comparison between the PICR and Kenya is required. The World Bank survey (de Weille, 1966) used mainly North American data (Winfrey, 1963) which employed few vehicles, used theoretical relationships and subjective decisions, and some of the data dates from the early 1940s. The de Weille tables are still popular with transport economists so they are included for comparison. The East and Central African study (Bonney and Stevens, 1967) gives no details of the surface condition for gravel roads and used a very small sample of buses and trucks for each of the two types of road. However, this study was important in establishing the potential of vehicle operating cost surveys, so it is included in this exercise.

It was decided to compare the cost differentials between unpaved and paved operations for these studies and the PICR. The results are shown in Table 4.16 for cars, medium trucks and buses. The PICR cost items which appear to vary significantly from the other studies (principally Kenya) are car tires, truck parts and bus parts/labor costs. The parts and labor costs are governed by the prevailing price and wage rates at the time of the surveys, so these items are expected to exhibit wide variations between countries and years. In addition, the vehicle assembly industry in Brazil is producing a range of bus types which help reduce operating costs (including parts) on different surfaced roads. The Brazilian medium truck is larger than those in the other studies and on unpaved roads is frequently operated in an overloaded condition. The parts costs differentials per km for paved and unpaved operations are therefore wider than other studies, although on a tonne/km basis the parts cost differential would be reduced. PICR car tire predictions are considered to reflect the consumption measured during the survey period.

The significance of the Brazil results can be appreciated when it is remembered that the PICR can produce cost differentials for five vehicle classes based on User Survey data and, furthermore, consistency between the class differentials is high. Further work on comparisons should be attempted when the Indian study results are available and more work completed on the issue of transferability.

TABLE 4.16 - VEHICLE OPERATING COST RATIOS OF UNPAVED TO PAVED ROADS IN BRAZIL, COMPARED WITH OTHER STUDIES

Vehicle Type	Cost Component	SOURCE			
		Kenya	de Weille	Bonney + Stevens	PICR 81
Car	Fuel	0.97	1.03		1.05
	Oil	2	1.20		1.27
	Parts	2.75	1.27		2.33
	Labor	1.49	1.26		1.59
	Tires	4.33	1.84		2.11
	Depreciation	1.30	1.36		1.39
Medium Truck	Fuel	1.04	-	0.90	1.07
	Oil	2	1.18	1	1
	Parts	1.71	1.57	3.33	2.48
	Labor	1.54	1.68	1.50	1.60
	Tires	1.36	2.72	1.24	1.16
	Depreciation	1.15	1.33	0.87	1.22
Bus	Fuel	1.06		1.00	1.04
	Oil	2		1.50	1.07
	Parts	3.48		3.51	1.24
	Labor	3.09		1.48	1.56
	Tires	1.36		0.94	1.18
	Depreciation	1.02		1	1.14

de Weille medium truck fuel was gasoline powered; RF = 27 m/km, ADC = 60^{o}/km, Altitude = 1300 meters, Roughness in Kenya = 6000 mm/km (gravel), 2500 mm/km (bitumen) corresponding roughness in Brazil (PICR Working Document No. 10) 108QI* unpaved and 42 QI* paved. Route length, cars 150, truck 200, bus 250 km. Age, car 100, truck 300, bus 250 (all '000 km units).

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5 *CONCLUSIONS AND RECOMMENDATIONS*

Throughout this report, recommendations have been made about the analysis of specific cost components and the choice of equations, so this section will concentrate on the major conclusions and recommendations as they appear to the User Cost Surveys Group after completing the second phase of analysis in December, 1981.

5.1 *CONCLUSIONS*

The PICR User Survey data are the most comprehensive collected anywhere to date and are unlikely to be exceeded in size by the Indian study, presently being analysed. They are most important both to Brazil, where modified de Weille tables are generally used to predict vehicle operating costs (MacDowell, 1972) and to the international research community, where they complement the Kenya, Caribbean and India studies. Therefore, they represent a most valuable resource for developing appropriate vehicle operating cost equations for highway planning and other cost-benefit analyses where these costs have to be estimated. The Brazil study covers a wide spectrum of vehicle types and is likely to be the only study with a full range of truck classes. The User Survey data have now passed through several phases of analysis and the results presented in this report, together with the relevant technical memoranda, can be regarded as in interim final form. The data are complex and there is little doubt that many of the equations in this report will be improved as further analyses are conducted. This is expected in basic research of this type where the data are extensive. Because of this, thorough documentation has been carried out to permit analyses to continue. However, these interim final equations are now ready for more extensive testing in the field and should be evaluated in a variety of cost-benefit exercises. The results of the comparisons between PICR estimated costs and prevailing transport service prices were encouraging and suggest that the equations will provide better estimates of vehicle operating costs than anything now being used in Brazil. Survey data are temporal, however, and it should be recognized that undue delay in dissemination may diminish the usefulness of the results.

The Phase I results reported a lack of any statistically significant effect of vertical or horizontal geometry on operating costs, other than for gradient on fuel consumption and vehicle speed. The analyses over the subsequent two years have concentrated on the estimation of the geometry/operating cost relationships and to this end, many thousands of regression equations have been estimated, with and without vehicle and company characteristics and utilizing a selection of the analysis methods described in Chapter 2, in an attempt to comprehensively address this issue. Some progress has been made and significant geometry effects estimated for some vehicle class cost components. However, an important feature of the interim results is the lack of any consistent pattern in the significance, sign and size of the geometry coefficients between vehicle classes. There are at least four likely explanations for the irregular pattern of geometry effects. The first is the high correlatios between vertical and horizontal variables that are present in certain cost component data sets which make it very difficult for the analyst to estimate geometry effects correctly. Secondly, the geometry effects may be so subtle over the ranges encountered in the Survey that regression analysis based on operators' records and single statistics for each highway characteristics cannot capture these effects. Thirdly, the effects may be better estimated using other types of analyses, for example, non-linear methods. Fourthly, the effects may be vehicle class specific, so that geometry may affect the consumption of a particular item in different ways depending on the vehicle type. This would then explain why the significance , signs and sizes of geometry coefficients display irregular patterns.

It is difficult to reach a decision about which explanation is more likely and, to complicate matters, some combinations of these explanations may be responsible for the phenomenon. It is a highly complicated problem with little vehicle engineering evidence available to help form hypotheses. Furthermore, other operating cost studies shed little light on the problem and the results from the Kenya and Caribbean studies were broadly similar to the Phase I PICR results. It seems that more work needs to be carried out before a decision can be made to use all the geometry effects estimated in the last two years in Brazil. In addition, the results from the Indian study may be very useful in providing corroborative evidence for using particular geometry effects. It is for these reasons that the interim results have concentrated on roughness, vehicle age, vehicle characteristics if appropriate, and geometry effects where these appear to be unambiguous.

The PICR results confirm the findings in Kenya and the Caribbean with respect to road roughness which is found to exert the biggest influence on most individual cost items and therefore on total vehicle operating costs. The unit of roughness, QI*, which has been used as the roughness statistic in all the PICR regressions, is being investigated and may be modified in the near future. It is not known what effects this will have on the user cost equations and this can only be resolved if it is included in a future workplan. It may be that QI* overstates roughness on certain road types and results in it picking up effects which would otherwise be attributed to road geometry, but this is speculation at this moment. Furthermore, how QI* relates to other roughness measures currently employed throughout the world is not accurately known over the entire ranges of surface types. An exercise to compare and calibrate the various roughness devices most commonly employed to measure road surface/vehicle response is planned to take place in Brazil in 1982. After that time, more reliable comparisons between the PICR results and those of other studies with respect to roughness can be made and a firmer position reached concerning the use of QI* as an appropriate roughness statistic for vehicle operating cost analyses.

The interim final results include items and areas not previously addressed in vehicle operating cost surveys. A cost breakdown for heavy truck operations on paved roads was not presented in the Kenya report and these vehicles are not found in India, so the PICR is one of the few sources of such data in recent years. Light trucks (utility vehicles) are also considered in the PICR so that results are presented for five vehicle classes, representing most of the spectrum of vehicle types found in Latin America. The effect of vehicle age in kilometers on parts consumption and utilization levels has been investigated and particular importance was given to this in the estimation of parts costs, since parts costs were found to be sensitive to age in kilometers in Kenya. In the PICR this measure of vehicle age is found to be important for parts consumption but is not as potent as in Kenya. Furthermore, there is good consistency between the sizes of the age coefficient between vehicle classes in the PICR data and age enters as a normal independent variable rather than contributing to a complex dependent variable as in Kenya. Maintenance labor costs have been estimated as a function of parts costs and, for some vehicle classes, road roughness and type of fuel. It is now possible to predict labor costs for all five PICR vehicle types without prorating parts costs and this is an important advance over the 1979 results. Finally, utilization has been estimated by vehicle class and although highly dependent on the type of vehicle operation and general level of economic activity, it remains a useful guide to the appropriate levels of vehicle use required by many cost-benefit exercises. Therefore, it can be seen that the 1981 PICR User Survey results are both comprehensive and detailed, including items not previously investigated.

The position reached at the end of the second analysis phase of the User Surver data is that the recommended interim final results are ready for testing in the field after some checks have been carried out. At present, most transport economists in Brazil refer to cost tables that are largely out-of-date, make a few changes and input the resulting data into their cost-benefit exercises. Few would want to have to work through a volume of the size of the present document to extract relevant predictions. It therefore seems logical to produce an updated version of the tables and data presently used to estimate vehicle operating costs in Brazil, using the equations in this report to predict the various costs. This would provide a more convenient mode of dissemination and testing than the present volume. Some thought will have to be given to the appropriate format, but it would probably be similar to de Weilles' handbook in that various combinations of highway characteristics would form cells for which cost breakdowns would be presented. A handbook which would enable economists and highway planners in Brazil to rapidly assemble predictions of vehicle operating costs to various combinations of highway characteristics would be a natural complement to this report and the technical memoranda associated with the analyses contained within. The feedback from field testing would then assist in the development of user cost equations in final form.

5.2 *RECOMMENDATIONS*

The User Survey data base is sufficiently extensive to ensure that further analyses and new techniques in modelling vehicle operating costs will continue to improve the PICR predictions of individual cost items for many years to come. The recommendations in this section will not be speculative however, and will simply detail what is possible with a small team based in Brasília over the next year. Some work items are small, others require more resources but all are considered to lead to a more coherent understanding of how vehicle operating cost/highway characteristics relationships can be best estimated in Brazil.

- The cruzeiro costs are presently expressed in terms of December, 1981 prices or January 1976 prices in the technical memoranda and these have to be inflated to the date required by the user. Evaluation of inflation correction index used by PICR has shown it to be appropriate over the full survey period, as detailed in Appendix XII. This method should be continued so that a mechanism is available to prospective users which will enable them to inflate the predicted costs from their base month and year to the appropriate date required. An alternative to this would be to express the parts consumption in terms of a percentage of the relevant new vehicle price and this could be calculated relatively easily.

- Bus maintenance parts data should be quickly examined and alternative equations reported in the technical memorandum on parts analysis should be evaluated to ensure that the unpaved to paved operation differentials are consistent. There are valid reasons why bus parts differentials might be expected to be small in Brazil but nevertheless checking will increase the confidence in the relevant equations

- Further work on estimating geometry effects for parts consumption should be curtailed until the Indian results are available and then the extensive number of existing equation forms containing geometry can be better evaluated. Alternatively, if resources permit, parts and labor costs could be combined and then regressed on highway characteristics, including geometry, to see if more consistent estimates of the geometry effects are produced.

- If new roughness statistics are derived, or alternative versions of QI* produced, then some reanalysis should be undertaken to compare the effects with the present unit of measure. The bus parts data set is the obvious candidate to be analysed since it is the one where the correlation between highway characteristics are lowest.

- Fuel consumption has not been throughly analysed with all the available econometric methodologies and some inconsistencies are present in the interim results. A re-estimation of User Survey fuel will lead to improvements in the prediction of this important item. This will enable the revised aggregate MTC predictions to be checked for consistency with the Survey data and fuel equations. However, the revised MTC aggregate fuel and speed predictions should still be the main source of fuel and speed data in the vehicle operating cost manual.

- The predicted PICR total cost comparisons with prevailing tariffs were found to give encouraging results. Further collection of tariffs and their subsequent comparison with estimated costs will be a important consistency check on the PICR results.
- The production of a handbook or manual based on this report and the relevant technical memoranda will be an important product of the PICR and complement the series of User Survey documents. It could be the main mode for field testing the recommended interim final equations.

These then are the main recommendations for future work which, while not consuming large quantities of resources, will give more confidence in the PICR Survey results. A crucial time has been reached and these results must be evaluated in the field before substantial improvements can be made. These cannot reasonably be expected to emerge from further extensive in-house analyses and theoretical discussions. The big contributions will come from the pragmatic testing of the existing equations and subsequent feedback, in various cost-benefit highway planning exercises incorporating both construction and maintenance issues, in Brazil.

APPENDIX I - DESCRIPTION OF VARIABLES USED IN THE REGRESSION ANALYSES

I.1 DEFINITION OF CONTINUOUS VARIABLES

ADC	The sum of the central angles of all horizontal curves on the link, divided by the extension of the link. Units in degrees per km (^{o}/km).
BS	Average bus running speed (km/h) for the route.
CS	Average car running speed (km/h) for the route.
D	Route extension in kilometers, one way.
Fuel	Fuel consumption, in liters per 1000 km.
K	Vehicle age, in units of 1000 km. Calculated as the arithmetic mean between the total kilometers travelled since new on entry to the survey and the total kilometers since new on leaving the survey.
KPT	Kilometers per equivalent new tire, in units of 10,000 km.
NSTOP	Number of bus stops per km of route extension.
PC	Parts cost. The maintenance parts costs as estimated from PICR equations, in Cr$December, 1981.
PW	Power-to-Weight Ratio. Calculated as the power of the engine in kilowatts, divided by the average loaded weight of the vehicle. If a vehicle ran empty one way on a trip, the average loaded weight was taken as the mean of the tare and gross vehicle weights.
QI*	The pavement roughness statistic adopted by the PICR project. It is fully described in a project document (Visser and Queiroz, 1979). Maysmeter data for each route link were transformed to QI* values by a procedure described in the above reference. QI* values per 320 m were then grouped into homogeneous bands of roughness within each link (Moser, 07/1977). The average link QI* value was calculated as the weighted average of band means, using band length as the weight.
Q40	This is a piecewise linear form which defines Q40=QI* when QI* > 40 and Q40=40 when QI* < 40.

RF	Rise plus Fall, in meters per km. This is the average gradient of the road x 10.
RL	Route length in kilometers, counted both ways.
TC	Predictions from either the MTC aggregate final equation (km per liter) or aggregate speed equation (km per hour).
US	Predictions from PICR survey speed equations, (km per hour).
UT	Vehicle utilization per month, in units of 1000 km.
V_A	Value of vehicle aged A years on the second-hand market, expressed as a proportion of the new vehicle price.
XOIL	Frequency of oil changes per 1000 km.

I.2 BINARY VARIABLES

AX2	1 if vehicle is a 2 axle rigid, non-tipping vehicle; 0 otherwise.
C2	1 if vehicle is a utility vehicle; 0 otherwise.
C3	1 if vehicle is bus; 0 otherwise.
C4	1 if vehicle is 2 or 3 axle rigid vehicle; 0 otherwise.
C5	1 if vehicle is a heavy articulated vehicle; 0 otherwise.
CARB	1 if car engine has 2 carburettors; 0 otherwise.
DC	Driver Control. 1 if company's control of driver is above average; 0 otherwise.
LE	Engine Location. 1 if engine is mounted at the front; 0 otherwise.

OW	Owner Driver. 0 if owner is driver; 1 otherwise.
SM	Standard of Maintenance. 1 if maintenance is above average; 0 otherwise.
ST/CS	Semi-Trailer. 1 if the vehicle is the tractor of a heavy articulated vehicle; 0 otherwise.
TACH	1 if vehicle has a tacograph; 0 otherwise.
TIP/CT	Tipper. 1 if vehicle is a tipper; 0 otherwise.
TF	1 if vehicle is gasoline powered; 0 otherwise.
U248	1 if the vehicle is operated by company 248; 0 otherwise.

