VEHICLE REPAIR & MAINTENANCE COSTS

LITERATURE REVIEW & OPERATOR COST SURVEY

Transfund New Zealand Research Report No. 118

VEHICLE REPAIR & MAINTENANCE COSTS

LITERATURE REVIEW & OPERATOR COST SURVEY

OPUS CONSULTANCY SERVICES LTD,
in association with
BECA CARTER HOLLINGS & FERNER LTD,
Auckland, New Zealand

Transfund New Zealand Research Report No. 118

ISBN 0-478-11076-6
ISSN 1174-0574

PO Box 2331, Lambton Quay, Wellington, New Zealand
Telephone (04) 473-0220; Facsimile (04) 499-0733

Opus Consultancy Services Ltd, Beca Carter Hollings & Ferner Ltd. 1998. Vehicle repair and maintenance costs: Literature review and operator cost survey. *Transfund New Zealand Research Report No. 118.* 100pp.

Keywords: costs, literature, maintenance, New Zealand, operator, repair, road condition, user survey, vehicle

AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transit New Zealand when it had responsibility for funding roading in New Zealand. This funding is now the responsibility of Transfund New Zealand.

While this report is believed to be correct at the time of publication, Transit New Zealand, Transfund New Zealand, and their employees and agents involved in preparation and publication, cannot accept any contractual, tortious or other liability for its content or for any consequences arising from its use and make no warranties or representations of any kind whatsoever in relation to any of its contents.

The report is only made available on the basis that all users of it, whether direct or indirect, must take appropriate legal or other expert advice in relation to their own circumstances and must rely solely on their own judgement and seek their own legal or other expert advice.

The material contained in this report is the output of research and should not be construed in any way as policy adopted by Transit New Zealand or Transfund New Zealand but may form the basis of future policy.

CONTENTS

TABLES

FIGURES

ACKNOWLEDGMENTS

NAFA Asset Management Ltd, Auckland, are acknowledged for their data on vehicle repair and maintenance costs.

GLOSSARY

AA	NZ Automobile Association
AKM	Average kilometres of travel per year
ARRB	Australian Road Research Board
AASHTO	American Association of State Highway & Transportation Officials (after 1974)
AUSTROADS	National Association of Road Transport & Traffic Authorities in Australia
BCHF	Beca, Carter, Hollings & Ferner Ltd
BI	Roughness measured by TRRL bump integrator mm/km
BTCE	Bureau of Transport and Communications Economics
CF, CFLAB, CFPART	Correction factor, for labour, for parts
CKM	Average accumulated kilometres of travel
CKM'	Maximum upper limit for CKM in HDM model
Clhpc, Clhqi, Colh	Coefficients in HDM labour hours model
Cosp, Cspqi	Coefficients in HDM parts consumption model
CP	Parts cost
CRRI	Central Road Research Institute, New Delhi
CSIR	Commonwealth Scientific & Industrial Research (South Africa)
DEP	Annual depreciation as a proportion of the new vehicle price
EIU	Economist Intelligence Unit
GEIPOT	Empresa Brasileira de Planejamento de Transportes
HDM	Highway Design & Maintenance Standards Model
IRI	International Roughness Index
IRRD	International Roads Research Database
ITS	Institute of Transport Studies
k	Age exponent in the HDM III model
K	Accumulated vehicle kilometres, termed vehicle age
km	Kilometre(s)
LAB	Labour cost per 1000 kilometres (various currency units)
LH	Labour hours per year
LIFE	Vehicle life expressed in years
MIRA	Motor Industry Research Association, UK
MOT	Ministry of Transport New Zealand
NAASRA	National Association of Australian State Road Authorities
NITRR	National Institute for Transport & Road Research (South Africa)
NRB	National Roads Board, New Zealand
NZ	New Zealand
NZVOC	New Zealand Vehicle Operating Cost
OECD	Organisation for Economic Co-operation & Development
PC	Parts consumption, equal to parts cost per 1000 km divided by new vehicle price
PEM	Project Evaluation Manual (Transit New Zealand)
QI	Roughness on quarter car index scale
QIosp	Exponential/linear transition value of QI roughness in HDM parts model
R&M	Repairs and maintenance
RRU	Road Research Unit, National Roads Board, New Zealand
RTA	Road & Traffic Authority, New South Wales, Australia
RTIM	Road Transport Investment Model
TNO	Road Vehicles Research Institute, Netherlands
TNZ	Transit New Zealand
TRB	Transportation Research Board, Washington DC, USA
TRDF	Texas Research & Development Foundation
TRRL	Transport & Road Research Laboratory, UK (until 1991, TRL after 1992)
UK	United Kingdom
UNDP	United Nations Development Programme
USA	United States of America
VOC	Vehicle Operating Cost(s)
VP	New vehicle price
VTI	Swedish Road & Traffic Research Institute

EXECUTIVE SUMMARY

Research Tasks and Schedule
This report records progress up to and including Task 2 of Stage 2 of a research study of road vehicle repair and maintenance costs (R&M) in relation to road operating conditions. The project tasks carried out between 1992 and 1995, i.e. up to this reporting stage, are listed here.

Stage 1 (commenced in mid-1992 and completed in mid-1993)

- Task 1 Contact international researchers and undertake a literature review of research into vehicle R&M costs and approaches to modelling vehicle R&M costs in relation to road and traffic conditions.
- Task 2 From the results of the review, identify appropriate methods for incorporating R&M costs in a vehicle operating cost model for New Zealand conditions.
- Task 3 Assess the available New Zealand sources for R&M cost data, and designing surveys to obtain R&M costs from representative groups of transport operators.

Stage 2 (commenced in January 1994 and completed at the end of 1995)

- Task 1 Execute the operator surveys; and
- Task 2 Provide a preliminary analysis of the results.

Further Stages 3 to 6 of the research, as originally envisaged at the inception of the project, were to have been as follows:

Stage 3 Constituent Component Cost Analysis Survey

Stage 4 Derivation of Mean R&M Costs per kilometre and Models for Cost Variation with Road and Traffic Conditions

Stage 5 Calibration of a Mechanistic Model of Vehicle R&M Costs

Stage 6 Report on Model Methods and Operation

The extent to which research data would allow the development of the more sophisticated forms of R&M model was unknown at the commencement of the research. No commitment had been made to undertake these later proposed stages of the project as at March 1997.

Literature Review
Available literature on the subject was reviewed, in particular the HDM III model and its associated research base, the vehicle operating cost modelling work in South Africa, and the Swedish VETO model. Also a number of possible data sources were investigated. These gave good reason to anticipate a successful outcome to an operator survey.

Overseas Contacts and Database Search
Extensive computer searches were made through the TeLIS system and through the ARRB TRIS database. A certain limited amount of reference material was obtained by this means but overall the payoff from the computer search must be regarded as disappointing. Most of the useful reference material was obtained by direct contacts made with international researchers and New Zealand agencies and individuals. The most important sources remain the World Bank HDM model and associated research, the South African CSIR research, and the Swedish VETO model which is an example of a fully mechanistic but also a very demanding approach to the problem.

Data Sources for Vehicle Operating Costs

A large number of organisations in the public and private sectors were contacted to enquire their willingness to allow access to data records on R&M costs for the project. Apart from individual vehicle owners and fleet operators, over the last decade there has been growth in vehicle fleet management and accounting services in New Zealand, such as FLEETCARD and NAFA Asset Management Ltd. Both were approached to participate in the project. In particular, the NAFA management was engaged to extract information from its database on company-owned cars and light commercial vehicles. The highly detailed allocation of R&M costs to a number of sub-categories made this a key data source for the project.

For heavy commercial vehicles and buses, a number of fleet operators agreed to co-operate in a user survey, and a proportion of these provided useful data. However there was wide variation in the detail and quality of their data records.

There was no readily available source of data on vehicle operating costs for private car owners. A retrospective survey of vehicle owners' records was rejected at this stage because of likely sample bias and difficulty in identifying potential survey respondents. For future work, it is proposed that either this section of the fleet be excluded from any further user surveys, which would be undesirable given the size and importance of the private car stock, or monitoring of randomly selected private motorists' costs be carried out over a minimum one year period, with some sort of incentive for participants.

