THE EFFECT OF ROAD ROUGHNESS ON VEHICLE OPERATING COSTS FOR MEDIUM-SIZED TRUCKS - A CALIBRATION OF EXISTING MODELS

Adrian McLean Finlayson

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 1991

DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the partial fulfilment of the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

A. M.

The 11th day of October 1991

SYNOPSIS

In the development of highway design alternatives, total costs, especially those borne by the community, must be given top priority. A large portion of these community costs can be attributed to vehicle operation which is affected, inter alia, by the riding quality (in terms of road roughness). Models have been developed to quantify the financial benefit, in terms of vehicle operating costs, associated with a better quality riding surface, although these models may not be universally applicable. This research attempts to calibrate these models to South African conditions for medium to heavy trucks. These models may then be employed in the economic appraisal of highway design alternatives in the South African environment.

DEDICATION

In memory of my Grandmother

Elizabeth "Betty" Davids

1916 - 1991

Who influenced my life in a very special way, and who was a great little lady

ACKNOWLEDGEMENTS

I would like to express my appreciation to the Council for Scientific and Industrial Research, Division of Roads and Transport Technology, for allowing me to use their library and other facilities for the completion of the literature survey, and also for allowing me the opportunity to undertake this research.

I also wish to extend my gratitude to the Department of Transport who funded the work, and to the private concerns who made cost data and other information available.

Furthermore, I extend my thanks to Hennie du Plessis for his guidance and to Linda Brilleman and Priscilla Dickson for typing up the report. Their input was greatly appreciated, and it was a pleasure working with them.

I am also indebted to Dr. R. F. del Mistro for his patience, invaluable counselling and advice.

LIST OF CONTENTS

PAGE

PART II
METHODOLOGY OF DATA COLLECTION - BOTH VOCs AND ROUGHNESS

PART III
RESULTS AND COMPARISONS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

In the economic and social development of any country, an effective road transportation system is an important factor However, it also consumes a large proportion of the total infrastructure costs, while the costs borne by the road user for vehicle operation and depreciation are even greater. A policy must therefore be adopted in which total community costs for any road link or network are minimized. To do this meaningfully, alternatives must be developed and compared and the trade-offs between them carefully assessed. This, in turn, requires the ability to quantify the different cost functions for the desired period of analysis.

A study initiated by the World Bank in 1969 led to the production of the Highway Design and Maintenance Standards Study. This study documents the research carried out on the quantification of the trade-offs between the costs of road construction, road maintenance, and vehicle operating costs and on the development of planning models simulating total life-cycle costs which are used as a basis for decision making. To emerge from this study was the Highway Design and Maintenance Standards Model (HDM III) -a computer simulation model allowing for the comparison of different alternatives.

The HDM III model employs four sub-models for this purpose, of which the vehicle operating cost (VOC) sub-model is of relevance to this research. Vehicle operating costs are those costs directly attributable to owning, operating and maintaining a vehicle, and are the largest cost element in road transport.

There is direct physical evidence compiled around the world that shows that pavement roughness influences vehicle operating costs (Chesher and Harrison, 1987). Improvements in road conditions, although costly, can therefore pay substantial dividends by reducing VOCs and hence generate large net benefits to the national economy as a whole. It is necessary, though, to quantify these benefits by using, for example, the HDM III model.

However, the VOC sub-model cannot be employed in South Africa until it's relevance has been established since results from other socio-economic environments may not be universally applicable. A calibration of the model, to local conditions, is therefore imperative to ensure it's applicability to South Africa and to promote confidence in the validity of the output. This is the focal point of the proposed exercise, which is to calibrate the HDM III vehicle operating cost sub-model to South African conditions for trucks only. This research forms part of a larger road user cost study, in which models are being developed for use in road management for general and economic appraisal of highway projects. Furthermore, the exercise will be undertaken for only one vehicle class - that of medium to heavy trucks - as all other classes have already been accounted for in previous local studies. This class covers mostly 2 or 3 axled, 4 to 16 ton vehicles.

The first Part of this report covers the available literature and allows for the deduction of those relationships requiring calibration to local conditions. It also provides the necessary background needed to analyse both road roughness and vehicle cost data and discusses any extenuating factors influencing VOC relationships. The form of the relationships developed are highlighted since a similar form will be adopted for local conditions - it is a calibration of the variables that is required.

The second Part of this document discusses the logistics and policies of the company used for data collection. The methodology of the data collection as well as the actual data collected is discussed with regards to both operating costs and road roughness. The processing of data is briefly explained and problems encountered during this phase of the research touched upon. Furthermore, the controversial method of "averaging-out" roughness measurements is delved into and an alternative method of roughness assessment proposed.

In the third Part the results and comparisons are furnished, in which the vehicle operating cost components are analysed using both the conventional and alternative method of roughness assessment. The two methods are compared and conclusions drawn as to the viability of employing each in an economic assessment of highway design alternatives. The last Chapter in Part III compares the relationships arrived at in this research with those of the overseas models.

Part IV draws conclusions on the work undertaken, and summarises those VOC relationships which are to be employed in future cost analyses in the South African environment. Furthermore, recommendations are made with respect to the theoretical and practical application of the alternative method of roughness assessment.

PART I

LITERATURE SURVEY AND STATUS QUO REPORT

2 LITERATURE REVIEW

This Chapter serves as a literature review and explores and summarizes most of the available literature on the subject in order to provide guidance as to the methodology of the research. It covers most of the aspects of vehicle operating costs and also exposes the areas which require extra attention.

Both international and local studies are covered in this literature review, with emphasis on those studies that are similar to this one, or those that provide guidance to the research. The report begins with a brief background to the HDM III model followed by a description of most of the studies reported on. Different factors which may influence the outcome of the research are then discussed, followed by information pertaining to each VOC component.

2.1 Introduction

The lack of road surface smoothness (or, roughness) and its effect on ride comfort, dynamic loading and vehicle operating costs (VOCs) has received much attention through the years and engineers worldwide have spent considerable effort in quantifying road roughness and its relationship to user cost and comfort. du Plessis, Visser and Curtayne (1988) and Zaniewski and Butler (1985) report that the upgrading of road surface quality may be justified purely on the grounds of user cost savings. By reducing vehicle operating costs by even a fraction of a percent contributes enormously to reduce the total transportation costs of an economy. The following diagram illustrates this conceptually:

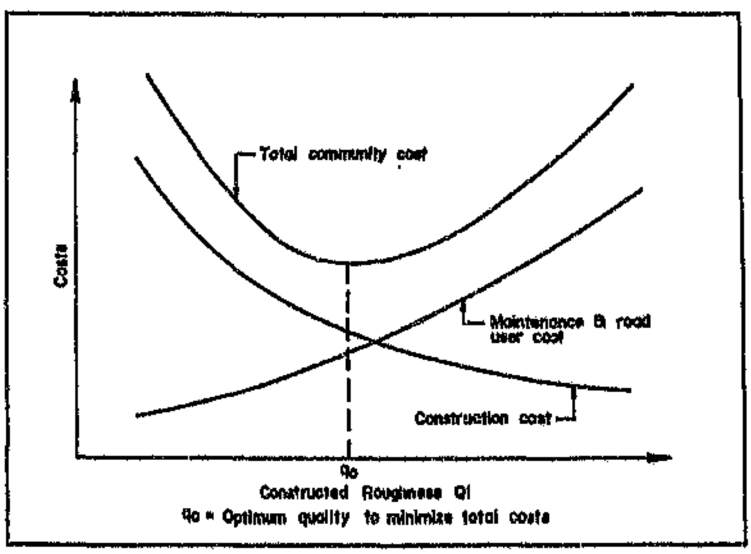

FIGURE 2.1: OPTIMIZATION OF TOTAL COMMUNITY COSTS WITH REGARD TO MAINTENANCE, ROAD USER AND CONSTRUCTION COSTS (du Plessis and Curtayne, 1990)

Within the realm of total vehicle operating costs, there are also obviously different contributions made by each cost component. The approximate magnitude of these costs are illustrated in Figure 2.2.

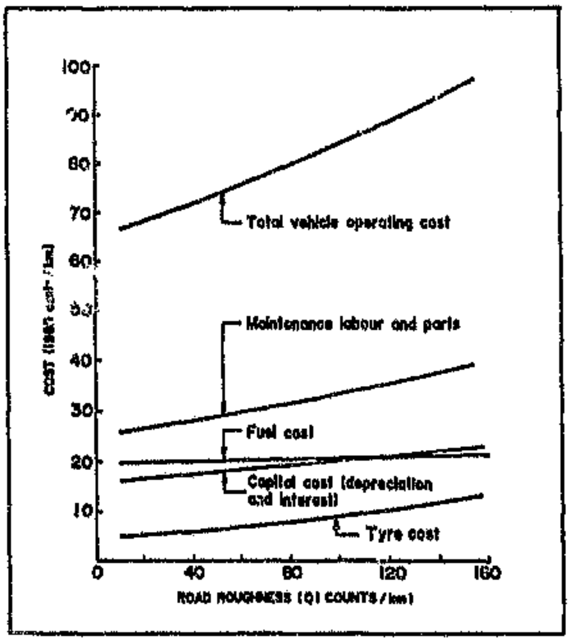

FIGURE 2.2: 1986 VEHICLE OPERATING COSTS FOR A BUS ON ROLLING TERRAIN (du Plessis and Curtayne, 19?0)

Taking all the above factors into account it is clear that there was a need to develop vehicle operating cost relationships in order to quantify these effects. Only once all the costs associated with any design alternatives are established, can an economic feasibility study be undertaken assisting in the decision making process of the different alternatives. The World Bank thus initiated a series of VOC projects.

These major VOC studies were conducted in Brazil, India, Kenya and the Caribbean, which confirmed that road roughness and geometry are of paramount importance in determining levels of road user cost. From these and other VOC studies extensive experimental and survey data bases have been employed to determine the different vehicle cost versus roughness relationships. An effort was made to ensure that these relationships could be used in different countries which obviously may have different geographical and climatic conditions. The onus, however, is on the user to ensure the applicability of the relationships to local conditions. This point cannot be over-emphasized, and it forms the entire crux of the proposed research. The process by which this is achieved is termed calibration.

2.2 The HDM III Model

South African pavement management systems are in need of models to evaluate the consequences of alternative maintenance strategies. The World Bank's Highway Design and Maintenance Standards Model (HDM III) is certainly the most comprehensive study on the subject to date. It is also adaptable to different conditions. For these reasons it is believed to contain the road deterioration relationships best suited to South African conditions. This model, however, cannot be applied as a basis for decision-making until the applicability of the model has been thoroughly investigated and modifications made where necessary. This requires the comparison of model predictions against values of actual, local, road user costs.

The basic task of the HDM III package is to enable comparisons to be made between alternatives using the predictions of total transport costs over a certain analysis period. The total costs are made up of construction costs, maintenance costs and road user's costs. Four sub-models are employed by the program to calculate these costs, of which only the road user costs sub-model is to be calibrated in this project.

Two distinct principles emerge from the HDM III model. Firstly, roughness has a direct influence on VOCs, and secondly, different modes of distress influence the rate of roughness progression of a road. These principles are not to be confused - it is the effect of road roughness on VOCs that is to be investigated in this project.

2.3 The Measurement of Road Roughness

As the need arose for the quantification of road condition in terms of its serviceability, two classes of measuring systems evolved - those that measure actual longitudinal profiles and those that measure vehicular response to roughness. This latter type is collectively known as *response-type road roughness measuring systems (RTRRMSs)*. These instruments measure either:

i. axle-body movements which are usually summed to give cumulative "bumps" per unit distance, or;

ii. accelerations of axle or body via accelerometers.

Of the RTRRMs available, Visser & Curtayne (1982) have developed the Linear Displacement Integrator (LDI), which is gaining wide-spread acceptance because of its simplicity and reliability.

While developing the LDI, Visser and Curtayne (1982) had to constantly relate their outputs to some form of roughness scale, since the prediction of roughness under any given circumstance is dependant on the ability to relate that measure of roughness to the measures used in the major empirical studies. The need for an international scale of roughness has led to a range of roughness measuring scales to be considered (Paterson, 1986). One such a scale is the QI (quarter-car index) roughness scale, derived from the simulated response of a quarter-car to road profile inputs. This measure of roughness was employed in the Brazil study. In the establishment of calibration procedures for RTRRMSs used in South Africa, Visser (1982) found good correlations between QI and outputs of the LDI roadmeter (units of mm/km).

In the other local studies similar to this one, Wessels (1989) and Curtayne et al (1987) used the Linear Displacement Integrator to obtain roughness measurements. These measurements were then converted to the QI scale of roughness by the following formula:

$$QI = 34{,}60\ (LDI) + 2{,}49 \qquad \text{......... Eq.2.1}$$

The LDI has proven to be reliable and gives repeatable results, and the QI scale of roughness is gaining world-wide acceptance. The roughness measurements, obtained by this method, were used by Curtayne et al (1987) in the analysis of both tyre wear and maintenance parts consumption. They did, however, average out the roughness measurements and the possible inaccuracies of this method are discussed further at the end of this Section.

In the following table, du Plessis and Curtayne (1990) give an approximation of how the QI scale relates to road condition :

TABLE 2.1: COMPARISON OF THE QI-SCALE OF ROUGHNESS TO ROAD CONDITION (du Plessis and Curtayne, 1990)

QI (counts/km)	Road condition
0 - 25	smooth paved
25 - 40	fair paved
40 - 50	rough paved to fair unpaved
50 - 80	rough unpaved
80 - 150	poor unpaved
150 - 200	very rough unpaved
200 +	virtually impassable

At an international level, the provision of a common quantitative basis with which to reference different measures of roughness led the World Bank to initiate the International Road Roughness Experiment (IRRE) in Brazil in 1982. This resulted in the establishment of the International Roughness Index (IRI) as a standard against which roughness measurements can be monitored. This index is essentially similar to the QI scale and was also shown to be strongly related to subjective ratings of riding quality (Paterson, 1986). Furthermore, very high correlations were found to exist between the QI and IRI scales of roughness, so that a conversion between the two can be made with reasonable confidence. From 49 observations, the correlation coefficient (R^2) between the QI and IRI scales was 0,962.

In a paper by Paterson (1986) the major roughness scales, which were investigated in the International Road Roughness Experiment, are referenced against the IRI. A chart and a series of equations are provided for the purpose of converting between any two scales. The conclusions that can be drawn from this is that although the IRI is being internationally advocated as *the* scale of roughness, it is feasible to use the QI scale since they are readily interchanged. A diagram is also given by du Plessis and Curtayne (1990) in which conversions can be made between different roughness classes, including the QI and IRI scales.

A further point raised concerning the measurement of road roughness is what effect, if any, different types of vehicles have on the results. Paterson and Watanatada (1985) addressed this issue, and they discuss the quantification of the effect of vehicle type on the response-speed relationship. After comparing three different vehicles and four different instruments they found that the results were of the same order, expect for an instrument installed in a trailer. They conclude, however, that specific speed correlation relationships need to be established for individual vehicles, and that this is a requirement of calibration procedures. Furthermore, the response of a measuring vehicle will be different at different speeds and a universal roughness scale must therefore address the issue of a reference speed. This implies that there will be an adjustment across speeds when the measuring vehicle has had to reduce or increase speed. This topic is discussed further in Section 2.5.

One last factor influencing the measurement of road roughness is that of the trucks' load condition. Chesher and Harrison (1987) explain that it is very costly to obtain accurate estimates of loads carried. In fact, only in the Caribbean study were accurate vehicle load data obtained (gross vehicle weights were determined at weigh stations). Attempts were made to introduce weight effects into the Brazilian and Kenyan studies. The validity and accuracy of these attempts are, however, dubious as some of the loads were estimated visually. Taking these factors into consideration it is unlikely that vehicle loads will be included in the present study.

In closing it should be noted that misleading results can be produced by averaging out roughness measurements. For example, a 1 km unpaved road and a 10 km paved road with roughness measurements of 250 QI and 19 QI respectively will yield an aggregate roughness of 40 QI. This could be misleading since the 1 km section of unpaved road could be causing 80 % of the vehicle operating costs, whereas it is assumed, by averaging out the roughness, that it is causing only 57 %. This is of significant importance in the research and it may be necessary to develop an acceptable method of correctly proportioning vehicle operating costs to road roughness. A method which could be employed is one which attempts to incorporate the effect of road roughness directly. This would prevent the "loss" of the direct link between roughness and VOCs which occurs when averaging out roughness measurements.

2.4 Facets of Calibration

A fundamental process employed in this research is that of calibration. A number of methods could be used to obtain results and this Section outlines those available and those most likely to be implemented. Calibration activities can be based on both primary and secondary data sources. Primary studies are those which compare directly costs and roughness characteristics whilst secondary studies provide information on a region. This regional information is used to calibrate primary study data to that region.

Curtayne et al (1987) say that calibration work can be based on a combination of secondary data and experimental or survey activities if adequate resources are available. Furthermore, economic growth and free competition, or regulation, for transport services influence loads carried, utilization and vehicle speed. Knowledge of these effects in the countries in which the primary studies were conducted is very important when calibrating primary relationships. This provides valuable secondary information for the interpretation of predicted values. It is unfortunate, however, that most study reports do not adequately describe such effects. The present economic position, of South Africa, however, will certainly play a role when justifying relationships produced in this study.

Furthermore, during the undertaking of such a study, it may happen that resources prove inadequate, and a calibration is attempted in which parts of equations from the primary studies are combined to suit local conditions. However, Curtayne et al (1987) state that equations from various studies should not be mixed especially for the maintenance parts, labour, depreciation and interest results. They go on to say that if resources do not permit much calibration, then that study closest to the local environment should be chosen and efforts to calibrate it centred on the critical cost components that were identified by secondary data as being sensitive. To best achieve this, a variety of calibration activities that are influenced by study resources and data availability are identified, making it possible to determine a program of priorities which focus on the most important components to be addressed.

Data should then be collected and this is accomplished either by experimentation or by a survey of the costs of vehicle ownership. In the case of survey data, a single company that provides similar service over a representative range of road roughnesses is the ideal company to survey. This is because analysis of the Brazilian and Indian VOC survey data shows the importance of differences between companies and within a company in the estimation of survey data (Chesher and Harrison, 1987).

In summary, the calibration of VOC results ranges from the selection of available relationships on the basis of very little data to the estimation of local relationships using specially collected data to calibrate model forms reported in the various major, primary studies. This latter method is the one to be employed in this research as resources did not permit a primary study in order to relate road roughness to vehicle operating costs.

2.5 Elements of Speed

A fair percentage of the available literature covering VOCs and related subjects is devoted to speed and the relationship between speed and vehicle operating costs. The subjects referred to in this literature are:

i. The relationship between speed and the measurement of road roughness with regard to vehicle response,
ii. The road roughness measurement error at different speeds, and
iii. The reduction of travel journey times resulting in a reduction of total community costs.

Delving into the relationship between speed and the measurement of road roughness, one finds that the quality of a vehicle's ride varies with travel speed, the dynamic characteristics of the vehicle, and the roughness of the road. The assessment of road roughness by measuring the response of a typical vehicle is thus dependant on the speed and dynamic characteristics of that vehicle. In an attempt to model user costs and road roughness, speed predictions should therefore be a primary objective.

In the Brazil study, passenger cars calibrated to 80 km/h were used for the measurement of road roughness. When conditions such as poor geometry, traffic, bad weather, low light or high levels of road roughness prevailed, and speeds had to be reduced, it was necessary to estimate the equivalent output at 80km/h. This was done in order to express the roughness in terms of the QI reference scale.

Paterson and Watanatada (1985) also mention that, when lower speeds are necessary, the conversion of the response speed to the reference speed is required to estimate the road roughness. From data sets on all different types of roads they produced an equation that can be used to calibrate roughness measurements at different speeds. Their equation, however, is suited to overseas conditions as well as to the use of an Opala Mays meter to measure road roughness (and not the LDI roadmeter). It is thus not applicable to this research and an alternative equation may have to be sought.

Moving onto the subject of road roughness measurement error at differing speeds, it was found that the literature was extremely limited. Paterson and Watanatada (1985), in their analysis of the Brazil speed-roughness data showed that, when measuring roughness, there is a measurement error, which increases with increasing roughness; typically the error increases in proportion to the square root of the roughness. They go on to say that surface-type effects are primarily, though not completely, explained by different roughness levels. These points will have to be considered in the research as any "outlying" roughness data points may be exaggerated due to the measurement error. Also any relationship produced by Paterson and Watanatada (1985) would not be applicable to South African conditions, especially the LDI roadmeter.

Paterson and Watanatada also estimated speed statistically, in which conclusions are drawn which would be of benefit to this research. They based their predictions on some 100 000 individual speed observations obtained from over 200 road sections, for six vehicle classes, ranging from passenger cars to articulated trucks. In their results it became apparent that at low roughness levels, in the range of up to 80 QI, safety and speed limit considerations tend to dominate. This makes the predicted speeds relatively insensitive to roughness. As the roughness gets larger, in the middle range of 80 to 200 QI, it's effect on the predicted speeds becomes more pronounced. In the high range of roughness (above 200 QI) the predicted speeds are almost totally dominated by roughness.

du Plessis, Morden and Coetzee (1989) attempted to show, locally, that speed is directly affected by roughness or by road type. In their pilot study, speed was measured against roughness and modelled for all the vehicle classes. They found, however, that the relationship that exists between road type and road roughness complicates the interpretation of results. This complication is to be expected, since a gravel road will by nature have poorer riding quality than a paved road. Other factors such as dust, road width, and the presence of loose sand, which are associated with gravel roads, also cause drivers to maintain lower speeds on unpaved roads. The data obtained in their survey was therefore insufficient to identify a roughness-speed relationship for all vehicle classes, since other factors related to road type should have been included in their predictions.

The results of the study by du Plessis, Morden and Coetzee (1989) were therefore inconclusive and, unfortunately, no other local work has been done to quantify the effects of road roughness on vehicle speed. Furthermore, it cannot be assumed that the work done by Paterson and Watanatada (1985) may be used locally to address roughness-speed effects since their relationships were developed overseas.

The third and last salient point regarding speed is that of the prediction of the savings to journey time. Chesher and Harrison (1987) mention that the prediction of vehicle speed is central to the prediction of road user costs since they influence the journey times. A quantification of travel time savings are necessary in order to undertake a full cost-benefit analysis of highway improvements so that total community costs may be minimized. This prediction, however, falls outside the scope of this study and shall not be addressed. This exercise must, however, be undertaken during a cost - benefit analysis of any highway improvement alternatives.

2.6 Components of VOCs - Applicable Literature and Summaries

With the background to most of the introductory aspects being discussed in previous sections, it is now possible to move on to international and local developments with respect to VOC's and road roughness. The available literature and the methodology of the investigations are discussed in this Section. The first sub-section, Section 2.6.1, outlines the broader aspects of each study with respect to the scope of the study and the methodology of the research. In the following Sections each component of vehicle operating costs is addressed separately, being discussed and reviewed in the light of the task to be accomplished.

The order of discussion of each component is according to the relative importance attached to each with regard to this research. Maintenance and repair costs are crucial to this investigation since they constitute a large percentage of total VOCs on which very little research has been undertaken locally. Consequently, this aspect is discussed first, followed, for similar reasons to those outlined above, by tyre consumption. The third component to be discussed is that of depreciation and interest charges. The last two components, fuel and oil consumption, are addressed last as it is unlikely that an attempt will be made to model these two components - adequate relationships between these two components and road roughness have already been established locally. Also, an attempt has been made to include only relevant literature, although it is necessary, in places, to provide other literature to facilitate better understanding of the subject.