I.3 INTERCEPTS

Tire Sizes A=9.00 x20
B=10.00x20
C=11.00x22

APPENDIX II - EQUATIONS FOR PREDICTING THE EFFECT OF ROAD GEOMETRY ON VEHICLE PARTS CONSUMPTION

II.1 INTRODUCTION

The results and comments presented here are taken from a more detailed PICR technical memorandum (Chesher and Harrison, 09/1981). It is important to determine whether parts costs are sensitive to road geometry. Considerable effort has been expended in an attempt to address this issue. The problem was first considered in 1980 and the analyses reported in a PICR technical memorandum (Chesher, 09/1980) which examined the data using in OLS method. Evidence for geometry effects were found but the signs of the effects were inconsistent across vehicle classes.

In 1981 the problem was addressed for a second time and three statistical methods were used, ordinary least squares on all data (OLS), ordinary least squares estimating company effects (OLSCE) and, finally, error components (EC). These methods are described and referenced in Chapter 2 of this report.

The 1981 equations examined interactions between geometry and road roughness since vehicle damage is a function of surface condition and vehicle speed over the surface. Equations containing interactions are presented in the technical memorandum cited in the first paragraph of this Appendix. Here geometry effects are introduced as main effects rather than interactions. They give an idea of the problems that arise on introducing geometry into vehicle parts equations. No geometry effects were found in Kenya, virtually none in the Caribbean and the Indian results are presently preliminary and tentative. In India the analysts are finding some geometry effects but like the PICR results they are not always consistent and are sometimes hard to explain.

Each vehicle class is considered in turn and a selection of equations presented for each class. For a complete presentation of equations reference should be made to the technical memorandum from which these equations are taken.

II.2 CAR PARTS CONSUMPTION

Examining the OLSCE and EC methods in Table II.1, increases in either rise plus fall (RF) or average degrees of curvature (ADC) are

TABLE II.1 - CARS - DEPENDENT VARIABLE IS LN(PARTS CONSUMPTION)

Method	Intercept	QI*	RF	ADC	R^2	Su^2	Sw^2
OLS	6.010	.0138	.0030	-.000728	.33		
OLSCE		.0204 (5.03)	-.0318 (-1.58)	-.00713 (-2.95)	.24		
EC	6.660	.0168 (4.68)	-.0199 (-1.04)	-.00538 (-2.42)		.409	.207
OLS	6.009	.0137	.00218		.33		
OLSCE		.0128 (3.92)	-.0419 (-2.03)		.17		
EC	7.033	.0119 (3.93)	-.0291 (-1.58)			.291	.224
OLS	6.117	.0134		-.00070	.33		
OLSCE		.0207 (5.07)		-.00778 (-3.23)	.22		
EC	6.116	.0174 (5.03)		-.00584 (-2.75)		.363	.210

S_u^2 is an unbiased estimate of the company error variance.

S_w^2 is an unbiased estimate of the vehicle specific error variance.

Figures in parentheses are T ratios and costs are at December 1981 prices.

predicted to decrease parts costs. The ADC effect is significantly different from zero at the 5% level (using a test with an asymptotic justification for the EC method) and the coefficient alters little on including RF. The RF coefficient is poorly determined. The QI* coefficient is insensitive to the inclusion of RF and ADC. Table II.2 gives linear rather than log-linear equations which have similar features. The EC result in the first equation of Table II.1 predicts a 24% reduction in parts costs for every 50°/km increase in ADC. This effect seems unrealistically large.

Including interactions (see below) improves the explanatory power and gives better determined coefficients. However, the predicted geometry effects are large and until some other basis exists for accepting such effects, the car parts equation incorporating roughness and vehicle age is preferred.

II.3 UTILITY PARTS CONSUMPTION

In Table II.3 it is noted that when RF and ADC are simultaneously introducted, the large geometry coefficients are statistically insignificant. The RF effect is negative, the ADC effect positive. The QI* coefficient falls a little on introducing RF and ADC as main effects. For this vehicle class, even when interaction terms are introduced poor results are obtained. An equation which excludes geometry is therefore recommended and appears as Equation 3.10. This is believed to be the first equation of its type ever obtained for utilities parts consumption from a user survey.

II.4 BUS PARTS CONSUMPTION

In Tables II.4 and II.5 rise plus fall always takes a negative coefficient and average degrees of curvature takes a positive coefficient when both RF and ADC are included. The QI* coefficient is insensitive to the inclusion of RF and ADC. Further, the RF coefficient alters little as ADC is included. In this data set, the correlations amongst the highway characteristics are weak. The negative RF effect is found within companies and is not attributable to the disposition of companies by highway type. This effect appears when vehicle

TABLE II.2 - CARS - LINEAR EQUATIONS - DEPENDENT VARIABLE IS PARTS CONSUMPTION

Method	Intercept	QI*	RF	ADC	R^2	S_u	S_w
OLS	151.19	19.78	3.51	-3.66	.47		
OLSCE		17.54 (3.54)	-23.58 (-.96)	-7.27 (-2.45)	.13		
EC	1128.79	16.41 (4.06)	16.34 (-.73)	-6.64 (-2.58)		627	557
OLS	149.02	19.02	-.63		.43		
OLSCE		9.83 (2.49)	-33.82 (-1.35)		.08		
EC	1644.08	11.54 (3.21)	-32.48 (-1.50)			570	571
OLS	277.27	19.34		-3.63	.47		
OLSCE		17.76 (3.59)		-7.75 (-2.65)	.13		
EC	657.61	17.54 (4.52)		-7.14 (-2.94)		595	556

Costs are at December 1981 prices.

TABLE II.3 - UTILITIES PARTS; WITH VEHICLE CHARACTERISTICS, WITH VEHICLE AGE.
DEPENDENT VARIABLE IS LN(PARTS CONSUMPTION)

Method	Intercept	DC	LE	SM	TF	OW	QI*	RF	ADC	ln(K)	R^2	S_u^2	S_w^2
OLS	6.198	.735	.548	.152	.245	-.782	.00299	.04432	-.00416	.0806	.37		
OLSCE					-.166 (-1.04)		.00441 (2.11)	-.0197 (-1.43)	.00247 (1.38)	.344 (4.52)	.31		
EC	7.469	.023 (.04)	-.290 (-.46)	-.226 (-.42)	-.175 (-.26)	-.445 (-.77)	.00365 (1.65)	-.0132 (-.78)	.00244 (0.90)	.316 (3.59)		.226	.154

NOTE: See Appendix I for definitions of variables.

TABLE II.4 - BUSES WITHOUT VEHICLE CHARACTERISTICS, WITHOUT VEHICLE AGE - DEPENDENT VARIABLE IS LN (PARTS CONSUMPTION)

Method	Intercept	U248	QI*	RF	ADC	R^2	S_u^2	S_w^2
OLS	8.530	-.992	.00764	-.0224		.42		
OLSCE			.00532 (5.13)	-.0210 (-2.71)		.08		
EC	8.674	- .106 (-2.50)	.00554 (5.87)	-.0190 (-2.73)			.173	.296
OLS	7.983	-.869	.00767		-.00021	.39		
OLSCE			.00587 (4.85)		-.000636 (-.31)	.06		
EC	8.176	-1.023 (-2.00)	.00563 (5.11)		-.000169 (.10)		.197	.301
OLS	8.542	-1.100	.00747	-.0233	.000816	.42		
OLSCE			.00525 (4.30)	-.0211 (-2.69)	.000215 (.10)	.08		
EC	8.685	-1.251 (-2.49)	.00516 (4.68)	-.0201 (-2.80)	.00116 (.67)		.185	.297

NOTE: U248 denote vehicles operated by Company 248 and costs are in December 1981 prices.

TABLE II.5 - BUSES - WITH VEHICLE CHARACTERISTICS, WITH VEHICLE AGE - DEPENDENT VARIABLE IS LN (PARTS CONSUMPTION)

Method	Intercept	PW	LE	SM	TACH	U248	QI*	RF	ADC	ln(K)	R^2	S_u^2	S_w^2
OLS	7.171	-.095	.136	.357	-.637	-.436	.00418	-.0189		.422	.66		
OLSCE		-.095 (-3.52)	.137 (1.94)		-.386 (-3.65)		.00191 (2.15)	-.00655 (-1.06)		.436 (14.11)	.46		
EC	7.097	-.091 (-3.45)	.144 (2.02)	.182 (.94)	-.385 (-3.86)	-.639 (-1.61)	.00213 (2.55)	-.00924 (-1.62)		.433 (13.96)		.129	.174
OLS	6.677	-.106	.211	.431	-.630	-.360	.00370		.000222	.435	.64		
OLSCE		-.099 (-3.74)	.151 (2.16)		-.375 (-3.53)		.00201 (2.02)		.000266 (-.17)	.438 (14.19)	.46		
EC	6.873	-.097 (-3.67)	.165 (2.36)	.203 (.96)	-.368 (-3.65)	-.562 (-1.19)	.00214 (2.30)		-.00237 (-.17)	.436 (14.07)		.153	.174
OLS	7.162	-.096	.138	.376	-.638	-.534	.00402	-.0193	.000705	.423	.66		
OLSCE		-.095 (-3. 52)	.137 (1.92)		-.386 (-3.62)		.00191 (1.91)	-.00655 (-1.04)	.000004 (.00)	.436 (14.08)	.46		
EC	7.096	-.091 (-3.45)	.142 (1.99)	.185 (.91)	-.384 (-3.80)	-.664 (-1.45)	.00207 (2.23)	-.00923 (-1.58)	.000173 (.12)	.433 (13.95)		.139	.174

Costs are in December 1981 prices.

characteristics are included like age, power to weight ratios and so forth. Using the first EC equation of Table II.4, each 10 m/km increase in rise plus fall is predicted to reduce parts costs by 20%. The RF coefficients and signs are similar irrespective of the statistical method used for estimation. This is a significant effect and until evidence is provided to confirm its existence in other bus operations it is recommended that geometry not be used. Extensive checks have been performed on the raw vehicle data and these geometry effects cannot be attributed to errors in the user cost data.

II.5 TRUCKS PARTS CONSUMPTION

In Tables II.6 and II.7, when RF and ADC are simultaneously included, RF takes a negative coefficient and ADC a positive coefficient. On occasions both are substantial but neither are well determined. When ADC is omitted, RF takes a positive coefficient which is close to significant but too poorly determined to use. There does seem to be evidence in this data set for a positive rise plus fall effect and if the user is prepared to proceed with equations with marginally insignificant coefficients then one of the equations including QI* and RF could be used. These generally suggest that each 10 m/km increase in rise plus fall increases parts consumption by about 10-15%.

The results briefly referred to in the four vehicle classes above are intended to give an impression of the analyses dealing with geometry and vehicle parts consumption. Equations utilizing geometry variables as main effects have been presented. Interactions between highway characteristics are dealt with in the basic PICR technical memorandum already referenced but at the moment there seems little evidence to recommend any equations with such interactions. An interaction term can be quite potent and care must always be taken when predicting from equations with interactions. It is true that geometry can take a positive sign if roughness is not entered as a main effect, but as one part of an interaction term. However, omitting a main variable and including it as an interaction may simply be 'forcing' a positive sign on the coefficient of the interaction term. Therefore, such equations may be misspecified and thus misrepresent the PICR user survey data. There is little evidence from the data or from other sources to suggest what should be the correct sign for geometry in a parts equation.

TABLE II.6 - TRUCKS - WITHOUT VEHICLE CHARACTERISTICS, WITHOUT VEHICLE AGE - DEPENDENT VARIABLE IS LN (PARTS CONSUMPTION)

Method	Intercept	TIP	ST	Ax2	QI*	RF	ADC	R^2	Su^2	Sw^2
OLS	7.685	-.493	.745	-.283	.00937	.0212		.60		
OLSCE			-.072 (-.26)	-.169 (-.60)	.0175 (5.72)	.00510 (.24)		.17		
EC	7.762	-.400 (-1.98)	.416 (2.31)	-.298 (-1.27)	.0132 (5.88)	.0150 (1.51)			.101	.148
OLS	9.144	-.572	.647	-.306	-.000376	-.0173	.00627	.63		
OLSCE			-.070 (-.25)	-.157 (-.55)	.0148 (3.15)	-.0245 (-.55)	.00314 (.75)	.17		
EC	8.418 (7.98)	-.445 (-2.28)	.431 (2.49)	-.297 (-1.29)	.00892 (2.22)	-.00350 (-.18)	.00304 (1.14)		.083	.148

NOTE: See Appendix I for definitions of the variables.

TABLE II.7 - TRUCKS - WITH VEHICLE CHARACTERISTICS, WITH VEHICLE AGE
DEPENDENT VARIABLE IS LN(PARTS CONSUMPTION)

Method	Intercept	TIP	ST	Ax2	PW	TACH	QI*	RF	ADC	ln(K)	R^2	S_u^2	S_w^2
OLS	6.226	-.117	.698	.273	-.057	-.116	-.0122			.432	.66		
OLSCE			-.105 (-.41)	-.135 (-.52)	-.014 (-.39)		.0190 (7.35)			.364 (6.39)	.32		
EC	6.284	-.191 (-1.00)	.290 (1.62)	.0049 (.02)	-.035 (-1.00)	.185 (.93)	.0166 (7.72)			.368 (6.58)		.097	.123
OLS	6.836	-.295	.686	.078	-.061	-.113	.0071	-.00136	.00321	.364	.71		
OLSCE			-.102 (-.40)	-.077 (-.30)	-.029 (-.76)		.0128 (2.90)	-.0901 (-2.16)	.00818 (2.06)	.391 (6.72)	.33		
EC	6.750	-.273 (-1.48)	.338 (1.99)	.0129 (.06)	-.0512 (-1.44)	.173 (.96)	.0122 (3.28)	-.00766 (-.44)	.00309 (1.24)	.359 (6.44)		.072	.121
OLS	5.903	-.245	.743	.105	-.059	-.136	.0122	.0181		.397	.71		
OLSCE			-.109 (-.42)	-.133 (-.51)	-.008 (-.22)		.0198 (7.00)	-.0145 (-.72)		.371 (6.41)	.32		
EC	6.004	-.232 (-1.31)	.380 (2.30)	.0039 (.02)	-.043 (-1.24)	.148 (.85)	.0159 (7.81)	.0117 (1.40)		.364 (6.54)		.066	.123

NOTE: See Appendix I for definitions of the variables.

At the moment the best available parts equations are those using roughness and vehicle age effects, as presented in the main text. Geometry effects can, at present, be discerned but without a clear understanding of their meaning or apparent inconsistencies. Therefore, it is recommended that they not yet be used as a basis for highway planning. The difficulty of obtaining geometric effects may be partly due to the small range of geometry in the routes surveyed, or it may be partly due to the weakness of the hypothesized form in the parts-geometry relationship. In the light of experience gained in both the Brazil and Kenya studies, it is suspected that there are elements of truth in both explanations. If a strong parts cost-geometry relationship exists, it may only operate over a small range representing severe geometry. In Brazil such geometry is rarely observed on representative routes and when it does appear it is frequently averaged out when the vehicle geometry is calculated. Accordingly it may be more appropriate to wait until further evidence on the parts-geometry relationship is made available from the Indian study. The existing equations from the Brazil study can then be reassessed and further work carried out.

APPENDIX III - EQUATIONS FOR PREDICTING THE EFFECT OF ROAD GEOMETRY ON VEHICLE UTILIZATION

III.1 INTRODUCTION

The utilization equations presented in the main text do not include geometry effects. However, when it was decided to reanalyse vehicle utilization with the 1981 data set, the effects of geometry were specifically addressed since it was expected that these effects, acting through speed charges, would exert a significant influence on utilization. Previous analyses (GEIPOT, 1980) had always shown weak or insignificant geometry effects. The results of estimating geometry effects on vehicle utilization presented in this Appendix are taken from a more detailed PICR technical memo (Chesher and Harrison, 10/1981).

III.2 COMMERCIAL CAR UTILIZATION

The utilization of privately owned cars has already been reported in the main text and since no regression equations involving highway characteristics were derived for this vehicle class (private cars being always underutilized), only results for commercial cars will be reported here. The linear equation, estimated by the EC method, reported in the main text is:

$$\begin{array}{lllll} UT = & 5.797 & -0.0259QI^* & +0.00733RL & +0.00268K \\ & (5.13) & (-2.99) & (5.19) & (1.34) \end{array} \qquad \text{(III.1)}$$

$$G=0.90 \qquad S_u=1.6442 \qquad S_w=2.2153$$

No geometry effects can be found, which is probably due to the limited variation in geometry with the commercial car data set. Since it may be important to have an equation containing a geometry effect a correction is now made to (III.1) to produce such an effect. This correction is derived from the aggregate speed equation of the time and fuel algorithm (MTC) developed by the Experimental Fuel and Speed Group within the PICR. The latest version of this equation (Moser, 05/1980) was used.