Information Requirements for Project Evaluation

Uncertainty exists about the accuracy both in the average costs of R&M for the vehicle classes used in the Transit New Zealand Project Evaluation Manual (PEM 1991), and in the relationship between road roughness, sealed/unsealed surface and R&M costs. Possible differences between R&M costs under urban and rural operating conditions are also undefined. In addition, the slope of the roughness/maintenance curve for relatively smooth surfaces is uncertain.

Ideally, R&M cost relationships against road geometric features such as horizontal curvature, gradient, and speed change through intersections should be obtained, although the international research shows the difficulties of achieving this from user cost records.

It is also important to have a better grasp of the relationship between R&M costs (and operating costs generally) and vehicle capital depreciation. From the review, the researchers held serious doubts concerning the present simplified treatment of depreciation, justified on grounds of lack of time stability of depreciation relationships, which has no link with operator cost minimising behaviour. Consequently it was recommended that the operator surveys be eclectic in collection of cost data and operator behaviour. Data collection would include: vehicle purchase, resale costs and depreciation; vehicle and fleet utilisation; and maintenance practice so that interactions could be studied.

Selection of a Modelling Approach

This report describes a hierarchy of modelling approaches, ranging from simple mean values of R&M cost for each vehicle class, through to a detailed mechanistic modelling approach with costs identified for each vehicle component. The simpler approach was judged to be achievable and useful but not very ambitious, whereas the fully mechanistic approach was regarded as almost certainly impractical within the budget and time-frame available for the research.

Modelling approaches were also considered from the viewpoint of data requirements, either using existing records or monitoring future costs. The time and cost budget originally envisaged permitted only the first approach to be taken. Sufficient operator cost data were available to be able to establish average R&M costs for each vehicle class. Indications obtained from the vehicle operators before the surveys were carried out gave reasonable confidence that the data would allow differentiation of average values of R&M cost by urban/rural location, and of general operating conditions such as sealed/unsealed and flat/hilly terrain, through analysis of the domicile of vehicle fleets and road system data (such as roughness measurement).

While the data collected were sufficient to allow significant differences by region and urban/rural running to be identified, the mean values of sample R&M costs by region were not great enough for the preliminary analysis to unequivocally conclude whether any significant differences exist. Further analysis may show statistically significant differences by region or by urban/rural use, but this is not certain. The data quality at present is not good enough to discriminate R&M costs by terrain type or by sealed/unsealed road surfaces.

Execution of Vehicle Operator Surveys
The surveys of vehicle operators were carried out successfully. The vehicle sample from operator records provided most data on heavy trucks and buses. The NAFA database provided most data on cars and light commercial vehicles. Data on medium commercial vehicles were drawn equally from the two sources. The surveys took much longer to conduct than originally anticipated, and did not yield the quantity of data promised, attributable mainly to vehicle operators' staff time constraints. The NAFA data, while a very valuable source of information, took a long time to acquire because of staff and computer system changes.

Results of the Preliminary Analysis of the Vehicle Operator Survey Data
The main results from the analysis are summarised:

1. Parts costs and total R&M costs for cars and light commercial vehicles from the operator surveys are 40 to 45% lower than the costs in the present NZ Vehicle Operating Cost (NZVOC) model. However, if the "local calibration" factor in the NZVOC model is removed, then the operator survey costs and the model costs are within 20% of each other.

2. For all other vehicle types the operator surveys give mean R&M costs which are greater than those from NZVOC. If the local calibration is removed, truck and bus costs fall below those observed in surveys. Surveyed medium commercial vehicle costs are 40% above NZVOC modelled costs or 100% above if the local calibration is removed.

3. The operator surveys indicate that R&M costs per kilometre are relatively constant for the first 3 to 4 years of vehicle life but thereafter rise with age until at least 8 years (data beyond this age were not available).

4. The proportion of R&M costs in routine servicing as opposed to specific maintenance and repair work is significant and decreases over time, for example from 75% of total R&M costs for new cars to less than 20% for cars of 7 years or older.

5. Parts costs contribute between 44% and 61% of total R&M costs on average. Parts cost contribution does not appear to vary greatly with vehicle age.

6. R&M costs expressed as a proportion of new vehicle price (parts consumption), vary with vehicle size within each vehicle class. For example, R&M cost in cents//km increases with increasing car engine size whereas, in contrast, parts consumption reduces with increasing engine size. That is, vehicle price against engine size rises faster than R&M cost.

7. There is some evidence for distinguishing between vehicles according to body type. For example in the heavy vehicle class, tanker trucks were found to exhibit 75% greater R&M

cost/km than bulk materials trucks; and in the light commercial category light truck-body vehicles exhibited 50% higher R&M costs than vans and utilities.

8. The analysis showed no clear differences in R&M costs on urban versus rural roads, or by region of operation, other than those attributable to differences in mean vehicle age within each sub-sample. The possibility remains that a more detailed statistical analysis might detect significant variation but, if so, this seems likely to be small. Also there were insufficient data to compare R&M costs on sealed versus unsealed roads or on flat versus hilly terrain.

Conclusions & Recommendations

The analysis of the operator survey responses provided some interesting results on matters which were not anticipated. These included a relationship between R&M cost and vehicle age, and the proportion of R&M cost in routine servicing with vehicle age. There was also a variation in R&M costs between vehicle subtypes which had not been previously identified.

As the useful data received fell short of target for certain industry sectors and types of vehicle duty, it may be worth considering supplementary user surveys to fill these gaps. However, further analysis of the data acquired so far and, in particular, an exploration of the "constituent component" approach to R&M cost estimation, should be made before timing and designing further surveys.

The user surveys did not provide adequate data to investigate variation in R&M cost against road surface roughness. The vehicle fleets included in the survey did not have patterns of utilisation which allowed differences in road roughness to be readily distinguished and correlated with R&M costs. Relationships between R&M costs and road surface roughness are unlikely to be identifiable through the methods employed in the user cost survey, even with an extended sample. It is concluded that there is an absence of vehicle fleets in New Zealand which operate consistently on roads of markedly different roughness but are comparable in other respects, that can form the basis for such an analysis.

The two main areas where further action is recommended are:

1. Adjustments required to the NZVOC Model to take account of findings from the R&M study; and

2. Follow-up work on the R&M project, in particular progression of work on the constituent component modelling approach utilising data obtained in the operator surveys but not so far analysed. Following this, the desirability of carrying out supplementary operator surveys should be reviewed.

ABSTRACT

This report describes the work undertaken between 1992 and 1995 under the first and second stages of a research project into road vehicle repair and maintenance costs in relation to road operating conditions. The report first describes the results of a literature review and contacts made with international researchers made in 1992/93. A staged modelling approach was proposed following this review. Potential sources of vehicle repair and maintenance data across six vehicle categories were investigated with respect to the likelihood of obtaining data appropriate to the proposed modelling approaches. Details of the proposed research plan are outlined, giving time scales for the phases of the work. The execution and preliminary analysis of a survey of vehicle fleet operators and a centralised fleet-asset management agency are reported.

1. INTRODUCTION

1.1 Background

The New Zealand Vehicle Operating Costs Model (NZVOC[1]), which forms the basis of vehicle operating cost tables and graphs in the Transit New Zealand (TNZ) Project Evaluation Manual (PEM) (TNZ 1991), includes a sub-model for vehicle repair and maintenance (R&M) costs. This sub-model is composed of:

1. A relationship between vehicle parts consumption and road roughness; and
2. A maintenance labour component which is currently specified as a fixed percentage of parts consumption, with an added constant term for medium and heavy trucks to give agreement with empirical New Zealand data on R&M costs.

The NZVOC parts consumption sub-model is based on the World Bank Highway Design and Maintenance Standards Model (HDM III), and in particular on an extensive research programme carried out in Brazil by GEIPOT (1981) which included a survey of vehicle fleet operating costs. The structure of the HDM model allows the cost relationships to be adjusted to local conditions by applying unit cost data and parameter values for vehicle physical and performance characteristics. However some parameters, ostensibly to be calibrated to suit the country of application, are not easy to modify without affecting the integrity of the model.