Further, the literature documenting the four major VOC studies (specifically by Chesher and Harrison, 1987) is extensive. Therefore, a summary of most of this work is provided in Section 2.6.7 while only a few references are made in Sections 2.6.2 through 2.6.6.

2.6.1 General

At present, it is cost differentials of different design alternatives which are being employed in the economic aspects of the decision-making process. In order, therefore, to make effective cost-benefit decisions of different highway alternatives it is imperative to have available, the different levels of costs associated with each. Results from the primary VOC studies showed that vehicle operating costs were sensitive to roughness but that this sensitivity varied between the different components. Furthermore, and perhaps more importantly, the studies showed variances in cost magnitudes and differentials of each component. These variations thus highlight the need to develop a series of cost-roughness relationships specifically for Southern Africa.

Primary research on VOC relationships on a large scale is, however, both time consuming and very expensive. A number of smaller scale VOC projects were thus initiated in South Africa in which an attempt was made to calibrate the available cost-roughness relationships to local conditions. In the South African context this is obviously an important phase in the entire VOC exercise - it ensures a fair degree of confidence when using the HDM III model locally.

In the results obtained locally over the past six to eights years similar trends were indicated to those from other studies. A few of these projects were reported on by Curtayne et al (1987), du Plessis, Visser and Curtayne (1988), Wessels (1989) and du Plessis, Morden and Coetzee (1989), amongst others. Curtayne et al (1987) recently attempted a small-scale VOC study, designed to select a set of cost-roughness relationships that were reported in major primary VOC studies and to calibrate them to local conditions. As far as maintenance parts and labour costs, and their trade-off with depreciation and interest charges are concerned, they do not recommend that these be modelled mechanistically. This is because economics, and not technology, is the key factor in the prediction of these components.

Road user surveys were therefore conducted in rural areas which showed that vehicle maintenance, tyre wear and depreciation are adversely affected by increasing levels of roughness. Data was subsequently obtained from a company that operated 740 buses from 9 depots with a combined annual fleet use of 50 million kilometres. In order to provide the best range of road roughness values, operating cost data were taken from five of the 9 depots over a complete calender year, as recommended by Hide et al (1974).

Concurrent to this research, rolling resistance experiments were done in order to permit the mechanistic determination of fuel consumption. The mechanistic method of modelling assumes that fuel consumed is directly related to the energy required to overcome resistance to motion. This involves coasting a vehicle down a hill from a relatively high speed (usually about 80 km/hr) over a road section of which the grade and roughness characteristics are known. Furthermore, rolling resistance is a function of road roughness and the suspension characteristics of a vehicle. The basic equations of motion can then be applied to derive a formula for fuel consumption in which speeds and coefficients for rolling, air and gradient resistance are the independent variables.

Work was carried out with passenger cars, buses and medium trucks that has quantified the effect of road roughness on fuel consumption (du Plessis, Visser and Curtayne, 1988). In this report du Plessis, Visser and Curtayne produce fuel consumption - road roughness relationships which are thought to apply to local conditions. They also discuss the methodology and comprehensibility of their research, in which theoretical considerations were employed to produce these relationships. A further very important point to emerge from their document was that mechanical differences between vehicle types within a class are appreciated, although these are not taken into account - largely because relationships developed from empirical studies of this type are applied to typical vehicle fleets travelling over a road facility and no finer distinctions are made at that level of analysis.

Their report provides a foundation on which to build the current research for the following reasons:

i. The user survey falls along much the same lines as the presently proposed exercise;

ii. Their results are comprehensive and are being employed locally until better results become available;

iii. Lessons learnt in their research are thought to also apply to other vehicle classes;

iv. The research was done locally and can therefore provide guidance and assistance, and;

v. Their methodology and results are well documented.

In another user survey study, by Wessels (1989), the maintenance cost predictions did not calibrate well with results from other studies. In addition to this, tyre data was found to be insufficient to attempt a tyre data analysis. Wessels suggests that, in this case, depot records be re-consulted to gain a better understanding of the data. Individual depots should also be visited so that geometric attributes as well as greater quality data can be obtained. This research provides guidance in as much as it shows appreciation for the correct and comprehensive collection of data.

In most user surveys, for reasons that are outlined by Chesher and Harrison (1987), data was sought from a single company, operating over a wide range of road roughnesses. It should be noted, however, that in these surveys companies are usually chosen because they operate over various combinations of route characteristics. This is not wholly correct in that they should be chosen because they form a representative sample of vehicle operators. It is because of this that the operating costs reported in the various studies cannot be taken to represent general cost levels. Users who require absolute cost levels as well as cost differentials are advised to conduct an extensive calibration of equations to suite local conditions.

As far as overseas literature is concerned a report offering assistance to this project is that produced by Zaniewski and Butler (1985). Their report was being compiled during the time that the World Bank was doing its research on VOCs. Because of this, judgement and theoretical considerations were employed to produce sets of VOCs.

In their research five components of VOCs, for trucks only, were studied, including fuel, oil and tyre consumption, maintenance (and repair) and depreciation. Using a large data base their approach was to identify the consumption involved for each parameter and then to price these components to obtain VOCs. Data were received for 12 489 trucks from 15 fleets. These data were sufficient to provide updated cost estimates for all cost components except use-related depreciation.

Zaniewski and Butler had available to them the preliminary results of the Brazil project and used these to quantify the influence of roughness on VOCs. They state that, in general, allocation of the non-fuel components of VOCs must be determined by judgement and theoretical considerations. This is because direct evidence of the influence of roadway parameters and pavement condition on the non-fuel components of vehicle operating costs is difficult to obtain, since long periods are necessary to observe consumption of these components.

However, when judgement was the sole basis for cost allocation, they invariably used the distributions originally developed by Winfrey (1969). When subjective judgements could be augmented with theory, distribution costs could be calculated using standard equations of force and horsepower.

Most of the other literature documenting the major, international VOC studies is summarised by Chesher and Harrison (1987) and is discussed further at the end of the Section. Each component of vehicle operating costs is now examined under it's respective heading, with attention focused on the relationships produced by each.

2.6.2 Maintenance and Repair Costs

Maintenance costs are crucially important in the calculation of benefits derived from road improvements. They form a large component of VOCs (as is evident from overseas and local studies), they are sensitive to road conditions and the cost progression of maintenance as vehicles age is influential in determining vehicle replacement expenditures, and thus depreciation and interest costs.

Chesher and Harrison (1987) refer to "preventative maintenance" as that which influences the relationship between maintenance costs and vehicle age. The extent to which this preventative maintenance is carried out varies from country to country due to differences in prices of maintenance labour, parts and new vehicles. Adding to this, Curtayne et al (1987) mention that maintenance expenditures are sensitive to price and wage levels, and the trade-offs of depreciation and interest charges. All of these are linked to the size, strength and structure of the local economy. Therefore, there is a strong argument for developing relationships suitable for South African conditions.

In most of the previous studies concerning this subject, when analyzing vehicle operating costs, the total maintenance costs of a vehicle are split up into 2 separate costs - that of parts and that of labour. For an individual vehicle, the exact parts and labour expenses incurred will depend on the care taken by the owner and the specific conditions under which the vehicle operates.

The two maintenance costs (parts and labour) are discussed separately under the headings Maintenance costs - Parts and Maintenance costs - Labour.

Maintenance costs - Parts

In order to deal with maintenance parts costs, results from the primary studies indicate methods of manipulating data in order that influencing factors can be readily taken care of. It has become apparent that the importance of vehicle age in kilometres cannot be ignored, and must be taken into account whilst processing data. This has been emphasized by all major VOC primary studies. In addition to this, different rates of inflation for different types of vehicles must be accounted for. This is achieved by dividing average spares costs by the new vehicle price, since it has been found that this ratio remains approximately constant, despite inflation. This concept is discussed in greater detail by Chesher and Harrison (1987).

In the study by Curtayne et al (1987) the consumption of engines, gearboxes and differentials, which were changed at 300 000, 350 000 and 450 000 km respectively were considered to be only partially related to road condition. They were therefore not included in the preliminary analysis of maintenance costs.

For reasons that have been discussed, the bus data were assigned kilometre ages and the maintenance costs were divided by new vehicle prices. Once the preliminary data analysis was complete, various models reported in the major primary VOC studies were estimated. The following equation, which is similar to the Brazilian bus maintenance parts equation showed the best fit:

$$ln\,(P/VP) = -0{,}7894 + 0{,}4153\,ln\,(QI) + 0{,}6313\,ln\,(AGE) \qquad \text{.............. Eq.2.2}$$

where

P = spare parts costs in South African rands/10^3 km, (2,5 SA rands = 1 US dollar),
VP = new vehicle price (in 10^5 SA rands),
AGE = bus age (in 10^3 km), and
QI = road roughness (counts/km).
For this model the correlation coefficient (R^2) = 0,82

Again the results were regarded as encouraging and further work should be undertaken for the estimation of relative parts consumption for trucks. Also, it became clear in their research that the trade-off between maintenance costs and depreciation costs are crucial to vehicle operations. This is because these costs determine purchasing, maintenance, selling and scrapping decisions, and form a significant portion of total vehicle operating costs. These factors will be addressed in detail in this research.

Maintenance costs - Labour

Curtayne et al (1987) treated labour costs by dividing the total wages paid by the kilometres travelled. This item therefore contains no evidence of how road roughness will affect labour costs, although it is expected that more time will be spent on repair work on very rough roads than on smooth or paved roads. However, this is not the only labour-influencing cost - they also depend on prevailing wage rates. This method is therefore clearly unsuitable for application in South Africa.

An alternative method of treating labour costs was adopted by du Plessis (1987). Because of the similarities between local and Brazilian operating conditions and in view of how bus fleets are operated in that country, he decided to use the Brazilian model to predict local labour costs. To evaluate these predictions, the bus operator was then asked for his comment on the values calculated at certain roughness levels.

du Plessis assumed that conditions in rural South Africa and in Brazil were similar at the time that the Brazilian model was developed, and that the model allowed for the socio-economic circumstances in Brazil at that time. After converting from the different monetary systems, and allowing for inflation, the following equation emerged :

$$\ln L = 1{,}29 + 0{,}517 \ln P + 0{,}00548\ QI \qquad \text{............... Eq.2.3}$$

where

L	=	labour costs (Rands) per 1000 km,
P	=	spare parts costs (Rands) per 1000 km, and
QI	=	road roughness (counts/km)

However, it has to be noted that the exchange rate/price increase has its limitations. Firstly, the exchange rate is largely dependent on political and economic expectations and does not necessarily reflect the relative buying power of the two currencies, making any price comparisons meaningless. Secondly, socio-economic differences between the two countries may result in vastly different labour-capital trade-offs within the respective transport sectors. This was reflected by the fact that the operator found the predicted values to be up to 50 % higher (at high roughness levels) than the actual operating costs.

Based on the above, it is clear that original work in South Africa will have to be done to quantify the local labour cost-roughness relationship.

2.6.3 Tyre Consumption

As in the calculation of other VOC components, theoretical, as well as data collection, considerations can be employed in relating tyre consumption to surface roughness. Like fuel and oil, tyres are consumed continuously as vehicles travel. However, two types of wear occur on tyres - ablative and abrasive. The former is due to premature failing of the casings and the latter purely to shedding of material over time. Furthermore, tyres are expensive and carcass's robustly built.

It makes sense therefore to retread tyres provided the carcass is still in a serviceable condition. For this reason, a calculation is performed in which any ablative and abrasive wear as well as any retreads are taken into consideration when relating tyre wear to road conditions. This "equivalent new tyre life" calculation is performed in order to take into account the ablative wear of the tyres at any particular depot since it would be unfair to allocate tyre wear due to premature failings of the casing, eg. penetrations, to the roughness conditions at a depot. Although it is generally agreed that a higher roughness level would lead to a higher ablative wear, this may not be the case.

Adding to this, Chesher and Harrison (1987) discuss the research undertaken in the Indian study. This was to investigate differences in tyre lives for tyres of different brands and for tyres made from different materials. No significant differences were found and henceforth all tyres were treated similarly. This is of obvious significance to the present study.

In their analysis at the Kwazulu bus tyre data Curtayne et al (1987) adopted the user survey technique - similar to that which is proposed for this project. Monthly average tyre costs for both new and recapped tyres were provided. This made it possible to calculate equivalent new tyre life values as was first done in Kenya and subsequently adopted by all major studies. Equivalent new tyre lives were derived from the following equation :

$$\mathbf{ENT = TK/(1 + NR/R)} \qquad \text{.............. Eq.2.4}$$

where

ENT = equivalent new tyre life (10^3 km/tyre),
TK = total kilometrage per casing (km),
NR = number of retreads per casing, and
R = ratio of new tyre price to retread price.

The ENT data points were then plotted and a simple log-linear relationship was determined from the various models that were fitted to the data. The relationship is as follows :

$$\mathbf{ENT = 131{,}5 - 21{,}0\ \mathit{ln}\ QI} \qquad \text{.............. Eq.2.5}$$

where

ENT = equivalent new tyre life (10^3 km/tyre)
R^2 = 0,81; standard error of estimate = 5,42

Once this equation was established, Curtayne et al (1987) performed a comparison with results from the major VOC studies. They found the following:

There was a degree of similarity between the local bus tyre predictions and those of the TRRL studies in Kenya and the Caribbean, but a divergence was shown in the results of the Brazilian and Indian studies. The Brazilian study used data generated by a mechanistic tyre wear model, which appears to yield conservative figures by comparison. But the Indian study differences could not be explained and it is thought that they could be attributed to either driver behaviour, which is extremely difficult to quantify, or to the characteristics of the gravel materials. These comparisons are discussed in detail in later Chapters of this report. Furthermore, it is evident from available data that local gravel materials cause many premature failures and tread wear due to penetrations of the tyre casings.

Adding to this, Chesher and Harrison (1987) warn that considerable across-company differences in tyre lives can be expected. This is due to the effects of company policy differences (with respect to recapping, etc) and to across-company variation in types of business. Furthermore, they say that tyre data are difficult to collect because, at least in large organisations, tyres are moved from vehicle to vehicle.

In their experiments, Zaniewski and Butler (1985) used the slip energy model, developed by the US Forest Service in 1973, in order to calculate tyre wear. This is similar to the method adopted in the Brazilian study. The approach selected was to relate tyre wear to both the level of tractive force exerted by a vehicle and the tyre slip which occurs at the tyre/road interface. The best model was produced by relating the volume of tread rubber worn to the amount of slip energy expended at the tyre/road interface. Slip energy is simply the product of the total distance slipped by the tyres and the total horizontal force.

However, proper use of the model requires the quantification of data from the tyres, surfaces, and vehicles for which predictions are to be made. Furthermore, it is difficult to choose coefficients for the slip energy tyre wear model which are typical of a particular tyre construction on a particular surface.

The method employed by Zaniewski and Butler (1985) has severe limitations since tread wear is only one aspect of tyre life. Carcass deterioration is as, if not more, important since it limits the owner's ability to recap. Furthermore, their model does not consider complete tyre failure caused by blowouts or ablative tyre wear. It is important that the current study takes these above factors into consideration. This will facilitate a comparison with the other, non-theoretical studies.

2.6.4 Depreciation related Expense

A substantial cost for vehicle owners is that which is reflected in the change of capital value over time and use - otherwise known as depreciation. The major area of contention in the debate concerning depreciation expense is what, if any, portion of the expense should be assigned to operation on the road. As Winfrey (1969) notes, only the portion of the new price of a vehicle that is assignable to road use is valid in discussions related to road design alternatives.

None of the primary studies reported relationships of vehicle values as a function of age (in km or calendar years) and of the route characteristics over which the vehicles travelled. Instead they reported average vehicle age (in years) relationships that were generally obtained from national surveys of used vehicle prices. The effect of highway design characteristics appears to relate only indirectly to depreciation through the number of kilometres travelled. Therefore, fixed depreciation costs per time period can be placed on a per-unit time basis by changes in vehicle kilometres travelled.

There is a point at which a case could be made to sell a vehicle when running costs exceed revenue (or capital return) or scrapping that vehicle when depreciation and interest costs are zero. Chesher and Harrison (1987) have developed an optimal scrapping model that requires that vehicle life, s, satisfies the following equation :

$$\int_0^s [m(s) - m(t)]e^{-rt}\, dt = VP \qquad \text{............... Eq.2.6}$$

where

m(t) and m(s)	=	the per year rate of running costs for a t-year-old and s-year-old vehicle respectively,
r	=	per time period continuous discount rate, and
VP	=	new vehicle price.

Given the discount rate, the new vehicle price, and the predictions of running costs over time, the optimal vehicle life(s) can be determined using this equation. Furthermore, the flow of running costs at the scrapping date, m(s), is equal to the sum of the flows of depreciation costs, D(t), interest costs, I(t), and running costs, m(t), at any vehicle age, so that

$$\mathbf{m(s) = D(t) + I(t) + m(t)} \qquad \text{............... Eq. 2.7}$$

The latter condition implies that depreciation and interest costs are zero at the date of scrapping, and that total operating costs are invariant with respect to vehicle age, with increases in running costs (m(t)) being offset by decreases in depreciation and interest costs (D(t) + I(t)).

These two equations are important for this research for the following reasons. Equation 2.6 provides a way of predicting vehicle lives because, given the discount rate, r, new vehicle prices, VP, and the study's information concerning the flow of running costs (m(t)) and it's increase with vehicle age, equation 2.6 can be solved for vehicle life, s (Chesher and Harrison, 1987). Using this optimal vehicle life, equation 2.7 may be used to predict time-dependant depreciation and interest costs.

Curtayne et al (1987) note, however, that this equation is optimal only as long as vehicle use does not vary with vehicle age. It is likely that this method will be employed to estimate depreciation and interest charges for trucks in the South African environment.

Another method employed overseas to estimate depreciation and interest cost attributable to use was that of Zaniewski and Butler (1985). Their theoretical approach was to quantify the life mileage of vehicles in the highest 3 % annual mileage category. The depreciation of these vehicles was assumed to be totally assignable to use . The life mileage of the vehicle was divided into the depreciable value of the vehicle to obtain a current estimate of the depreciation expense attributed to use. The statistical approach used by Zaniewski and Butler was only possible, however, because of the large data base available to them and is obviously not possible in this research. Again these two researchers then used the Brazil project to adjust their depreciation expenses to reflect changes in road roughness.

2.6.5 Aspects of Fuel Consumption

In most of the previous studies, the fuel consumption component of VOCs has received a fair share of the attention, since it allows for relatively easy modelling and accounts for a large proportion of total VOCs. Despite this, there is considerable variance between reported results. This can be ascribed to two factors. First, the earlier studies in particular failed to relate fuel consumption to an objective measure of road condition (such as roughness). Second, even though later studies related fuel consumption to road roughness, results differ widely as to the contribution of roughness to fuel consumption.

In all primary studies, except the Brazilian study, the so-called aggregate-empiric approach was used to relate fuel consumption to road characteristics. Fuel consumption was measured directly in a number of types of instrumented vehicles on a great number of roads that varied in geometric properties and roughness. Regression analysis was then used to obtain the required relationships. The relationships obtained through this approach are, however, inflexible as they cannot be readily adapted to suit different engine types. Also, changes in technology will also necessitate a completely new experiment since the majority of aggregate-empiric results do not transfer easily and convincingly to the local conditions encountered.

In Brazil, fuel consumption was modelled mechanistically by accounting for engine and drive trains, wind and rolling resistance. The advantage of this approach is that new technology in tyres or vehicle design can be incorporated by revising estimates for the various coefficients, without having to re-run a major experiment. Furthermore, a fuel consumption equation for a specific vehicle type can easily be adjusted to suit another by adjusting the relevant coefficients.

du Plessis, Visser and Curtayne (1988) performed their experiment along these lines, in which relationships for the rolling resistance of a passenger car, 2 buses and 2 fourteen-ton trucks were derived. The following approach was adopted by them because of the flexible nature of such models.

Coast-down tests were performed on a series of road sections (from good paved to poor unpaved) with roughness levels ranging from about 20 to more than 200 QI. In addition to road roughness, the effects of road surface texture and tyre pressure were also investigated. The results obtained by them explained the variances between earlier fuel consumption models and provided a set of relationships believed to be the most reliable of those developed so far in South Africa.

It is not necessary to delve into the methodology or mathematical process by which they achieved their results for the following reasons :

i. Due to the comprehensive nature of their experiment it has been suggested that their results be employed in the development of VOC relationships for local use, and

ii. If a fuel consumption relationship were to be developed in the present project it would not be done using this method; the user survey approach would be adopted since the entire study focuses around this procedure.

In their experiment it was found that the roughness coefficients in the regression model of the different vehicles did not differ significantly and the data were thus pooled. Testing of various model forms showed that tyre pressure and roughness were significant in the relationship with rolling resistance, but that texture depth, vehicle mass, depth of loose material, and surface aggregate size were not. The following regression model of rolling resistance in terms of road roughness and tyre pressure emerged from their analysis :

$$A = 0{,}199 + 0{,}000322\ QI - 0{,}000177\ TYREP \quad \text{.............. Eq.2.8}$$

where

A = rolling resistance coefficient (N/kg)
QI = road roughness (counts/km), and
TYREP = tyre pressure (kPa).
R^2 = 0,56; and standard error of estimate = 0,0164

Consequently, their research showed that for a constant tyre pressure, the fuel consumption on very poor, unpaved roads (approximately 220 QI) is 23 percent higher than on good, paved roads (approximately 25 QI). Also, an increase in tyre pressure resulted in a reduction in fuel consumption. The above formula can be used to obtain rolling resistance in the prediction of fuel consumption for local conditions.

du Plessis, Visser and Curtayne (1988) conclude that the coast-down method employed in their experiment yielded repeatable results and proved to be of practical value. Verification of the results through a comparison of calculated and measured gradients supported confidence in the test procedures applied. Furthermore, the linear relationship between roughness and rolling resistance is, in form, similar to the results reported in overseas studies. The relationship to be used locally, until a better one is established, for fuel consumption, is therefore:

$$F = 151{,}078 + 0{,}524.QI + 2520/V + 0{,}0307.V^2 + 15\,970{,}7.G \qquad \text{.............. Eq.2.9}$$

where

F = fuel consumption (ℓ/1 000 km),
V = speed (km/h), and
G = gradient (m/m) or percentage.

As far as the overseas studies are concerned, Harrison and Visser (1985) report that the Brazil data suggests that the effect of road roughness on fuel consumption is significant. The other studies, however, have indicated an almost negligible effect. They go on to say that this follows from the difficulties of isolating the contribution of roughness from all the other factors affecting fuel consumption.

If an attempt were made to improve the fuel consumption relationships (du Plessis, Visser and Curtayne, 1988), it would obviously also require a speed variable input to match the comprehensibility of that study. This may be very difficult since the user survey may not provide speed data. In this case the researchers would have to employ some or other substitution variable which could lead to inaccurate fuel consumption predictions. Because of these factors it was decided not to model fuel consumption in this research. Equation 2.9 is thus the one to be employed for future fuel consumption predictions under South African conditions.

2.6.6 Aspects of Oil and Lubricant Consumption

Engine oil and lubricant consumption constitute a very small component of the total running costs of a vehicle and are rather difficult to analyze. They have therefore not been researched to the same degree as the other components.