Let H be hours driven per month and S be speed in kilometers per hour. From (III.1) these can be incorporated to form:

$$S = \frac{1000}{H}(5.797-0.0259QI^*+0.00733RL+0.00268K) \qquad \text{(III.2)}$$

This can be regarded as speed at the mean rise plus fall (RF) and average degrees of curvature (ADC) of the car user survey data. If the geometry terms from the MTC aggregate speed equation are extracted the following expression is obtained:

$$(-.114RPF11-.164CRV11-.078CRV12) \tag{III.3}$$

Where

$$\begin{array}{llll} RPF11 & = RF & RF & < 27 \\ & = 27 & RF & \geq 27 \\ CRV11 & = ADC & ADC & < 125 \\ & = 125 & ADC & \geq 125 \\ CRV12 & = 0 & ADC & < 125 \\ & = (ADC-125) & ADC & \geq 125 \end{array}$$

The interaction terms between roughness, surface type and geometry in the MTC aggregate equation have been addressed by estimating the percentage of paved and unpaved operation for the car data set, together with the average roughness for each surface type. These values have been substituted into the interaction terms in the MTC aggregate equation to eliminate surface type and roughness. The resulting geometry terms have been added to the main geometry effects to give the expression above although the changes are, in fact, only small.

Car routes in the survey data set have an average rise plus fall of 29 m/km and average ADC of 56^{o}/km. Substituting these values into the expression (III.3) gives a value of -12.262. This is then added to (III.3) to give:

$$SC = 12.262-.114RPF11-.164CRV11-.078CRV12 \tag{III.4}$$

The car speed term SC in (III.4) is added to (III.2), the implied speed term from the utilization equation, and the resulting expression multiplied by hours driven, H, to give the following adjusted utilization equation:

$$\begin{aligned} U = {} & 1000(5.797-0.0259QI^{*}+0.00733RL+0.00268K) \\ & +H(12.262-.114RPF11-.164CRV11-.078CRV12) \end{aligned} \tag{III.5}$$

Note that U is km/month and not in units of 1000 km/month.

If the average geometry values found in the car data set are used in (III.5), then it behaves exactly like the estimated equation (III.1). The advantage of (III.5) is that it allows a geometry effect on utilization to be calculated while maintaining the survey results regarding roughness, route length and vehicle age. Estimated values of H, hours driven per month for the PICR survey, are given in Table III.1.

III.3 UTILITY, BUS AND TRUCK UTILIZATION

The linear equation estimated by the EC method for these vehicle classes incorporating road roughness, route length and vehicle age but no geometry, as reported in the main text is:

$$\begin{array}{ll} UT = 8.172C2+8.543C3+11.143C4+11.268C5 & \text{(III.6)} \\ \quad (9.80) \quad (13.83) \quad (16.19) \quad (0.16) & \\ \quad -(0.0407C2+0.0159C3+0.0352(C4+C5))QI^* & \\ \quad\quad (-6.13) \quad (-6.17) \quad (-6.76) & \\ \quad +(0.00147+0.00485C3)RL-0.003(C3+C4+C5)K & \\ \quad\quad (5.77) \quad (6.89) \qquad (-10.14) & \\ G=0.92 \qquad S_u=1.9904 \qquad S_w=1.4433 & \end{array}$$

Where

C2 = 1 if utility (non-delivery) , 0 otherwise

C3 = 1 if bus , 0 otherwise

C4 = 1 if medium truck (2 axle or 3 axle), 0 otherwise

C5 = 1 if heavy articulated vehicle , 0 otherwise

Following the same procedure detailed in section III.1, corrections can be made to equation (III.6) so that geometry effects as estimated in the MTC aggregate speed equation are incorporated. This produces the following set of equations:

Utilities (non-delivery) (III.7)

$$U = 1000(8.172-0.0407QI^*+0.0014RL)+H(12.652 -.186RPF11-.178CRV11-.055CRV12)$$

Buses (III.8)

$$U = 1000(8.543-0.0159QI^*+0.0063\ RL-0.003K\ )+H(10.451 -.195RPF11-.164CRV11-.051CRV12)$$

Medium trucks and articulated vehicles (III.9)

$$U = 1000(11.143C4+11.266C5-0.0352QI^*+0.00147RL-0.003km) +H(16.852-.284RPF11-.164CTV11-.051CRV12)$$

As for commercial cars, the dependent variable U is utilization in kilometers per month.

TABLE III.1 - ESTIMATED HOURS DRIVEN PER MONTH

Vehicle Class	Hours Driven
Cars	130
Utilities	150
Medium Trucks	170
Heavy Trucks	150
Buses	200

NOTE: Vehicles employing two shifts of driver per day are excluded from these averages.

TABLE III.2 - AVERAGE VALUES FOR GEOMETRY

Vehicle Class	RF(m/km)	ADC °/km	%Paved	QI*
Cars	29	56	100	58
Utilities	24	46	72	75
Buses	25	34	51	93
Trucks	31	56	83	63

In calculating the corrections the full vehicle terms have been given a weight of 0.75 and the empty vehicle terms a weight of 0.25. The average values for geometry are shown in Table III.2.

Equation (III.6) estimated from the user survey data does not include road geometry. When rise plus fall is introduced with or without ADC, a positive, poorly determined coefficient is obtained. Introducing ADC alone does give a negative coefficient but its standard error is large. Nevertheless, a pooled equation incorporating ADC is presented to show how the equation alters on including horizontal geometry. The linear equation, estimated by the OLSCE method is reported below.

$$\begin{array}{ll}
UT = 11.776C2+8.136C3+11.386C4+10.745C5 & (III.10) \\
\quad -(.0585C2-.0128C3-.0412(C4+C5))QI^{*}-.00427ADC & \\
\qquad (-8.88)\quad (-4.57)\quad (-5.32)\qquad\qquad (-1.15) & \\
\quad +(.000504+.00578C3)RL+(.00765-.01076(C3+C4+C5))K & \\
\qquad (1.46)\quad (8.85)\qquad\quad (7.74)\quad (-9.76) & \\
R^{2}=0.45 \qquad\qquad S=1.4075 &
\end{array}$$

It is recommended that this equation is not used until estimation using the EC method has been completed. It appears as though the EC method will yield the best equations. As an example of future work a linear bus equation is presented, estimated by the EC method:

$$\begin{array}{ll}
UT = 8.8073-0.0148QI^{*}+0.00562RL-0.00352K & (III.11) \\
\qquad (15.78)\ (-5.12)\qquad (7.94)\qquad (-10.09) & \\
\quad -0.00662ADC & \\
\qquad (-1.51) & \\
G=0.51 \qquad\qquad S_{u}=1.4253 \qquad\qquad S_{w}=1.5186 &
\end{array}$$

This gives predictions that are very similar to those obtained by the pooled EC equation III.6. The effect of horizontal geometry is small: raising ADC by 50^{o}/km reduces utilization by 4 percent. It would be most useful to estimate separate vehicle class utilization equations , using the EC method, in the future. The pooled equation and separate vehicle class equations would complement each other and geometry effects may be more easily estimated by vehicle class.

III.4 RECOMMENDATIONS

If utilization equations incorporating the effects of road geometry are required, then a selection of equations reported in this

Appendix can be used. At this stage equation (III.5) is recommended for commercial car utilization. The specialized nature of the commercial car business should be noted as it gives rise to high levels of utilization. Private car utilization rates have been examined and reported (Harrison, 12/1980), as stated earlier. If the type of business activity is unknown for cars in the traffic stream, then it is safer to adopt private car utilization rates.

Equations (III.7), (III.8) and (III.9) are recommended for utility, bus and truck utilization respectively. It should be noted that the utility vehicles are engaged in non-delivery work where high utilization levels can be attained. Predictions from equation (III.7) should therefore always be checked with other sources of information.

The equation for commercial cars shows a positive age coefficient and this has been investigated. Is is the result of special features of the user survey car data set where vehicles with different ages in kilometers are treated similarly. It is likely that this effect will not be reproduced equally strongly in applications elsewhere and accordingly users are recommended to set age in kilometers to the user survey average, 101,000 for commercial cars, before using the equation.

Finally, a peculiar feature in the MTC aggregate speed equation is noted which affects the correction. Speed is not affected by rise plus fall once this exceeds 27 m/km. This needs investigation and when a new MTC aggregate speed equation is estimated, equations (III.5), (III.7), (III.8) and (III.9) will have to be altered.

APPENDIX IV - COMPANY DATA FOR COMPARISON WITH TARIFF AND RATES

IV.1 INTRODUCTION

Details on the companies specified in Tables 4.12 and 4.13 appear in Tables IV.1 to IV.8 of this Appendix. Each company is briefly described in terms of its business activity, the route and vehicle type selected and the highway characteristics of the route specified. These characteristics are derived from the User Survey route inventory. An estimate of total cost per km is then made using the recommended equations for each cost item reported in the main text. Finally, the information on rates and tariffs collected in August is given and therefore the estimated and prevailing operating costs can be compared.

TABLE IV.1 - COMPANY 1

This company hauls sand and gravel 100 km to Brasilia. Vehicles are 2 axle tippers, aged 5 years or 500,000km.

Highway Characteristics: 47 QI*, 31 RF, 32 ADC

PICR Cost/km Estimate

Fuel		13,68
Oil		0,83
Parts		4,27
Labor		1,03
Tires		3,74
Depreciation		1,27
Interest		0,87
		25,69
Driver		3,25
	Total	28,94

Company Tariffs

The company receives 9380 cruzeiros per trip and after expenses has 7080 cruzeiros to cover transport costs, overheads and profit. Therefore earnings are 3.54 cruzeiros per tonne.km and PICR estimated transport costs 2.89 cruzeiros. Hired owner-drivers are offered 2.28 cruzeiros per tonne.km.

TABLE IV.2 - COMPANY 2

This company hauls quarried material 20 km to a crushing plant. The vehicles employed are 2 axle tippers and average 5 years or 400,000km.

Highway Characteristics: 183 QI*, 37 RF, 54 ADC

PICR Cost/km Estimate

Fuel	15,84
Oil	0,96
Parts	15,14
Labor	2,52
Tires	6,22
Depreciation	3,39
Interest	2,33
	46,40
Driver	8,08
Total	54,48

Company Tariffs

Operators on the most heavily used route, measured above, receive 201 cruzeiros per tonne for the 40 km round trip. Their vehicles exceed the legal axle and gross limits. If the legal load limit for this vehicle type is applied to both estimated and actual costs, the earnings per tonne.km are 5.03 cruzeiros and the PICR estimated transport costs are 5.45 cruzeiros.

TABLE IV.3 - COMPANY 3

This company has a contract to take minerals 50 km to a smelter. It runs its own fleet and also hires 2 axle tipping vehicles. The rates it receives from the smelting company include a portion for the maintenance of 35 km of unpaved road. Therefore the rates the company offers owner-drivers after deducting for this road service and general overheads are used. The vehicles are 2 axle tippers 5 years old or with 400,000 km.

Highway Characteristics: 118 QI*, 47 RF, 271 ADC

PICR Cost/km Estimate

Fuel	14,77
Oil	0,83
Parts	11,62
Labor	2,46
Tires	6,44
Depreciation	2,00
Interest	1,37
	39,49
Driver	4,75
Total	44,24

Company Tariffs

The company pay 486 cruzeiros per tonne and the load is limited to its legal maximum 10 tonnes, yielding 4860 cruzeiros per trip. The earnings are therefore 4.86 cruzeiros per tonne.km and the PICR estimated costs are 4.42 cruzeiros per tonne.km.

TABLE IV.4 - COMPANY 4

This company has two distinct haulage operations carrying charcoal and minerals. A 3 axle truck is selected to represent charcoal haulage and operates on a route of 400 km. The vehicle is aged 4 years or 400,000 km. A two axle tipping vehicle is chosen for mineral haulage running 15 km to the smelting plant. It has an average age of 4 years or 350,000 km.

Highway Characteristics Charcoal 62 QI*, 31 RF, 27 ADC
Minerals 100 QI*, 38 RF, 60 ADC

PICR Cost/km Estimate

	Charcoal	Minerals
Fuel	13,90	14,48
Oil	0,83	0,96
Parts	7,14	10,18
Labor	1,91	2,30
Tires	6,75	4,75
Depreciation	1,77	1,74
Interest	1,22	1,19
	33,52	35,60
Driver	3,72	4,46
Total	37,24	40,06

Company Tariffs

The vehicles hired by the company were standardized so that their loads did not exceed the legal limit for either type. Therefore a 14 tonne cargo for the 3 axle yielded cost per tonne.km of 2.29 cruzeiros and the mineral tipper's cost per tonne.km was 4.68 with its load of 10 tonnes, compared with the PICR estimated costs per tonne/km of 2.66 and 4.01 cruzeiros, respectively.

TABLE IV.5 - COMPANY 5

This company runs its own fleet of vehicles as well as hiring owner-drivers on a regular basis. Two vehicle/routes are chosen; a 3 axle truck carrying cement in bags 30 km to a distributor and a heavy articulated bulk cement unit operating over a route of 37 km, both paved routes.

Highway Characteristics Bags 40 QI*, 38 RF, 60 ADC
Bulk 52 QI*, 36 RF, 58 ADC

PICR Cost/km Estimate

		Articulated(Bulk)		3 Axle(Bags)
Fuel		30,95		13,57
Oil		1,06		0,83
Parts	Tractor	11,27	vehicle	5,38
Labor		3,47		1,65
Parts	Trailer	4,85		
Labor		1,60		
Tires		9,25		6,69
Depreciation		3,72		2,29
Interest		2,80		1,57
		68,97		31,98
Driver		6,51		4,62
	Total	75,48		36,60

Company Tariffs

The company pays 10 cruzeiros per bag and the 3 axle truck carries 250 bags over the 60 km round trip. Its per km earnings of 41.69 are standardized by the load of 12,5 tonnes to yield 3.33 cruzeiros per tonne km. The PICR costs equally standardized are 2.93. The heavy articulated vehicles (26 tonne load) are operated by the company and it allocates 85.03 cruzeiros per km for this vehicle which yields 3.27 cruzeiros per tonne.km; compared with 2.90 cruzeiros per tonne.km for the PICR estimated costs.

TABLE IV.6 - COMPANY 6

This company distributes milk products and occasionally hires vehicles to supplement its own fleet. The vehicle selected for this exercise is a hired heavy tractor (only), age 4 years or 400,000 km.

Highway Characteristics: 20 QI*, 28 RF, 11 ADC

PICR Cost/km Estimate

Fuel	23,48
Oil	0,83
Parts	10,12
Labor	3,28
Tires	2,81
Depreciation	2,98
Interest	2,44
	45,94
Driver	5,17
Total	51,11

Company Tariffs

This company said that it paid 52 cruzeiros for the hire of this tractor and when standardized with a 26 tonne load, the hire yields 2 cruzeiros per tonne.km and the PICR estimated cost is 1.97 cruzeiros per tone.km.

TABLE IV.7 - COMPANY 7

This bus company operates predominantly on unpaved routes and the one selected for this exercise is 280 km in length. The buses are of chassis construction with a unsophisticated, but strong, body. The vehicles average age is 5 years or 400,000 km.

Highway Characteristics: 158 QI*, 30 RF, 28 ADC

PICR Cost/km Estimate

Fuel	12,84
Oil	1,62
Parts	8,52
Labor	3,33
Tires	5,02
Depreciation	4,40
Interest	3,13
	38,86
Crew	9,94
Total	48,80

Company Tariffs

The data furnished for this route were impossible to analyse in the above form because the number of passengers leaving and joining the vehicles along the route could not be collected. However, the per km ticket charge is 2.634 cruzeiros and a 70 percent seat occupancy was given. This gives 65.85 cruzeiros per km, given a capacity of 36 seats. The PICR estimated passenger.km cost is 1.95.

TABLE IV.8 - COMPANY 8

This company operates on paved routes and one of 180 km is selected. The buses are of monocoque construction and the average age is 4 years or 400,000 km.

Highway Characteristics: 41 QI*, 33 RF, 13 ADC

PICR Cost/km Estimate

Fuel	11,88
Oil	1,44
Parts	5,84
Labor	1,50
Tires	3,75
Depreciation	4,86
Interest	3,65
	32,92
Crew	8,37
Total	41,29

Company Tariffs

The per km ticket charge is 1.77 and occupancy on this route was given at 75 percent which, with a seating capacity of 36, gives 27 passenger per bus. The total earnings per km are therefore 47.68 and the estimated PICR cost per passenger km for the same occupancy is 1.53 cruzeiros.