In 1985/86 HDM III was first introduced into the National Roads Board's (NRB) Economic Appraisal Manual for road improvement projects (NRB Technical Recommendation No. TR9). At that time there were difficulties in reconciling modelled vehicle R&M costs using the HDM III model of parts and labour costs with other estimates of R&M cost, in particular the annual publications produced by the Economics Division of the NZ Ministry of Transport (MOT) on typical truck operating costs. The MOT data were based on an annual indexing of R&M costs derived from an earlier user survey, believed to be of the former Ministry of Works vehicle fleet.

As an interim solution to the lack of agreement, and in view of the uncertainties surrounding both sources of information, the labour cost sub-model in HDM III was substituted with a fixed percentage of the parts cost, and a constant term was added to the modelled R&M costs for medium and heavy trucks. This constant was chosen to match the HDM predictions of R&M cost at an average level of road roughness with the costs derived from the MOT sources.

It was known that a considerable research effort would be required to improve the basis for R&M cost modelling to better represent New Zealand conditions, and no further progress was made until the current project.

1 See Glossary for acronyms, abbreviations and mathematical terms, on p.8 of this report.

1.2 Research Objectives

The objectives of the research plan up to the completion of Stage 2 were:

- To identify the various approaches to vehicle R&M cost modelling in relation to their ability to accommodate changes to the road conditions, vehicle fleet mix, and economic environment, with a view to selecting the most appropriate for New Zealand conditions and determining the required input parameters.

- To investigate New Zealand sources of vehicle operating costs data to determine their appropriateness for determining and validating the R&M cost model, and also to establish the cost of accessing this data.

- To design and execute an operator survey to collect data on vehicle R&M costs, and other information of relevance.

- To conduct a preliminary analysis of the data to establish, among other things, mean values of R&M costs per kilometre for different classes of vehicle, compare these findings with the present approach to R&M cost built into the Transit New Zealand project evaluation procedures (TNZ PEM 1991), and to recommend further courses of action.

1.3 Outline of the Report

Chapter 2 provides details of a search of the available literature on the topic and describes the results of personal communications with international agencies working in the field of vehicle operating costs, with emphasis on the status of R&M models. As the literature review was carried out between October 1992 and mid-1993, it is now somewhat dated but is presented here for the sake of completeness.

In Chapter 3 a review is given of the different modelling approaches identified in the literature search and international enquiries. Emphasis is placed on the conceptual basis for R&M cost studies and the relationship with other vehicle operating costs components, the development of the World Bank HDM Model, the current NZVOC Model, and the other R&M cost studies, surveys and modelling approaches found in the literature review.

In Chapter 4, a hierarchy of modelling approaches is presented and an attempt is made to grade the approaches with respect to a list of attributes, leading on to the selection of a modelling approach for this project.

Having decided on a modelling approach, in Chapter 5 the investigation of the potential sources of data to provide the necessary information to formulate and calibrate the model is discussed.

Chapter 6 provides a description of the elements of the proposed research plan. This includes descriptions of the survey questionnaires, interviewer requirements, sample size, data manipulation, time scales and outputs.

Chapter 7 describes the execution of the vehicle operator cost survey, acquisition of data and its manipulation.

Chapter 8 summarises the responses, and provides a preliminary analysis of the results of the vehicle R&M cost survey.

Chapter 9 provides a comparison of the results with the Transit New Zealand Project Evaluation Manual.

Chapter 10 assesses the level of achievement of the project aims, up to the end of the Stage 2, and recommends a course of action for further work.

2. LITERATURE REVIEW

2.1 On-Line Database Search

An extensive literature review was undertaken, using TeLIS, of all available international and local databases. These databases have included: DIALOG, TRIS, NTIS, COMPENDEX PLUS, NZBN, KIWINET - STIX and other KIWINET databases.

Through the library of the Australian Road Research Board (ARRB), further searches were conducted on IRRD, the International Roads Research Database on ESA-IRS. However, no significant new overseas literature was uncovered. To those obtained from the listed databases, other references were added from the researchers' library sources. These references are listed in the Bibliography to this report.

Overall, the results of the on-line database search were somewhat disappointing. Most of the useful technical literature came from sources already available to the study team or from personal contacts.

2.2 Contacts with Overseas Research Agencies

As well as undertaking a literature review, direct contact has been made with as many overseas researchers as possible in order to obtain up-to-date comment on the state of models being used in other countries. Information from the countries with which contact has been possible is as follows.

2.2.1 New Zealand

Discussions were held with Dr Christopher Bennett who was involved with the development of the New Zealand vehicle operating model in the late 1980s, and provided contacts to a number of overseas researchers.

The New Zealand Ministry of Transport (MOT) was contacted, but advised that since the disbandment of the Economics Division nobody in the organisation held information on vehicle operating costs.

2.2.2 Australia

Mr Thorolf Thoresen of the ARRB provided a report on a survey of freight vehicle costs (Thoresen 1991). The conclusions state that the results of the survey can provide ... *control totals to determine whether aggregate vehicle operating cost estimates generated by road infrastructure evaluation models such as NIMPAC or HDM-III, which is currently being 'Australianised', are appropriate.* ... He noted that each state in Australia has its own evaluation models to which there have been many undocumented changes.

He also noted an AUSTROADS project in 1992 that compared the vehicle operating cost models developed by each state. A copy of part of the draft report (ARRB 1993) was obtained from Mr Quentin Reynolds at the Roads and Traffic Authority (RTA) Programming Branch. Sixteen rural and nine urban models were identified. The rural evaluation models were found to fall into two families based on either the NIMPAC road evaluation model or HDM III. Considerable variation in the vehicle operating costs estimates was observed in terms of both magnitude and sensitivity. Also analysis of the components of vehicle operating costs indicated that the cost grouping most subject to variability in response to variations in road roughness was repair and maintenance.

Mr John Cox indicated also that ARRB was putting a proposal to AUSTROADS in an attempt to get a consistent vehicle operating costs model across the states of Australia, and then to develop a preferred vehicle operating costs model which, it was hoped, the states would adopt.

Dr David Hensher at the Institute of Transport Studies (ITS), Sydney, advised that ITS was currently undertaking a vehicle operating cost study but was unable to release details on the grounds of confidentiality.

The Australian Department of Transport & Communications and the Bureau of Transport and Communications Economics (BTCE) were contacted but were unable to add further to the data on the topic.

2.2.3 South Africa

Mr Peter Curtayne of the Division of Roads and Transport Technology at Commonwealth Scientific & Research Institute (CSIR) advised of a 1991 report embracing the past eight years of research into vehicle operating costs in South Africa (Du Plessis & Schutte 1991), a copy of which was obtained.

Other than research covered by this report and reference material already obtained, the only other R&M cost research in progress was a survey of the long-term maintenance cost performance of cars.

2.2.4 Sweden

Mr Ulf Hammarström of the Swedish Road and Traffic Research Institute (VTI) reported that there had been little recent work on improvements to their VETO vehicle operating cost model in respect of R&M cost modelling. A recent report on the VETO model had been provided to Transit New Zealand and was available to the researchers.

2.2.5 Canada

Mr Henry Hide of Cole, Sherman and Associates Ltd at Thornhill, Ontario, advised of two recent studies undertaken by his company of bus operating costs. In both of these studies, vehicle life cycle cost analyses were undertaken for bus fleets, culminating in recommendations on bus replacement policies. Data were gathered from well kept records to provide age-related maintenance costs, but no modelling related to road conditions had been undertaken.

Mr Peter Bein of the Canadian Ministry of Transportation and Highways, Planning Services Branch, was contacted and provided copies of three recent papers (Bein 1993a, 1993b, Bein & Biggs 1993). He had reviewed nine models from around the world and had considered factors such as transferability of results and estimation methodology. He concluded that ... *only the mechanistic models (VETO, ARFCOM and partly HDM III) are transferable between the conditions they were derived from and the new conditions of a particular application.* ... He also stated that the current choice of model in the US highway policy, planning and project evaluation, the Texas Research and Development Foundation (TRDF) model, and MicroBENCOST, the current application of the TRDF data, ... *are not suitable, and they need to be urgently replaced with more advanced and mechanistically based models.* ... Of concern was the most obvious limitation of a lack of a representative of a modern heavy truck in the TRDF model.

In Canada the TRDF data had been incorporated into the HUBAM model of Transport Canada and into a vehicle operating costs model in Alberta. The library and report lists of Transport Canada were also reviewed but no relevant studies were identified.