As far as local research is concerned, Pienaar (1985) illustrates the effect of speed on oil consumption. Schutte (1987) fitted regression equations to the values obtained by Pienaar to produce a relationship between oil consumption and speed.

For medium trucks the equation is :

$$\text{OIL} = 0{,}38453 + 11{,}06646/V \text{ if } V \leq 50 \text{ kph} \quad \text{............... Eq. 2.10}$$

or

$$\text{OIL} = 0{,}74051 - 0{,}00624\,V + 0{,}000064V^2 \text{ if } V > 50 \text{ kph} \quad \text{................ Eq. 2.11}$$

where

OIL = oil consumption in litres/1 000 km, and
V = speed (kph).

In a different approach the HDM III model predicts the oil consumption as a function of roughness. This equation is as follows :

$$\text{OIL} = 3{,}07 + 0{,}000211\,\text{BI} \quad \text{............... Eq.2.12}$$

where

OIL = as above, and
BI (mm/km) = 35 QI (counts/km), from Paterson (1986).

Furthermore, it is believed that oil consumption is strongly related to travel speed and indirectly related to road roughness through variations in travel speed. The work by Pienaar (1984), however, is the first to allow for a good representation of operating conditions and speed on oil consumption. Consequently it is recommended that it should continue to be used in South Africa until better relationships are established. Further work on oil consumption was therefore not undertaken in this research.

2.6.7 Summary

As mentioned previously the documented literature covering the four major VOC studies is extensive. For this reason a summary is provided, giving some of the more relevant aspects of the major studies. This summary can be found in Table 2.2.

Furthermore, when taken out of context, many experimental results and observations could give a false impression of correctness. This is also true for survey data. This inefficiency may, however, be put right by comparing results to similar studies performed elsewhere. So, although overseas results are being calibrated to local conditions, it is still necessary to compare observations in order to prove their worth or otherwise. Where discrepancies arise, the differences must be substantiated and objectively reviewed. This Section also provides a summary of the relationships developed by the four major VOC studies, as well as other relevant studies.

Table 2.3 displays the equations which will be used for comparison purposes against the local observations. Relationships already shown in previous sections of this Chapter are not included so as to keep the table as short as possible.

TABLE 2.2: SUMMARY OF RELEVANT ASPECTS PERTAINING TO THE MAJOR VOC STUDIES (extracted from Chesher and Harrison, 1987)

STUDY	METHOD OF RESEARCH	FLEET SIZE	METHOD OF ROUGHNESS MEASUREMENT	PERIOD OF OBSERVATION	GEOMETRY OBSERVATIONS	OTHER
Kenya	User survey except fuel - aggregate-empiric approach	78 trucks (5 - 26 tonnes payload) for user survey, 1 truck for fuel experiments	Bump Integrator, units of mm/km	2 years, with 12 month periods of vehicle operation	Geometry obtained from maps or measured	Limited range of roughness and geometry
Brazil	User survey except fuel and tyres - mechanistic modelling	1675 vehicle records for all vehicle classes	Maysmeter, units of QI (counts/km)	Up to 3 years. average period of 18 months	Geometry surveyed and/or measured	Extensive fuel consumption experiments, wide range of roughness
Caribbean	User survey except fuel - aggregate-empiric approach	96 trucks (> 3 tonnes GVW), 19 for tyre analysis	Bump Integrator, units of mm/km	2 years, with 12 month periods of vehicle operation	Geometry obtained from maps or measured	Very low annual utilization (16 000 km), wide range of geometry
India	User survey except fuel - aggregate-empiric approach	232 trucks, 2 trucks for fuel experiments	Bump Integrator, units of mm/km	Up to 2 years, average period of 17 months	Geometry surveyed	Very broad study, including accident rate, road width, etc. Wide range of geometry, wide range of roughness

TABLE 2.3: RELATIONSHIPS PRODUCED IN THE MAJOR VOC AND OTHER RELEVANT STUDIES (Harrison and Visser, 1985)				
VOC COMPONENT	**STUDY**	**DEPENDANT VARIABLE**	**RELATIONSHIP**	**CONSTANT INPUT VARIABLES**
Fuel consumption	India - light	F =	85,07 + 3905/V + 0,0206V² + 0,066 QI + 3,328 RS - 1,777 FL - 6,24 PW	Will be studied if a comparison is undertaken.
	India - heavy		266,52 + 2517/V + 0,0362V² + 0,363 QI + 4,265 RS - 2,737 FL - 6,26 PW	
	Brazil		Falls outside the scope of this study	
	Caribbean		29,4 + 2219/V + 0,02031V² - 2,6 FL + 0,0132 FL² + 0,8478 GVW.RS	
	Kenya		121,99 + 796/V + 0,015V² + 4,176 RS - 2,216 FL - 2,619 PW + 1,969 D + 0,03 QI	
Maintenance-relative parts consumption	India	P/VP =	EXP(1,1213 + 0,00787QI + 0,0531 GVW)	GVW = 4 tons, AGE = 100
	Brazil - light		(1,931 + 0,4862QI) AGE^0,371	AGE = 100
	Brazil - heavy		(11,168 + 0,3944QI)AGE^0,371	AGE = 100
	Caribbean		(-6,54 + 0,1738QI - 0,00001155QI^2)(AGE + 6)	AGE = 100
	Kenya		(0,48 + 0,0204QI)(AGE + 23)	AGE = 100
Maintenance-labour consumption	India	Labour hours/ 1000 km =	1,296 EXP (0,001375 QI)(P/VP)^0,654	AGE = 100
	Brazil		(0,766)(P/VP)^0,519	AGE = 100
	Kenya		(0,0298 - 0,0000429QI)(P/VP)	AGE = 100
	Caribbean	Labour cost =	Parts cost x 0,45	
Tyre consumption	India	ENT =	6/(51,766 - 0,088 QI)	
	Brazil		6/(84,592 - 0,077 QI)	
	Caribbean		GVW (0,00706 + 0,0000743 QI)	GVW = 12 tons
	Kenya		GVW (0,0083 + 0,0000616 QI)	GVW = 12 tons

Note :

F	=	fuel consumption ($\ell/10^3$ km),
V	=	vehicle speed (km/h),
QI	=	road roughness (counts/km),
RS	=	rise (m/km), FL = fall (m/km),
PW	=	power to GVW ratio (kW/ton),
GVW	=	gross vehicle weight (tons),
D	=	depth of loose material on gravel roads,
P/VP	=	relative parts consumption (refer to section 7.4.1),
AGE	=	vehicle age at survey midpoint (10^3 km),
and		
ENT	=	equivalent new tyre life (per 10^3 km, per vehicle)

2.7 Other Aspects

The method used to express the different data and the recommended ranges of vehicle attributes and roadway characteristics are clearly of significant importance in this project. It would be unfeasible, for example, to do research on vehicles which have excessive kilometrage or are very old since the VOCs may not provide a true reflection of how roughness affects VOCs. In a report by du Plessis and Rust (1988) they summarize the ranges recommended by the HDM III manual.

The recommended range of vehicle attributes for medium trucks are :

gross vehicle mass	5000 - 16000 kg
payload	0 - 11 000 kg
projected frontal area	5,0 - 8,0 m^2
cumulative kilometrage	0 - 600 000 km

The recommended range of roadway characteristics are :

road roughness	0 - 200 QI
positive and negative gradient	0 - 12 %
horizontal curvature	0 - 1200 degrees/km
altitude	0 - 5000 m

In their report they also cover the method of expression for the different VOC components and the unit cost or multiplying factor used when converting from units to costs. Table 2.4 displays the method of expression and multiplying factors.

In their research, Zaniewski and Butler (1985) express the components as the following percentages of the overall costs :

(a) maintenance and repair - the percentage of the average cost per kilometre of operation, and

(b) tyres - the percentage of the cost of a set of tyres,

(c) depreciation - the percentage of the depreciable value for a new vehicle.

These dependent variables were selected because they are readily available and, hence, operating costs can be readily updated or computed for specific regions. This method of expression may thus have applicability to this project.

COMPONENT	METHOD OF EXPRESSION	UNITS	UNIT COST OR MULTIPLYING FACTOR
Maintenance parts	P/VP	Proportion of new vehicle price per 1 000 km	Cost of new vehicle
Maintenance labour	L	Hours per 1 000 km	Wage cost/hour
Tyre wear	ENT	No. of equivalent new tyres per 1 000 km	Cost per tyre
Depreciation and interest costs	D(t) + I(t)	Time - dependant Rands	Rands
Fuel consumption	F	Litres per 1 000 km	Cost per litre
Lubricants usage	OIL	Litres per 1 000 km	Cost per litre

TABLE 2.4: METHOD OF EXPRESSION AND MULTIPLYING FACTORS FOR THE VOC COMPONENTS

2.8 Summary and Proposals

In the development of a policy in which the total community costs for any road link or network are minimized, the quantification of vehicle operating costs plays a vital role. To eliminate the inclusion of vehicle operating costs in an economic appraisal of highway alternatives is to totally undermine the confidence and validity of the decision.

For these reasons, there has been an international attempt at predicting the benefits to be derived from VOCs in the upgrading of any road or road network. However, relationships produced in different socio-economic climates may not be employed in a particular region until their validity has been established. In order to produce South African relationships it is necessary, within time and money constraints, to calibrate international results to local conditions, and to quantify the effect of road roughness on vehicle operating costs.

This Chapter attempted to document most of the available literature on the vehicle operating costs for trucks and to expose those areas in which further research work should be carried out. It's purpose was, however, twofold since it also exposed those areas in which comprehensive work has already been undertaken and as such need not be readdressed. Furthermore, it facilitated the understanding of the subject in order that the research be correctly undertaken.

It is clear, from the documented literature, that the following vehicle operating cost components for trucks require attention and a calibration of overseas relationships to local conditions :

i. maintenance consumption - both parts and labour, and
ii. tyre consumption,
iii. depreciation and interest costs.

The work done by Pienaar (1985) and Schutte (1987) have produced oil consumption relationships which are thought to apply to local conditions. du Plessis, Visser and Curtayne (1988) produced a comprehensive set of fuel consumption equations which take into account most of the variables affecting this component. Their mechanistic model for fuel consumption has great advantages over a user survey study since speed and other variables can be readily included. It would be unrealistic to assume that these variables can be modelled from a user survey study in which the likelihood of them being available is minimal.

A definite attempt must be made to model tyre and maintenance consumption as these are not available for trucks operating under South African conditions. But, because good data are expensive to collect, the challenge is to develop effective calibration procedures based on secondary data. Once accomplished, the overseas results can be calibrated to South African conditions for future use in economic evaluations of highway alternatives. Furthermore, the relationships should be developed so as to be applicable over a period of time and should be efficiently transferrable to other environments.

As far as depreciation and interest costs are concerned, an attempt should be make to relate these to road condition. The methodology of the exercise will be that proposed by Chesher and Harrison (1987) and reported on in Section 2.6.4. The major VOC studies dealt with these costs by relating them to vehicle life (in years) and value, but non related depreciation and interest to road condition. It is anticipated, therefore, that a few problems may arise during this phase of the research. Table 2.5 summarises the existing status of VOC components for medium trucks, in tabular form, and shows which are those to be addressed in this research.

TABLE 2.5: STATUS QUO OF VOC COMPONENTS FOR MEDIUM TRUCKS IN SOUTH AFRICA							
	Maintenance Consumption						
	Parts	Labour	Tyre Cons.	Deprec-iation Charges	Fuel Cons.	Oil Cons.	Speed Predic-tions
Comprehensive local relationships exist					X	X	
Comprehensive local relationships do not exist, but the calibration thereof falls outside the scope of this study							X
Existing relationships must be calibrated to suit local conditions	X	X	X	X			

Finally, it is also recommended that once the results are known, a comparison be made with other studies, both international and local, in order to ascertain the validity of the results. This would indicate those relationships which would best suit local conditions in the analysis of truck vehicle operating costs for South Africa.

PART II

METHODOLOGY OF DATA COLLECTION - BOTH VOCs AND ROUGHNESS

3. PREAMBLE

By definition, research involves the collection and observation of some or other type of information or data and analysing it in order to produce worthwhile information. It is the data collection phase of any research which must be afforded critical examination; one cannot produce results from data which is incorrect or has been erroneously assimilated.

It is in light of this that these 4 Chapters have been prepared, as they outline the methodology of the data collection undertaken in this research. Considering all the factors laid out in Part I of this report it was necessary that certain requirements be fulfilled. These are:

(i) A large firm operating a relatively large fleet of medium to heavy trucks over an extensive area should be sought;

(ii) The route characteristics of the fleet should cover as wide a range as possible, with specific reference to road roughness;

(iii) As far as the vehicle operating cost records of the firm are concerned, they should be regularly updated, accurate, comprehensive and easily assessable. In addition, the records should cover a period of at least 12 months.

In accordance with previous studies, it was necessary to use data from a single company that provides a similar service over a representative range of road roughness's. This is because analysis of the Brazilian and Indian VOC survey data shows that fundamental differences exist between companies, especially with respect to recording systems, maintenance procedures, and the like.

Consequently, a few firms and associations were approached, with the idea of finding a suitable one that satisfied all the above criteria. They were, however, dismissed as prospects for data collection, since their vehicles travelled solely on paved roads and vehicle operating costs at high roughness levels were thus unattainable. Subsequently, a holding company which has 7 forestry operations under it's leadership was approached. Five of these operations were selected as inspection of both their macro and micro levels of operation and cost recording systems proved to satisfy the precedented conditions. Combining their data laid the foundation on which the research could be carried out. For the five operations the total fleet comprised 91 vehicles with a combined annual usage of 3 500 000 km. (For the 1990 financial year). The fleet vehicles are used predominantly for logging operations, i.e. carting logs from within the forest to the sawmill and then returning for another load. The road conditions range from smooth, paved roads to very rough roads (> 200 QI).

The five forestry operations, the geographical location of each, and the size of the respective fleets are given in Table 3.1. It should be noted, however, that there is an obligation on the part of the researchers to keep the names of the different operations confidential. The names have therefore been substituted by the letters A, B, C, D and E.

TABLE 3.1: DEPOT LOCATION AND FLEET SIZE

OPERATION	GEOGRAPHICAL LOCATION		FLEET SIZE (AT SEPTEMBER 1990)
	TOWN	REGION	
A	Sabi	Eastern Transvaal	23 vehicles
B	Tzaneen	Northern Transvaal	9 vehicles
C	Pietermaritzburg	Natal Midlands	19 vehicles
D	Weza	Southern Natal	11 vehicles
E	Singisi	Northern Transkei	29 vehicles

The next 3 Chapters broadly outline the operating principles of the logging firms involved and give details of the modus operandi of the data collection - both VOCs and road roughness.

4. COMPANY POLICIES AND OPERATIONS

As mentioned previously, the business concern approached was merely a holding company, which had 7 forestry operations under its administration. It is important to note, however, that each operation was a separate entity, with its own autonomy and management. Each operation had very little to do with the others bar the interaction provided through the holding company.

Furthermore, the holding company is instrumental in ensuring that the different forestry operations have, fundamentally, the same operations policies. This is to say that they all maintain their vehicles to approximately the same standards, their missions, goals, objectives, accounting and bookkeeping systems were the same, and their approach to financial principles are similar. In addition to this the decisions made by management teams are globally affected by the holding company. It can be assumed, therefore, the condition that data be collected from a single company (Chesher and Harrison, 1987) is satisfied.

Of the 7 operations, 5 were chosen for proposes of data collection for reasons mentioned previously. Each depot used the same computer software to record their information in terms of a vehicle ledger. This sub-program formed a part of their larger, company ledger and as such could not be copied onto a disk without revealing the depot's financial position. The data was therefore entered manually from copies of the vehicle ledger print-outs.

The data from these ledger print-outs were in purely monetary units with no reference to any quantities whatsoever. The exception was, of course, the kilometres travelled by the vehicles. This was to the advantage of the researchers since no conversion had to be made between unit quantities and monetary values. It was still necessary, however, to obtain statistics showing the amount of new tyres bought and the number of retreads per casing in order to calculate the "equivalent new tyre life" value for the formulation of VOC relationships for tyres.

At each depot at the end of every month the costs per vehicle for the different components are entered onto computer. The software then calculates the total for each VOC component for each vehicle for 3 periods - the month that is entered, the year-to-date figure, and the costs for the life of the vehicle. The year-to-date statistic provides information on the sum of VOCs for a particular vehicle from the beginning of the financial period (in this case the 1st of April) to the month in question. It was necessary therefore to obtain only 3 printouts to cover the 18 month period. These were the year-to-date figures for September 1989, March 1990 and September 1990. The year-to-date figures for September provided the 6 month totals from April to September (both months inclusive) for that year. Since the year-to-date figure for March 1990 is the entire financial year total, the 6 month year-to-date figure for September 1989 was subtracted to obtain figures for the 6 months October 1989 to March 1990 (both months inclusive).

During the 18 month period used for the research a number of new vehicles were purchased by each depot. The VOC data for these vehicles was then used only in that period for which it incurred costs.

Routine maintenance was performed on a regular basis at every depot, consisting of a lubricant change every 2 weeks, a regular service every 4 weeks and a major service every 6 months. This converts, on average, into a service every 3000 - 4000 km. Insofar as engine overhauls or rebuilds were concerned, there was no company policy as to when these be undertaken. Most vehicles were either scrapped or sold before the depots considered rebuilding them. Depot B, however, has recently given consideration to the matter and has decided it would be financially viable to rebuild their vehicles at 300 000 km. Depot E used to rebuild their vehicles but now consider it financially viable to sell their vehicles once they attain an age of 5 years.

5. COLLECTION OF DATA AND DISCUSSION OF OPERATING COST DATA

The data that was eventually extracted from the depot records proved to meet and even better expectations. Vehicle operating costs were available for 18 months and were treated as three separate periods - the 3 six months periods leading up to and including the months of September 1989, March 1990 and September 1990. Each operation was visited, in turn, to obtain vehicle operating cost data and, at a later stage, to measure the roughness of the roads.

The data that was made available to the researcher's comprised of fuel, oil, tyres, parts and labour costs (all in monetary units) per vehicle per 6 month period. Furthermore, and of equal importance, the kilometres covered by each vehicle for each 6 month period and the kilometrage age of the vehicles was provided. The make and model of each vehicle was also furnished in order that the prices for the equivalent new vehicle may be obtained. Other aspects not relevant to this survey were also included. A sample data report sheet is provided in Appendix A.

The data collected allowed for the deduction of relationships for maintenance (parts and labour), tyres and for depreciation/interest charges. These relationships were calculated using the same form that was adopted for the major VOC studies, the VOC component being expressed in terms of road roughness and, sometimes, other variables.

It was thought initially that roughness comparisons would be made within each separate operation. It turned out, however, that comparisons of roughness and VOCs were made between depots and not within depots. The reasons for this are discussed in Chapter 6 of this report along with further salient points concerning the collection of roughness statistics.

From reports for three consecutive 6-month report periods starting April 1989, a data file was compiled containing the following information per vehicle, per period and per depot:

Vehicle type and fleet number
Total distance travelled (km)
Vehicle age (months and km)
Total spares cost (R)
Total labour cost (R)
Total tyre cost (R)

These figures were then used to calculate spares and labour costs per km. The final data file is shown in Appendix B. Furthermore, a number of data files were constructed, with each serving its own purpose - usually to allow for the calculation of relationships or to allow for the construction of Figures shown in later Chapters. Appendix C shows an example of one of these data files containing average figures per depot which was used in the regression analysis for parts and labour consumption.

Inspection of the data revealed that certain vehicles were reported to attract extremely high costs during certain 6-month periods and were quite obviously out of line with the cost trends within that depot. Each of these suspected cases was followed up with the depot fleet manager concerned to ascertain probable causes. In cases where the vehicle had undergone a major overhaul or major unit (engine, gear box or rear axle) replacement, that vehicle was removed from the file, since large cost items of that nature should, in fairness, be discounted over the whole vehicle life, and not only over a 6-month period.

A further data file was constructed which contains the average tyre life and the number of retreads per tyre casing for each depot for each period. From this data file the average distance travelled per tyre casing was calculated which permitted the computation of an "equivalent new tyre life " for each depot. This calculation, which is explained in detail in Section 2.6.3, was first used in Kenya and was subsequently adopted by all major studies. It is used to incorporate the number of aborted tyre casings due to premature failings, eg. tyre penetrations, tyre splits and the like. This is to ensure that the number of casings used is not wholly attributed to tyre wear on a particular surface but also to premature failings. Table 5.1 displays the extra tyre data collected at each depot in order to perform these calculations.

TABLE 5.1: EXTRA TYRE DATA PER DEPOT						
DEPOT	NEW TYRES		RETREADS		NO OF RETREADS PER CASING	AVERAGE DISTANCE ACHIEVED PER CASING (km)
	NO USED	PRICE (RANDS)	NO USED	PRICE (RANDS)		
A	114	632	227	250	2	35 000
B	X	609	X	293	1	33 000
C	55	630	167	393	2	30 000
D	X	313	X	216	1	10 000
E	106	844	314	220	3	90 000

X - information not available

In addition to the data assimilated from the depots and from roughness measurements, it was also necessary to approach vehicle manufacturers to obtain new vehicle prices. This was necessary for the analysis of parts maintenance and these figures represented the new vehicle price of all the different vehicles used, at the mid-point of each of the 3 six month periods. Table 5.2 presents these new vehicle prices

TABLE 5.2: NEW VEHICLE PRICES			
MAKE AND MODEL	NEW VEHICLE PRICE (RANDS)		
	APRIL 1989 - SEPTEMBER 1989	OCTOBER 1989 - MARCH 1990	APRIL 1990 - SEPTEMBER 1990
Nissan CM15	130 660	137 815	143 675
Nissan UG780	96 115	101 175	104 480
Nissan CW45PAN	240 095	256 185	266 550
Hino 13136	115 193	122 055	126 045
Hino 14177	133 303	141 243	145 858
Hino 39240	222 570	239 175	246 990
Hino 26280	248 245	261 835	270 390
Isuzu 8000DFN	116 083	122 180	126 295
Isuzu F9000DFT	134 063	140 443	145 210
Mercedes Benz 1113	110 375	117 830	117 830
Mercedes Benz 1413	132 235	149 565	158 270
Samag 70L	170 890	179 298	189 263
Samag 240/16	239 688	255 681	266 134

6. MEASUREMENT AND ANALYSIS OF ROAD ROUGHNESS

Section 2.3 of this report delved into the somewhat difficult subject of road roughness. It also explained the use of the LDI roadmeter in quantifying road roughness by converting it's measurements into units of the QI scale (counts/km) - a widely used measure of roughness. This facilitated in the comparison of results with other studies. However, the controversial method of "averaging out" roughness measurements in order to achieve a roughness value for a particular stretch of road was merely touched upon. This Chapter serves to explain how and what measurements were taken and then investigates the method of analysis of roughness measurements. Both the traditional ("averaging out") and an alternative method are discussed.