APPENDIX V - MTC AGGREGATE EQUATION FOR FUEL CONSUMPTION

V.1 INTRODUCTION

This equation is derived from analyses completed in 1980 and more details are contained in the relevant PICR document (Moser, 05/1980).

TABLE V.1 - FUEL AGGREGATION REGRESSION

Parameter	Estimate	Std. Error of Estimate
Intercept$_1$	1.7	0.05
RPF11	-.0059	0.002
CRV11	-.0016	0.00036
CRV12	-.00099	0.00021
ALT	-.01785	0.0015
Intercept$_2$	.25	0.014
QI*11	-.0025	0.0003
QI*12	-.0025	0.00069
QI*21	-.0022	0.00015
QI*22	-.0007	0.00054
CRV12.ST	.00016	0.000056
QI*22.RPF11	-.000057	0.000021
QI*12.CRV11	-.0000094	0.0000068
QI*12.CRV11	-.000013	0.0000034
QI*12.CRV12	-.000019	0.0000044
V2	-.0376	0.0036
V3	.144	0.0113
V4	.144	0.0113
V6	.215	0.0148
V7	-.218	0.0137
V8	-.580	0.0150
V2.ALT	-.0015	0.00034
V3.ALT	.0030	0.00034
V4.ALT	.0014	0.00034
V6.ALT	.0023	0.00046
V7.ALT	-.0016	0.00046
V8.ALT	-.0064	0.00046
V3.RPF11	.0031	0.00047
V4.RPF11	.0024	0.00047
V6.RPF11	-.0023	0.00061
V7.RPF11	-.0013	0.00061
V8.RPF11	-.0050	0.00061
V3.CRV11	.00037	0.000071
V4.CRV11	.00014	0.000071
V6.CRV11	-.00089	0.000092
V8.CRV11	-.00020	0.000092
V7.CRV12	.00014	0.000039
V3.ST	.0163	0.0026
V2.QI*12	.00071	0.00014
V8.QI*22	-.00089	0.00016
V8.PWI	-.006	0.0031
RPF11.PWI	.00031	0.000038
V8.RPF11.PWI	.00023	0.00014
CRV11.PWI	.00004	0.0000092
V7.CRV11.PWI	.00022	0.000014
V8.CRV11.PWI	.00018	0.000022
CRV12.PWI	.000021	0.0000054
V7.ST.PWI	.0038	0.0013
V8.ST.PWI	.0048	0.00090
ALT.PWI	.00021	0.000046
V7.ALT.PWI	.00043	0.00015
V8.ALT.PWI	.00038	0.00011

Where

V2 = 2 if bus ; 0 if not car or bus ;-2 if car

V3 = 2 if empty utility ; 0 if not car or empty utility ;-2 if car

V4 = 2 if full utility ; 0 if not car of full utility ;-2 if car

V6 = 1 if light diesel truck ; 0 if not car or light diesel truck;-2 if car

V7 = 1 if medium diesel truck; 0 if not car or medium diesel truck;-2 if car

V8 = 1 if heavy diesel truck ; 0 if not car or heavy diesel truck;-2 if car

PWI= (PW-29.0) if light diesel truck;
(PW-14.9) if medium diesel truck;
(PW-13.4) if heavy diesel truck.

RPF11 = RPF if RPF < 27 and = 27 if RPF > = 27

RPF12 = 0 if RPF < 27 and = (RPF-27) if RPF > = 27

CRV11 = CRV if CRV < 125 and =125 if CRV > =125

CRV12 = 0 if CRV < 125 and = (CRV-125) if CRV > =125

ALT = (Rise - Fall) m/km

ST = -1 if paved and = 1 if unpaved

QI*11 = QI* if ST=-1 and QI* <=65; 65 if ST=-1 and QI*> 65

QI*12 = 0 if ST=-1 and QI* <=65; (QI*-65) if ST=-1 and QI*> 65

QI*21 = QI* if ST=-1 and QI* <=135;135 if ST=1 and QI*>135

QI*22 = 0 if ST=1 and QI* <=135;(QI*-135)if ST=1 and QI*> 135

The equation is difficult to work with in the form presented in Table V.1. Since the equation was generated within the four levels of each experiment it can simply be aggregated to provide one overall equation for fuel. However, the vehicle class definitions are complecated and therefore the final equations are presented per vehicle class for fuel in Table V.2. The values in this table represent the coefficient for the independent variable listed at the side of each row.

TABLE V.2 - COEFFICIENTS FOR THE FUEL AGGREGATION EQUATION

H.DIESEL	M.DIESEL	L.DIESEL	F.UTILITY	E.UTILITY	BUS	CAR	
1.37	1.73	2.17	2.24	2.24	1.88	2.61	INTER
-.0109	-.0072	-.0082	-.0012	0	-.0059	0	RPF11
-.0018	-.0016	-.0025	-.0013	-.00086	-.0016	-.00047	CRV11
-.00099	-.00085	-.00099	-.00099	-.00099	-.00099	-.00127	CRV12
-.02430	-.01941	-.01555	-.01505	-.01185	-.0208	-.00123	ALT
0	0	0	0	.033	0	-.033	ST
-.0061	0	0	0	0	0	0	PWI
.00054	.00031	.00031	0	0	0	0	PWI.RPF11
.00022	.00026	.00004	0	0	0	0	PWI.CRV11
.00021	.00021	.00021	0	0	0	0	PWI.CRV12
.0048	.0038	0	0	0	0	0	PWI.ST
.00059	.00064	.00021	0	0	0	0	PWI.ALT
-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	QI 11
-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	QI 12
-.0022	-.0022	-.0022	-.0022	-.0022	-.0022	-.0022	QI 21
-.00159	-.0007	-.0007	-.0007	-.0007	0	-.00032	QI 22
.00015	.00015	.00015	.00015	.00015	.00015	.00015	ST.CRV12
-.000057	-.000057	-.000057	-.000057	-.000057	-.000057	-.000057	QI 22.RPF11
-.000009	-.000009	-.000009	-.000009	-.000009	-.000009	-.000009	QI 12.CRV11
-.000013	-.000013	-.000013	-.000013	-.000013	-.000013	-.000013	QI 22.CRV11
-.000019	-.000019	-.000019	-.000019	-.000019	-.000019	-.000019	QI 12.CRV11

APPENDIX VI - AUGUST 1981 PRICES FOR REPRESENTATIVE VEHICLE TYPES

TABLE VI.1 - CAR

Model VW 1300	Cr$407.000,00
Tire	Cr$ 3.125,00
Tire Inner Tube	Cr$ 750,00
Motor Oil	Cr$ 156,00
Gasoline	Cr$ 75,00
Transmission Oil	Cr$ 175,00
Washing and Lubrification	Cr$ 1.350,00
Driver's Salary	Cr$ 12.600,00

NOTES FOR ALL TABLES: 1. All gasoline, diesel, motor and transmission oils are in liters.

2. Drivers' salary is per month.

TABLE VI.2 - UTILITY DIESEL

Model 608D	Cr$	1.764.776,00
Body/Tipping Body	Cr$	32.600,00
Tire	Cr$	10.900,00
Recap Tire	Cr$	3.300,00
Tire Inner Tube	Cr$	1.170,00
Motor Oil	Cr$	156,00
Diesel Oil	Cr$	42,00
Transmission Oil	Cr$	175,00
Washing and Lubrification	Cr$	2.390,00
Driver's Salary	Cr$	12,600,00

TABLE VI.3 - UTILITY GASOLINE

Model VW Kombi	Cr$	738.204,00
Tire	Cr$	5.425,00
Tire Inner Tube	Cr$	750,00
Motor Oil	Cr$	156,00
Gasoline	Cr$	75,00
Transmission Oil	Cr$	175,00
Washing and Lubrification	Cr$	1.560,00
Driver's Salary	Cr$	12.600,00

TABLE VI.4 - MEDIUM TRUCK, 2 AXLE TIPPER

Model LK1313	Cr$2.229.018,00
Body	Cr$ 256.000,00
Tire	Cr$ 27.410,00
Recap Tire	Cr$ 5.000,00
Tire Inner Tube	Cr$ 1.650,00
Motor Oil	Cr$ 156,00
Diesel Oil	Cr$ 42,00
Transmission Oil	Cr$ 175,00
Washing and Lubrification	Cr$ 3.720,00
Driver's Salary	Cr$ 16.000,00

TABLE VI.5 - MEDIUM TRUCK, 3 AXLE FLAT

Model L2013/42	Cr$2.355.488,00
Body	Cr$ 422.000,00
Tire	Cr$ 27.410,00
Recap Tire	Cr$ 5.000,00
Tire Inner Tube	Cr$ 1.650,00
Motor Oil	Cr$ 175,00
Diesel Oil	Cr$ 42.00
Transmission Oil	Cr$ 175,00
Washing and Lubrification	Cr$ 2.760,00
Driver's Salary	Cr$ 16.000,00

TABLE VI.6 - BUS MONOCOQUE

Model OM352	Cr$6.085.798,00
Tire	Cr$ 27.410,00
Recap Tire	Cr$ 5.000,00
Tire Inner Tube	Cr$ 1.650,00
Motor Oil	Cr$ 156,00
Diesel Oil	Cr$ 42,00
Transmission Oil	Cr$ 195,00
Washing and Lubrification	Cr$ 4.080,00
Driver's Salary (intercity)	Cr$ 32.720,00
Driver's Salary (urban)	Cr$ 26.000,00
Conductor's Salary (urban)	Cr$ 10.438,00

NOTE: BUS CHASSIS: Model LPO1113 Cr$2.486.411,00
BODY : Cr$3.200.000,00

TABLE VI.7 - HEAVY ARTICULATED TRUCK

Model Scania T112M	Cr$6.012.000,00
Body	Cr$2.500.000,00
Tire	Cr$ 42.000,00
Recap Tire	Cr$ 6.800,00
Tire Inner Tube	Cr$ 2.760,00
Motor Oil/(liter)	Cr$ 156,00
Diesel Oil	Cr$ 42,00
Transmission Oil	Cr$ 175,00
Washing and Lubrification	Cr$ 5.150,00
Driver's Salary/(month)	Cr$ 29.000,00

APPENDIX VII - MTC AGGREGATE EQUATION FOR VEHICLE SPEED

VII.1 INTRODUCTION

This equation is derived from analyses completed in 1980 and more details are contained in a PICR document (Moser, 05/1980).

TABLE VII.1 - SPEED AGGREGATION REGRESSION

Parameter	Estimate	Std. Error of Estimate
Intercept$_1$	75.5	2.4
RPF11	-0.195	0.097
CRV11	-0.180	0.017
CRV12	-0.047	0.0099
ALT	-0.282	0.026
Intercept$_2$	7.88	0.452
ST	-1.14	0.596
QI*11	-0.089	0.012
QI*12	-0.082	0.033
QI*21	-0.072	0.008
QI*22	-0.048	0.015
ST.CRV11	-0.016	0.004
ST.CRV12	0.016	0.002
QI*22.RPF11	-0.0024	0.00062
QI*12.CRV11	-0.001	0.00022
QI*21.CRV11	0.00013	0.000047
QI*22.CRV12	0.00010	0.000066
CI	7.02	0.50
C2	-5.88	0.48
C3	1.70	0.45
C4	1.36	0.45
C5	0.64	0.30
C1.RPF11	0.081	0.018
C3.RPF11	0.037	0.018
C2.CRV11	0.007	0.002
C3.CRV11	0.007	0.002
C4.CRV11	-0.016	0.002
C1.CRV12	-0.015	0.001
C2.CRV12	0.005	0.001
C3.CRV12	-0.003	0.001
C5.CRV12	0.005	0.001
C1.ALT	0.135	0.010
C2.ALT	-0.170	0.010
C3.ALT	0.127	0.010
C4.ALT	0.082	0.010
C1.ST	2.3	0.39
C2.ST	-1.6	0.39
C3.ST	1.9	0.27
C4.ST	2.6	0.39
C5.ST	-1.5	0.29
C1.QI*11	0.035	0.010
C2.QI*11	0.042	0.010
C3.QI*11	0.030	0.010
C4.QI*11	-0.038	0.010
C5.QI*11	-0.043	0.010
C2.QI*12	0.031	0.010
C4.QI*12	-0.021	0.010
C5.QI*12	-0.016	0.010
C1.QI*21	-0.029	0.004
C2.QI*21	0.033	0.005
C4.QI*21	0.026	0.004
C2.QI*22	0.026	0.004

TABLE VII.1 - SPEED AGGREGATION REGRESSION (CONT'D)

Where

RPF11 = RPF if RPF < 27 and = 27 if RPF ≥ 27

RPF12 = 0 if RPF < 27 and = (RPF-27) if RPF ≥ 27

CRV11 = CRV if CRV < 125 and =125 if CRV ≥ 125

CRV12 = 0 if CRV < 125 and = (CRV-125)if CRV ≥ 125

ALT = (Rise - Fall) m/km

ST = -1 if paved and = 1 if unpaved

QI*11 = QI* if ST=-1 and QI*<=65; 65 if ST=-1 and QI*>65

QI*12 = 0 if ST=-1 and QI*<=65; (QI*-65) if ST=-1 and QI*>65

QI*21 = QI* if ST=-1 and QI*<=135; 135 if ST=1 and QI*>135

QI*22 = 0 if ST=1 and QI*<=135;(QI*-135)if ST=1 and QI*>135

C1 = 1 if CLASS=cars; 0 if CLASS not cars or full trucks;
-1 if CLASS=full truck

C2 = 1 if CLASS=buses; 0 if CLASS not buses or full trucks;
-1 if CLASS=full truck

C5 = 1 if CLASS=empty truck; 0 if CLASS not trucks;
-1 if CLASS=full truck

TABLE VII.2 - COEFFICIENTS OF THE SPEED AGGREGATION EQUATION

The speed equation is difficult to work with in the form presented in Table VII.1. Since the equations were generated within the four levels of each experiment they can be summed together to provide one overall equation for speed. However, the class definitions are complicated and therefore the final equations are presented per vehicle class for speed in Table VII.2. The values in the Table VII.2 represents the coefficient for the independent variable listed at the top of each column.

Class	Inter	RPF11	CRV11	CRV12	ALT	ST	QI*11	QI*12	QI*21	QI*22	ST CRV11	ST CRV12	QI*22 RPF11	QI*12 CRV11	QI*21 CRV11	QI*22 CRV12
Car	90.3	-.114	-.180	-.062	-.147	1.2	-.054	-.082	-.101	-.048	-.016	-.016	-.0024	-.001	.00013	.0001
Bus	77.4	-.195	-.173	-.042	-.452	-2.7	-.047	-.051	-.039	-.022	-.016	-.016	-.0024	-.001	.00013	.0001
Empty Utility	85.0	-.158	-.173	-.050	-.155	0.7	-.059	-.082	-.072	-.048	-.016	-.016	-.0024	-.001	.00013	.0001
Full Utility	84.7	-.195	-.196	-.047	-.200	-3.7	-.127	-.103	-.046	-.048	-.016	-.016	-.0024	-.001	.00013	.0001
Empty Truck	82.9	-.195	-.180	-.042	-.282	-2.7	-.132	-.098	-.072	-.048	-.016	-.016	-.0024	-.001	.00013	.0001
Full Truck	78.5	-.313	-.178	-.039	-.456	-0.4	-.115	-.076	-.102	-.074	-.016	-.016	-.0024	-.001	.00013	.0001

APPENDIX VIII - BUS OPERATING COSTS PER KM, PAVED AND UNPAVED ROADS, FROM SUTEG DATA

VIII.1 INTRODUCTION

Each State is responsible for fixing passenger.km charges for routes within its boundaries. A visit was made during the tariff and rate survey to the State agencies in Goiás and Minas Gerais which fix the passenger rates. In Goiás, the Agency, SUTEG - Superintendência de Transportes e Terminais de Goiás, furnished considerable information on the pricing procedures and this has been evaluated by PICR staff. The data used for the evaluation of bus fares comes from the companies themselves and is rather dominated by one large company. The SUTEG Agency does not have a large staff, nor does it collect corroborative data so some distortions may be present. In addition, the method of adjustment heavily depends on providing evidence of price changes for key items . The changes provide coefficients which are then applied to previous charges and this updating process clearly runs the risk of perpetuating mistakes in the basic method. However, it remains a rich and valuable source of data, particularly on the cost items not collected by the PICR but nevertheless appropriate to bus operations. In this Appendix a percentage breakdown, by all cost items, in units of bus cost/km is presented, based on SUTEG data at May, 1981. The costs are in cruzeiros at April, 1981 and are based on vehicles operating on 31 paved and 17 unpaved routes.