2.2.6 Netherlands

Advice was received from Mr van der Weide of the Road Vehicles Research Institute (TNO) that this group had no expertise in the field of R&M cost modelling.

2.2.7 Britain

The Kenya studies were the major effort on vehicle operating costs research identified by the Transport and Road Research Laboratory (TRRL, now TRL). No relevant recent work on R&M costs versus road condition was identified.

The Motor Industry Research Association (MIRA), while able to assist with literature searches, had no particular knowledge of vehicle operating costs studies.

2.2.8 USA

There was a surprising absence of recent vehicle operating costs information from the USA despite early influential studies from that country by Winfrey (1969), Claffey (1971), de Weille (1966) and Zaniewski et al. (1982), all of which were available to the study team. Information received from Mr Peter Bein, referred to in Section 2.2.5, confirmed that there appeared to be little work being done in the USA to produce a mechanistically based replacement for the TRDF model.

3. REVIEW OF R&M MODELLING APPROACHES

This section of the report is arranged as follows:

- Section 3.1 discusses the conceptual basis for R&M cost studies and the relationship between R&M and other vehicle operating costs components.
- Section 3.2 introduces the World Bank HDM Model and the associated user surveys and research. HDM is the largest body of vehicle operating costs research and has formed the basis of practice in New Zealand and many overseas countries.
- Section 3.3 discusses the New Zealand Vehicle Operating Cost (NZVOC) Model which has been used to produce the tables and graphs of vehicle operating costs in Technical Recommendation No. TR9 (Bone 1985) and the Transit New Zealand Project Evaluation Manual (PEM 1991). NZVOC uses HDM III as its main source of R&M prediction modelling relationships.
- Section 3.4 discusses other R&M cost studies, surveys and modelling approaches encountered in the literature review.

3.1 Conceptual Basis

3.1.1 Introduction

3.1.1.1 Difficulties in identifying R&M costs Vehicle R&M costs constitute about one third of vehicle operating costs. For a number of reasons they are both difficult to measure empirically and to predict. This is because:

- Some of the larger repair costs occur infrequently during the lifetime of the vehicle;
- Variations in R&M costs between vehicles of similar general type and utilisation patterns can be large;
- To associate R&M variation with road characteristics is difficult because these tend to be averaged out over the range of vehicle use.

3.1.1.2 Relationship with depreciation and interest costs Vehicle R&M costs are often considered in isolation from vehicle replacement policy and costs, the depreciation regime and interest on capital, which is unrealistic. Operators use various strategies to minimise lifetime vehicle costs. Some may invest in preventive maintenance to minimise downtime and the size of their vehicle fleet by not having to support as many standby vehicles. Others may select more robust vehicle construction and greater engine power at higher capital cost, in the expectation of lower ongoing maintenance costs. (This type of trade-off gives difficulties for the convention of treating parts consumption as the ratio of parts cost to replacement cost.) Some operators may purposely buy secondhand equipment to avoid high depreciation costs in the first few years.

Warranty periods, taxation and depreciation regulations can affect expenditure decisions, so that in seeking to minimise financial costs, operators may not necessarily minimise economic resource costs. Other divergences between resource and bookkeeping costs arise where parts are obtained by companies at a bulk or trade discount, and where in-house labour either is not charged at all or is charged at a nominal rate that does not fully account for the costs of employment.

Vehicle depreciation is the loss in financial value of the vehicle to the operator, or in the resource value to the economy, over time and accumulated vehicle use (normally expressed in kilometres or hours run). Depreciation related solely to time takes account of physical degradation of vehicle components unconnected with the use of the vehicle and loss of value through obsolescence. Depreciation related to use is the loss of value associated with degradation not made good by repairs, such as fatiguing of materials, loss of tolerances and distortions in chassis, bodywork, joints, connections and bearings.

The division between time-related and use-related depreciation is difficult to determine. There is obviously an interaction between maintenance effort and vehicle value, although this will not always be reflected in market prices. Inferring the resource value depreciation from market prices is complicated by depreciation regimes for taxation purposes, vehicle rebuilds and engine replacements for heavy vehicles, and possibly the use of vehicle age as a convenient peg for assessing market value by dealers.

3.1.1.3 Division into parts and labour components R&M costs are generally separated into parts costs and labour. In countries where skilled labour costs are low, but imported vehicle and/or parts costs are high, there is a tendency to repair rather than replace. High labour cost economies with relatively low prices for vehicle parts will tend to replace rather than repair. Local conditions such as relative rates of taxation, import duties, mark-ups on built-up vehicles and spares, profit/loss position of the operator and tax liability, can also influence the balance between labour and parts inputs.

Both HDM and, in consequence, the NZVOC model separate labour and parts costs in their analysis. Parts costs are expressed as a ratio of parts cost to vehicle replacement cost, termed parts consumption, while labour hours are expressed as a function of parts consumption. This limits the cost inputs to the model to vehicle replacement cost and labour wage rate. The model then seeks relationships between parts consumption and vehicle type and use characteristics, and similarly for the relationship between labour hours and parts consumption.

The way in which parts consumption and labour inputs are separately modelled as functions of vehicle physical characteristics, age, utilisation, operating conditions, operator practices etc., and the linkages between parts consumption and labour inputs are important aspects of R&M cost modelling. As later described, existing model structures, such as HDM, contain implicit assumptions on which factors are important in describing the variation in R&M cost with road and traffic conditions.

3.2 The World Bank HDM Model

3.2.1 Introduction

3.2.1.1 Background One of the most widely used models internationally for vehicle operating costs versus road and traffic conditions, which is borne out by the literature survey, is the Highway Design and Maintenance Standards Model (HDM). HDM was developed by the World Bank from a research programme extending over the last 20 years, first based on TRRL research in Kenya, East Africa, at which stage it was known as HDM II, and followed by research in the Caribbean, India and Brazil, after which it was released as HDM III (detailed in Section 3.2.4 of this report). With the release of HDM III, the Brazil relationships were preferred, being based on more extensive and recent user surveys, although the Kenya, Caribbean and India research bases and modelling formulae were also made available for potential users. The TRRL research base, comprising the Kenya and Caribbean studies, has also been incorporated into the Road Transport Investment Model (RTIM), currently in version 2.

3.2.1.2 Documentation HDM is documented in Watanatada et al. (1987) as a Model Description and User Manual and an associated publication on vehicle operating costs is Chesher & Harrison (1987). They both discuss the research base for the R&M cost components of the vehicle operating costs sub-model in each of the four countries. For Brazil, the original research was conducted under the UNDP by GEIPOT (Empresa Brasileira de Planejamento de Transportes 1981). Volume 5 of the final report on *Research on the Interrelationships between Costs of Highway Construction, Maintenance and Utilization* deals with road user costs. Other references to the Brazil research include Butler et al. (1979), and Wyatt et al. (1979). In the case of the Kenya research, a number of TRRL publications provide the research foundation (Hide et al. 1975) together with the earlier work of the Economist Intelligence Unit (Daniels 1974) and Bonney & Stevens (1967). The Caribbean research is reported by Hide & Keith (1979a,b).

3.2.1.3 Transferability between countries The attraction to practitioners of HDM lies in the apparent ease of transfer between different economic regimes. This is so if users confine themselves to inputs such as unit labour costs, capital value and descriptive characteristics of vehicle performance and utilisation. However, calibration of the coefficients in the parts consumption and labour hours model cannot be attempted lightly.

3.2.1.4 Observations on R&M modelling Chesher (1987) observes that the Brazil study measured costs over a longer period and over a larger number of vehicles than the other HDM surveys. He notes that operators will aim at cost minimisation and that this, together with the relative unit costs of operation, will influence their trade-off behaviour between vehicle loading, operating speed, maintenance and replacement policy. So, for truly transferable models of operating cost, not only the physical relationships between road conditions and vehicle wear have to be measured, but also the commercial behaviour of the vehicle operator.

HDM relationships internalise the commercial behaviour aspect, which makes it difficult to satisfactorily transfer the models.

Chesher draws attention to the inter-relationships between maintenance cost, interest and depreciation, noting that in a rational model of operator behaviour these will sum to the same value irrespective of vehicle age. An outflow from this argument is that, given a variation in maintenance cost against road roughness, a change is implied in the depreciation relationship.