The Council for Scientific and Industrial Research provided the LDI vehicle with which roughness measurements were carried out. Before these measurements took place, however, the depot fleet managers were asked to prepare the following information, which is required in the assessment of measurements:

(i) A depot route map;

(ii) A specific route which was broken up into subjective classification. These classifications were in terms of road roughness and had to represent, as far as that particular depot was concerned, the average travel in that roughness category by a fleet vehicle on an average day in the 18 month period. This was done because it was practically impossible to travel on all the roads in a particular depot in order to measure road roughness. A far more feasible method was to obtain this "average" route which the depot fleet manager felt represented the mean at the routes, travelled by all of his vehicles, over the entire period;

(iii) The classifications that were used to represent the different roughness categories were:

* paved surface
* good unpaved (gravel surface)
* fair unpaved (gravel surface)
* poor unpaved (earth/unimproved surface)

(iv) The average percentage of travel of the vehicles in each of these categories throughout the 18 month period.

It should be noted, however, that problems were experienced in this regard. They were mainly the inability of the depot managers to find such a route and, once found, the deterioration of these routes, due mainly to rain before the measurements could take place. These problems did not become an obstacle, though, and were easily overcome.

Once this information had been prepared by the depot fleet managers, the LDI roadmeter measured the roughness of each different representative section at each depot. The information that was obtained is set out in Table 6.1. The weighted QI value (or the "average QI") is obtained by weighting the QI value by the percentage of travel on that road category. This is the conventional method of obtaining a representative road roughness value and is discussed further in the next section.

TABLE 6.1: QUANTIFICATION OF ROAD ROUGNESS PER DEPOT

DEPOT NAME	TOPO-GRAPHY	ROAD CATEGORY	% TRAVEL	QI	WEIGHTED QI
A (Sabie)	Rolling to mountainous	Paved Good unpaved Medium unpaved Poor unpaved	50 25 15 10	30 110 250 300	110
B (Tzaneen)	Rolling to mountainous	Paved Good unpaved Medium unpaved Poor unpaved	40 50 10	20 100 235	80
C (Pieter-maritzburg)	Rolling to flat	Paved Good unpaved Medium unpaved Poor unpaved	8 60 32	30 75 250	130
D (Weza)	Rolling, 5 % mountainous	Paved Good unpaved Medium unpaved Poor unpaved	30 70 	30 200 	150
E (Singisi)	Rolling, 5 % mountainous	Paved Good unpaved Medium unpaved Poor unpaved	55 12 25 8	25 40 160	40

6.1 Conventional roughness assessment

It became apparent on examination of the roughness measurements that the classification of routes into the different roughness categories did not turn out as expected. The subjective assessments of road condition varied widely between depots, as is evident from the measurements taken per depot on "similar" road classes. These assessments therefore were only valid as relative assessments within a deport - there was barely any correlation between corresponding categories at different depots.

Furthermore, it was thought that there may be a possibility that vehicles could be matched to certain routes and thereby certain roughness levels. In this case a direct comparison between VOCs and road roughness could take place. However the primary difficulty with relating cost figures to these roughness assessments is that cost figures apply to the depot as a whole and not to a specific vehicle traversing a specific road section with a known roughness value. Vehicles are subjected to a wide variety of road conditions at any one depot. Therefore, a direct comparison between VOCs and roughness proved impossible and the formulation of an "average" road roughness value per depot was necessary. The vehicle operating costs at a particular depot could then be matched to the "average" roughness at that depot and compared to VOCs at different roughness levels at other depots.

In developing the vehicle operating cost model, the depot roughness values are regressed against the dependent variable. For purposes of this research the dependent variables are parts, labour and tyre consumption and indirectly, depreciation costs. Other factors also play a part in these regression models but these have been discussed in Chapter 2. Furthermore, the equations take a similar form to those described in Chapter 2 of this report.

6.2 Alternative method of roughness assessment

Clearly, the conventional method of roughness assessment has its shortcomings in that it fails to address the direct link between VOCs and road roughness. It can be argued that, in averaging out roughness measurements to achieve a specific roughness value for a particular depot, the fundamental principle that the two are directly linked breaks down.

A new method of roughness assessment has consequently been proposed, in which an attempt has been made to overcome these complications. Instead of expressing roughness as a weighted average of the measurements obtained at a particular depot, it is expressed as a percentage of travel per roughness class. All roughness measurements are grouped into specific classes and the percentage of travel in this class is regressed directly against the dependent variable.

The classes that roughness measurements were grouped into are:

(i) percentage of travel in the 0-35 QI class;

(ii) percentage of travel in the 35-75 QI class;

(iii) percentage of travel in the 75-150 QI class;

(iv) percentage of travel in the > 150 QI class.

Table 6.2 shows the percentage of travel in each roughness class for each depot. The nominal QI value in the respective class is also displayed.

TABLE 6.2: PERCENTAGE OF TRAVEL IN EACH QI CLASS PER DEPOT

DEPOT	QI (COUNTS/km)			
	0-35	35-75	75-150	> 150
A	50	0	25	25
B	40	0	50	10
C	8	30	30	32
D	30	0	0	70
E	55	37	0	8
NOMINAL QI	25	50	100	200

The regression techniques for this method of roughness assessment are similar to that of the conventional method, although the equations take a different form. Instead of having just the one roughness independent variable there are now 4, and the form of the equation is:

$$\text{Independent variable} = C_1 + C_2 \cdot K + C_3 \cdot QI_{25} + C_4 \cdot QI_{50} + C_5 \cdot QI_{100} + C_6 \cdot QI_{200}$$

where

C_1	=	constant,
C_2	=	coefficient for other independent variables, e.g. AGE
K	=	other independent variables,
QI_{25} - QI_{200}	=	% at travel in each respective roughness class,
C_3 - C_6	=	coefficients for QI_{25} - QI_{200}

In both the conventional and the alternative method of roughness assessment it has been assumed that the roughness values obtained were representative of the entire period over which data was assimilated. The importance of this is that there are 3 identical values of roughness being regressed against 3 different VOC component costs at each depot. This, unfortunately, masks the effect of roughness on vehicle operating costs to a certain extent and the ideal situation would have been to obtain roughness measurements during each 6 month period. However, time and money constraints were the limiting factor in this regard and it is still felt that, despite this deficiency, the results will be of benefit to potential users.

PART III

RESULTS AND COMPARISONS

7. COMMENTARY

The dilemma in the research thus far is what method of roughness should be recommended for future implementation of vehicle operating cost analyses. This enigma can be found in most research concerning the relationship between road roughness and vehicle operating costs.

Part III serves to elaborate on the subject with regard to data collected and results obtained. In so doing it paves the way for a firm decision with respect to which of the methods is a more accurate and reliable representation of the above-mentioned relationships.

Part I concluded with a recommendation of the VOC components to be addressed in this study, being maintenance, tyre and depreciation/interest costs. Each of these are discussed and analysed using both the traditional and alternative method of roughness measurement. The regression equations obtained in each case are compared with one another to facilitate in the understanding of the concepts.

Furthermore, a Chapter is provided in which comparisons are made between results produced in this study and those of the major, international VOC studies.

8. THE DETERMINATION OF VOC RELATIONSHIPS - CONVENTIONAL METHOD

In this Chapter the 3 components of VOCs being researched are analysed using conventional roughness assessment methods. A brief description of the numerical operation involved for each component is entered into and then the regression equation provided. In addition to this, graphs are provided showing the actual data collected as well as the regression line which best fits the data. The influence of outside factors on each component is also addressed and, where applicable, graphs are provided showing these effects.

8.1 Maintenance and repair costs

8.1.1 Maintenance costs - Parts

As discussed in Chapter 2 of this report the analysis of parts costs requires that the parts cost be divided by new vehicle prices. This yields a relative parts consumption variable insensitive to price increases and allows for a comparison between this study and previous work where similar practice was followed (Chesher and Harrison 1987). Thus maintenance parts rates were calculated per vehicle, per depot and per period.

Furthermore, the effect of vehicle age has become apparent in studies concerning parts consumption and this is clearly indicated in Figure 8.1. Vehicle age is plotted against parts consumption for a roughness of 70 QI for locally collected data. In this case the parts consumption was normalised in order to show the effect of vehicle age.

The process of normalising data involves the use of the corresponding regression model (obtained from the data). It can probably best be depicted as attempting to find the numerical value of the dependant variable at a certain numerical value of the independent variable. The following conceptual equation illustrates this further, in which a normalised value of P/VP is obtained for a QI value of 70:

$$\text{Parts} = \text{Constant} + \text{AGE} + \text{QI}$$

So, if one wants to plot AGE against Parts for a QI of, say, 70, then:

$$\frac{\text{Parts}_{(70)}}{\text{Parts}_{(actual)}} = \frac{\text{Constant} + \text{AGE} + \text{QI}_{(70)}}{\text{Constant} + \text{AGE} + \text{QI}_{(actual)}}$$

therefore,

$$\text{Parts}_{(70)} = \text{Parts}_{(actual)} * \frac{\text{Constant} + \text{AGE} + \text{QI}_{(70)}}{\text{Constant} + \text{AGE} + \text{QI}_{(actual)}}$$

Using this equation the normalised Parts consumption can be calculated at a QI of 70 for different AGE values. In this way the normalised data shown in Figure 8.1 was obtained, and the same principle is applied elsewhere in this report.

The parts consumption regression equation arrived at for this study, using the conventional method of roughness and accounting for the effect of both roughness and vehicle age is:

$$\ln(P/VP) = -3.0951 + 0.4514\, ln(AGE) + 1.2935\, ln(QI) \qquad \text{............... Eq. 8.1}$$

where

P	=	parts cost in $R/10^3$ km,
VP	=	new vehicle price in R 10^3,
AGE	=	vehicle age in 10^3 km, and
QI	=	road roughness in counts/km.

An R^2-value of 0,75 was obtained from 15 observations, with a standard error of estimate of 0,35.

Figure 8.2 displays this regression model, as well as the normalised data for a vehicle age of 110 000km. This vehicle age was chosen as it represents the average age of the vehicles at all depots at the midpoint of the data collection period.

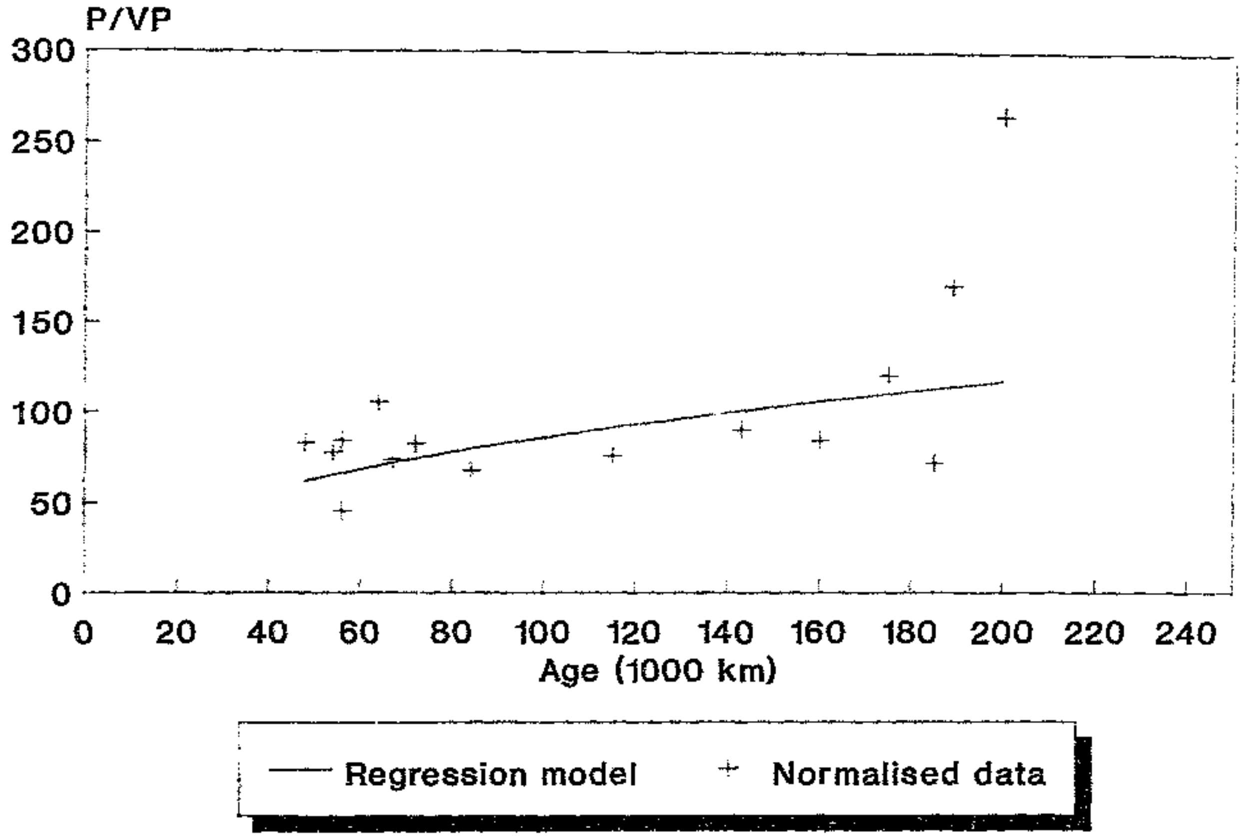

FIGURE 8.1: P/VP vs AGE, QI=70

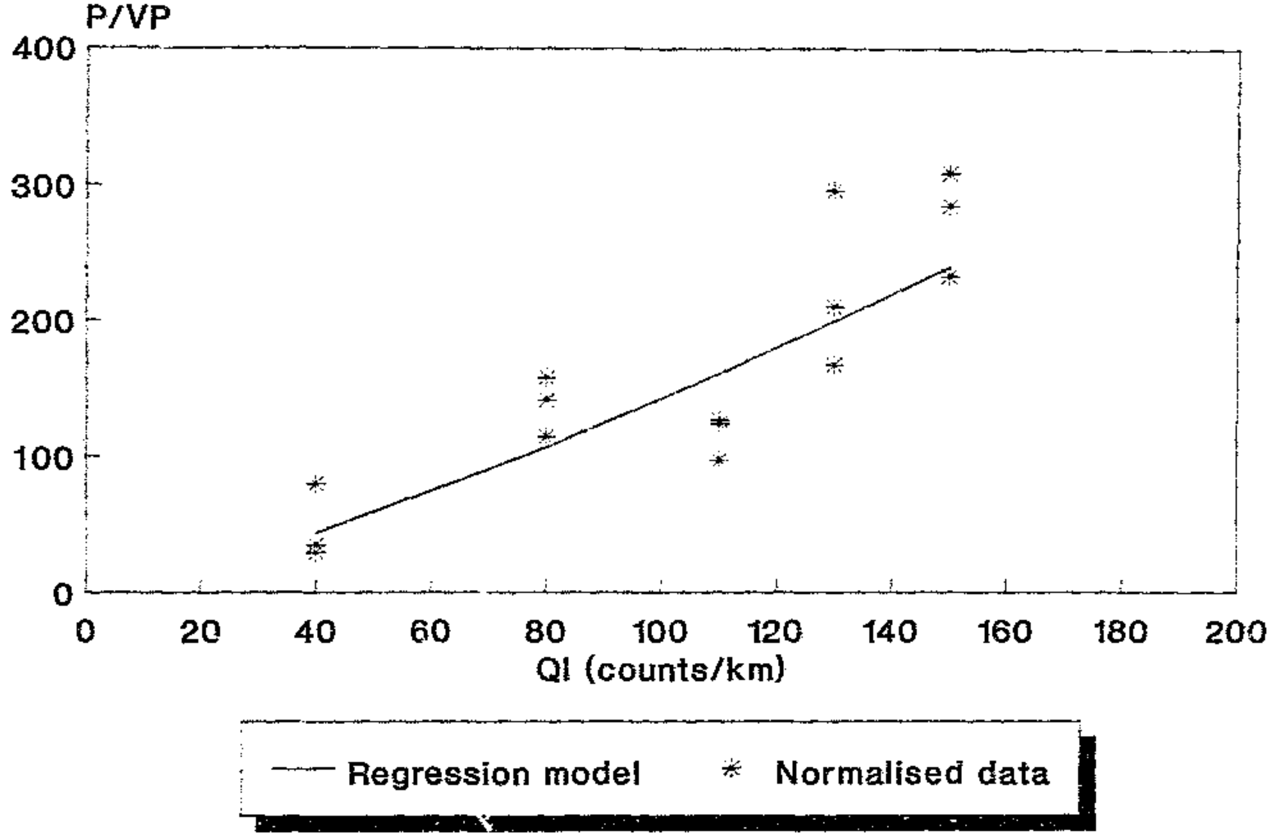

FIGURE 8.2: P/VP vs QI, AGE=110 000 km

8.1.2 Maintenance costs - Labour

As mentioned in the previous Section the relative parts consumption of vehicles is affected by the vehicle age as well as road condition. The fact that labour costs usually increase with a general increase in parts consumption indicates that labour costs are also affected by vehicle age and road condition. This is to say that more time will be spent repairing vehicles travelling on rougher roads than those travelling on smooth roads, as well as vehicles that have a high kilometrage age. These notions were also confirmed by the fleet managers and the data analysis.

Part I of this report indicated that labour consumption should be regressed against both parts consumption and road roughness. In an attempt to justify the regression of labour using a parts consumption variable, the two costs were graphically and mathematically compared. A regression between the two produced an extremely well correlated pair - with a correlation coefficient of 0,92. A visual representation of this is highlighted in Figure 8.3 where parts costs are plotted against labour costs. The regression model is also displayed, although it is not necessary for purposes of this research to provide the equation.

Labour costs were expressed in R/1000 km and regressed against average depot roughness and relative parts consumption. It was unnecessary to include vehicle age in the regression as this influence is implicitly accounted for by regressing against relative parts consumption. In addition to this the effect of inflation is also considered by regressing against relative parts consumption.

A plot of the normalised average labour figures per depot, together with the regression equation is shown in Figure 8.4. A P/VP value of 200 is used since it represents the average value encountered in this research. The following model proved to best fit the data :

$$\mathbf{LAB} = \mathbf{-18{,}7453 + 0{,}8572\ (P/VP) + 0{,}6753\ QI} \quad \text{.............. Eq.8.2}$$

where

LAB = labour costs in $R/10^3$ km, and
P, VP and QI are as in Section 8.1.1

An R^2-value of 0,88 was obtained from 15 observations, with a standard error of estimate of 40,2.

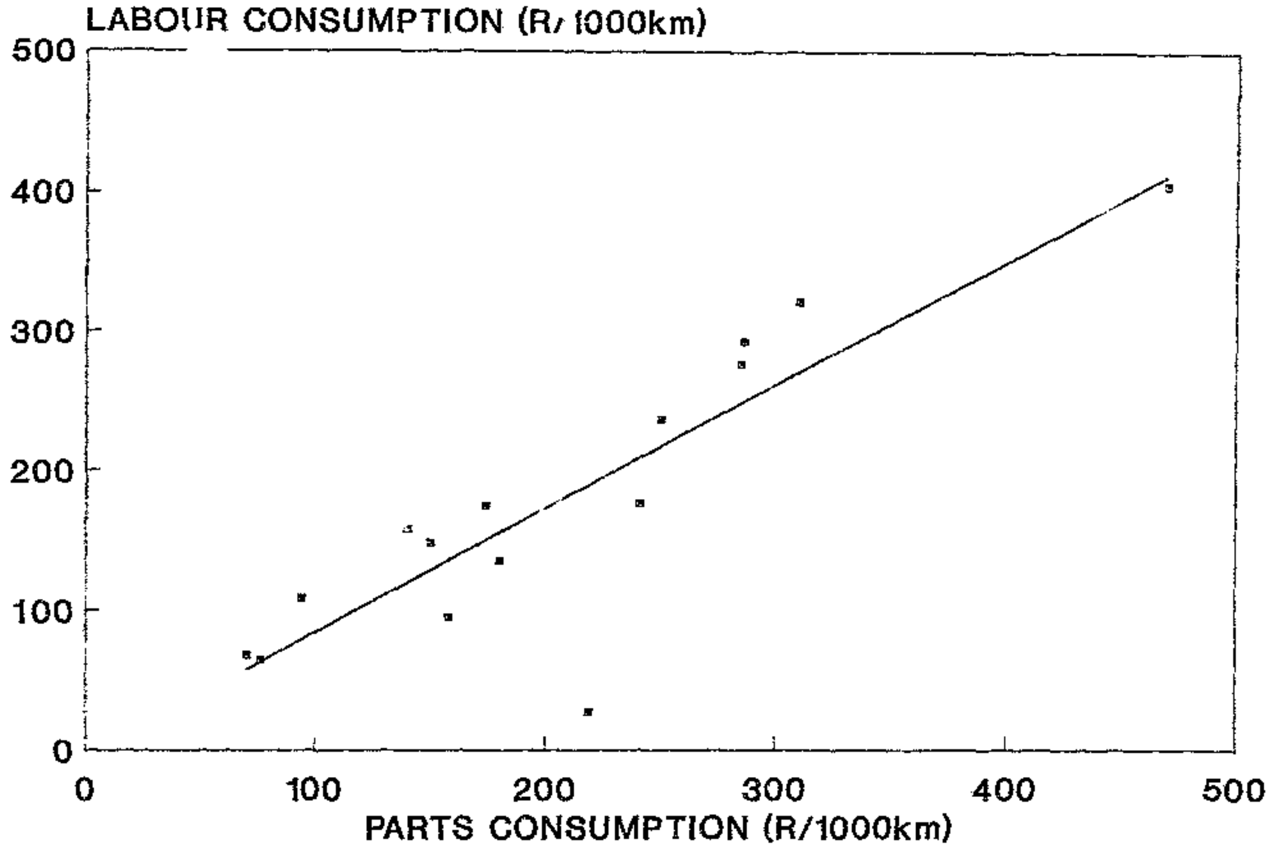

FIGURE 8.3: PARTS vs LABOUR CONSUMPTION

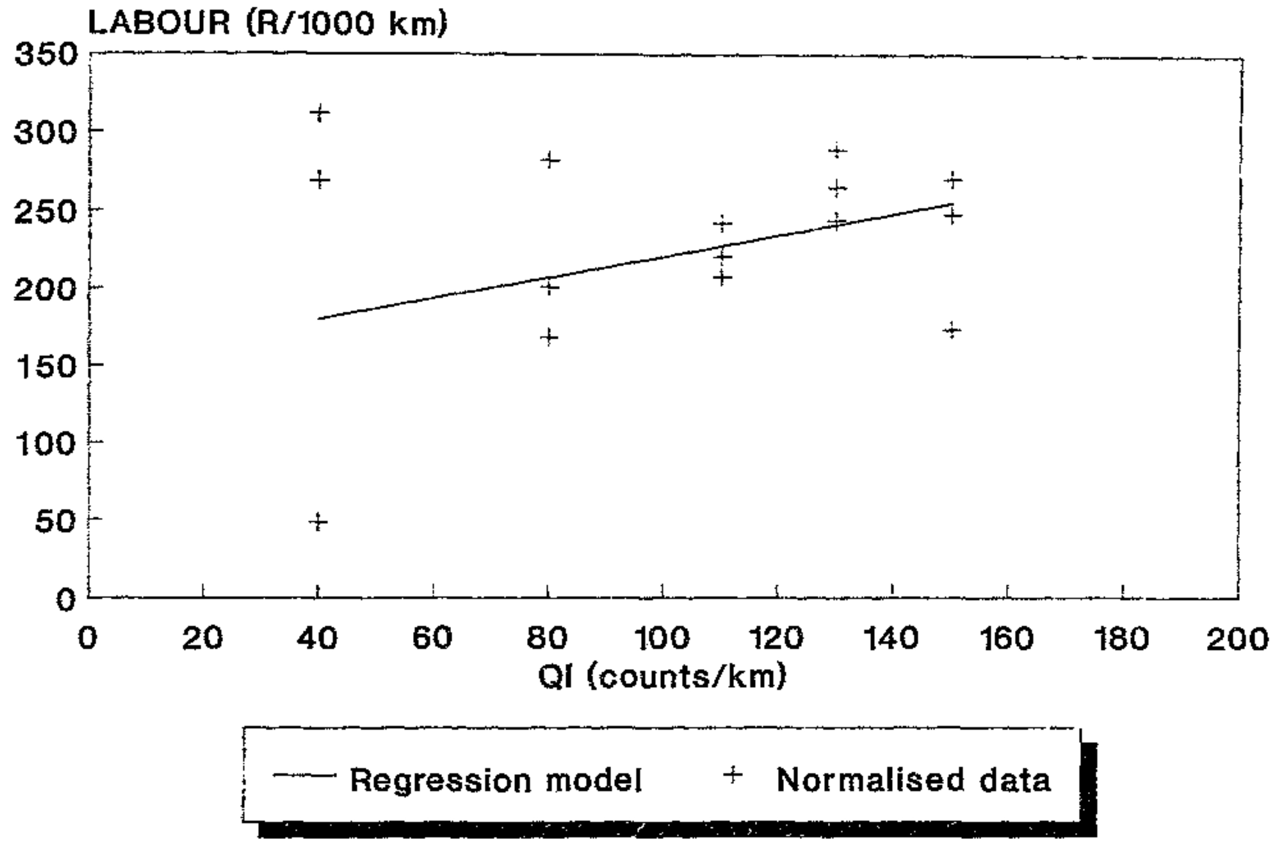

FIGURE 8.4: LABOUR COSTS vs QI, P/VP=200

8.2 Tyre consumption

A detailed explanation of the way in which tyre consumption is dealt with in research of this kind was provided in Part I. This Section analyses this vehicle operating cost component according to the methodology laid out.