TABLE VIII.1 - PERCENTAGE BREAKDOWN OF BUS OPERATING COSTS/KM, PAVED AND UNPAVED ROUTES, FROM SUTEG DATA

Operating Cost Item	PAVED		UNPAVED	
	Item %	Totals	Item %	Totals
1. Operational Costs:				
i) Fuel	20		13	
ii) Oils + Grease	1		1	
iii) Tires	4		4	
iv) Maintenance Parts	7		12	
v) Maintenance Labor	8		6	
vi) Other Labor				
a) drivers	17		23	
b) traffic staff	4		3	
vii) Other Costs	1		1	
Total 1		62		63
2. Depreciation:				
i) Vehicle	15		19	
ii) Equipment	1		1	
Total 2		16		20
3. Interest Charges	9	9	8	8
4. Overhead Costs:				
i) Taxes, Insurance	1		1	
ii) Administration	10		6	
Total 4		11		7
5. Expansion Allowance	2	2	2	2
Overall Total	100	100	100	100

APPENDIX IX - GOODNESS OF FIT MEASURES IN ERROR COMPONENT MODELS

Consider the Vehicle Operating Cost Model

$$Y_{it} = \sum_{j=1}^{k} \beta_j x_{itj} + u_i + w_{it} \qquad \text{(IX.1)}$$

Where

i indexes companies;

t indexes vehicles within companies;

y_{it} is a cost item;

x_{itj} is an explanatory variable;

u_i is an unobservable company specific effect; and

w_{it} is an unobservable vehicle specific effect.

In the parts analysis β_j was estimated in (IX.1), regarding the u_i as variables whose variance is to be estimated, using the technique known as estimated generalized least squares. In the labor, tire and utilization analyses the β_j's in (IX.1) and the u_i's were estimated. That is, a separate intercept was estimated for each company and for reporting, the estimated company intercepts were averaged.

How can one measure the goodness of fit of the estimated version of (IX.1)? In the conventional regression model (IX.2) where there is a single error ε_t,

$$y_t = \sum_{j=1}^{k} \beta_j x_{tj} + \varepsilon_t \qquad \text{(IX.2)}$$

the coefficient of multiple correlation (R^2) is commonly used. The R^2 is defined as one minus the ratio of the variance of the residuals, $\hat{\varepsilon}_t$, to the variance of the dependent variable y_t. The residuals $\hat{\varepsilon}_t$ are defined as the difference between the observed y_t and the predicted $\hat{y}_t$. The conventional R may also be regarded as the simple coefficient of correlation between y_t and $\hat{y}_t$.

Those observations suggest two ways of developing a goodness of fit measure for error component models.

Method 1

The basic question is the extent to which variation in the dependent variable y_{it} is not attributed to variations in the x_{itj}'s or the relative magnitudes of the variability of the error term $u_i + w_{it}$ and the variability of the dependent variable y_{it}. By assumption, in the error components model, u_i and w_{it} are uncorrelated so that the variance of $u_i + w_{it}$ is the sum of the variance of u_i and the variance of w_{it}. In the course of the error components estimation these two variances are unbiasedly estimated by estimates which are denoted by S_u^2 and S_w^2. The variance of the observed y_{it}'s is also available. This is denoted by S_y^2. The first measure of goodness of fit is defined by:

$$G = 1-(S_u^2 + S_w^2)/S_y^2 \tag{IX.3}$$

Example

For the parts equation (3.11) the relevant values are:

$S_u^2 = 0.166$ $S_w^2 = 0.188$ $S_y^2 = 0.716$

giving $G = 0.506$

There is no guarantee that G will lie between zero and one. However, in well specified models applied to large samples it is expected to behave well.

It is known that S_u^2 and S_w^2 are unbiased and consistent estimators of the corresponding population variances. S_y^2 is a consistent estimator of the variance of the dependent variable in the population of Brazilian vehicles if the relative company fleet sizes appearing in the sample are representative of whose found in Brazil. If this is the case, then G can be regarded as consistently estimating $1-(\sigma_u^2 + \sigma_w^2)/\sigma_y^2$ where the σ^2's are the population counterparts of the s^2's.

Method 2

The first method closely parallels the procedure used in conventional regression models which defines R^2 as one minus the ratio of unexplained to total variation. The second method considers the correlation between the predicted and observed values of the dependent variables.

Define $\hat{y}_{it}$ as $\sum_{j=1}^{k} \hat{\beta}_j x_{itj}$

Where

$\hat{\beta}_j$ is the estimated generalized least squares estimator of β_j. Then we define our second measure of goodness of fit, H by:

$$H = \frac{\left[\sum_{i=1}^{N} \sum_{t=1}^{T_i} (y_{it}-\bar{y})(\hat{y}_{it}-\bar{\hat{y}}) \right]^2}{\sum_{i=1}^{N} \sum_{t=1}^{T_i} (y_{it}-\bar{y})^2} \qquad (IX.4)$$

That is H is the simple correlation between $\hat{y}_{it}$ and y_{it}. In (IX.4) we assume N companies, T_i vehicles in company i. $\bar{y}$ and $\bar{\bar{y}}$ are the means of y_{it} and $\hat{y}_{it}$. By definition H always lies between zero and one.

H is more difficult to calculate because the statistics used to produce it are not available on the listings produced by the present computer programs. Hence no example of the calculation of H is provided. In situations in which G is negative, calculation of H may be advisable.

When the u_i's are estimated, that is, when a separate intercept is estimated for each company, the R^2 reported in the PICR reports and memoranda measures how much of the within company variation in the dependent variable y_{it} is attributable to within company variation in the explanatory variables x_{itj}. It is important to realise that the R^2's reported are much lower than those obtained in the equations in which the company intercepts appear. Company effects typically explain around 40 to 50% of the variation in user costs. By knowing which company a vehicle comes from it is possible, without knowledge of highway characteristics and so forth, to make quite a good prediction for vehicle costs. This reflects the researchers' judgement that it would be misleading to report the necessarily high R^2's obtained when company effects are estimated.

It is important to note that, by estimating company effects, it was elected to not exploit much of the variation in costs and highway characteristics that are in the data. This decision was made to avoid biases in the estimated coefficients which could arise if company effects were spuriously correlated with highway characteristics. Thus, where company effects have been estimated, it was deliberately chosen to accept a lower R^2 than one could obtain in return for obtaining robust, unbiased estimates of the coefficients in the models.

In general, the fitted company intercept was grouped and averaged in order to provide an equation that is useful for predicting user costs. Method 2 above could be used to calculate the goodness of fit measure H for the resulting equations. To date this has not been done but the calculated H is expected to exceed the reported R^2.

APPENDIX X - LABOR COST EQUATIONS

X.1 INTRODUCTION

A variety of equations predicting labor costs of a function of parts costs are presented in this Appendix. They are grouped into two Tables. Table X.1 gives equations estimated using the OLS method and Table X.2 gives equations estimated using the OLSCE method. The numbers of vehicles and companies in each vehicle class is given in Table X.2. Labor costs are in December 1981 prices.

TABLE X.1 - EQUATIONS RELATING LN(LABOR COSTS) to LN(PARTS COSTS) ESTIMATED USING INDIVIDUAL VEHICLE DATA (OLS)

Vehicle Class	R^2	Intercept	ln(Parts Consumption)	Roughness	Type of Fuel	Tachograph	Engine Location	Power of Weight Ratio	2 Axle	Owner Driver	Driver Control	Standard of Maintenance	U 248	Tipper	Semi Trailer
Cars	0.57	1.302	0.713 (7.77)												
Util	0.45	2.861	0.983 (5.00)												
Util	0.60	2.441	0.932 (4.74)		0.501 (0.65)		0.397 (0.48)			1.047 (2.15)	0.053 (0.08)	-0.942 (-2.62)			
Util	0.62	2.251	0.725 (3.04)	0.0050 (1.46)	0.444 (0.58)		0.658 (0.79)			1.357 (2.60)	0.288 (0.43)	-1.078 (-2.96)			
Buses	0.09	4.793	0.346 (2.79)												
Buses	0.89	1.335	0.659 (11.04)			0.0179 (0.11)	0.220 (2.18)	-0.007 (-.27)				1.256 (10.48)	0.475 (2.98)		
Buses	0.27	5.305	0.163 (1.36)	0.021 (4.38)											
Buses	0.92	1.563	0.570 (9.98)	0.0085 (4.40)		-0.105 (-.73)	0.052 (0.53)	0.015 (0.59)				1.315 (12.16)	0.324 (2.21)		
Trucks	0.72	2.668	0.475 (6.73)			-0.057 (-.19)		0.193 (4.86)	-0.571 (2.08)		-0.891 (-3.25)	0.121 (0.39)		-0.270 (-2.07)	0.941 (2.89)
Trucks	0.73	2.485	0.476 (6.76)	0.0020 (1.33)		-0.057 (-.19)		0.190 (4.80)	-0.500 (-1.80)		-0.766 (-2.65)			-0.259 (-1.99)	1.003 (3.01)

TABLE X.2 - EQUATIONS RELATING LN(LABOR COSTS) TO LN(PARTS COSTS) ESTIMATED USING WITHIN COMPANY VARIATION (OLSCE)

Vehicle Class	R^2	Intercept	ln(Parts Consumption)	Roughness	Type of Fuel	Tacho-graph	Engine Location	Power of Weight Ratio	2 Axle	No. of Obs	No. of Companies
Cars	0.29	2.522	0.547 (4.24)							48	4
Util	0.60	5.183	0.309 (1.73)							33	8
Util	0.70	2.697	0.585 (4.41)		0.841 (5.32)					33	8
Util	0.70	2.705	0.547 (4.64)	0.00403 (2.73)	0.632 (3.96)					33	8
Buses	0.47	3.475	0.515 (8.17)							81	5
Buses	0.48	3.721	0.510 (8.00)			-0.124 (-.78)	0.050 (0.50)	-0.016 (-.48)		81	5
Buses	0.50	3.232	0.516 (8.40)	0.00514 (2.23)						81	5
Buses	0.51	3.228	0.514 (8.24)	0.00531 (2.11)		0.167 (-1.06)	0.018 (0.18)	0.009 (0.26)		81	5
Trucks	0.50	3.702	0.519 (11.84)							150	13
Trucks	0.51	4.036	0.508 (11.27)					-0.035 (-1.03)	0.042 (0.20)	150	13
Trucks	0.50	3.628	0.520 (11.80)	0.00090 (0.42)					0.005 (0.02)	150	13
Trucks	0.51	4.599	0.510 (11.22)	0.00067 (0.31)				-0.034 (-.99)	0.044 (0.21)	150	13

APPENDIX XI - GRAPHS FOR A SELECTION OF RECOMMENDED EQUATIONS

XI.1 INTRODUCTION

This Appendix contains a series of graphs for a selection of the recommended interim final equations. The graphs concentrate on the effect of roughness on the predicted user cost item, although parts cost and route length are also included as the independent variable for labor and utilization relationships, respectively. Values for the independent variables used to derive the graphs are specified in Table XI.1.

TABLE XI.1 - VALUES OF INDEPENDENT VARIABLES USED TO DERIVE GRAPHS

Equation Number	INDEPENDENT VARIABLES							
	QI*	ADC	RF	K	RL	SM	CARB	TF
3.1		54					.025	
3.2		47						
3.4		43				.5		
3.9				114				
3.10				245				
3.11				284				
3.15	88							0
3.16: paved	40							
unpaved	120							
3.24		65	29					
3.25	54			101	320			
3.26: utility	65				824			
bus	96			348	340			
med.truck	67			230	912			
artic.truck	39			322	760			

NOTE: See Appendix I for definitions of variables.