In Section 3.2.2, HDM as presently presented in Watanatada et al. (1987) is described, followed by a discussion of the research background and of the differences between the studies in the four countries, Kenya, Caribbean, India and Brazil.

3.2.2 The HDM III R&M Sub-model

Parts consumption (PC) is expressed as the parts cost per 1000 kilometres of vehicle travel divided by the new vehicle price. This normalisation of the parts cost component of maintenance is convenient when comparing the results from different studies but, as noted by Chesher & Harrison (1987),

> *... this is to a large extent a cosmetic operation since there is little reason to expect there to be a static relationship between vehicle prices and maintenance costs transferable across environments even under common highway conditions. ...*

PC is modelled against road roughness, expressed as the quarter car index QI, and vehicle age, expressed as cumulative kilometreage using the results of the Brazil studies. The relationship against roughness has been modelled as a gently sloping exponential curve except at high levels of roughness. Above this high level of roughness defined by QIosp, a linear relationship was found more appropriate. Parameters given a suffix "o", such as CKMo, are to indicate that the user may specify the value rather than use HDM defaults, although this is not easily done in practice.

The general formulae are:

$$PC = CKMo^{k} . Cosp.e^{(Cspqi . QI)} \quad \text{for } QI =< QIosp \quad (1)$$

and

$$PC = CKMo^{k} \, (a_0 + a_1 . QI) \quad \text{for } QI > QIosp \quad (2)$$

CKMo is the average cumulative kilometres of travel for the vehicle type, and is the lesser of half the vehicle life in years multiplied by the annual average kilometres (2.LIFEo.AKMo), or a maximum value (CKM'). The coefficients Cosp and Cspqi are constants and both are declared in the HDM manual to be an *optional user-input model parameter*. Default values given in the model are as derived for Brazil. "k" is another fixed exponent against vehicle average age, also with a default calibrated from the Brazil data.

The mathematical form of the second formula is linear and tangential to the exponential curve at the transition roughness QIosp. It can be shown that for this to be so, the coefficients a_0 and a_1 must be:

$$a_0 = Cosp \cdot e^{(Cspqi.QIosp)} (1 - Cspqi \cdot QIosp) \quad (3)$$

$$a_1 = Cosp \cdot Cspqi \cdot e^{(Cspqi.QIosp)} \quad (4)$$

The CKMo value is treated in the model as a user-specified input, otherwise unrelated to the form of the model, although it is admitted that the average accumulated kilometres will be related to the decision to scrap the vehicle, which in turn is related to the maintenance cost relationship against age and the replacement cost of the vehicle. The model parameters from the HDM III manual are shown in Table 3.1.

Table 3.1 Model Parameters from the HDM III Manual.

Vehicle Class	k	Cosp (10^{-6})	Cspqi (10^{-3}/QI)	QIosp (QI)	CKM' (10^3 km)
Cars and utilities	0.308	32.49	13.70	120	300
Large bus	0.433	1.77	3.56	190	1,000
Light truck *	0.371	1.49	251.79	0	600
Heavy truck	0.371	8.61	35.31	0	600
Articulated truck	0.371	13.94	15.65	0	600

* petrol or diesel powered

Maintenance labour hours (LH) are modelled as a function of parts consumption and road roughness:

$$LH = Colh \cdot PC^{Clhpc} \cdot e^{(Clhqi.QI)} \quad (5)$$

where Colh, Clhpc and Clhqi are all constants for which Brazil default values are provided but which may be substituted by user-input parameters. Default values are given in Table 3.2.

Table 3.2 Default Values used in the Brazil Study.

Vehicle Class	Colh	Clhpc	Clhqi (QI^{-1})
Car and utility	77.14	0.547	0
Large bus	293.44	0.517	0.0055
Light truck	242.03	0.519	0
Heavy truck	301.46	0.519	0
Articulated truck	652.51	0.519	0

The defaults give an S-shape curve for cars and utilities, an upward sloping exponential curve for large buses, and a downward sloping exponential curve for heavy and articulated trucks. In each case the curvature is quite gentle and whether the relationships are superior to a straight line calibration may be questioned as there is no obvious physical explanation of the different shapes between vehicle types.

3.2.3 Depreciation Treatment

In the HDM Model, depreciation and interest costs are considered independently of other operating costs. The options given for depreciation are:

- Straight line over a predetermined service life, expressed as kilometres of travel (de Weille's varying vehicle life method);
- Constant vehicle life method (in terms of years).

The depreciation calculation then depends on annual utilisation for which there are again choices of:

- Constant annual kilometres,
- Constant annual hours,
- An adjusted utilisation method (a more realistic hybrid of the first two).

In these choices the annual cost of operation does not enter into the vehicle life or annual utilisation calculation.

3.2.4 Road User Studies Supporting HDM

The Kenya, Caribbean and India studies provide an alternative to the Brazil submodels used in the HDM. Each was based on surveys of vehicle fleet operators.

3.2.4.1 Kenya survey and cost model The Kenya road user survey (Hide et al. 1975) covered a sample of 43 cars, 47 light goods vehicles, and about 90 trucks of various sizes and in different size fleets but excluding any articulated or heavy single unit trucks. The mean roughness of the roads run, the distance, gradient and curvature, and accumulated mileage of each vehicle were recorded. The calibrated model is of a multiplicative linear form with independent variables CKM and roughness measured using the TRRL bump integrator (BI) measure, using the parameter values listed in Table 3.3, as follows:

$$PC = CKM^k . Cosp \ (b_0 + b_1 . BI) \qquad (6)$$

Table 3.3 Parameter Values for the Calibrated Kenyan Model.

Vehicle Class	k	Cosp	b_0	b_1	b_2	b_3
Cars and utilities	1	10^{-8}	- 2.03	0.00180	851	-0.078
Buses	0.5	10^{-5}	- 67	0.06000	2975	-0.078
Light/Medium Trucks	1	10^{-8}	0.48	0.00037	2640	-0.078

Note that the bus model correlated best with the square root of accumulated kilometres of travel in contrast to the other vehicle types. Again, maintenance labour data were insufficiently reliable to be modelled in the same way, although it was possible to detect a variation against road roughness. Labour hours were related to the ratio of parts cost to new vehicle cost with a linear correction for roughness, in the form:

$$LH = PC\ (b_2 - b_3 \,.\, BI) \tag{7}$$

3.2.4.2 Caribbean survey and cost model The Caribbean user cost surveys are described in Hide et al. (1983). Road conditions offered a wide range of variation, including very rough bituminous surfaces. Costs were collected from a range of operators (government, institutions and private) over a 12-month period, and the characteristics of the routes run were measured using a TRRL vehicle-mounted roughness meter. A relationship was calibrated including horizontal and vertical curvature, but because of correlation between these two factors, a second best relationship using only the roughness parameter was preferred. This relationship gave a formulation similar to the Kenya model (see Equation 6) except for the introduction of a quadratic form against roughness, in which:

$$PC = CKM^k \,.\, Cosp\ (b_0 + b_1 \,.\, BI + b_2 \,.\, BI^2) \tag{8}$$

A quite high ($r^2 = 0.91$) correlation was obtained in the model for cars, as seen by the calibrated parameter values given in Table 3.4.

Table 3.4 Calibrated Parameter Values for the Caribbean Model.

Vehicle Class	k	Cosp	b_0	b_1	b_2 (10^{-6})
Cars	1	10^{-8}	-5.501	0.002620	0
Trucks	1	10^{-8}	-6.538	0.000316	0.21

No reliable data were available on maintenance labour, and an overall figure of 45% of parts cost was eventually adopted.

3.2.4.3 India survey and cost model The India parts-cost relationships were estimated by Chesher (1987) using data collected by CRRI (1982). These were later transformed to a parts consumption relationship using data collected by Chesher & Harrison (1987) to bring them into a form similar to those of the relationships obtained in the other countries. The model is loglinear in form and is exceptional in incorporating generalised road geometry through rise and fall, horizontal curvature and road width. For trucks, vehicle gross weight is also introduced rather than separating this class into medium and heavy weight groups. The model form, with the parameter values as in Table 3.5, is:

$$PC = C_0 \,.\, CKM^k \,.\, e^{(C_1.BI + C_2.C + C_3.RF + C_4/W + C_5.GVW)} \tag{9}$$

Table 3.5 Parameter Values for the Indian Parts Cost Model.