From Table 5.1 the equivalent new tyre life (ENT) in kilometres per tyre were calculated using equation 2.4:

$$ENT = TK/(1 + NR/R) \qquad \text{.............. Eq. 2.4}$$

where

ENT = Equivalent new tyre life (1000 km/tyre),
TK = Total distance per casing (1000 km),
NR = Number of retreads per casing, and
R = Ratio of new tyre price to retread price.

Table 8.1 displays the calculated ENT values per depot, at the respective roughness levels.

TABLE 8.1: ENT VALUES PER DEPOT

DEPOT	ROUGHNESS (QI)	ENT (10^3 KM/TYRE)
A	110	19,5
B	80	22,3
C	130	13,3
D	150	5,9
E	40	50,5

It is unfortunate, however, that this method of analysis allows for only 5 data points since only one ENT value is available per depot for the entire period. Hence the regression contains 5 variables and it can be argued that the relationship produced may not be statistically reliable. With this in mind, 2 points must be raised:

(i) Even though only 5 data points exist, each data point, in itself, consists of a fair amount of information; many tyres were consumed at each depot resulting in acceptable estimates of ENT values, and

(ii) This research serves to calibrate existing models to South African conditions and very little work has been dc .e on a national level in this area. There is thus very little information upon which to base a decision.

It is therefore recommended that this information be used for local conditions, albeit statistically insufficient. Furthermore, as will be shown in Chapter 11, the relationship produced when taking all the extenuating factors into account compares well to overseas and local studies (Curtayne et al, 1987 and Chesher and Harrison, 1987).

As with the other VOC components, the data was used to determine a simple log-linear relationship, based on previous models. The equation that best fitted the data was:

$$\mathbf{ENT = 166{,}47 - 31{,}83 \; \ell n \; QI} \qquad \text{................ Eq. 8.3}$$

where

ENT = equivalent new tyre life (1 000 km/tyre), and
QI = r..d roughness (counts/km).

A R^2-value of 0,97 was ootained from 5 observations, with a standard error of estimate of 3,43.

This relationship is shown in Figure 8.5 along with the data points. The correlation is easily noticed although one cannot overlook the fact that only 5 observations were used in the regression.

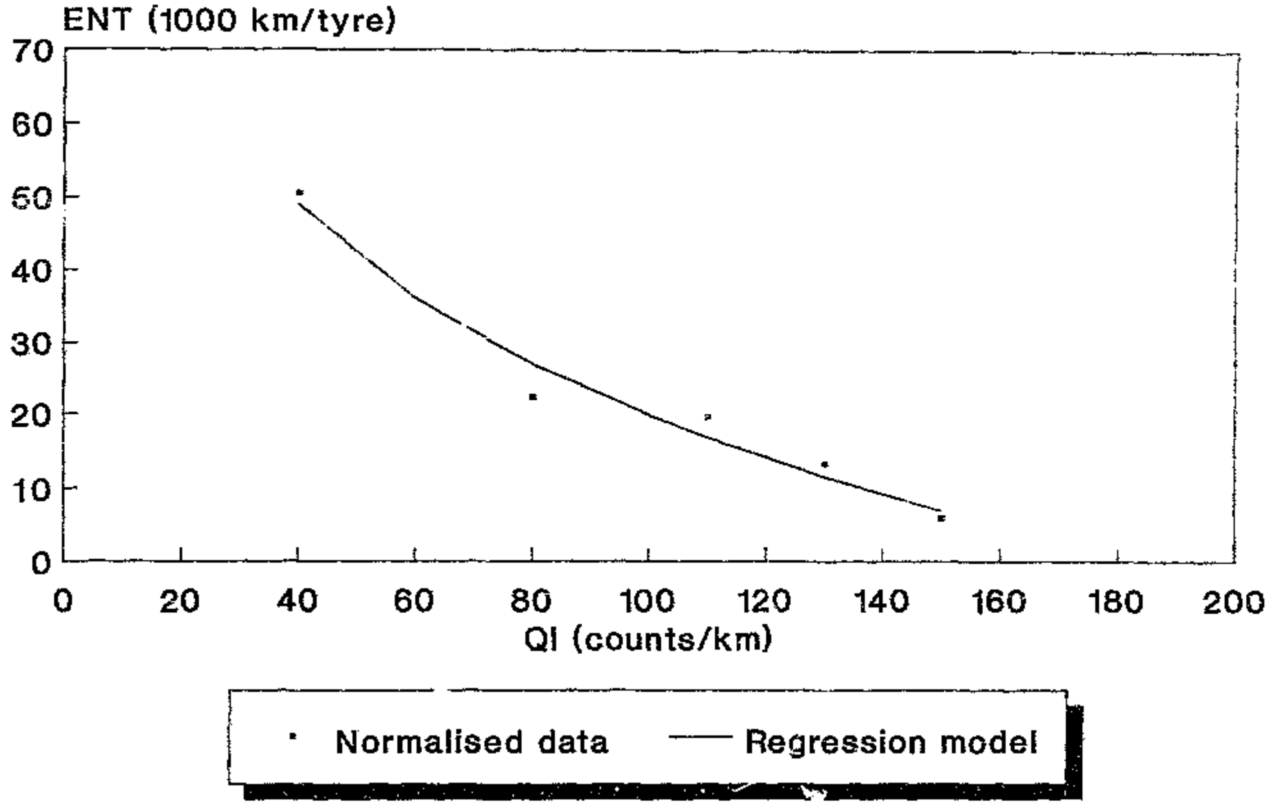

FIGURE 8.5: ENT vs QI

8.3 Depreciation related expense

As discussed in Section 2.6.4 the costs, to the economy, of owning as well as operating a vehicle cannot be ignored in the analysis of road design alternatives. Furthermore, depreciation and interest costs are generally of the same order of magnitude as maintenance and running costs and therefore constitute an important and significant portion of total VOCs.

In the analysis of depreciation and interest costs, the equations developed by Chesher and Harrison (1987) are used, since these comprehensively take into account the effect of road roughness on these costs. In so doing, the portion of vehicle operating costs assignable to road use, with regard to depreciation expense, are accounted for.

These equations are:

(i)
$$\int_0^s [m(s) - m(t)]e^{-rt}\,dt = VP \qquad \text{............... Eq.2.6}$$

where

s	=	optimal vehicle life,
m(t) and m(s)	=	the per year rate of running costs for a t- and s-year-old vehicle respectively,
r	=	per time period continuous discount rate, and
VP	=	new vehicle price

Given the maintenance costs per annum and assuming different vehicle lives, Equation 2.6 can be used to compute the optimal vehicle life, s. It should be noted that the per time period continuous discount rate, r, refers to the interest rate in real terms. The analysis is thus undertaken in constant prices, i.e. inflation is not included in the interest rate.

(ii)
$$m(s) = D(t) + I(t) + m(t) \qquad \text{.........Eq.2.7}$$

where

m(s)	=	running costs at the scrapping date,
m(t)	=	running costs at any vehicle age,
D(t)	=	depreciation costs, and
I(t)	=	interest costs.

This condition implies that depreciation and interest costs are zero at the date of scrapping, and that total operating costs are invariant with respect to vehicle age, increases in running costs, **m(t)**, being offset by decreases in depreciation and interest costs, (**D(t) + I(t)**).

Since both **m(s)** and **m(t)** are expressed in terms of road roughness an expression can be obtained for s, also in terms of road roughness. By using Equation 2.6 and obtaining the optimal vehicle, s, Equation 2.7 can be solved to produce the time-dependent depreciation and interest costs.

In using Equation 2.6 the following input constants were used:

(i) The per time period continuous discount rate (in real terms), r_t = 8%. This figure was recommended by the Central Economic Advisory Services (CEAS) in their report 'Manual for Cost-Benefit Analysis in South Africa, August 1989'.

(ii) The new vehicle price = R150 000. This corresponds to both the average new vehicle price encountered in this study as well as to a survey of national data, available from Transportek, Council for Scientific and Industrial Research.

(iii) Average annual vehicle utilisation = 70 000km. Although this figure represents just less than double the average amount covered by the vehicles in this study it was felt to be more applicable. This can be ascribed to the fact that, by the very nature of logging operations, the vehicles travel relatively short distances and spend a large percentage of their time being on- and off-loaded. Furthermore, an interview was carried out with another comparatively large firm, operating a fleet of 25 vehicles, of the same vehicle class, but having a combined annual fleet use of approximately 2 500 000km per annum. This converts to an annual average utilisation of 100 000km per vehicle, per annum. The figure of 70 000km p.a. was therefore felt to be more applicable to this study, especially if the results are to be employed on a national level.

(iv) The average labour rate = R50/hour. This was obtained from the logging operations used in this study and is discussed further in Chapter 11.

The relationships developed in this study for parts and labour costs were then used to numerically solve Equation 2.6 to obtain vehicle life s. As is to be expected, the value of s depends on, inter alia, road roughness and the above-mentioned input constants. The method used to solve Equation 2.6 can be summarised as follows:

After calculating the maintenance costs per annum using the regressed labour and parts relationships, the integral was obtained by summing the values of these costs multiplied by the exponent. This summation is based on the mathematical principle of adding increments (or slices) of the area under a particular graph. In so doing an approximation of this total area is obtained and the value represents an estimate of the integral. This was done for 4 different QI values, and the optimal vehicle life, s, was obtained for each (obviously, for each QI, s was the age at which the total area, or integral, was equal to the new vehicle price). An iterative process thus allowed for the deduction of s.

These s values were then regressed against QI, resulting in the following equation for the effect of road roughness on optimal vehicle life:

$$s = 24,0 - 0,1383.QI \qquad \text{.................Eq. 8.4}$$

An R^2 of 0,98 was obtained, with a standard error of estimate of 0,89.

It should be noted, however, that this equation is only valid in the 0-170 QI roughness range since, at greater roughness values, vehicle life will be predicted as a negative value. It is highly unlikely though, that average roughness values higher than this will be obtained in practice, since the highest recorded in this study was 150 QI, and this at a depot which was considered to have very rough roads.

Equation 8.4 was then used to recalculate maintenance cost streams m(t) and ultimate maintenance costs m(s) for different levels of road roughness, in order to solve Equation 2.7. This yielded the following relationship:

$$D(t) + I(t) = 0,3592 - 0,0185.\ell n\ QI - 0,1128\ \ell n\ t \qquad \text{................ Eq. 8.5}$$

where $D(t) + I(t)$ = time-dependent depreciation and interest costs, in % of new vehicle price per 1000 km, and

t = vehicle age, years.

An R^2-value of 0,82 was obtained, with a standard error of estimate of 0,03. The data generated from this relationship is displayed in Figure 8.6 overleaf, for an arbitrary vehicle age of 5 years.

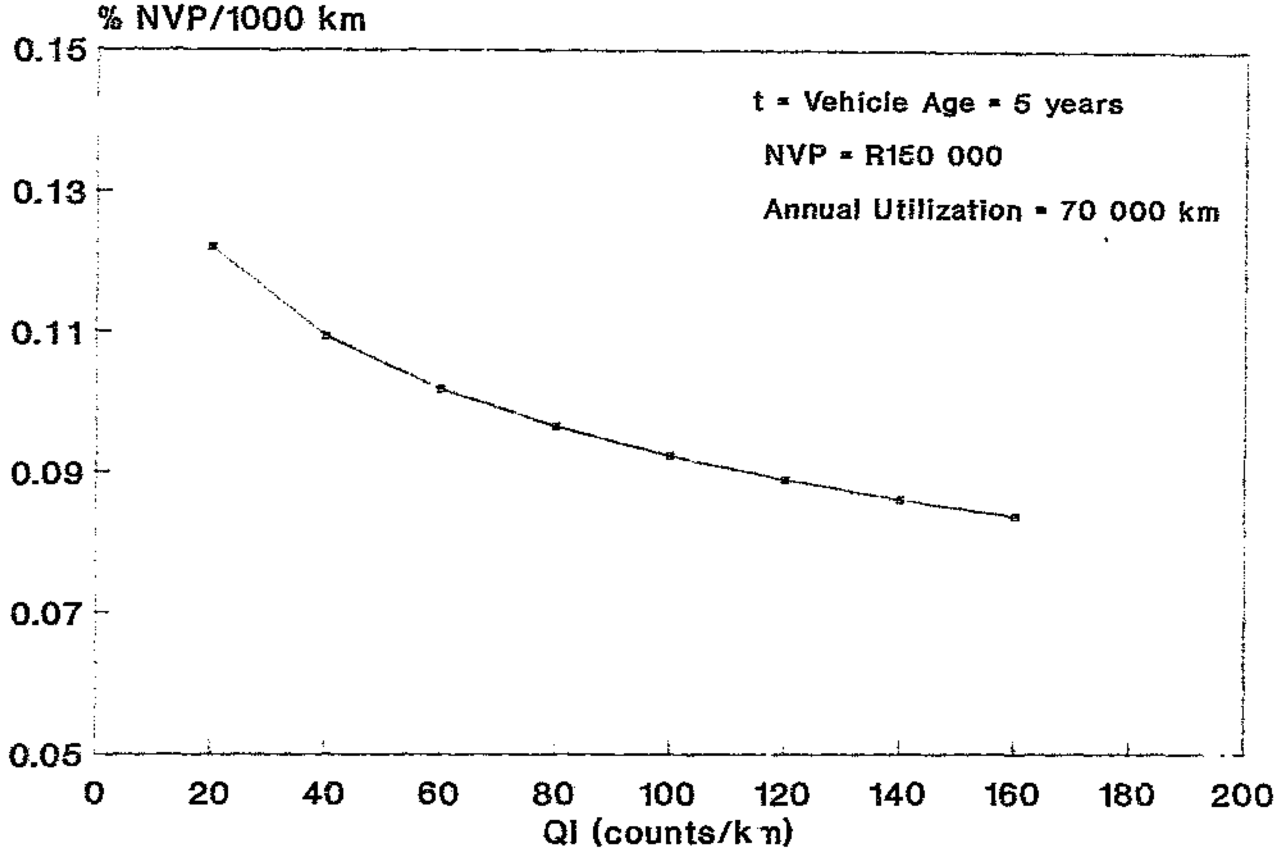

FIGURE 8.6: DEPRECIATION AND INTEREST

9. THE DETERMINATION OF VOC RELATIONSHIPS - ALTERNATIVE METHOD

This Chapter takes a similar form to that of the previous Chapter, although the emphasis is placed more on the validity of the newly proposed alternative method of roughness assessment. The emphasis in Chapter 8 fell more directly onto the numerical operations employed for each component and addressed the influence of outside factors on the regression equations.

The form of equation used in the alternative method of roughness assessment is discussed in detail in Section 6.2. Consequently, only the actual data manipulation and regression results are shown, and an attempt is made to employ similar graphical aids to those used in the previous Chapter.

9.1 Maintenance and repair costs

9.1.1 Maintenance costs - Parts

Using the percentage of travel in each QI class per depot shown in Table 6.2 and regressing these values against relative parts consumption, the following equation was arrived at:

$$P/VP = 1{,}5403\ (AGE) - 2{,}4\ (QI_{25}) - 2{,}9474\ (QI_{50}) + 1{,}4545\ (QI_{100}) + 2{,}6224\ (QI_{200}) \quad \text{..........Eq.9.1}$$

where

P/VP, AGE and QI_{25} - QI_{200} are as set out in Section 6.2.

An R^2 value of 0,88 was obtained from 15 observations, with a standard error of estimate of 37,9.

Two points should be noted at this stage:

(i) This regression required that the equation be forced through the origin, since the line became almost asymptotic to the y-axis and a large value of the constant was obtained.

(ii) Unlike previous relative parts consumption equations, which are logarithmic in form, this equation is a direct relationship. Natural logarithms were used in a regression exercise and the "better" result employed in Equation 9.1.

A noticeable feature of this regression is the high correlation coefficient (0,88 compared to 0,75 obtained in the conventional use of roughness assessment). This seems to imply that a "better" relationship is obtained using the new roughness method.

An attempt was made to display Equation 9.1 in graphical form although this proved to be merely an objective exercise of very little value. The reason for this was that the "averaging-out" method would have to be employed in order to obtain QI values against which Parts consumption could be plotted.

A comparison for relative parts consumption using the 2 methods of roughness is presented in Chapter 10, where conclusions drawn are also discussed.

9.1.2 Maintenance costs - Labour

As done in normal labour regressions, in addressing labour costs and their relationship with the alternative method of roughness assessment, the parts consumption variable is also included. A similar regression was then performed to that shown in Section 9.1.1.

The following equation was the one to emerge from this exercise:

$$\mathbf{LAB} = \mathbf{0 + 0{,}6216\ (P/VP) - 0{,}8218\ (QI_{25}) + 1{,}3507\ (QI_{50}) + 1{,}8736\ (QI_{100}) + 2{,}0057\ (QI_{200})} \quad \text{..........Eq.9.2}$$

where

LAB = labour costs in $R/10^3km$, and
P/VP and QI_{25} - QI_{200} are as set out in Section 6.2

Furthermore, the correlation coefficient is marginally better than that obtained in the conventional labour regression (0,87), which again seems to imply that a "better" relationship is obtained using the alternative roughness method. These indications are certainly worthy of further consideration and are discussed in Chapter 10.

As far as showing this relationship in a graphical form is concerned, the same arguments that applied to relative parts consumption are applicable. The reason given for having to force the equation through zero is also the same.

A comparison between the use of the conventional and alternative method in obtaining a labour consumption model is undertaken in Chapter 10.

9.2 Tyre consumption

An initial attempt at regressing equivalent new tyre life against the percentages of travel in each QI class proved impossible. This is because, in any statistical regression, the number of observations must be greater than the number of variables plus one. For this exercise the number of observations is 5 and the number of variables 4. There are therefore insufficient observations which can be used to comment on the variables and a statistical regression was impossible.

9.3 Depreciation related expense

As discussed in Section 8.3 the analysis of depreciation is a complex procedure. It is not as simple as the other VOC components, in which a regression analysis is undertaken between different variables. A number of mathematical processes, including iterations, are used, and certain approximations with respect to integrating are employed.

A suitable method of performing these tasks using the alternative method of road roughness assessment will have to be developed before any optimal scrapping lives and depreciation and interest charges can be computed. The calculation of a depreciation and interest relationship with road roughness using the alternative method therefore falls outside the scope of this study. In addition to this, it may not be worth undertaking this analysis until such time as the alternative method of roughness assessment has proved it's value.

10. THE ROAD ROUGHNESS DILEMMA - COMPARISONS AND CONCLUSIONS

With the full analysis of VOCs with respect to both the conventional and alternative methods of roughness assessment realised, a comparison between the two methods can now be undertaken. The main purpose of this exercise is to ascertain whether the predictions using the alternative method of roughness assessment are valid and to identify those ranges of road roughness in which it is applicable. These predictions are represented graphically and any deviations can therefore be readily identified.

As mentioned in the previous Chapter, these comparisons are addressed for only relative parts consumption and labour costs.

10.1 Comparison of maintenance costs - Parts

Relative parts consumption predictions were computed using Equations 8.1 and 9.1. In keeping with previous graphical representations of these costs, a vehicle age of 110 000km is employed as the input constant.

The roughness values used for Equation 9.1 (alternative method) are shown in Table 10.1

TABLE 10.1: ROUGHNESS INPUT PERCENTAGES FOR THE PREDICTION OF PARTS AND LABOUR COSTS

QI class	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
0-25	25	50	50	50	0	0	0
25-50	25	50	0	0	50	50	0
50-100	25	0	50	0	50	0	50
100-200	25	0	0	50	0	50	50
Average QI	94	38	63	113	75	125	150

The average QI was again obtained by weighting the class of QI by the percentage of travel in each class. This average QI was used as the input for Equation 8.1, whilst the percentages of travel in each class were used in Equation 9.1. The comparisons are shown in Figure 10.1.