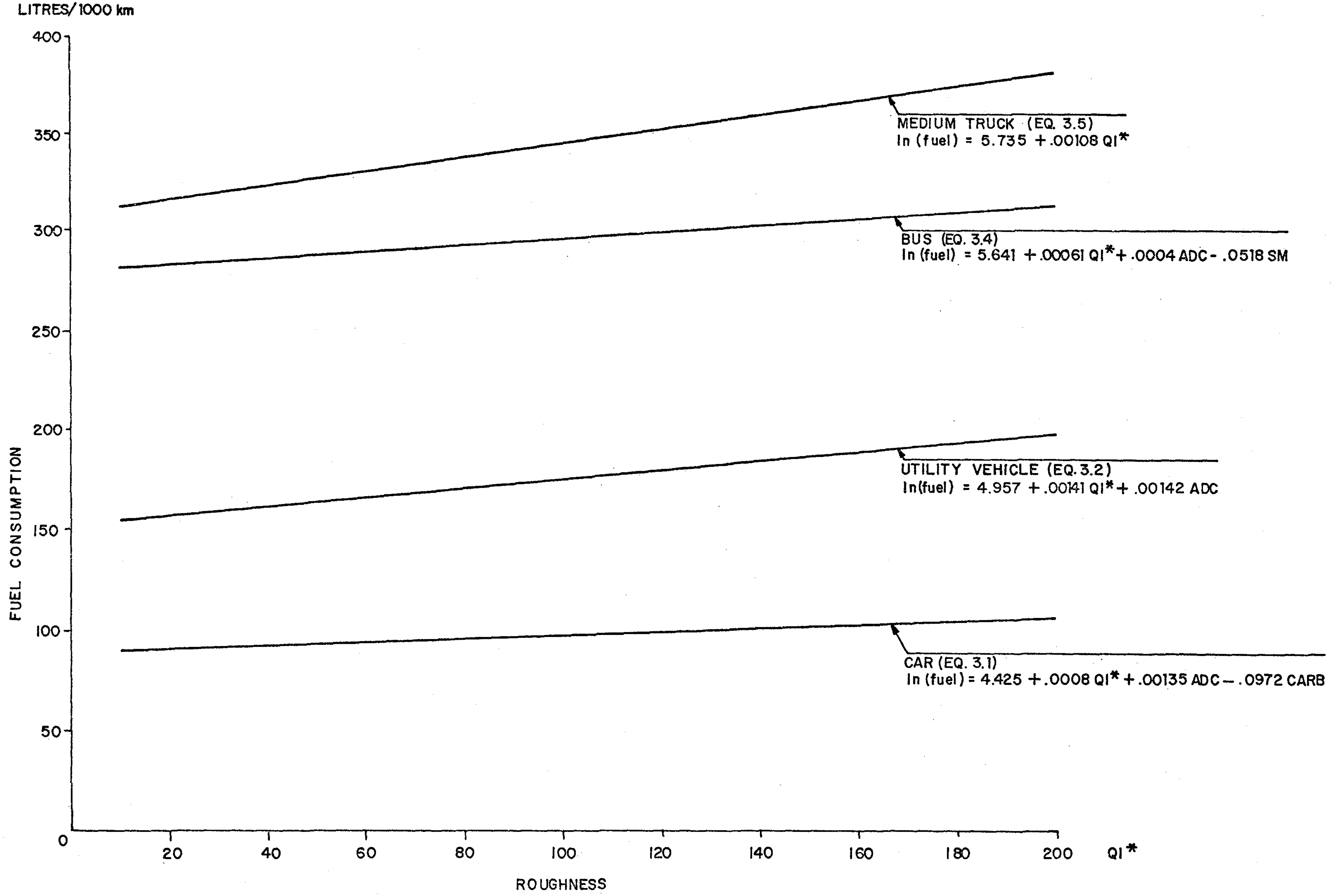

FIGURE XI.1 - THE EFFECT OF ROAD ROUGHNESS ON SURVEY FUEL CONSUMPTION

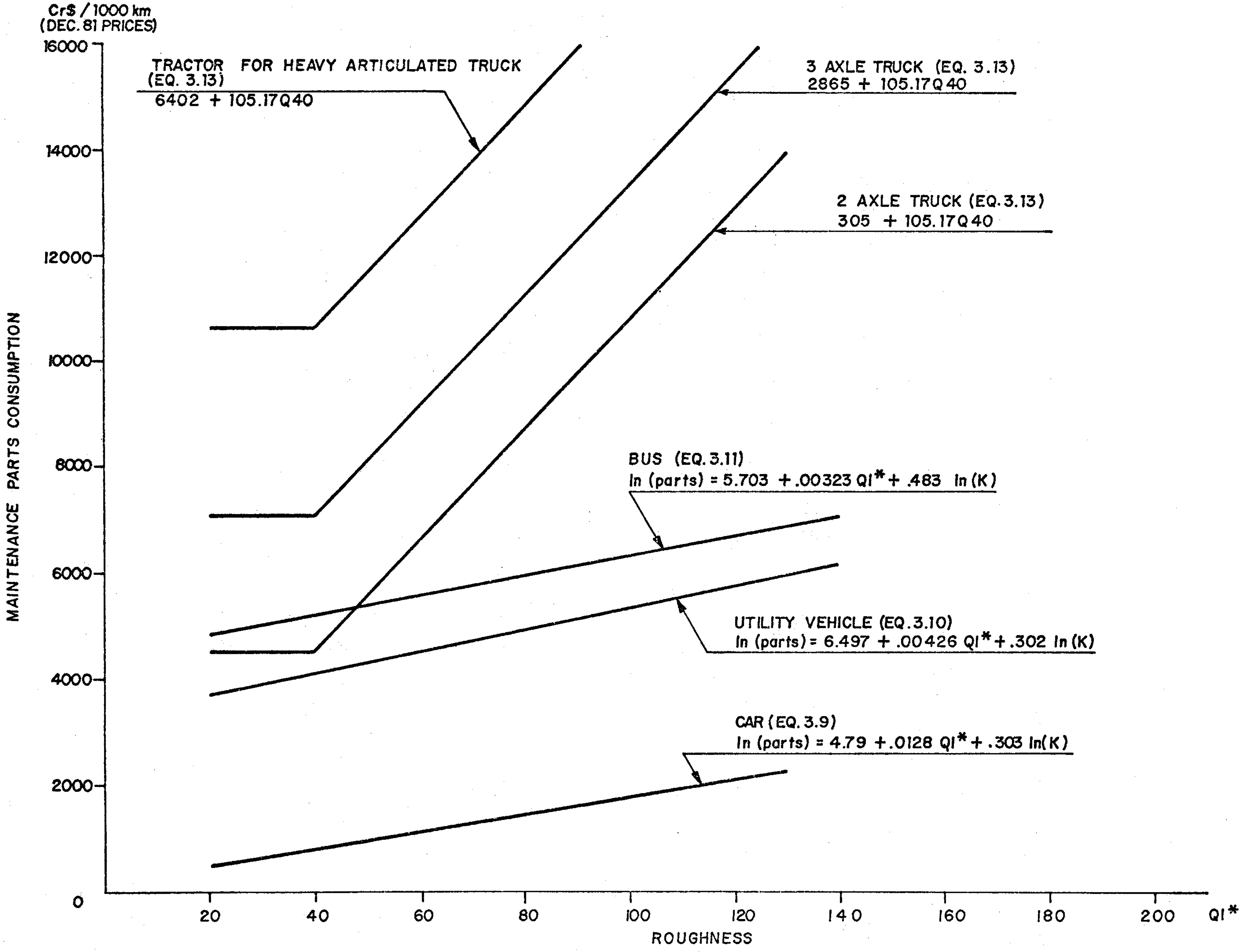

FIGURE XI.2 – THE EFFECT OF ROAD ROUGHNESS ON MAINTENANCE PARTS CONSUMPTION (DEC. 81 PRICES)

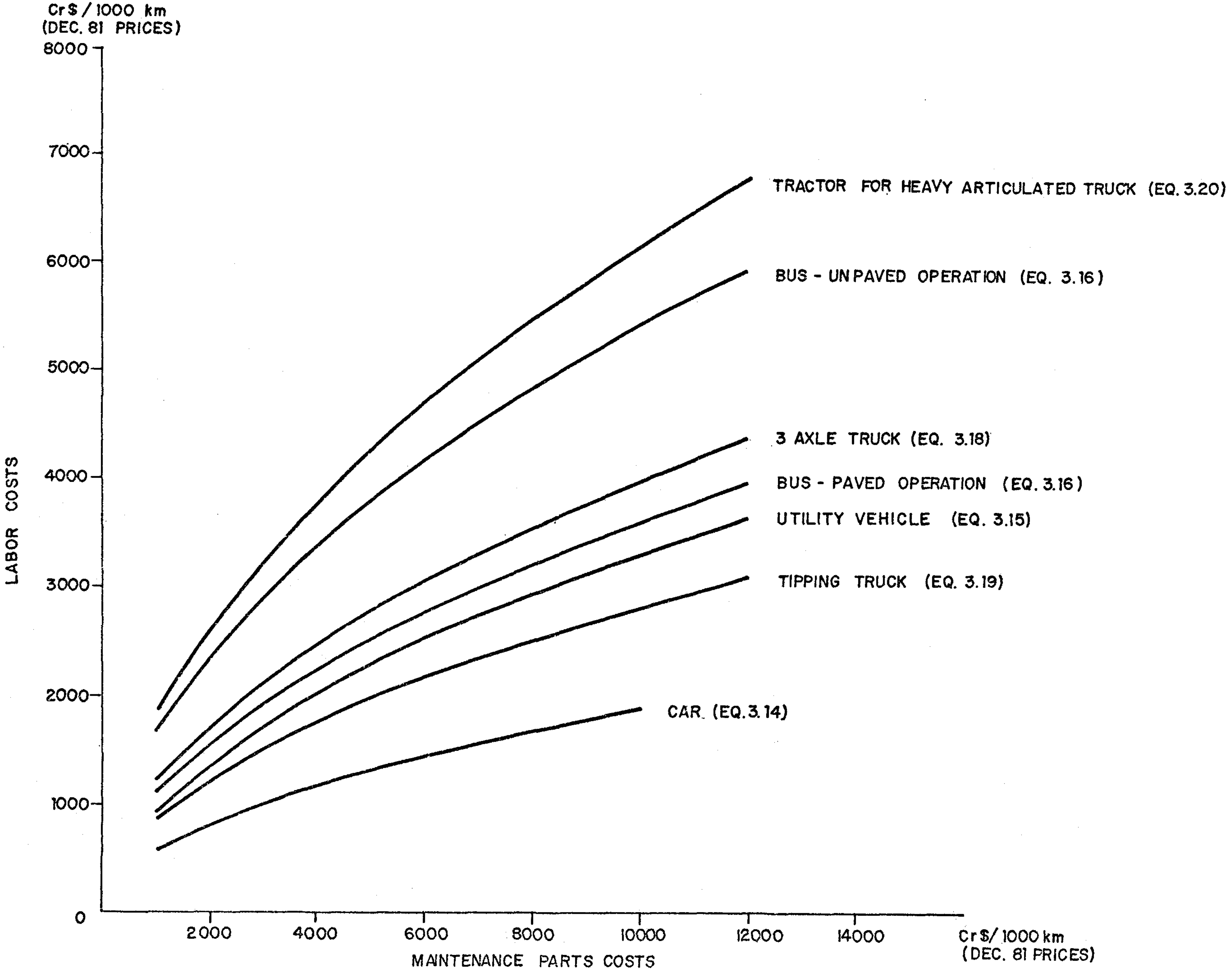

FIGURE XI.3 - THE EFFECT OF PARTS COSTS ON LABOR COSTS (DEC. 81 PRICES)