Vehicle Class	k	C_0	C_1 (10^{-4})	C_2 (10^{-4})	C_3 (10^{-4})	C_4	C_5 (10^{-2})
Cars and utilities	0	42.0	1.69	–	–	–	–
Buses	0.358	0.691	0.526	2.82	67.5	2.00	–
Medium & Heavy Trucks	0.359	0.924	0.618	6.86	5.45	0.853	7.65

The parts consumption model for cars and light utilities relies only on roughness and cumulative utilisation as independent variables.

Maintenance labour is predicted as a function of parts cost (rather than parts consumption as for the Brazil, Kenya and Caribbean surveys), and for trucks and buses, multiplied by an exponential function of roughness. The form of the model is similar to Equation 5, with the substitution of PC.VP for PC:

$$LH = Colh\ (PC.VP)^{Clhpc} . e^{(Clhqi.BI)} \quad (10)$$

Table 3.6 Parameter Values for the Indian Model.

Vehicle Class	Colh	Clhpc	Clhqi (10^{-4})
Cars	1.799	0.584	–
Utilities	4.42	0.445	–
Buses	1.839	0.473	0.426
Trucks	0.898	0.654	0.250

3.2.4.4 Brazil survey and cost model The Brazil user cost survey is reported in GEIPOT (1981) and Harrison & Chesher (1983). The survey was conducted after the Kenya research and built upon the experience already obtained. It involved a much larger sample of 1,675 vehicles, including 75 owner drivers and the remainder of company operated vehicles. The sample did not include fleets operating under common management policy but with a wide range of operating conditions spread around the country. Fleets were screened for suitability before being introduced to the survey. Once accepted, monthly visits were made to collect the vehicle operating costs data, either by photocopies of company records or, if company documentation was inadequate, through self-administered questionnaires. The surveys lasted from 1975 to 1981, including the initial pilot testing and final supplementary surveys, so data were collected over a protracted period.

The data processing system on its own took two years of development. Details of the data processing are detailed in a series of internal working papers of the project, contained mainly in Working Documents 11 and 28. In general, the variation in operation regimes within each company's fleet was small, so distinguishing road condition effects from other factors of inter-company variation was difficult. Also, although there were believed to be relationships between road geometry and maintenance parts consumption, when averaged over routes, geometric differences became very difficult to isolate. To quote:

> *... it is believed that road geometry affects parts consumption in some way although the relationship is complex and not yet well understood.*

The Brazil research initially attempted a mechanistic model for maintenance parts, relating parts consumption to vehicle suspension and propulsive energies (Watanatada et al. 1987) but this was unsuccessful because of data limitations. So recourse was made instead to a simpler correlation of parts and labour inputs against road characteristics as described in Chesher & Harrison (1987).

The parts model described in GEIPOT (1981) differs slightly from that presented in HDM III, including a lower linear section of curve at low levels of roughness (below QI = 40), as well as the linear extension at high roughness. The lower extension reduces the maintenance cost differences for changes in roughness between QI = 40 and QI = 10. Also the values of certain coefficients were changed between the GEIPOT and the subsequent Harrison & Chesher report.

The model forms in these earlier reports used parts cost (CP) as the dependent variable, rather than normalised parts consumption (PC = CP/VP). Also, the GEIPOT parts model was based on regression analysis using actual vehicle accumulated kilometres (K) as an independent variable representing the measure of vehicle age. (Later, in the application of HDM, this was substituted as opposed to the later substitution with a mean value (CKM) for the fleet as a whole.) The resulting relationships for the exponential section of the piecewise curve were:

$$CP = K^{D0} \cdot e^{(D1 + D2.QI + D3.TIP + D4.ST + D5.AX2)} \qquad (11)$$

where TIP, ST and AX2 are dummy variables for tipper trucks, semitrailers and 2 axle rigid vehicles respectively. (Alternatively this can be expressed as three separate equations without these dummy variables but with different D1 coefficients.) Parameter values are shown in Table 3.7, indicating slight differences between the GEIPOT and Harrison & Chesher analysis for the intercept of the roughness-related part of the function.

Table 3.7 Parameter Values for the Brazilian Parts Model.

Vehicle Class		D0	D1	D2	D3	D4	D5
Cars	GEIPOT	0.303	4.79	0.0128			
	H&C		5.055				
Utilities	GEIPOT	0.302	6.497	0.00426			
	H&C		–				
Buses	GEIPOT	0.483	5.703	0.00323			
	H&C		5.88				
Trucks	GEIPOT	0.374	6.083	0.0161	-0.251	0.365	-0.072
	H&C		6.189				

3.3 New Zealand Vehicle Operating Cost Model (NZVOC)

The genesis of the New Zealand Vehicle Operating Cost Model (NZVOC) lies with Bennett (1985). At this time the Road Research Unit (RRU) of the National Roads Board (NRB) was in the process of preparing Technical Recommendation No. TR9, *The Economic Appraisal of Road Improvement Projects* (Bone 1985), the successor to Roading Directorate Circular Memorandum 98. Further work was carried out on the NZVOC model and this was included as the basis of the tables and graphs of vehicle operating costs in TR9. This further work is reported in Bennett (1986).

Before TR9 was published, vehicle operating costs had been based upon Lawson et al. (1971) who obtained data from two major fleet operators in the public and private sector, covering 907 vehicles and with costs allocated to 32 categories. Costs had been updated annually using cost indices obtained from the NZ Department of Statistics.

3.3.1 NZVOC Model, 1985

In Bennett (1985) the aim was to calibrate HDM III to New Zealand conditions. However, the HDM model was not ready for release in time, and instead the reported research base of HDM III was used as the basis for part of this original NZVOC model.

In his review of the various HDM country studies, Bennett concluded that only the Brazil relationships covered the complete range of roughness values found on New Zealand roads and had the advantage of a large database of user surveys. Having decided to use the Brazil relationships he next compared the average values of R&M costs from the NZMOT and NZ Automobile Association (AA) with the HDM predictions of R&M costs versus roughness, once these had been partially calibrated from data on the composition and physical characteristics of the New Zealand vehicle fleet.

For passenger cars and light goods vehicles the MOT and AA averages agreed well with the R&M costs predicted by the Brazil model at the assumed mean roughness point. The New Zealand costs were below prediction for medium and heavy commercial vehicles. To avoid any modification which would alter the relationship between roughness and R&M cost, the Brazil relationships for medium and heavy goods vehicles were translated by subtraction of a constant term to align the curve with the New Zealand "observed" values at the average roughness point. As the labour hours are predicted from the parts cost in the HDM model, it was more convenient to make this correction to the labour cost component.

The uncertainties in this procedure include:

- Doubts regarding the accuracy of the MOT and AA operating cost data (e.g. when asked to explain the basis of their vehicle operating costs estimates to the RRU, the (then) Economics Division representatives were not able to give a clear indication of how well based the costs were). Thus some doubt exists whether even the average level of cost was representative of New Zealand conditions.

- Only average costs data were available from MOT and AA, so no means of testing the relationship of R&M costs against roughness was possible.

The relationships derived in Bennett (1985) were similar to the Brazil model (see Equations 1 to 4) with the correction to the labour hours formula:

$$LH = Colh \, . \, PC^{Clhpc} \, . \, e^{Clhqi} \, . \, QI + CFLAB \qquad (13)$$

The parts consumption relationships were:
Cars and light goods vehicles, parts cost:

$$PC \, . \, VP = 1.035 \, CKM^{0.308} \, . \, e^{0.0137.QI} \qquad QI < 120$$
$$PC \, . \, VP = 1.035 \, CKM^{0.308} \, (-3.33 + 0.0709. \, QI) \qquad QI > 120 \qquad (14a)$$

Medium and heavy commercial vehicles, parts cost:

$$PC \, . \, VP = 1.699 \, CKM^{0.371} \, . \, e^{0.0164. \, QI} \qquad QI < 120$$
$$PC \, . \, VP = 1.699 \, CKM^{0.371} \, (-6.93 + 0.1174. \, QI) \qquad QI > 120 \qquad (14b)$$

The labour hours relationships were:
Cars and light goods vehicles:

$$LH = 0.535 \, (PC \, . \, VP)^{0.519} - 4.9289 \qquad (15a)$$

Medium and heavy commercial vehicles:

$$LH = 0.600 \, (PC \, . \, VP)^{0.519} - 5.4780 \qquad (15b)$$

where the final terms are the correction to give mean values for New Zealand conditions at the mean roughness point for parts and labour costs combined.