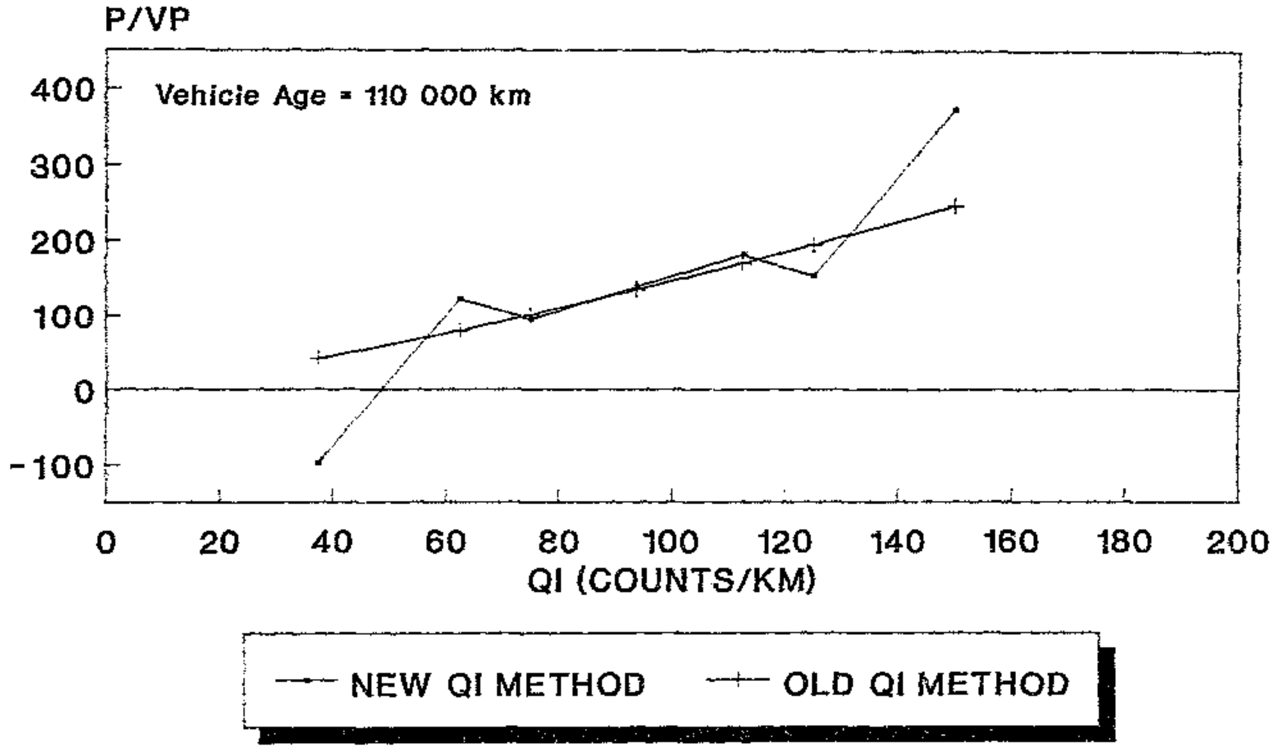

FIGURE 10.1: COMPARISON OF P/VP'S FOR DIFFERENT ROUGHNESS METHODS

The most striking aspect of this graph is the similarity between predictions in the range of road roughness of 50-140 counts/km. This is very encouraging and demonstrates that the "averaging-out" method of roughness assessment is good enough for application in VOC studies, and can therefore be applied with confidence. As far as the alternative form of roughness assessment is concerned, predictions seem to diverge rapidly when outside of the 50-140 QI class. This irregularity must be addressed in any future work in this field. It may be that the alternative form of road roughness is applicable only within a certain range with respect to parts consumption.

At this, the infant stages of such research, comments can only be made to the effect that the alternative method definitely has an application in this field. This holds until such a time as it is proved to be statistically or mathematically insufficient in it's representation of vehicle operating costs.

10.2 Comparison of maintenance costs - Labour

Equations 8.2 and 9.2 are applied for this comparison, in which the above QI percentages and values are used along with a common parts constant of R200/1 000km. The comparison is represented graphically in Figure 10.2.

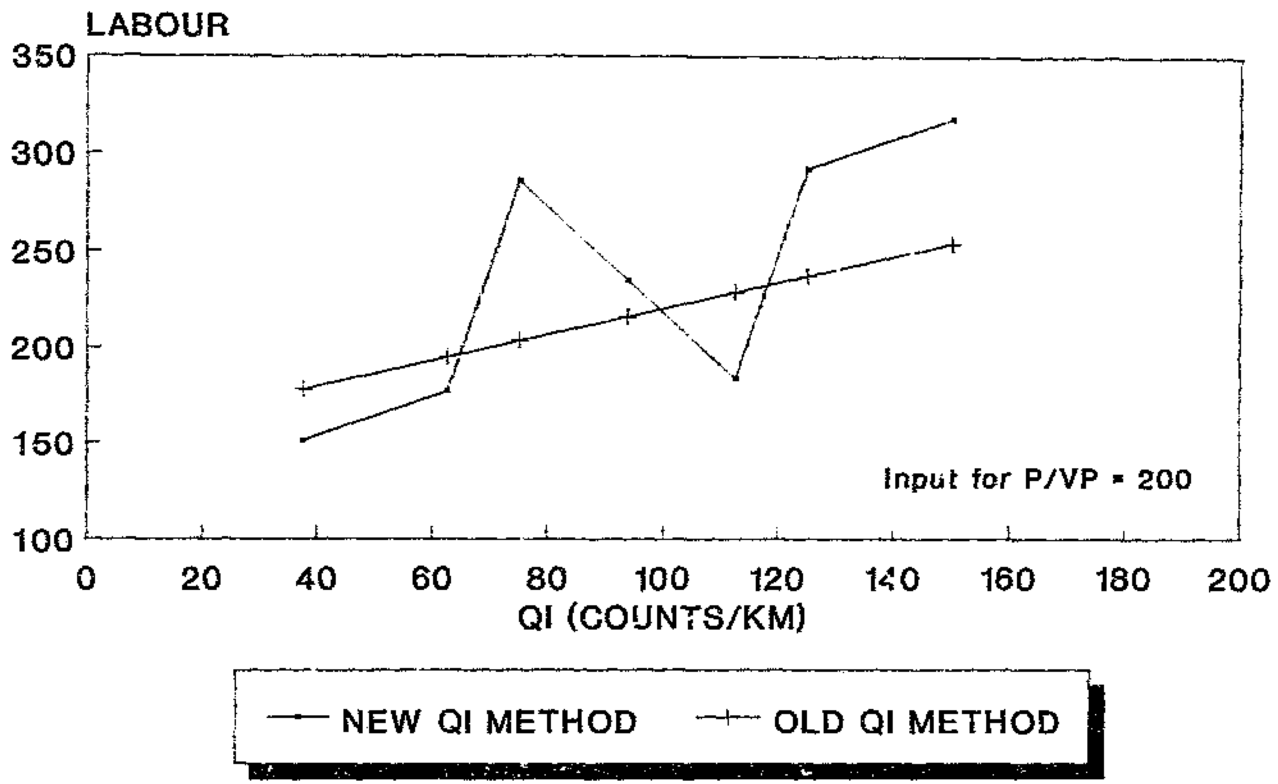

FIGURE 10.2: COMPARISON OF LABOUR COSTS FOR DIFFERENT ROUGHNESS METHODS

At first glance it appears that the new method of roughness assessment produces haphazard and irregular results. However, on closer examination of the equation, one sees that the constants of the different roughness classes vary significantly. This implies the roughness classes are too broad and need to be refined, since any difference in the values of the input variables will lead to a large different in the output. The equation produced for relative parts consumption also has this flaw, although it is not highlighted during the comparison. This is discussed in more detail in the next section.

Because of this inefficiency it is difficult to pass any valid comments on the use of the alternative method with respect to labour costs, suffice to say it requires a great deal more attention. This attention could be focused more directly on the classes of roughness to be employed in any such analysis.

10.3 Conclusions

The labour comparison highlighted an important point with regard to the new, alternative method of roughness assessment: The models are not versatile enough with regard to VOC analyses.

This research was planned to facilitate the conventional method of roughness assessment ar.d thus falls short in the other departmen· Any future research on the new method must be geared on obtaining proportions of .. .vel for far smaller roughness categories - say 10 counts/km on the QI scale. In this way the restrictions imposed on the user are limited, resulting in a more versatile relationship with applicability to most operating conditions. In so doing, the alarming rates of increase and decrease of costs shown in both Figures 10.1 and 10.2 will be "ironed out". This will also help with the problem of identifying the range of roughness, if any, in which this method is applicable.

A possible method which may be used to implement the results obtained using this method could be to develop a series of graphs. These could be on a common axis, where a user can read off cost predictions for certain combinations of travel in certain roughness classes.

In concluding it should be noted that this model, once refined, may not be robust enough for purposes of obtaining differentials in vehicle operating costs at different roughness levels. In the conventional method of analysis, the user can simply input two different roughness values and immediately extract an operating cost differential, which can then be used in the decision-making process of highway design alternatives. With the alternative method of assessment this procedure may not be as simple since the way in which the roughness categories are affected are not immediately known. They can be affected in one of, or by a combination of, the following ways:

(i) The category of roughness changes, just the percentage of travel in each remains constant, and

(ii) The roughness category remain constant, just the percentage of travel in each is adjusted.

Unless this fundamental aspect is addressed in future research, this method will have no applicability to this field of work.

Moreover, the argument that the direct link between costs and road roughness is lost when averaging-out roughness values is not strictly true. A direct comparison still takes place, it is now on a global scale with average VOCs from a depot related to average roughness measurements from a depot.

11. DISCUSSION OF RESULTS AND COMPARISONS WITH OTHER STUDIES

Since the validity of the conventional method of roughness assessment has been internationally accepted, it will be used for the remainder of this research. This Chapter provides a comparison between the locally produced truck VOCs and those obtained in the major VOC studies undertaken elsewhere. At the risk of labouring the point, it is only the conventional method of roughness which will be used in these comparisons.

When taken out of context, many experimental results and observations could give a false impression of correctness. This is also true for survey data. This inefficiency may, however, be put right by comparing results to similar studies performed elsewhere. It is therefore necessary to objectively review the results obtained in this research in order to prove their worth or otherwise. It must be borne in mind though, that if differences between the local and overseas studies are encountered, and cannot be substantiated, then those differences do not necessarily imply that local results are incorrect and the other results correct. This is especially true for overseas models being applied under local conditions.

Furthermore, putting the local results into context with overseas studies inspires confidence in the predictions of data. The order of discussion of this Chapter follows that of the report - maintenance costs (parts then labour), tyre costs and, finally, depreciation and interest changes.

11.1 Maintenance parts costs

Since maintenance is one of the critical cost components it must be reviewed accurately and objectively with emphasis on reasoning out the differences in results. If these differences can be substantiated, then it may be assumed that the local study can be confidently employed in South Africa.

Figure 11.1 displays the comparison of maintenance parts for the 4 primary studies and the local study for medium to heavy trucks.

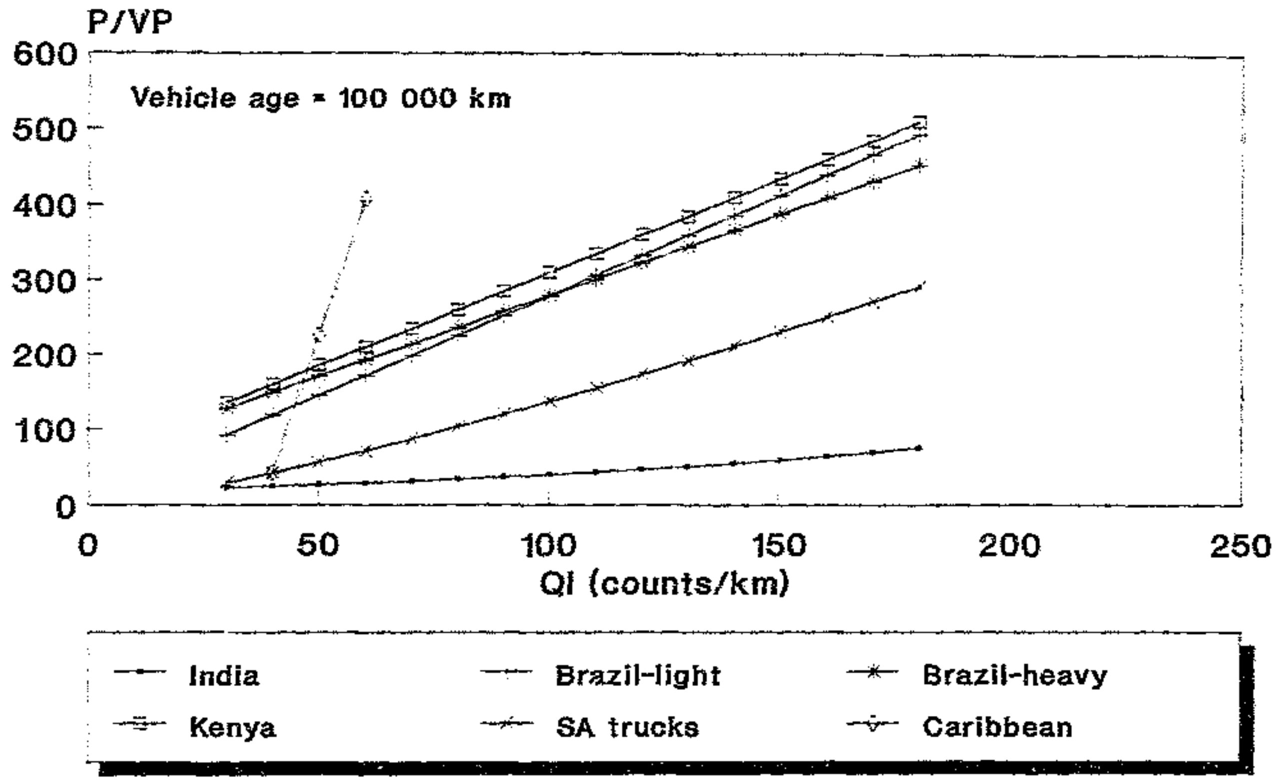

FIGURE 11.1: COMPARISON OF P/VP MODELS

It is clear that, except for India, the SA truck predictions are lower than that of the overseas models. The main reasons for this are twofold. Firstly, it can be said with reasonable confidence that a business enterprise, such as the one used for data collection in this study, has the resources, technology and capacity to carry out routine maintenance. These firms will run their operations to minimise costs and thereby increase profits and even without a comprehensive knowledge of VOCs will carry out routine maintenance in order to reduce long-term costs. In terms of overseas models, it is questionable whether such maintenance was carried out or whether the capacity exists to fulfil service requirements. It is a known fact that, in some third-world countries, "vehicle graveyards" exist comprising of a large percentage of usable vehicles - they are just in need of a few parts which are unobtainable. This lack of parts contribute to reduced maintenance and thus increased vehicle operating costs.

The second reason is that South African heavy vehicles carry a relatively high proportion of imported content. An unfavourable exchange rate will therefore artificially inflate new vehicle prices, thereby reducing the P/VP ratio. The parts are not affected in the same way since many locally produced pirate parts are used, incurring relative cost benefits. In most cases, and for this application, these pirate parts serve their purpose as well as the originals.

However, a most important point to be raised at this stage, is the slope of the line of the local prediction. In comparison with the other studies the slope indicates that the roughness trends are similar, i.e., the rate at which roughness affects the relative parts consumption is similar, to those reported in Kenya and Brazil. This is very encouraging since, as covered in Chapter 2, price differentials will ultimately be used in an economic analysis, and not absolute values.

As far as the Indian predictions are concerned, these are very much lower than that of the other overseas models. This can be credited to the fact that labour there is very cheap and, instead of purchasing replacement parts, the labourers physically repair any broken or damaged parts. India has always been, and is still presently, a highly labour-intensive country. This fact is confirmed by the maintenance labour prediction models (Figures 11.3 and 11.4) - the India model consistently predicts higher labour hours per unit distance.

Furthermore, the Caribbean model shows what appears to be an unrealistic rouganess effect. The reason for this is not known.

Figure 11.2 displays the comparison of the influence of vehicle age on parts consumption for the different studies, for a roughness of 70 QI. Again the SA Truck predictions are lower than the other models, except for India, and in accordance with the maintenance parts comparisons. This figure brings to light the fact that the local trucks appear to age better than overseas models, which can be credited to the regular maintenance and servicing carried out on them. This figure also provides assistance in understanding the effect of roughness on relative parts consumption (Figure 11.1) for local conditions.

11.2 Maintenance labour costs

In order to perform a comparison of the different labour models, it was necessary to obtain the hourly charge-out rate for labour per depot. This facilitates comparing predicted hours/1000 km, since the local data predicted Rands/1000 km and the overseas studies hours/1000 km. The labour rates at each depot as well as the average is shown in Table 11.1. The SA Truck predictions can then simply be divided by the average labour rate to obtain labour predictions in hours/1000 km.

TABLE 11.1: LABOUR RATES PER DEPOT

DEPOT	LABOUR RATE (R/HR) 1989	1990	AVERAGE	OVERALL AVERAGE
A	38	50	44	
B	60	60	60	
C	42	37	39,5	46,8
D	35	35	35	
E	52	59	55,5	

All of the labour predictions include a relative parts consumption variable, and take a similar form to Equation 8.2. The predicted P/VP values utilized in Section 11.1 were therefore used as an input to calculate labour consumption at the respective roughness levels.

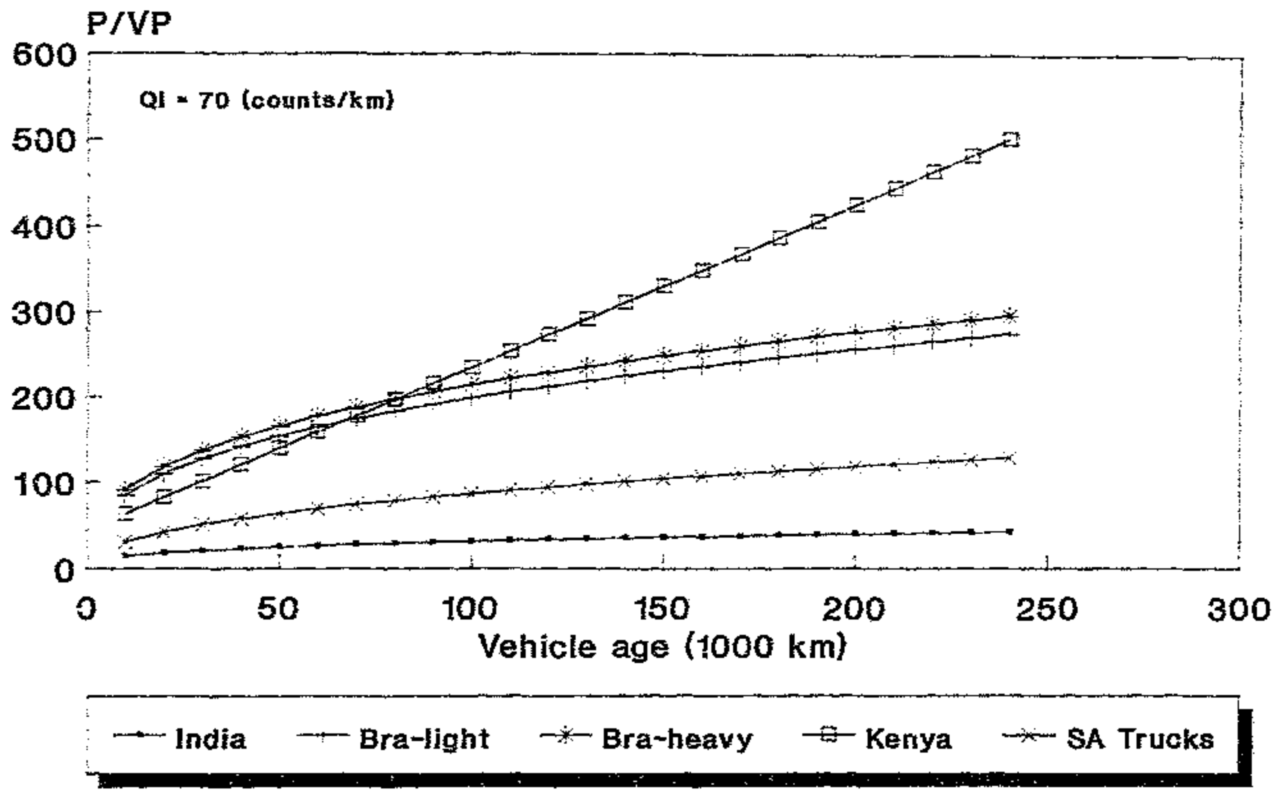

FIGURE 11.2: PARTS COST vs AGE MODELS

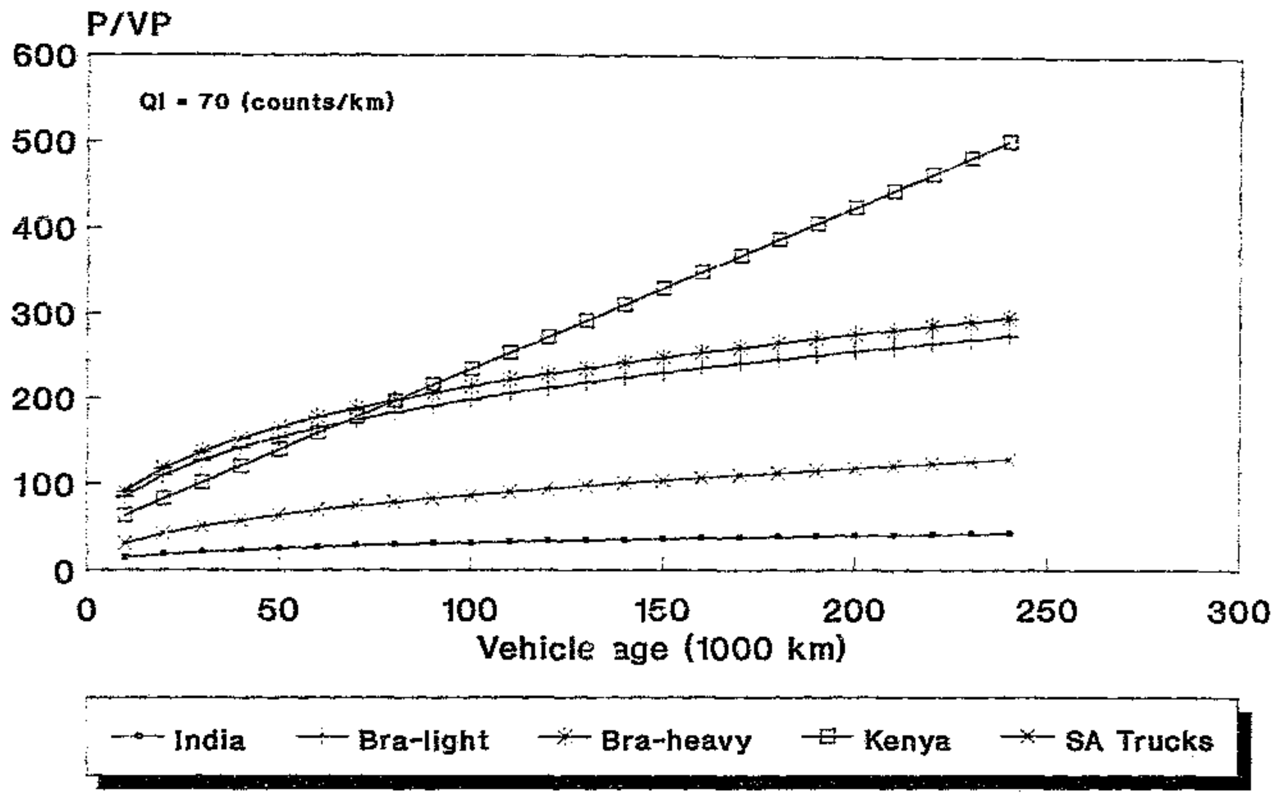

FIGURE 11.2: PARTS COST vs AGE MODELS

Figure 11.3 displays the comparison between the local labour model and the four major study models. The roughness effects are again similar between the various studies, with the level of predictions from India the highest (offsetting the low relative parts consumption).

The South African labour model predictions are the lowest. There may be two possible explanations for this trend. Firstly, the productivity of the average South African labour force is low whilst the wage demands by unions are relatively high. In effect, labour thus becomes expensive. The employers therefore have a tendency to buy parts in order to reduce the labour requirements and thus the labour force.

Secondly, the local buying power of the South African monetary unit is still relatively high compared to other third world countries, e.g., Brazil and Kenya. This may further swing the scale in favour of buying parts instead of repairing them. However, it should again be pointed out that the rate at which labour input increases with an increase in roughness is similar to the overseas models. This is important since differentials and not absolute values are used in an economic analysis of highway design alternatives.

It should be noted that the labour models use predicted P/VP values. Since the local P/VP values are lower then the other models, they will negatively influence the labour model predictions. It was decided therefore to attempt a labour prediction using the Brazilian P/VP values in the local labour model, to produce an unbiased comparison.