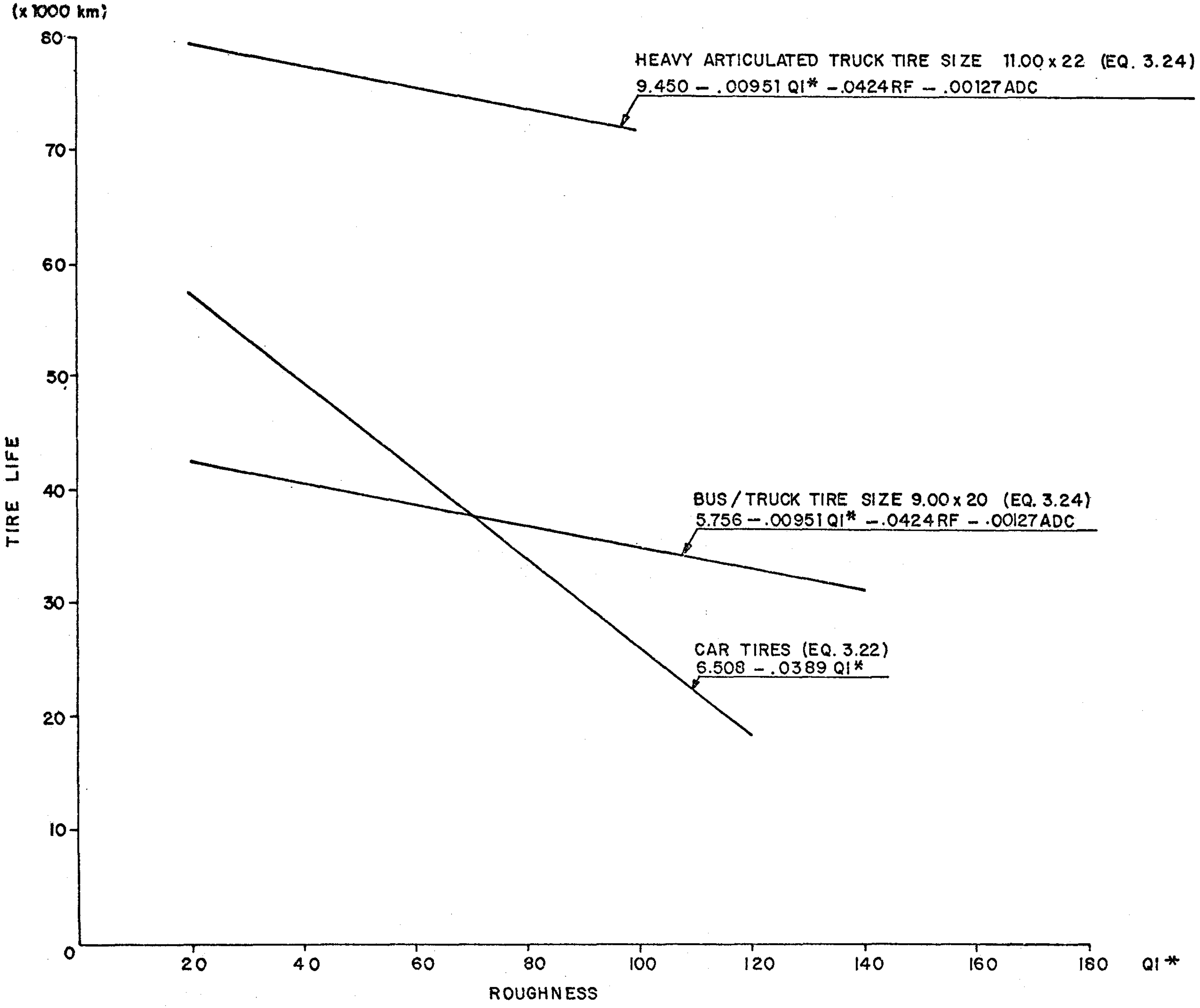

FIGURE XI.4 - THE EFFECT OF ROAD ROUGHNESS ON TIRE LIFE

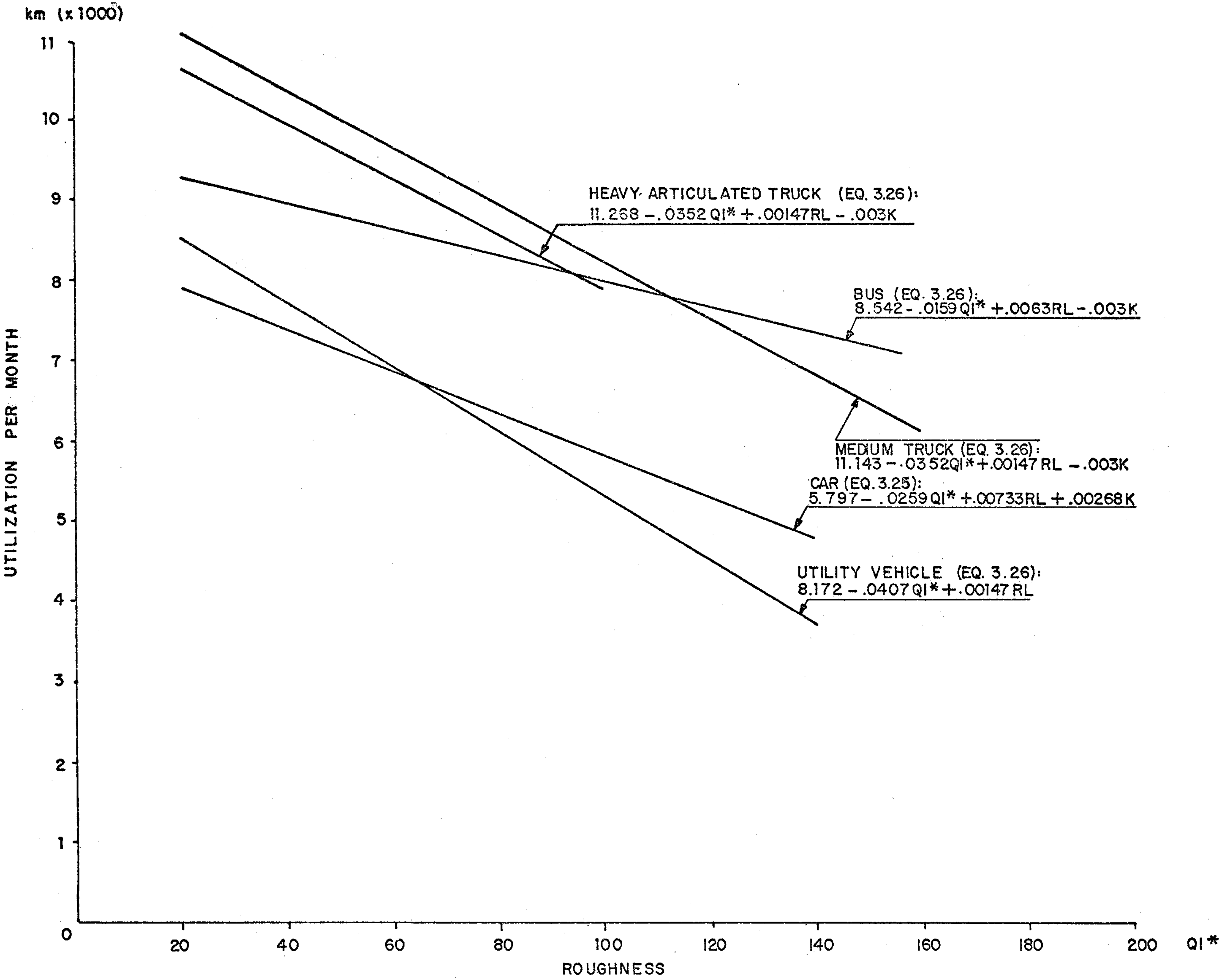

FIGURE XI. 5 - THE EFFECT OF ROAD ROUGHNESS ON VEHICLE MONTHLY UTILIZATION

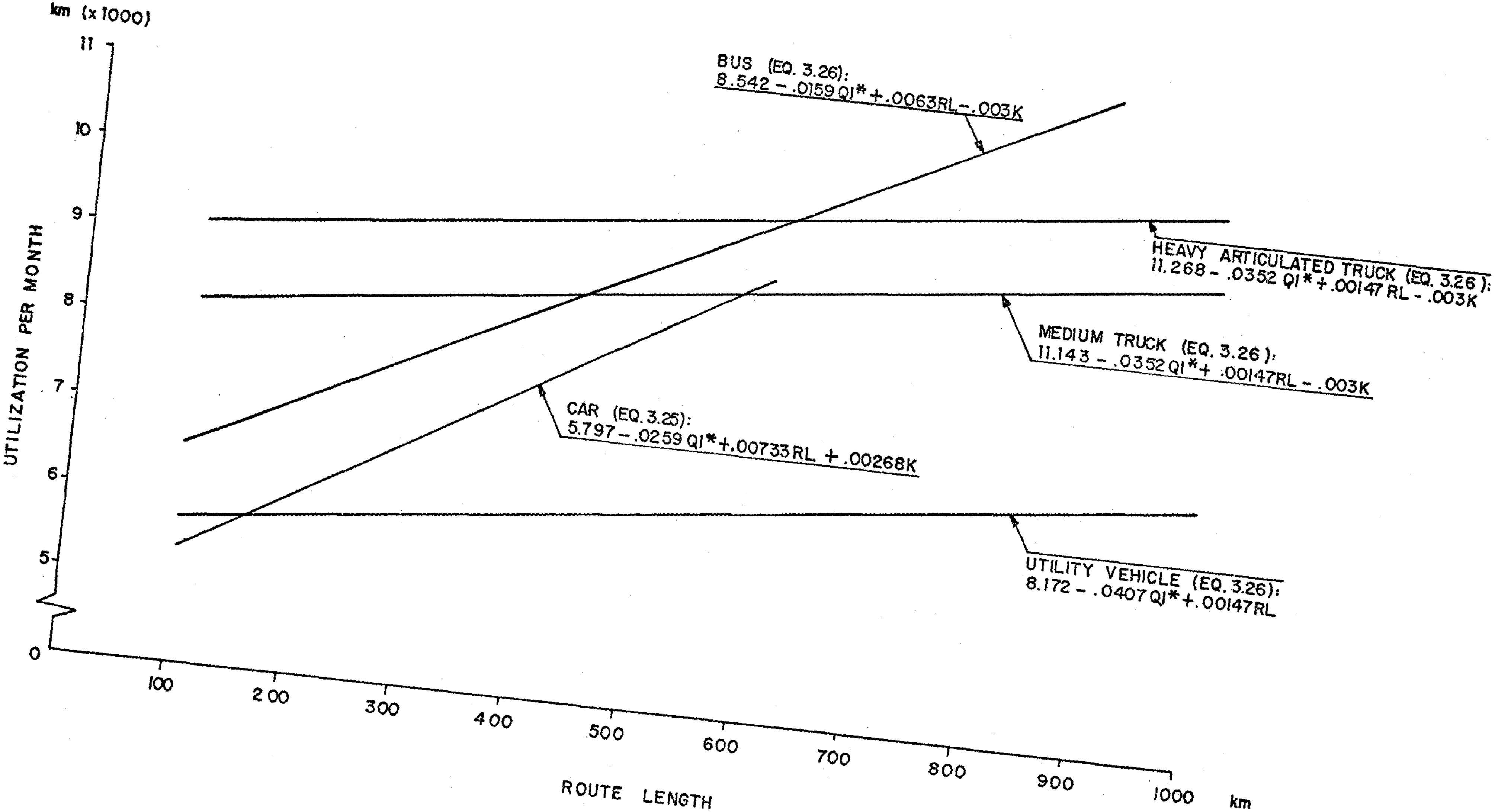

FIGURE XI. 6 – THE EFFECT OF ROUTE LENGTH ON VEHICLE MONTHLY UTILIZATION

APPENDIX XII - METHOD OF ADJUSTING COST DATA TO A CONSTANT BASE

XII.1 INTRODUCTION

The User Surveys Group sought data in the form of physical units, but parts and labor costs, together with vehicle prices, could only be collected in cruzeiro values. Therefore, it was recognized at an early stage in the project that some form of adjustment would be required to remove the effect of inflation and other disturbances from these values prior to analysis. This adjustment is normally made by using (or creating) a set of indices that reflect the relevant price charges and so enable the various cruzeiro values to be adjusted to same base point. In the case of the PICR survey, where data were collected monthly, this base point would be a month within the survey period and subsequently all prices would be expressed in terms of the prices prevailing at this month. This method is sometimes known as constant prices since all the values are expressed in terms of a single base period.

The index adopted by the PICR had to be simple enough to be determined in the office, be compatible with the data processing system and finally had to reflect the correct impact on vehicle operating costs of the wide range of cruzeiro increases identified by the various surveys.

XII.2 BACKGROUND

Meetings were held within GEIPOT and attended by senior economists from other departments to examine the possibility of using an existing set of indices but there appeared to be no established index that would be suitable. Accordingly visits were made to C.I.P. (Comissão Interministerial de Preços) and Fundação Getulio Vargas, in Rio. The former institution was able to give detailed information on the vehicle assembly sector of the economy and its pricing policy and stated that it was unlikely that any established index could serve the PICR. Fundação Getulio Vargas did not measure vehicle spare parts data in any of its work and recommended that a specific index be developed by the PICR for its own use. Agreement was reached to test an index comprising a set of spare parts prices by vehicle make and model, weighted by rates of utilization for each part. Rate of utilization was defined as the frequency of replacement for each part, in Kilometers. The assistance of the leading vehicle manufacturers was sought in formulating the index and visits made for discussions with their technical staff.

XII.3 ANALYSES 1977/78

This is fully detailed in a PICR memorandum (Harrison 06/78). Briefly, various indices were developed at GEIPOT and then meetings held with vehicle manufacturers technical staff to discuss the findings. They agreed to provide additional information and designate, for each major model in the PICR survey, a set a parts which would reflect:

- a range of prices;
- different frequences of replacement, and
- items that had not major technical changes over the previous three years.

Data were received for seven major models, five Mercedes Benz and one each for Volkswagen and Scania. Price charges per part for each model set, from January 1976 to May 1978, were identified from microfiche records. These were then weighted by the appropriate frequency of replacement, a monthly total for each set was obtained and smoothed where necessary using a three month moving average. January 1976 was chosen as the base month for the index as little data existed on the file before this date. The process proved extremely laborious, although it undoubtedly represented an accurate method of adjusting to a constant price base for vehicle spare parts.

Attention was then directed to see how close other, simpler, methods could get to providing the same answers. It had previously been suggested that new vehicle prices, suitably smoothed, might be able to give good results. Accordingly, a index based on new vehicle price changes was calculated for each class. Certain make and models were developed into specific classes and the average price change for each class calculated. The results were then graphed together with the data from the relevant weighted spare parts set. For the review period both methods had acceptable correlations and the new vehicle price index was able to predict changes in the vehicle spare parts. This is shown in Figures XII.1 through XII.3 which graph the data for a Volks-

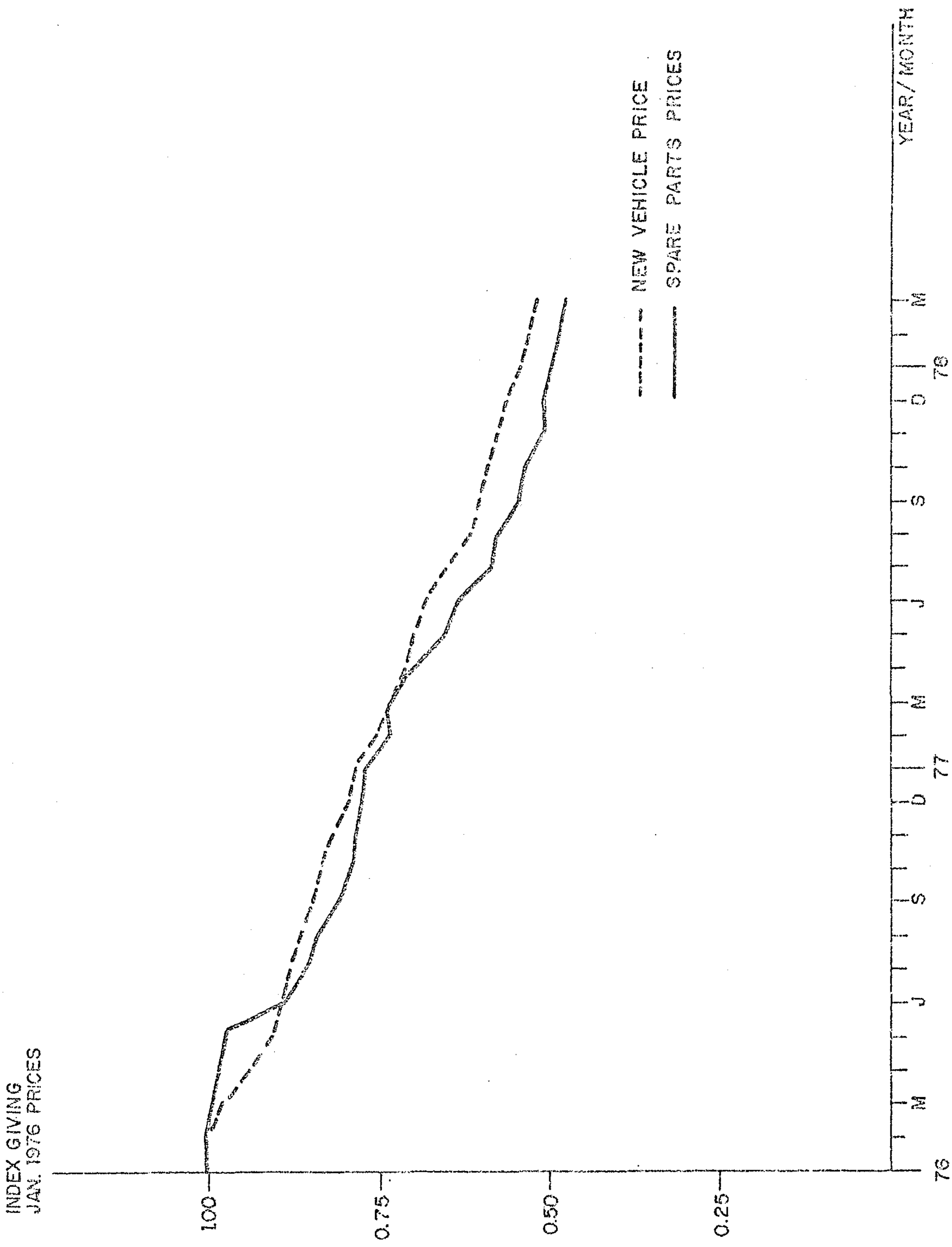

FIGURE XII.1 - NEW VEHICLE AND SPARE PARTS PRICE MOVEMENTS, DEFLATION TO JAN. 76 PRICES FOR VW 1300 L

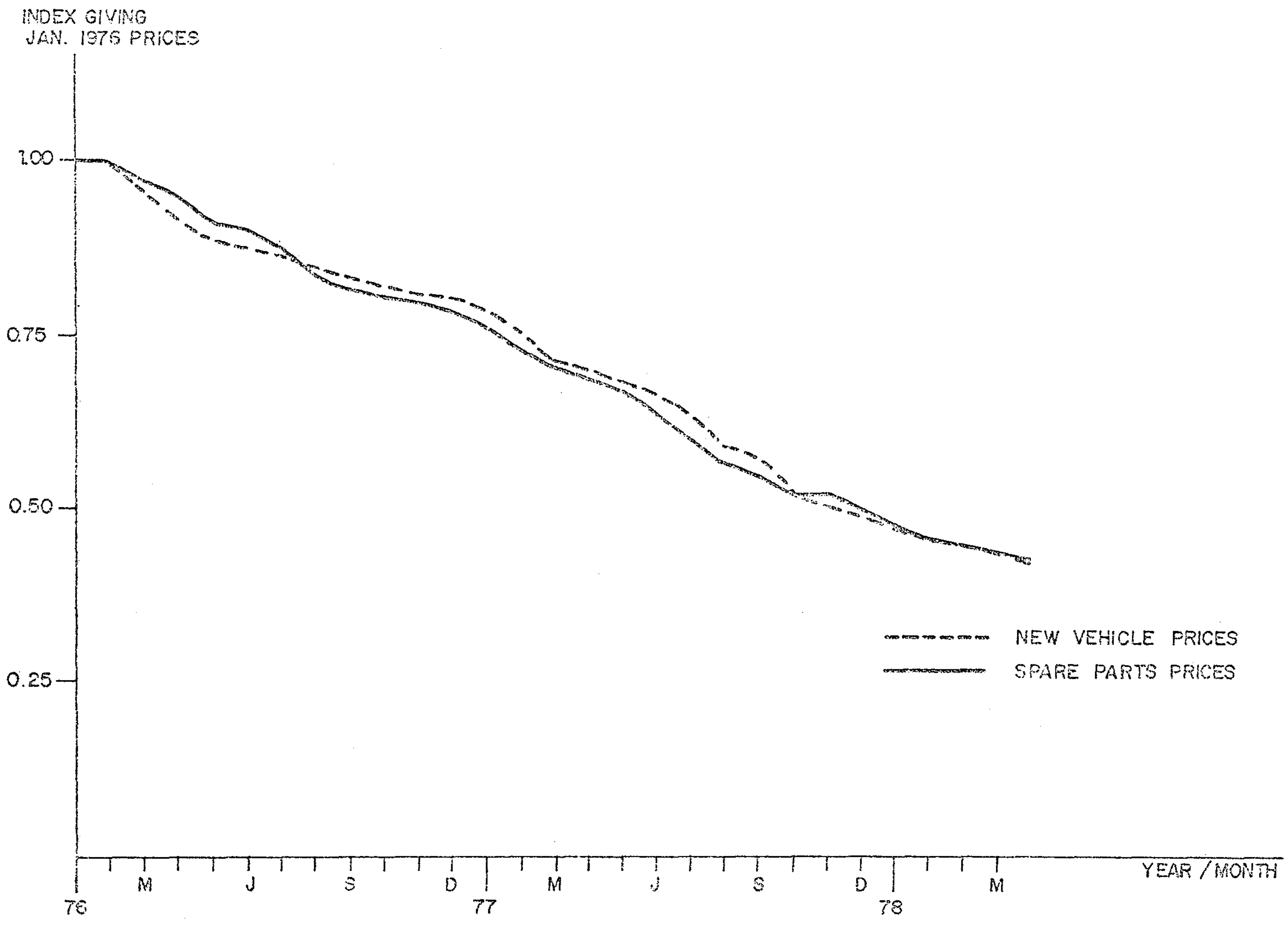

FIGURE XII.2 - NEW VEHICLE AND SPARE PARTS PRICE MOVEMENTS, DEFLATION TO JAN. 76. MERCEDES-BENZ 1113/1313 PRICES GROUP

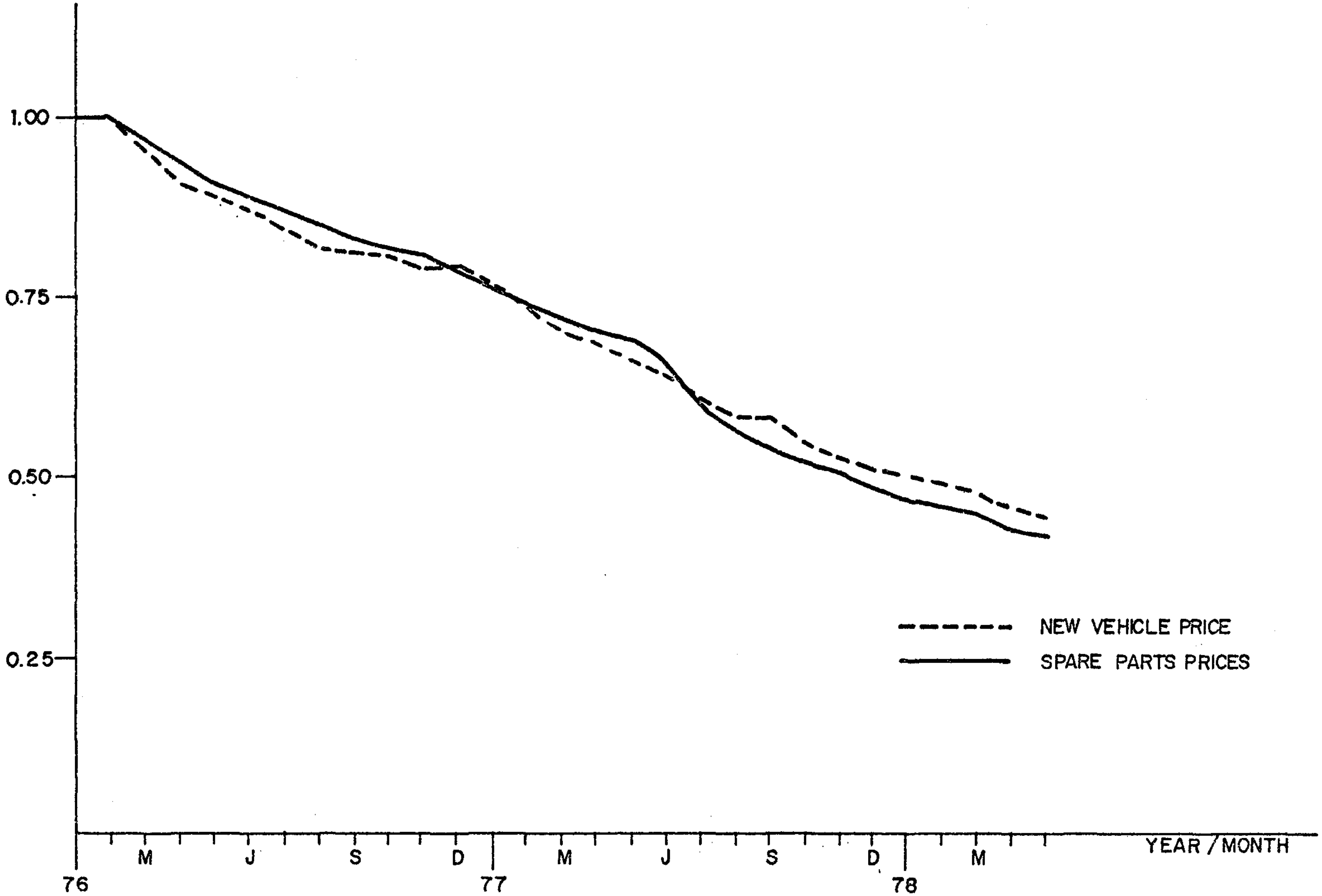

FIGURE XII.3 - NEW VEHICLE AND SPARE PARTS PRICE MOVEMENTS, MERCEDES-BENZ O-362 BUS, DEFLATION TO JAN. 76 PRICES wagen 1300, a Mercedes Benz 1113/42 and a Mercedes Benz 0362 (bus) respectively. A decision was therefore made to use vehicle price data to formulate the indices adjusting cruzeiro values to January 1976 prices. Nine indices were calculated and reflected the mix of make and model types in the survey. The index deflated any cruzeiro values collected in a particular month to base month January, 1976. The analysis file contained data with this base and all the technical memoranda covering analyses of price data in the Working Documents 24 and 28 are expressed in terms of January 1976 prices.