3.3.2 Developments for TR9, 1985/1986

The R&M treatment in the NZVOC model used for TR9 (1985) was a little different from that used in Bennett (1985). Over the period late-1985 to mid-1986, Bone and Bennett updated the vehicle physical and cost parameters, incorporated the ARRB fuel consumption model, and made changes to the R&M model to ensure a more realistic relationship between parts and labour. This was reported in WD Scott DH&S (1986). The concern initially arose because the parts:labour costs ratio appeared to be too great, even though the total mean R&M costs had been calibrated to agree for each vehicle type. Note was taken of a review by Maloney (1982) which indicated that the parts:labour costs ratio normally lies in the range of 50:50 to 60:40.

The Brazil formulation linking labour hours to parts consumption can give a ratio of parts:labour costs that either increases or decreases with roughness or even follows an S-shape curve. Unless the calibration conditions are similar to those obtained in Brazil at the time of the user surveys, then the coefficients in the model needed to be re-specified. However, there was no guidance on how to go about this. Considering the coefficients Cosp and Cspqi in the Brazil model, no even progression was found in these parameters between vehicle types.

As Cspqi controls the steepness of the curve in the portion of the curve below the transition value, it is the leading parameter controlling the relationship between roughness and parts consumption. So this parameter was considered reasonable to be kept fixed. The other coefficient Cosp in conjunction with CKM^K controlled the scaling of the parts consumption relationship.

From the Brazil defaults, the parts cost per 1000 kilometres for all vehicle types at a QI roughness of 2400 mm/km, which was determined to be a New Zealand average, was of the order of 0.2% of the new vehicle price. This was compared with the MOT figures assuming a 55:45 parts:labour split. Overall a similar result was found but the parts cost/1000 km was much lower than 0.2% for heavy diesel vehicles and much higher for light commercials.

For calibration, two options were available: either to calibrate the parts cost model to give the average of 0.2% for each vehicle class, or to calibrate to MOT costs. In the absence of further information the second course was taken. The calibration was made by adding or subtracting a constant to the parts cost model which was given the nomenclature CFPART. (A calibration to alter Cosp was also considered but rejected.)

The modified form of the model was then:

$$PC = CKM^K . Cosp . e^{(Cspqi.QI)} + CFPART \quad \text{for } QI \le QIosp \qquad (16)$$

$$PC = CKM^K (AP_0 + AP_1 . QI) + CFPART \quad \text{for } QI > QIosp \qquad (17)$$

where AP_0 and AP_1 are as defined for a_0 and a_1 in Equations (3) and (4).

The labour costs were then modelled as 45:55 (0.8182) of the parts cost, ignoring the labour hours component of the Brazil model.

3.3.3 NZVOC Model Version 3.0

The R&M cost model used in Version 3.0 and reported in Bennett (1989a) was essentially the same as the earlier version used in producing TR9. Some minor changes to the CFPART values were necessary to take account of revisions to the vehicle subtypes, annual utilisation, etc.

3.3.4 Trailer R&M Costs

In the 1986 version of the NZVOC model, relationships from the Brazil study (though not taken through into the HDM Manual) were used to model heavy trailer R&M costs. However, because of concerns about accuracy and reliability, Version 3.0 of NZVOC changed its basis of calculation to a limited survey of operators, giving a figure of 0.13% parts cost/1000km as a percentage of new vehicle price. Labour costs were treated in the same way as above.

3.3.5 Depreciation Treatment

Bennett (1985) adopted the results of a depreciation study carried out by the MOT in 1979 which calibrated the relationship:

$$DEP = a\ (AGE)^b\ (K/1.6)^c \qquad (18)$$

i.e. the annual depreciation as a proportion of the new vehicle price. Parameter values used were: a = 14.558, b = 0.5018 and c = 0.3108. The results are relatively flat curves showing annual depreciation increasing against both age in years and accumulated kilometres.

For commercial vehicle depreciation, Bennett (1985) carried out a similar study to the MOT, using Dealers Guide (1983) as the basis for values. The result was a relationship with parameter values: a = 0.0973; b = 0.4137; and c = 0.0955. This relationship gave a rapid rise in annual depreciation against both age and kilometres over the first three years or 150,000 km of travel, then flattening out to a more gradual increase. However there was a good deal of scatter in the data set which made the relationship somewhat tentative.

A later study (Bennett 1989c) found that the rate of depreciation was unstable with respect to time, and for this reason it was decided to revert to a simpler method based on the capital recovery factor. This reduced depreciation to a constant annual charge, taking account of the time value of money:

$$DEP = VP \cdot i \{(1 + i)^{LIFE} - RES)/(1 + i)^{LIFE} - 1)\} \quad (19)$$

Of the annual depreciation, the model allocated 30% to vehicle use for passenger cars and 15% for other vehicle classes. This was supported by Bennett (1989c) but it was a smaller use-related component than most other sources have estimated.

3.4 Other R&M Cost Modelling

3.4.1 CSIR South Africa Research

3.4.1.1 Introduction A considerable body of empirical study on vehicle operating costs was undertaken by the CSIR (previously the National Institute for Transport and Road Research or NITRR), in South Africa. The treatment of vehicle R&M costs varied between user surveys to obtain fleetwide average values and to allocate costs to routine and non-routine (distance-related inferred) operation (Schutte 1979), to regression models relating R&M costs to vehicle price, age and roughness, similar to HDM III (Curtayne et al. 1989). Between these approaches lies the constituent component approach (Pienaar 1981), which is to estimate the replacement period and costs of various vehicle parts, and to allocate these to portions of the driving cycle. As an example, all braking wear was attributed to stop/start cycles.

3.4.1.2 Du Plessis & Schutte (1991) This report of Du Plessis & Schutte summarised work carried out between 1984 and 1991 in South Africa to establish vehicle operating costs appropriate to local conditions. Vehicle R&M costs were investigated in the following controlled experiments and user surveys (discussed in Sections 3.4.1.3 to 3.4.1.5 of this report).

- Du Plessis & Meadows (1990) - study of three small passenger cars.

- Du Plessis, Visser & Harrison (1987); also Curtayne et al. (1989) - survey of 750 buses which gave relationships between road roughness, maintenance costs, service life and depreciation.
- Finlayson & Du Plessis (1991) - survey of forestry transport vehicles, involving 91 trucks, which examined relationships between maintenance cost and road roughness.

Throughout this work the conventions established by the World Bank research were used, in which maintenance parts costs were treated as a proportion of new vehicle price while maintenance labour was treated in hours. However it was admitted that there was little evidence to verify that there is a static relationship between parts costs and vehicle replacement cost.

Du Plessis & Schutte noted:

> *With the exception of fuel consumption, VOC models are generally developed from aggregate-empiric relationships, in which a large number of observations collected from transport operators are regressed against certain road condition parameters (such as road roughness). There is almost always a large scatter in data of this nature, since effects other than those modelled for are inevitably present. For example maintenance parts data for a fleet of vehicles will exhibit not only vehicle age and road condition effects, but also influences such as maintenance policies, driver behaviour and the trade-offs between capital and labour exercised by the operator. On the one hand the resulting regression models are inflexible and unable to reflect the effects of marginal changes in these variables, but on the other hand they do capture these effects to allow for very robust predictions.*

The report also noted the differences that general economic circumstances can bring, for example where labour costs were relatively low, the tendency was to repair rather than to replace expensive parts. Subsidies could also be reflected in higher costs than would otherwise be the case (although we note that these effects should be netted out of an economic analysis). Despite these uncertainties, the point was made that the relative differences in cost matter for road cost/benefit analysis, rather than the absolute magnitude of costs. Defining the variable component of vehicle operating costs against road condition was more important than achieving a high degree of accuracy in the totality of vehicle operating costs.

All of the user surveys showed maintenance costs to increase with road roughness, and the progression of maintenance cost with vehicle age to influence vehicle replacement costs and timing, and therefore depreciation and interest costs. Also the surveys showed that operator management practices, such as control of vehicle loading and driver behaviour, could influence maintenance cost; and so too could the amount invested in preventive maintenance, choice of new versus reconditioned spares, and so on.