Figure 11.4 shows the same labour comparisons as before, except that the South African values were obtained using the Brazilian P/VP values. Labour inputs are now marginally higher and closer to the Kenya predictions, but are still the lowest. It is therefore true to say that South African labour inputs appear to be lower than in any of the other studies, even when using "middle-of-the-range" prediction variables from overseas models. The above explanations therefore still apply.

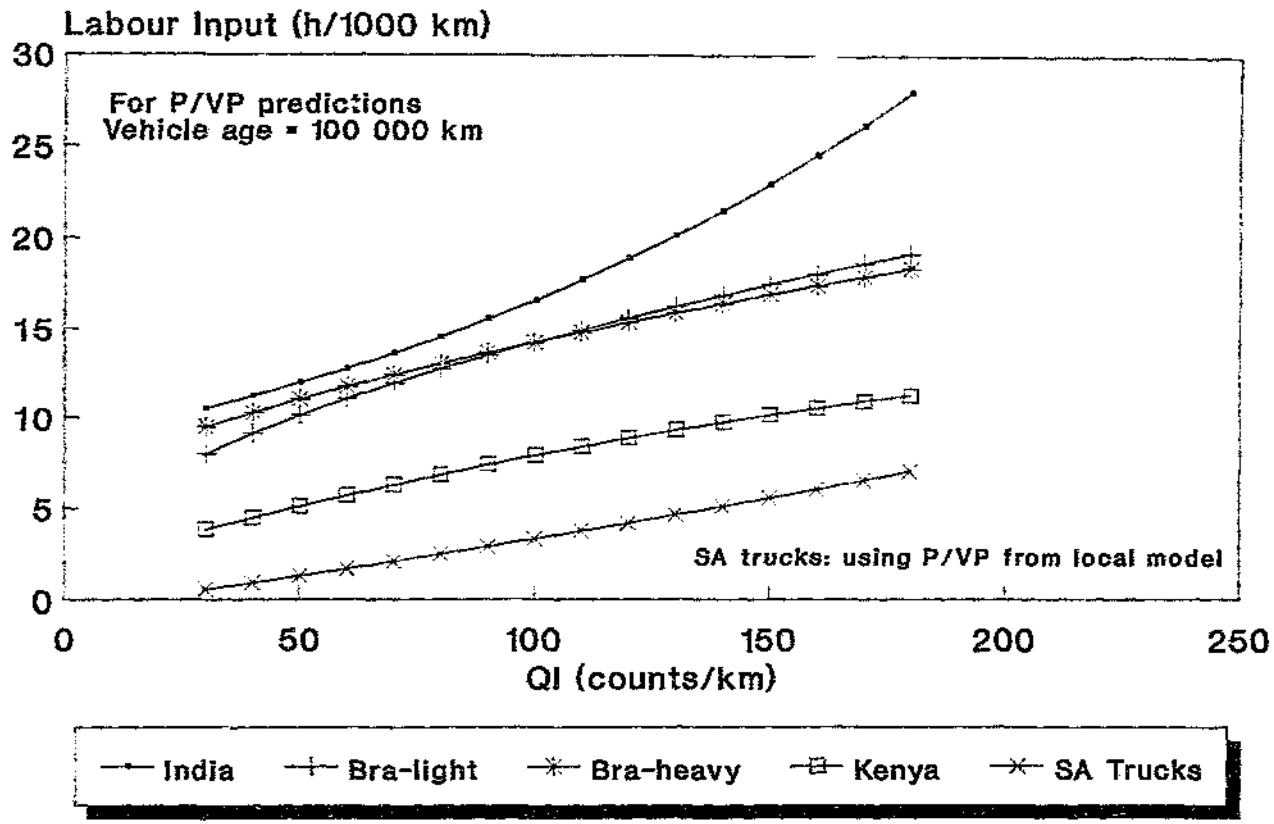

FIGURE 11.3: COMPARISON OF LABOUR MODELS

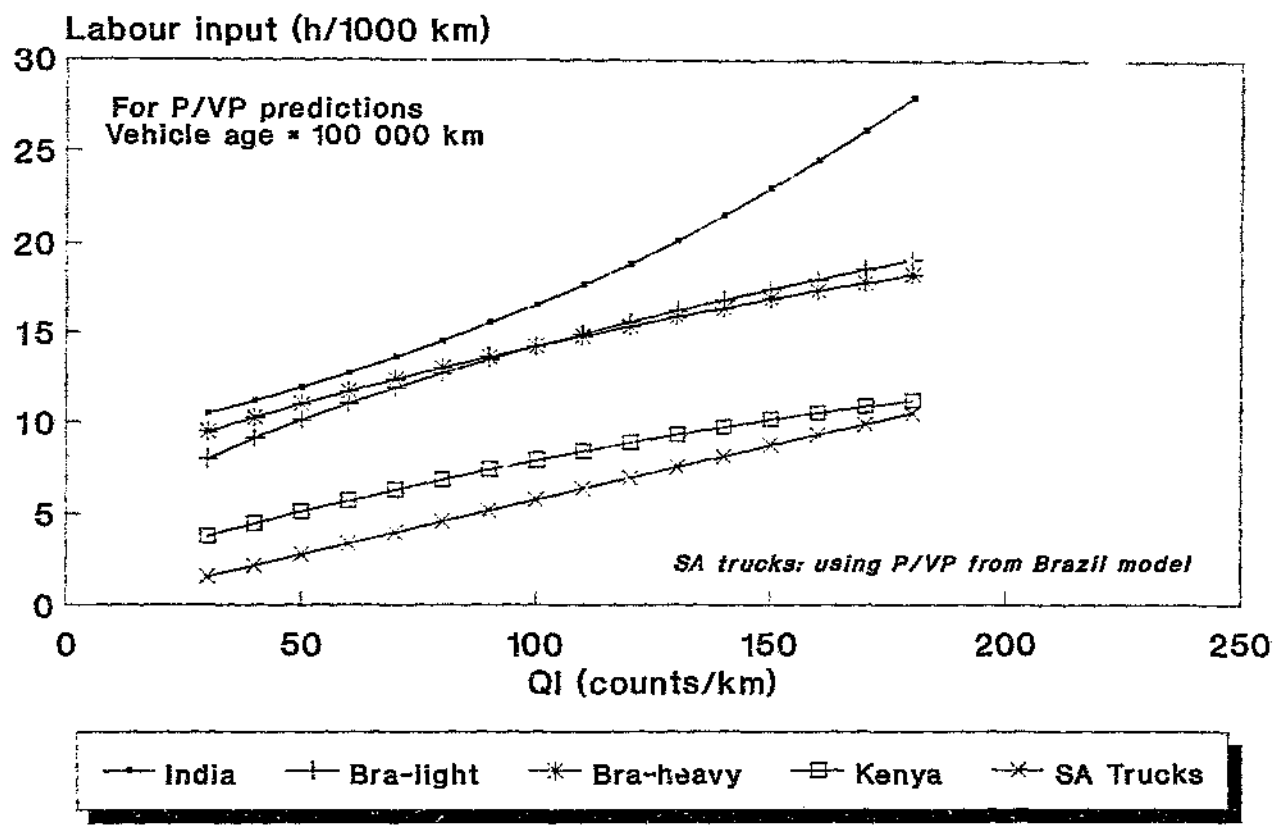

FIGURE 11.4: COMPARISON OF LABOUR MODELS

11.3 Tyre consumption

As explained in Chapter 2, all the major studies use the "equivalent new tyre life" variable as a tyre consumption measure. The comparison of the different ENT models appears in Figure 11.5. Also shown is the tyre wear model produced from survey data obtained in Kwazulu (Du Plessis et al, 1987).

There is excellent agreement in tyre life predictions between the Kwazulu, Caribbean and Kenyan models. The Brazilian relationship uses data generated by a mechanistic tyre wear model, which appears to yield conservative figures when compared to other studies. The reasons for this have been discussed in detail in Chapter 2. The relationship produced by the SA truck study shows a much higher roughness effect. This is thought to be caused by a high incidence of premature tyre failure and increased ablative wear on unimproved logging roads. This is especially true for forest conditions where broken sticks, etc penetrate the tyre. These conditions were prevalent at the forestry operations encountered in this study and are reflected in the low values of equivalent new tyre lives (Table 8.1).

It should be noted, however, that on very smooth roads the SA truck prediction for tyres is essentially similar to the values reported from Kwazulu, Kenya, India and the Caribbean. Table 5.1 shows, for depot E with the lowest roughness value, that the average number of retreads per casing is also the highest and is in agreement with values reported for similar conditions in Kwazulu (du Plessis et al, 1987).

11.4 Depreciation related expense

Although the major studies addressed the subject of depreciation and interest charges, none of them related it to road roughness. The local study produces a relationship between these charges and roughness and as such a comparison between the local and overseas studies cannot be made.

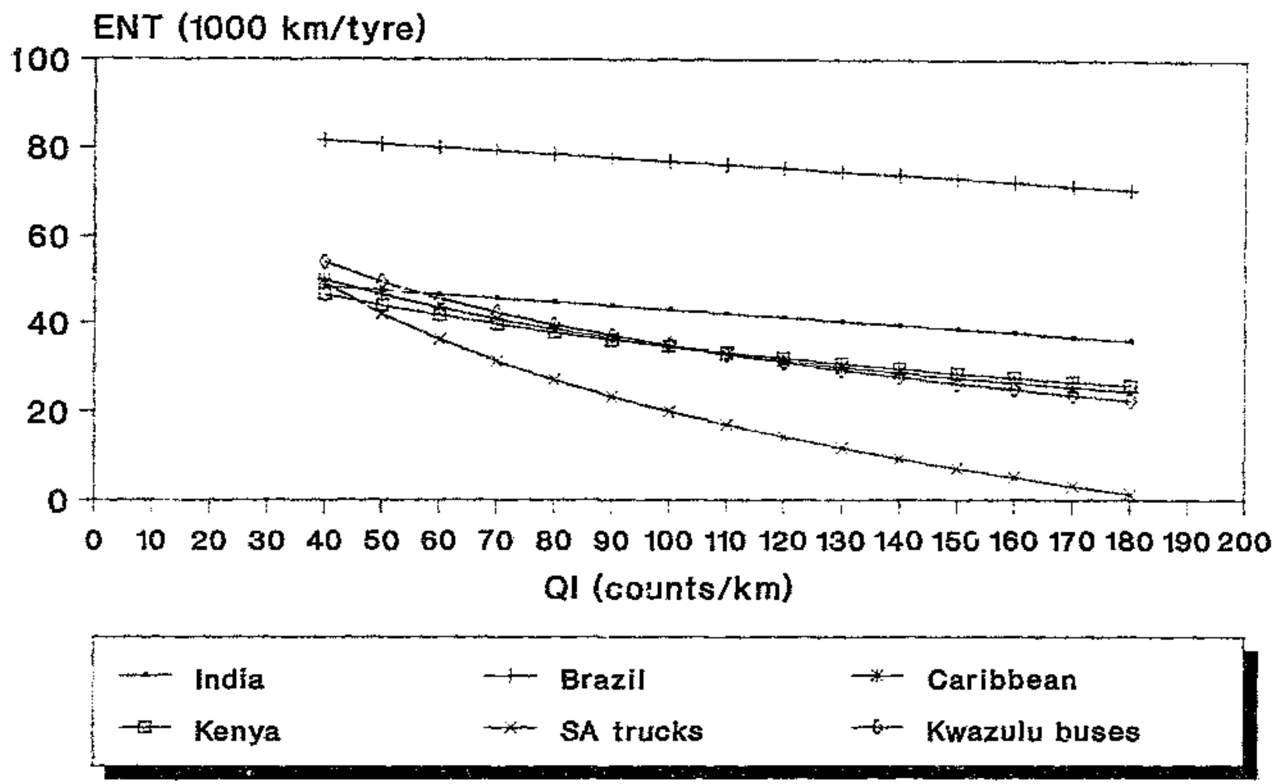

FIGURE 11.5: COMPARISON OF ENT MODELS

PART IV

CONCLUSIONS AND RECOMMENDATIONS

12. CONCLUSIONS AND RECOMMENDATIONS

This small-scale vehicle operating cost study was designed to select a set of cost-roughness relationships reported in the major primary VOC studies and to calibrate them to local conditions. A literature survey was undertaken, providing the foundation upon which the research could be built and more specifically to expose those relationships deemed to require calibration. Data was collected from a large logging enterprise, operating some 91 fleet vehicles with a combined annual utilisation of 3 500 000km. Data from 5 depots were collated and then analysed using mathematical regression techniques, based upon previous studies done internationally and locally. The relationship calibrated were specifically for medium to heavy trucks, operating over a broad range of road roughnesses, for the following cost components :

(i) maintenance costs - parts
- labour

(ii) tyre consumption

(iii) depreciation and interest charges.

Of prime importance was the ability to relate the calibrated relationships to other models. However, the absolute values of predictions may or may not be in accordance with expected values, since a great many variables act to influence operating costs. This, however, can be overlooked since the general trend of predictions should be in agreement with previously used and internationally reported models and it is fundamentally the cost differentials which are used in economic analyses of highway design alternatives.

The predictions used calibrated aggregate-empiric relationships estimated from user survey data, and will be employed in the World Bank's Highway Design and Maintenance Standards Model (HDM III) for South African conditions. The results compliment earlier research and can be used with confidence for medium- to heavy-sized trucks, in circumstances where road-surface types are similar to the experimental conditions.

Emerging during the course of the study was the controversial topic of "averaging-out" roughness measurements in order to achieve a rougtness value for a specific depot. It is argued that, by performing this calculation, the true effect of road roughness on VOCs is lost. The relationships produced are thus not wholly representative of the relationship between roughness and costs.

A newly proposed alternative form of roughness assessment was consequently addressed, in which proportional travel in different roughness categories was adopted. The same cost components as outlined above were analysed.

The method proved to have certain merits, although the relationships produced from this study proved to be inadequate for purposes of economic analyses. The reason behind this was that the study was not originally designed around the method and, as such, the roughness categories were not versatile enough. However, the method warrants further research and the following recommendations can be made:

(i) To ensure the applicability of the method, with regard to the mathematical approach used:

(ii) To develop a more versatile solution with regard to roughness categories;

(iii) To study the effect of a change in a roughness category on the predictions;

(iv) To study the effect of a change in the percentage of travel in a particular roughness category;

(v) To define a range of road roughness within which the model is applicable;

(vi) To develop a method allowing for the simple use of the model, ensuring that limited restrictions are placed on the user; and

(vii) To compare predictions using this model with predictions from the other VOC studies using the conventional method of road roughness assessment.

If these recommendations are satisfied, this new method of aggregating different roughnesses may well prove to be of assistance in the field of VOCs. As for the time being, the original method is adopted in cognisance of the fact that it has proved reliable in a number of such studies. The relationships produced for each VOC component are presented below, as well as those recommended for future use in the South African environment.

The analysis of maintenance consumption produced good correlations for the 2 separate components. The models to be employed in future economic analyses for trucks are therefore:

Relative parts consumption

$$\ell n\ (P/VP) = -3{,}0951 + 0{,}4514\ \ell n\ (AGE) + 1{,}2935\ \ell n\ (QI) \quad \text{..... Eq. 8.1}$$

$R^2 = 0{,}75$; standard error of estimate = 0,35

Labour consumption

$$LAB = -18{,}7453 + 0{,}8572\ (P/VP) + 0{,}6753\ QI \quad \text{............... Eq. 8.2}$$

$R^2 = 0{,}88$; standard error of estimate = 40,2.

where

P	=	parts cost (R/10^3km),
VP	=	new vehicle price (R10^5),
AGE	=	vehicle age (10^3km),
LAB	=	labour costs (R/10^3km), and
QI	=	road roughness (counts/km).

As far as tyre consumption is concerned, two different models will have to be recommended, depending on the ablative wear expected of the operating conditions. Both models produced good correlations and as such can be employed with confidence. If conditions result in low ablative wear, consistent with gravel or smooth roads, the model to be used will be that developed in Kwazulu (Du Plessis, Visser and Harrison, 1987), where

$$ENT = 131{,}5 - 21{,}0\ \ell n\ QI \quad \text{............... Eq. 2.5}$$

$R^2 = 0{,}81$; standard error of estimate = 5,42

If the prevailing conditions are that of angular stones and rocks, broken sticks or branches and a high ablative wear is expected, a tyre analysis can be carried out using the model developed in this study:

$$\mathbf{ENT} = \mathbf{166{,}47 - 31{,}83\ \ell n\ QI} \qquad \text{..............Eq. 8.3}$$

$R^2 = 0{,}97$; standard error of estimate = 3,43

where

ENT	=	equivalent new tyre life (10^3km/tyre),
QI	=	road roughness (counts/km).

The depreciation model reported in this study relates depreciation and interest charges to road roughness and vehicle age in years. Through roughness, it also incorporates the effect of maintenance policies and strategies employed by the operator in response to road conditions. As such, it provides for an improvement to current models used locally and also to models reported from the four major studies. Unfortunately the model is not as robust as the others reported on in this study, since it is defined for an annual utilisation of 70 000km and a new vehicle price of R150 000. This shortcoming should be addressed in future research in order to provide a more versatile solution.

The following models and input parameters can be used for the analysis of depreciation and interest charges :

Input parameters

annual utilization (km) = 70 000
new vehicle price (1990, Rands) = 150 000

Model predicting optimal vehicle life

$$s = 24{,}00 - 0{,}1383\ QI \qquad \text{............... Eq. 8.4}$$

R^2 = 0,98; standard error of estimate = 0,89

Depreciation and Interest costs

$$D(t) + I(t) = 0{,}3592 - 0{,}0185\ \ell n\ QI - 0{,}1128\ \ell n\ t \qquad \text{............... Eq. 8.5}$$

R^2 = 0,82; standard error of estimate = 0,03

where

s	=	optimal vehicle life (years),
D(t)	=	depreciation costs (Rands),
I(t)	=	interest costs (Rands),
t	=	present vehicle age (years), and
QI	=	road roughness (counts/km).

In concluding, it is recommended that the above relationships be employed in a practical sense, and the results compared to those predicted in the research. It may then be possible to further calibrate the models, on a micro scale, to suit specific conditions.

APPENDIX A : SAMPLE DATA REPORT SHEET

UNIT REGISTR.	DESCRIPTION	FUEL	OIL	TYRES	SPARES	W/SHOP LABOUR	SUB TOT OF COST	FIXED COSTS	TOTAL COST	KM/HRS	(-COST RAND PER KM/HR-) OPERATE	FIXED	TOTAL
TRANSPORT - 7 TONNERS													
MERCEDES BENZ													
0182 NH 8389	MERCEDES 1113 TRUC	1328	72	0	9766	1494	6872	883	5989	3779	1.82-	.23	1.58-
AQUIRED-03/85	AGE- 60 MONTHS	10982	1710	2919	10821	17464	43896	12571	56467	36072	1.22	.35	1.57
SEC. 47		41023	4031	10427	34349	34438	124518	58104	182622	235040	.53	.25	.78
0183 NH 8390	MERCEDES 1113 TRUC	1114	93	0	1165	1861	4233	883	5116	3405	1.24	.26	1.50
AQUIRED-03/85	AGE- 60 MONTHS	12979	1426	2381	22360	15754	54900	12571	67471	37649	1.46	.33	1.79
SEC. 47		48462	3843	12863	46382	34986	146536	57688	204224	266902	.55	.22	.77
0184 NH 8391	MERCEDES 1113 TRUC	956	2	782	1127	3452	6319	1603	7922	438	14.43	3.66	18.09
AQUIRED-03/85	AGE- 60 MONTHS	14896	345	6393	16723	19052	57409	21215	78624	39473	1.45	.54	1.99
SEC. 47		47171	1929	17751	27740	32915	127506	66732	194238	239086	.53	.28	.81
0185 NH 8506	MERCEDES 1113 TRUC	1800	143	0	118	1235	3296	1948	5244	5780	.57	.34	.91
AQUIRED-04/85	AGE- 59 MONTHS	13413	839	3820	17105	16014	51191	11882	63073	42276	1.21	.28	1.49
SEC. 47		42794	2121	16832	37869	32729	132345	54528	186873	194016	.68	.28	.96
0186 NH 8505	MERCEDES 1113 TRUC	1681	54	1704	151	1848	5438	1948	7386	4528	1.20	.43	1.63
AQUIRED-05/85	AGE- 58 MONTHS	12792	878	6364	21206	17271	58511	13745	72256	37941	1.54	.36	1.90
SEC. 47		37846	2219	20780	33652	33815	128312	56387	184699	187505	.68	.30	.97
0198 NH 8521	MERCEDES 1113 TRUC	755	70	1779	559	2961	6124	816	6940	2697	2.27	.30	2.57
AQUIRED-05/85	AGE- 58 MONTHS	14893	676	6353	21224	16973	60119	11761	71880	35701	1.68	.33	2.01
SEC. 47		38874	1961	16818	41131	32153	130937	52733	183670	163811	.80	.32	1.12
0199 NH 8523	MERCEDES 1113 TRUC	1700	33	1704	1682	2167	7286	743	8029	264	27.60	2.81	30.41
AQUIRED-05/85	AGE- 58 MONTHS	12877	423	5309	27739	15842	62190	10888	73078	27322	2.28	.40	2.67
SEC. 47		40223	1727	21676	38534	29561	131721	49257	180978	189222	.70	.26	.96
0200 NH 8522	MERCEDES 1113 TRUC	1283	7	2340	191	3037	6858	1576	8434	3992	1.72	.39	2.11
AQUIRED-05/85	AGE- 58 MONTHS	10064	598	4968	6230	13044	34904	13351	48255	34631	1.01	.39	1.39
SEC. 47		42763	2561	17318	31170	29719	123531	51496	175027	239165	.52	.22	.73
ALL- MERCEDES BENZ		10617	474	8309	4773-	18055	32682	10400	43082	24883	1.31	.42	1.73
		102896	6895	36507	143408	131414	423120	107984	531104	291065	1.45	.37	1.82
		339156	20392	134465	290827	260566	1045406	446925	1492331	1716747	.61	.26	.87