XII.4 ANALYSES 1981

It was considered important to ensure that the vehicle indices were appropriate for the entire survey period. It was not thought necessary to examine all the vehicle classes and the Mercedes Benz 1113 model group was chosen because it is most numerous in the PICR survey and Brazil's national fleet. All the manufacturers recommended parts data were checked with a local dealer and five were found to have changed their parts numbers in the microfiche records. Six years of data were chosen, divided into two periods 1976 -1979, to cover the main survey, and 1980 - 1981, to cover the period of high inflation. It was thought likely that increases in vehicle prices would probably differ widely from spare parts price rises during the latter period. The graphs of the new vehicle prices and spare parts prices for the period 1976 to 1979 are shown in Figure XII.4. They demonstrate a good correlation, suggesting that vehicle price movements remained a suitable method of correcting spare parts price changes. This continues in the period 1980 to 1981, although the correlation is weaker. Table XII.1 gives both indices for this period with the base month January 1976 at 100. The combination of regression and inflation has reduced the demand for new vehicles and it can be seen that spare part prices have accelerated faster than new vehicle prices for most of 1981. Manufacturers would be expected to follow such a policy although it is noted that vehicle prices caught up by the end of the year.

TABLE XII.1 - PRICE INDICES FOR SPARE PARTS AND NEW VEHICLES FOR MERCEDES BENZ 1113 GROUP. BASE JAN. 1976 = 100

MONTH	YEAR	SPARE PARTS DATA	NEW VEHICLE PRICES
JAN	1980	409	437
FEB		420	454
MAR		444	483
APR		505	510
MAY		564	532
JUN		589	552
JUL		590	578
AUG		629	633
SEP		697	704
OCT		766	775
NOV		815	813
DEC		833	885
JAN	1981	952	980
FEB		1.103	1.064
MAR		1.243	1.176
APR		1.402	1.299
MAY		1.500	1.470
JUN		1.761	1.587
JUL		1.822	1.639
AUG		1.902	1.695
SEP		1.983	1.818
OCT		2.081	1.961
NOV		2.100	2.083
DEC		2.117	2.222

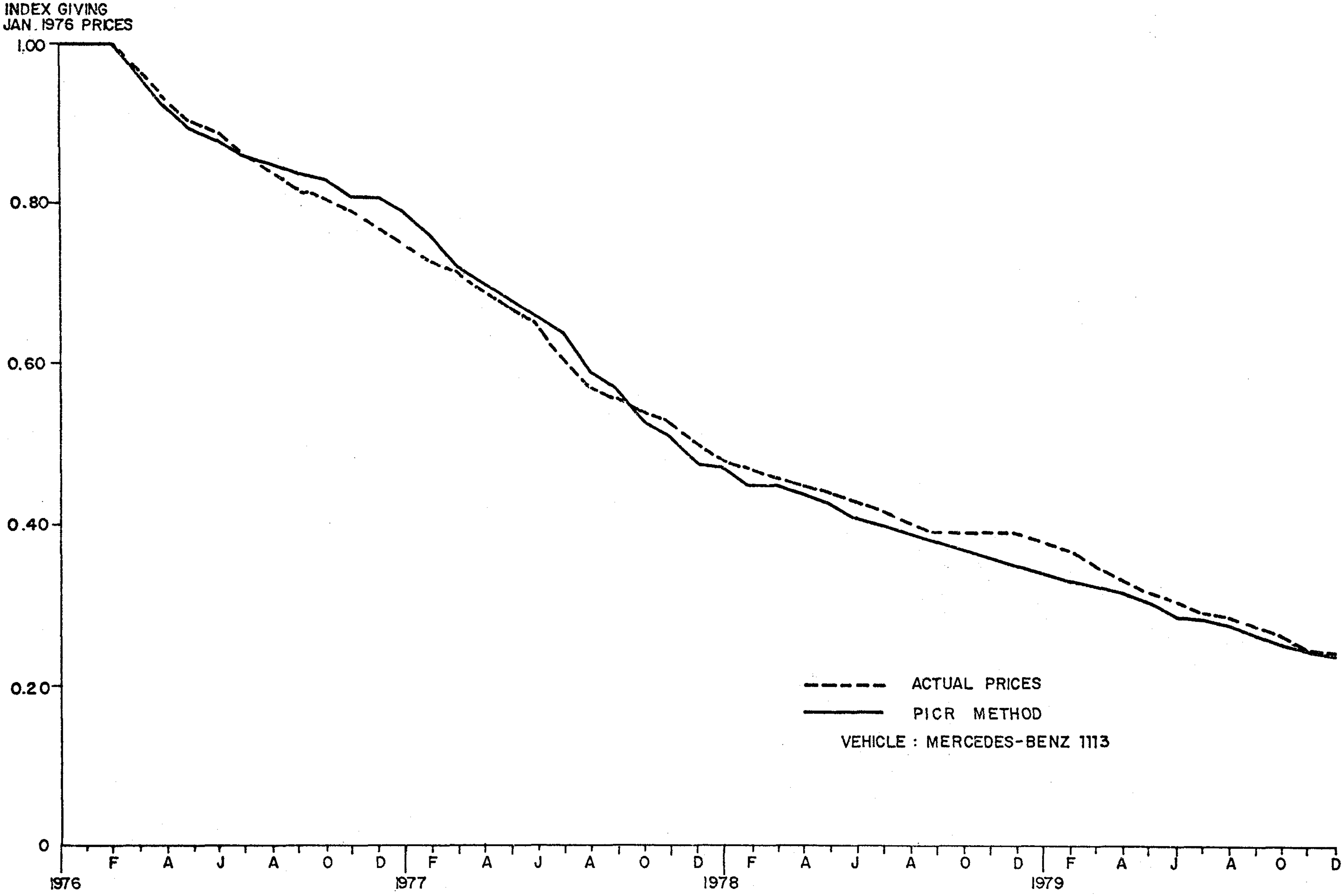

FIGURE XII.4 - COMPARISON BETWEEN ACTUAL PRICES AND PICR INDEX USED TO DEFLATE TO BASE JANUARY 1976 PRICES

XII.5 CONCLUSIONS

The relatively simple method of correcting for spare parts price rises by using the relevant new vehicle prices movements is shown to hold over the survey period. The correlation between rises in spare parts and vehicle prices has important consequences for the PICR results. It may be more useful to users of these results if parts consumption is expresses as a percentage of new vehicle price, as was done in the Kenya study. The user has then only to input new vehicle prices to derive cost predictions. If this is not done, then data will have to be continually collected to enable parts predictions be expresses in terms of current cruzeiro values. Finally, the data derived from this exercise were used to determine a new base period, December 1981. Equations predicting cruzeiro costs in this Volume reflect this change and predictions are in costs at December, 1981 prices. The technical memoranda produced before the end of the project remain in costs at January, 1976 prices.

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ADDENDA

Page 32, final paragraph, add the following:

Predicted log costs, when exponentiated, estimate geometric rather than arithmetic mean costs. Since the data sets exhibit positive skewness, geometric mean costs are less than arithmetic mean costs. To predict arithmetic mean costs, add 0.5 (S_w^2) to the intercept for OLSCE estimated equations and 0.5 ($S_w^2 + S_u^2$) for EC estimated equations, prior to exponentiation. Further details can be found in a PICR technical memorandum (Chesher and Harrison, 09/81).

Page 56, Table 3.9:

The sample sizes are cars 93, utility vehicles 65, buses 449 and trucks 200.

Page 69, last line:

S should read S_w

Page 71, 8th line from bottom:

S should read S_w

Page 93, second paragraph, include this sentence:

When log-linear equations are used to predict fuel consumption or parts and labor costs, a correction has to be made to ensure that arithmetic, rather than geometric, mean values are predicted. This is elaborated in Chapter 2 and the cost tables in this chapter are adjusted to give predictions of arithmetic means.

Page 94, Table 4.1:

Check against this.

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	6.72	55	7.28	41
Oil and Grease	0.26	2	0.39	2
Parts	0.78	6	2.70	15
Labor	0.41	3	0.79	4
Tires	0.24	2	0.68	4
Depreciation	0.53	4	0.81	5
Interest	0.36	3	0.56	3
Salary	3.05	25	4.68	26
Total	12.35	100	17.89	100

Add Note no. 8) The parts and labor predictions have been adjusted to give arithmetic mean costs, see Chapter 2.

Page 95, Table 4.2:

Check against this.

Cost Item	Paved Cr$	%	Unpaved Cr$	%
Fuel	7.73	38	8.11	25
Oil and Grease	0.27	1	0.42	1
Parts	4.48	22	6.68	20
Labor	1.45	7	2.72	8
Tires	0.99	5	1.78	5
Depreciation	1.22	6	2.90	9
Interest	1.19	5	2.80	9
Salary	3.21	15	7.56	23
Total	20.54	100	32.97	100

Add Note no. 8) The parts and labor predictions have been adjusted to give arithmetic mean costs, see Chapter 2.

Page 96, Table 4.3:

Check against this.

Cost Item	Paved		Unpaved	
	Cr$	%	Cr$	%
Fuel	11.94	30	12.69	26
Oil and Grease	1.43	4	1.63	3
Parts	5.46	14	7.52	15
Labor	2.20	5	4.35	9
Tires	3.55	9	4.60	9
Depreciation	4.84	12	5.47	11
Interest	3.45	9	3.89	8
Salary	7.25	17	9.52	19
Total	40.12	100	49.67	100

Add Note no. 8) The parts and labor predictions have been adjusted to give arithmetic mean costs, see Chapter 2.

Page 97, 8th line from bottom:

...to unpaved operations is 45 for commercial cars, 61 for the utility diesel truck, 24 for buses and 49 for medium trucks.

Page 100, line 28:

...terms and give a bus figure of 25 (24) percent.

Page 101, Table 4.6:

Check against this.

Cost Item	Paved		Unpaved	
	Cr$	%	Cr$	%
Fuel	5.68	21	6.04	17
Oil and Grease	0.72	3	0.82	2
Parts	5.06	18	6.96	20
Labor	1.33	5	2.62	8
Tires	3.09	11	4.00	12
Depreciation	4.17	15	4.71	14
Interest	2.97	11	3.34	10
Salary	4.37	16	5.72	17
Total	27.39	100	34.21	100

Add Note no. 5) The parts and labor predictions have been adjusted to give arithmetic mean costs, see Chapter 2.

Page 105, Table 4.10:

Check against this.

Cost Item	Paved 1979	 1981	Unpaved 1979	 1981
Fuel	19	21	14	17
Oil + Grease	2	3	2	2
Parts + Labor	24	23	32	28
Tires	11	11	14	12
Depreciation + Interest	29	26	24	24
Salary	15	16	14	17
Total	100		100	

Appendix XI, Figures 1 and 2.

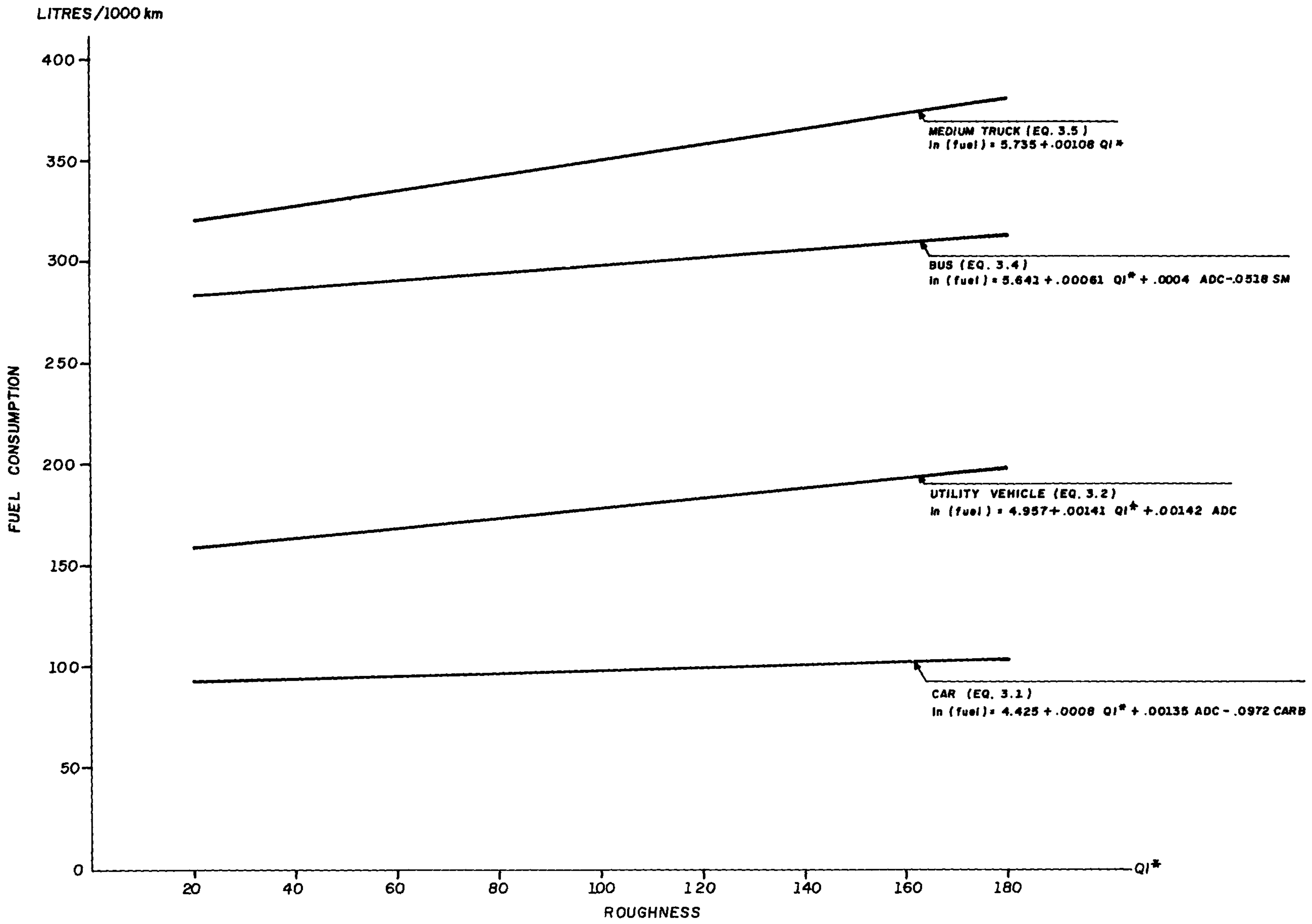

FIGURE XI-1 THE EFFECT OF ROAD ROUGHNESS ON SURVEY FUEL CONSUMPTION.