HIND

APPENDIX B : FINAL DATA FILE

RAW DATA FOR TRUCK VOC STUDY - MAINTENANCE AND NEW VEHICLE PRICE

DATA SAMPLED FOR 18 MONTH PERIOD - APRIL 1989 TO SEPTEMBER 1990

Depot	6 month period up to	Depot Weighted QI	vehicle type	veh no	new veh price	spares cost 6 mnths	labour cost 6 mnths	km recrd 6 mnths	veh age in km
A	Sep 89	110	Nissan CM15	173	130660	2756	5205	46364	89055
		110	Hino 39 240	172	222570	1384	3850	37550	79909
		110	Hino 14 177	161	133303	6022	7762	45690	134897
		110	Hino 14 177	162	133303	3717	6197	40578	130792
		110	Hino 14 177	164	133303	7502	5203	41176	121427
		110	Isuzu F9000DFT	167	134063	9456	6484	54125	62981
		110	Isuzu F9000DFT	166	134063	7786	6944	38933	75168
		110	Isuzu F9000DFT	165	134063	4088	4683	49465	99265
		110	Isuzu 8000DFN	168	116083	8085	6509	32244	49599
		110	Isuzu 8000DFN	169	116083	8470	7606	39674	56468
		110	Isuzu 8000DFN	170	116083	4635	5183	38772	38747
		110	Isuzu 8000DFN	174	116083	1341	3616	46783	62551
		110	Isuzu 8000DFN	175	116083	3399	5148	41308	14702
		110	Isuzu 8000DFN	176	116083	1637	3285	45797	4036
		110	Isuzu 8000DFN	177	116083	1318	1964	40701	13500
		110	Isuzu 8000DFN	178	116083	895	1694	25779	4512
		110	Isuzu 8000DFN	179	116083	1143	2265	34288	27486
		110	Isuzu 8000DFN	181	116083	181	315	8455	17546
		110	Isuzu 8000DFN	182	116083	421	540	7491	19964
		110	Isuzu 8000DFN	183	116083	132	270	9429	17201
A	Mar 90	110	Nissan CM15	173	137815	7646	8097	31937	120992
		110	Hino 39 240	172	239175	4480	4249	39540	119449
		110	Hino 14 177	161	141243	11530	7516	40033	174930
		110	Hino 14 177	162	141243	8042	6600	36362	167154
		110	Hino 14 177	164	141243	7925	6538	40761	162188
		110	Isuzu F9000DFT	167	140443	4619	3151	47430	110311
		110	Isuzu F9000DFT	166	140443	11445	9809	36641	111809
		110	Isuzu F9000DFT	165	140443	7659	5987	43215	142480
		110	Isuzu 8000DFN	168	122180	8640	8539	27949	77548
		110	Isuzu 8000DFN	169	122180	7574	7482	24178	80646
		110	Isuzu 8000DFN	170	122180	6156	7793	29100	67847
		110	Isuzu 8000DFN	174	122180	7434	6148	37310	99861
		110	Isuzu 8000DFN	175	122180	4899	4749	36954	51656
		110	Isuzu 8000DFN	176	122180	2908	4027	27347	31383
		110	Isuzu 8000DFN	177	122180	2706	3391	33286	46786
		110	Isuzu 8000DFN	178	122180	3477	4668	39832	44344
		110	Isuzu 8000DFN	179	122180	3043	3150	40152	67638
		110	Isuzu 8000DFN	181	122180	2014	2660	36734	54280
		110	Isuzu 8000DFN	182	122180	1044	2060	31178	51142
		110	Isuzu 8000DFN	183	122180	1616	2326	38638	55839
		110	Isuzu 8000DFN	184	122180	1874	2549	42659	40938
		110	Hino 13 136	185	122055	1481	1833	29111	21337
		110	Hino 13 136	186	122055	697	1660	16297	27284
A	Sep 90	110	Nissan CM15	173	143675	5408	7350	35798	156790
		110	Hino 39 240	172	246990	3335	4725	38031	157480
		110	Hino 14 177	161	145858	9474	8100	33823	208753
		110	Hino 14 177	162	145858	6563	4995	36721	203875
		110	Hino 14 177	164	145858	3649	6720	33102	195290
		110	Isuzu F9000DFT	167	145210	3216	4470	43768	154079
		110	Isuzu F9000DFT	166	145210	8165	6870	43019	154828
		110	Isuzu F9000DFT	165	145210	8221	7680	34736	177216
		110	Isuzu 8000DFN	168	126295	2709	7095	25904	103452
		110	Isuzu 8000DFN	169	126295	23167	9630	20484	101130
		110	Isuzu 8000DFN	170	126295	8379	5790	24825	92672
		110	Isuzu 8000DFN	174	126295	9002	7290	30386	130247
		110	Isuzu 8000DFN	175	126295	5422	4860	27429	79085
		110	Isuzu 8000DFN	176	126295	4911	5220	26665	57448
		110	Isuzu 8000DFN	177	126295	5835	5025	29460	76246
		110	Isuzu 8000DFN	178	126295	6458	5220	29873	74217
		110	Isuzu 8000DFN	179	126295	4181	3960	27462	95100
		110	Isuzu 8000DFN	181	126295	4476	4050	29795	84075
		110	Isuzu 8000DFN	182	126295	2393	4620	31851	82993
		110	Isuzu 8000DFN	183	126295	6615	4440	29042	84881
		110	Isuzu 8000DFN	184	126295	3752	3570	36740	77678
		110	Hino 13 136	185	126045	4605	5610	26491	47828
		110	Hino 13 136	186	126045	2574	2910	31818	59102

Depot	6 month period up to	Depot Weighted QI	vehicle type	veh no	new veh price	spares cost 6 mnths	labour cost 6 mnths	km recrd 6 mnths	veh age in km
B	Sep 89	80	Nissan CW45PAN	227	240095	440	853	8117	29960
		80	Hino 13 136	237	115193	3651	1050	13182	206191
		80	Hino 13 136	248	115193	2590	1088	10394	22767
		80	Hino 14 177	272	133303	1181	1085	8827	22232
		80	Hino 26 280	291	248245	1773	1083	8756	32355
		80	Hino 13 136	401	115193	2117	1063	10832	21228
		80	Hino 26 280	425	248245	703	680	9363	23402
		80	Hino 13 136	432	115193	1007	685	13227	26508
B	Mar 90	80	Hino 13 136	237	122055	3724	1999	19447	225638
		80	Hino 13 136	248	122055	5220	2402	16241	39008
		80	Hino 14 177	272	141243	3973	3146	13616	35848
		80	Hino 13 136	401	122055	3696	2483	18759	39987
		80	Hino 26 280	425	261835	1100	1560	14103	37505
		80	Hino 13 136	432	122055	754	1949	22934	49442
B	Sep 90	80	Nissan CW45PAN	227	266550	2712	3082	12131	54243
		80	Hino 13 136	237	126045	650	1705	10749	236387
		80	Hino 13 136	248	126045	2635	2621	14676	53684
		80	Hino 14 177	272	145858	2427	3285	13416	49264
		80	Hino 13 136	401	126045	2037	2470	24233	64220
		80	Hino 13 136	432	126045	5271	1878	26571	76013
		80	Hino 13 136	824	126045	823	1080	11222	13063
C	Sep 89	130	MERC BENZ 1113	183	110375	8443	8171	18399	224439
		130	MERC BENZ 1113	184	110375	8644	7491	24033	182611
		130	MERC BENZ 1113	185	110375	8273	7086	19961	161594
		130	MERC BENZ 1113	186	110375	9293	6533	18783	164020
		130	MERC BENZ 1113	198	110375	5584	6706	17084	104917
		130	MERC BENZ 1113	200	110375	1750	4232	8751	195402
		130	HINO 14 177	251	133303	11490	6768	31964	189628
		130	HINO 14 177	252	133303	10248	8668	29504	189387
		130	HINO 14 177	253	133303	5098	5651	31853	191229
		130	MERC BENZ 1413	254	132235	5325	5754	29500	170976
C	Mar 90	130	MERC BENZ 1113	182	117830	5446	10545	34838	208038
		130	MERC BENZ 1113	183	117830	13917	7583	19250	243689
		130	MERC BENZ 1113	184	117830	8079	11561	15440	198051
		130	MERC BENZ 1113	185	117830	8832	8928	22315	183909
		130	MERC BENZ 1113	186	117830	11913	10738	19158	183178
		130	MERC BENZ 1113	198	117830	15640	10267	18557	123534
		130	MERC BENZ 1113	200	117830	4480	8812	25880	221282
		130	HINO 14 177	206	141243	4779	3633	40656	82214
		130	HINO 14 177	251	141243	8503	9607	27812	217440
		130	HINO 14 177	253	141243	20016	9260	21578	212807
		130	MERC BENZ 1413	254	149565	9735	7713	16508	197484
C	Sep 90	130	MERC BENZ 1113	182	117830	1348	1249	3313	211351
		130	MERC BENZ 1113	184	117830	7359	7058	11250	209301
		130	MERC BENZ 1113	185	117830	1466	1079	7379	191288
		130	MERC BENZ 1113	186	117830	1645	2712	5086	189064
		130	MERC BENZ 1113	198	117830	7760	10417	11127	134661
		130	MERC BENZ 1113	200	117830	5155	6208	14000	235282
		130	HINO 14 177	206	145858	1534	1753	36121	118335
		130	HINO 14 177	251	145858	9685	6033	25208	242648
		130	HINO 14 177	252	145858	8519	5846	13643	223060
		130	HINO 14 177	253	145858	3444	5111	32310	245117
		130	MERC BENZ 1413	254	158270	11942	3773	20071	217565
		130	SAMAG 70L	262	189263	819	1021	14310	14311
		130	SAMAG 70L	263	189263	591	787	15275	15274
		130	SAMAG 70L	264	189263	1236	1415	9344	9343
		130	SAMAG 70L	265	189263	528	1769	14312	14311
		130	SAMAG 70L	266	189263	2044	1190	9899	9898
		130	SAMAG 70L	267	189263	330	1755	14091	14090

Depot	6 month period up to	Depot Weighted QI	vehicle type	veh no	new veh price	spares cost 6 mnths	labour cost 6 mnths	km recrd 6 mnths	veh age in km
O	Sep 89	150	Nissan UG780	441	96115	3156	4514	17702	152402
		150	Nissan UG780	872	96115	7308	7401	16991	76285
		150	Nissan UG780	873	96115	7791	3025	20200	42997
		150	Nissan CM15	881	130660	1778	2257	22239	50961
		150	Nissan CM15	882	130660	2718	3511	20352	50163
		150	Nissan CM15	883	130660	1735	2043	19969	35025
		150	Nissan CM15	891	130660	2471	1058	8932	12569
		150	Nissan CM15	892	130660	3184	608	9104	9101
O	Mar 90	150	Nissan UG780	441	101175	3283	3530	6049	158451
		150	Nissan UG780	873	101175	2292	1408	5195	48192
		150	Nissan CM15	881	137815	6053	3442	11076	62037
		150	Nissan CM15	882	137815	4175	4230	10420	60583
		150	Nissan CM15	891	137815	2148	1961	11392	23951
		150	Nissan CM15	892	137815	2215	1580	11556	20657
		150	Nissan CM15	887	137815	310	590	3554	4507
O	Sep 90	150	Nissan UG780	872	104480	6352	6789	13150	97033
		150	Nissan UG780	873	104480	2330	3643	41930	90122
		150	Nissan CM15	881	143675	4089	4183	17780	79817
		150	Nissan CM15	882	143675	6189	4410	17712	78295
		150	Nissan CM15	883	143675	3723	5435	15638	58754
		150	Nissan CM15	891	143675	4063	2700	18568	42519
		150	Nissan CM15	892	143675	4593	3320	19635	40292
		150	Nissan CM15	887	143675	2368	1806	12645	17152
E	Sep 89	40	SAMAG 70L	814	170890	1370	561	16990	234916
		40	SAMAG 70L	815	170890	3122	2991	24422	238373
		40	SAMAG 70L	816	170890	2351	1663	24990	234226
		40	SAMAG 70L	817	170890	2359	2802	30093	235492
		40	SAMAG 70L	818	170890	844	1336	23066	326130
		40	SAMAG 70L	819	170890	2276	3431	22520	289349
		40	SAMAG 70L	820	170890	1753	1628	29192	299507
		40	SAMAG 70L	821	170890	1992	1120	17809	302708
		40	SAMAG 240.16	827	239688	2869	1783	24054	207460
		40	SAMAG 240.16	828	239688	1473	1277	23757	198008
		40	SAMAG 240.16	835	239688	2062	2548	25240	121254
		40	SAMAG 240.16	836	239688	857	846	20766	106512
		40	SAMAG 70L	839	170890	3528	2140	28229	61896
		40	SAMAG 70L	840	170890	1727	1247	32409	78144
		40	SAMAG 70L	841	170890	2294	1313	35569	91586
		40	SAMAG 70L	842	170890	701	261	3492	195868
		40	SAMAG 70L	843	170890	583	369	4858	174390
		40	SAMAG 70L	846	170890	2075	1809	31837	76550
		40	SAMAG 70L	848	170890	506	828	23994	25509
		40	SAMAG 70L	849	170890	828	1206	28640	30144
		40	SAMAG 70L	850	170890	1095	962	20610	21375
		40	SAMAG 70L	851	170890	310	209	21074	21824
		40	SAMAG 70L	852	170890	1205	793	21333	16149
		40	SAMAG 240.16	857	239688	573	2590	21934	176905

Depot	6 month period up to	Depot Weighted Q1	vehicle type	veh no	new veh price	spares cost 6 mnths	labour cost 6 mnths	km recrd 6 mnths	veh age in km
E	Mar 90	40	SAMAG 70L	814	179298	1587	650	19669	254585
		40	SAMAG 70L	816	179298	1217	794	11929	246155
		40	SAMAG 70L	820	179298	1337	1242	22267	321774
		40	SAMAG 70L	821	179298	1694	952	15151	317859
		40	SAMAG 70L	827	255681	2351	1451	19207	226667
		40	SAMAG 70L	828	255681	1179	1022	18966	216974
		40	SAMAG 70L	835	255681	1587	1962	19430	140684
		40	SAMAG 70L	830	179298	2459	1491	19677	81573
		40	SAMAG 240.16	840	179298	1264	913	23731	101875
		40	SAMAG 240.16	841	179298	1786	1022	27693	119279
		40	SAMAG 240.16	843	179298	2556	1620	21290	195600
		40	SAMAG 240.16	844	179298	87	140	15763	265123
		40	SAMAG 70L	846	179298	1422	1240	21819	98369
		40	SAMAG 70L	848	179298	440	0	20893	46402
		40	SAMAG 70L	849	179298	722	1050	24966	55110
		40	SAMAG 70L	850	179298	1118	981	21028	42403
		40	SAMAG 70L	851	179298	1094	0	20564	42388
		40	SAMAG 70L	852	179298	1126	740	19934	36083
		40	SAMAG 240.16	857	255681	463	0	17703	194608
		40	SAMAG 70L	853	179298	4751	4599	42547	217594
		40	SAMAG 70L	854	179298	358	2015	10618.88	222155
		40	SAMAG 70L	855	179298	4801	1624	36965	230562
E	Sep 90	40	SAMAG 70L	814	189263	3271	4655	23845	270430
		40	SAMAG 70L	815	189263	8128	8011	15889	276123
		40	SAMAG 70L	816	189263	5412	5816	19905	266060
		40	SAMAG 70L	817	189263	9582	8726	19202	271712
		40	SAMAG 70L	818	189263	4602	6704	16766	359045
		40	SAMAG 70L	820	189263	4532	5046	24319	346093
		40	SAMAG 70L	821	189263	7003	6042	19457	337316
		40	SAMAG 240.16	827	266134	5509	6809	19670	246337
		40	SAMAG 240.16	828	266134	3345	4394	19477	236451
		40	SAMAG 240.16	835	266134	4274	7707	16898	157582
		40	SAMAG 70L	839	189263	4059	8011	21554	103127
		40	SAMAG 70L	840	189263	2056	4357	23102	124977
		40	SAMAG 70L	841	189263	5420	5167	33589	152868
		40	SAMAG 70L	842	189263	5617	6923	20509	234191
		40	SAMAG 70L	843	189263	2237	4768	15859	211539
		40	SAMAG 70L	844	189263	5433	5487	26107	291230
		40	SAMAG 70L	846	189263	1518	5337	22564	120923
		40	SAMAG 70L	848	189263	1677	3975	24847	71249
		40	SAMAG 70L	849	189263	3269	5034	31428	86538
		40	SAMAG 70L	850	189263	3847	5953	26937	69340
		40	SAMAG 70L	851	189263	2434	2412	24743	67131
		40	SAMAG 70L	852	189263	2808	3722	27699	63782
		40	SAMAG 240.16	857	266134	375	605	1784	196392
		40	SAMAG 70L	853	189263	6150	9572	23274	240868
		40	SAMAG 70L	854	189263	3694	5040	16691	238846
		40	SAMAG 70L	855	189263	4397	3087	21562	252124
		40	SAMAG 70L	856	189263	7426	3699	14599	14599

APPENDIX C : EXAMPLE OF A WORKING FILE

SUMMARY DATA FOR ALL DEPOTS:

Depot	Period 6 mnths up to	Reported Depot Tyres R/1000km	Reported Depot spares R/1000km	Reported Depot labour R/1000km	Wghtd Depot QI	Average vehicle price per depot	Rprtd spares per veh pr	Ave vehicle age km	lnQI	ln(AGE /1000)	Normalised SP/VP for QI=90	Prediction	ln(lab)	Reprtd ln(SP/VP)	norm P/VP age=110
A	Sep 89	125	94	109	110	127,400	73.78	56,000	4.70	4.03	11.95	65	4.69	4.30	97.01
A	Mar 90	105	159	.148	110	132,650	113.03	84,000	4.70	4.43	12.80	79	5.00	4.73	126.69
A	Sep 90	157	174	175	110	137,350	126.44	115,000	4.70	4.74	12.63	91	5.16	4.84	124.06
B	Sep 89	171	158	95	80	165,300	95.01	48,000	4.38	3.87	14.13	62	4.55	4.55	141.13
B	Mar 90	147	180	125	80	148,600	121.13	64,000	4.38	4.16	13.63	70	4.91	4.80	157.37
B	Sep 90	155	140	158	80	149,000	93.95	72,000	4.38	4.28	12.45	74	5.06	4.54	114.02
C	Sep 89	114	310	321	130	119,400	259.63	175,000	4.87	5.16	13.98	110	5.77	5.56	210.23
C	Mar 90	131	470	405	130	122,100	384.93	[illegible]	4.87	5.24	14.55	114	6.00	5.95	296.26
C	Sep 90	99	285	276	130	152,000	187.59	[illegible]	4.87	4.95	13.64	101	5.62	5.23	167.27
D	Sep 89	213	241	176	150	117,700	204.76	54,000	5.01	3.99	12.70	65	5.17	5.32	284.50
D	Mar 90	320	285	292	150	127,300	224.67	56,000	5.01	4.03	13.91	65	5.68	5.41	309.73
D	Sep 90	356	259	237	150	133,900	186.71	67,000	5.01	4.20	12.32	72	5.47	5.23	233.11
E	Sep 89	27	75	65	40	185,200	41.04	160,000	3.69	5.08	13.15	105	4.17	3.71	35.01
E	Mar 90	23	70	69	40	193,200	35.23	185,000	3.69	5.22	13.17	113	4.22	3.59	29.38
E	Sep 90	131	219	27	40	200,700	109.12	200,000	3.69	5.30	16.59	117	3.31	4.69	79.85

REFERENCES

1. CHESHER, A. AND HARRISON, R., Vehicle operating costs : Evidence from Developing Countries, The World Bank, Washington, D.C., 1987.

2. CURTAYNE P.C., VISSER, A.T., DU PLESSIS, H.W. AND HARRISON, R., Calibrating the relationship between operating costs of buses and road roughness on low-volume roads, RR514, CSIR, Pretoria, 1987.

3. DU PLESSIS, H.W., VISSER, A.T. AND CURTAYNE, P.C., Fuel consumption of vehicles as affected by road surface characteristics, Paper presented at the ASTM First Int Symp on Surface Characteristics, State College, PA, June 1988.

4. DU PLESSIS, H.W. AND RUST, U.A., A vehicle operating cost model for Southern Africa : Draft User's Manual, Contract Report DPVT-C23.1, Roads and Transport Technology, CSIR, September 1988.

5. DU PLESSIS, H.W., MORDEN, C.H., AND COETZEE C.H., A pilot study to determine the effect of road roughness on vehicle operating speeds, Research Report DPVT-145, CSIR, Pretoria, 1989.

6. DU PLESSIS, H.W. AND CURTAYNE, P.C., Road roughness, riding quality and aspects of construction quality control, Paper presented at the 10th Annual Transportation Convention (ATC '90), CSIR, Pretoria, 1990.

7. HARRISON, R. AND VISSER, A.T., Preliminary investigations into the applicability of available vehicle operating cost relations to South Africa conditions, NITRR Technical report RP/8, Pretoria, CSIR, April 1985.

8. HIDE, H., ABAYNAYAKA, S.W., SAYER, I. AND WYATT, R.J., The Kenya Road Transport Cost Study : Research on Vehicle Operating Costs, TRRL Report LR672, Transport and Road Research Laboratory, Crowthorne, England, 1974.

9. PATERSON, W.D O. AND WATANATADA, T., Relationships between vehicle speed, ride quality and road roughness, Measuring road roughness and its effects on user cost and comfort, ASTM STP 884, 1985, pp. 89-110.

10. PATERSON, W.D.O., International Roughness Index : Relationship to other measures of roughness and riding quality, Transportation Research Record 1084, World Bank, Washington, D.C., 1986.

11. PIENAAR, W.J., Olieverbruik van padvoertuie in Suid-Afrika, NITRR, Technical Report RT/5, CSIR, Pretoria, January 1985.

12. SCHUTTE, I.C., Computerization of CSIR draft manual K64 part II : Program COSTDATA, NITRR, Technical Report RT/50, CSIR, Pretoria, September 1987.

13. VISSER, A.T. AND CURTAYNE, P.C., The routine operation, calibration and control of the linear displacement integrator, Technical Report No. RC/7/82, NITRR, CSIR, Pretoria, 1982.

14. VISSER, A.T., A correlation study of roughness measurements with an index obtained from a road profile measured with rod and level, NITRR Technical Report RC/2/82, Pretoria, CSIR, March 1982.

15. WESSELS, M., Calibrating the relationship between operating costs of heavy goods vehicles and road roughness, Research for and on behalf of the South African Roads Board by Division of Roads and Transport Technology, CSIR, Pretoria, 1989.

16. ZANIEWSKI, J.P. AND BUTLER, B.C., Vehicle Operating Costs Related to Operating Mode, Road Design, and Pavement Condition, Measuring Road Roughness and Its Effects on User Cost and Comfort, ASTM STP 884, Philadelphia, 1985.

BIBLIOGRAPHY

1. BENNETT, C.R., A Highway economic evaluation model for New Zealand, M.Sc Thesis, University of Auckland, New Zealand, 1985.

2. DU PLESSIS, H.W. AND YORKE-HART, M.A. A study of the effects of road surface properties on the fuel consumption of trucks and buses, NITRR Contract Report C/PAD/46.7, Pretoria, CSIR, December 1986.

3. DU PLESSIS, H.W., The effects of road roughness on bus maintenance and labour costs in Kwazulu, NITRR Technical Note TM/8/87, Pretoria, CSIR, February 1987.

4. DU PLESSIS, H.W., VISSER, A.T. AND HARRISON, R., The effects of road condition on the operating costs of buses, RR488, Pretoria, CSIR, August 1987.

5. DU PLESSIS, H.W. AND MEADOWS, J.F., A pilot study to determine the operating costs of passenger cars as affected by road roughness, Research report DPVT-142, Pretoria, CSIR, May 1990.

6. KEMP, M.J., CURTAYNE, P.C. AND YORKE-HART, M.A. A study on the applicability of HDM III for use in assessing maintenance alternatives on South African rural roads, reprint of paper prepared for the 1989 Annual Transportation Convention, RR627, Pretoria, CSIR, August 1989.

7. PARSLEY, L.L. AND ROBINSON, R., The TRRL Road Investment Model for developing countries (RTIM2), TRRL Report 1057, Department of Environment Crowthorne, 1982

8. WATANATADA, T. et al, Vehicle speeds and operating costs : Models for road planning and management, The Highway Design and Maintenance Standards Study, Transportation Department, The World Bank, Washington, D.C., 1987.

9. WINFREY, R., Economic Analysis for Highways, International Textbook Co, Scranton, PA.