Du Plessis & Schutte adopted Chesher & Harrison's (1987) treatment of depreciation and interest which relies on a rational financial decision by the operator on when to sell his vehicle, and which recognises a relationship between maintenance expenditure and depreciation, unlike other treatments.

3.4.1.3 Du Plessis & Meadows (1990) This study involved three new identical rental passenger cars (1.3l VW Golf) which were driven over pre-selected routes for a three-month period, two cars on gravel roads and one car on paved (sealed) roads, each travelling about 40,000 km (i.e. equivalent to about 2 years normal driving). Trip details were recorded by tachometer (believed to mean tachograph). The routes were surveyed for roughness (QI scale) giving mean roughness values of 35 QI (range 18 to 56) for the sealed route, and 75 QI (range 30 to 200) for the gravel routes.

Marked differences were observed between the maintenance requirements for vehicles on the sealed versus gravel roads. Items such as chipped and cracked windscreens, clogged oil and fuel filters, loose fittings and frequent punctures contributed to the differences. Some of these items were considered likely to be roughness-related but others were related to the loose dust and stones on a gravel road.

The maintenance parts costs had to be adjusted because of a discount arrangement, of 35%, between the rental company and the service station. This shows that cost data must be treated with caution and should be accompanied by a description of the physical work. As a proportion of parts cost, labour ranged between 30% and 80% of the total costs. In fact the labour cost per kilometre varied only by 20% between gravel and sealed roads, and that the parts costs caused the difference in relativity between parts and labour. This result shows the pitfall of regarding labour as a simple percentage addition to parts cost.

Depreciation cost was obtained from dealers' estimates of vehicle value after the experiment. Three estimates were obtained and the variation between dealers was greater than the variation between the values for the ex-gravel and ex-seal vehicles. In one case the ex-gravel vehicle was rated at a higher value than the ex-seal vehicle and it appeared that the dealer's valuation was based on odometer reading rather than on vehicle condition.

When compared with the HDM Model relationships, the South African maintenance costs were found to be similar in relation to roughness, although the implied slope on the graph between sealed and unsealed road was greater. Uncertainties remained because of the differences in labour/parts substitution between the countries and possibly differences which were not related to roughness alone.

3.4.1.4 Du Plessis, Visser & Harrison (1987) Aspects of this study are also discussed in Curtayne et al. (1989). The project used 12 months of cost records from a single bus operator running 740 vehicles from eight depots. Operating and management practices varied between the depots, but were under central overall control in regard to policy decisions. Operating conditions between depots were on paved, fair gravel, and poor gravel surfaces, flat to mountainous terrain, and with mean QI ranging between 24 and 40 for sealed surfaces and between 80 to 200 QI for gravel. The study therefore had the advantage of a relatively large and homogeneous fleet of vehicles with different depots operating under conditions of road roughness and terrain that could be differentiated.

The company had specific mileage-based replacement policies for certain major components such as engine, gearbox and rear axle, with a relatively small allowed variation (of 10%).

The influence of company policy on maintenance requirements was significant. The bus company in question had adopted a rigorous inspection and preventive maintenance regime to avoid breakdowns and disruption to schedules. Consequently a number of parts replacements were carried out routinely at target mileages, not on a condition-responsive basis. The payback to the company was a smaller vehicle fleet, a trade-off which could easily be missed if the study had concentrated on R&M costs alone.

The results of the bus cost study were in fair agreement with the HDM III Brazil model for buses for parts cost, after comparing a number of model formulations. In comparing labour costs, the bus study was unable to relate labour hours to particular vehicles, but overall the Brazil relationship when transferred to South Africa appeared to be predicting a 50% higher cost than local experience would indicate.

3.4.1.5 Finlayson & Du Plessis (1991) The forestry truck study covered five separate forestry operations under a single holding company. These five vehicle fleets ranged from 9 to 29 vehicles in size, 91 in total, with an annual usage of 38,500 km. As only costs, and no physical data, were available, maintenance items were not readily definable. Costs over three 6-month periods (18 months total period) were used for the analysis. Where individual vehicles showed particularly high maintenance costs, the reason for them was checked and generally it was found to be traceable to major overhaul or unit replacements. These vehicles were removed from the analysis. Labour and parts costs were separable.

Road condition data applied to each depot as a whole, as the exact use of each truck could not be identified. Also the proportion of running on the different roads had to be estimated. Overall, these mean QI values ranged from 40 to 150 QI. Terrain showed relatively little variation.

The data set was therefore for each vehicle: i.e. vehicle type, age, distance, vehicle replacement cost, parts cost, labour cost. The effect of age on parts consumption was examined by regression analysis, with a log-log model providing the best fit with data normalised to a roughness value of 70 QI. Then both age and roughness were entered into the analysis, giving the relationship:

$$PC = K^{0.45} \,.\, e^{(-3.1 + 1.3.QI)} \qquad (21)$$

Maintenance labour cost (rather than hours) was regressed against parts consumption and roughness, vehicle age being excluded on the grounds that it was already included as an explanatory variable for parts (though why this logic did not also apply to vehicle age is not made clear). The resulting regression was:

$$LAB = -18.7453 + 0.857\,(PC) + 0.675\,QI \qquad (22)$$

3.4.1.6 Schutte (1979) This earlier study was carried out to revise an earlier set of vehicle operating costs relationships in use in South Africa, which had become obsolete after several years of high price inflation.

Schutte's approach to the determination of R&M costs involved a division of the costs into routine and non-routine categories. Data on maintenance costs were obtained from the Professional Hauliers Association for medium and heavy trucks, and from a sample of fleet owners for cars and light utilities. In order to determine the routine maintenance component, a series of assumptions were made about the average annual distance travelled, the total lifetime distance travelled and the frequency of the routine servicings, especially in the latter stages of the vehicle life. Using normal discounting procedures, the present worth of future servicings was obtained. For the calculation of the non-routine maintenance component the average distance life of a wide range of vehicle components which need to be repaired or replaced during the vehicle's life was calculated (similar to that used by Claffey 1971). On the basis of the expected average annual travel distance, the cost of the replacement or repair was discounted back to the time of the study (1979) as with the routine maintenance items.

3.4.1.7 Pienaar (1981) Pienaar's (1981) approach was based on Claffey (1971) and an unpublished report by Bester (1974). The average distance life for a wide range of vehicle components, both routine consumables and more major non-routine components, was established by reference to vehicle dealers. Some assumptions had to be made about the relative use of new versus reconditioned parts. The average per kilometre R&M cost was then calculated as the sum of the individual component per kilometre costs.

A list of parts requiring non-routine maintenance with estimates of distance travelled before a repair is required is reproduced from Claffey (1971) in Table 3.8. This procedure lends itself to the determination of R&M costs for cars, more than for other vehicle classes, because cars are more regularly used. Light commercial vehicles were also included by Claffey (1971) and Schutte (1979) in their studies.

Where estimates of the interval between parts replacement rely on averages or ranges from operator records, or on general knowledge of the fleet manager, correct interpretation of the data is important. The responses may relate to the general experience in parts replacement so that vehicles exhibiting no need for replacement of a particular part are excluded, or conversely parts which fail prematurely are also unreported. An appropriate correction to the mean parts cost is required in such cases.

Table 3.8 Average Maintenance Cost as Affected by Travel Distance for Standard Size Passenger Cars [1] Source: reproduced from Claffey (1971)

Vehicle Part	No. of Vehicles with data available	Travel Distance before needing repairs (x 1000 miles)		Cost of Repairs ($)		Average Cost (cents/ mile)
		Range	Mean	Range	Mean	
Automatic transmission	850	54-103	66	100-255	178	0.27
Engine block	395	50-90	70	65-130	93	0.13
Shock absorbers	1350	30-60	44	28-51	37	0.08
Brake system	1350	40-77	54	40-58	41	0.08
Distributor	1050	10-21	14	5-20	12	0.08
Exhaust	1350	30-56	39	18-33	26	0.07
Carburettor	1050	32-60	45	21-40	29	0.06
Universal	1050	30-54	44	20-31	28	0.06
Rear axle	50	100-113	106	54-75	66	0.06
Generator	1050	42-60	52	18-40	32	0.06
Water pump	1050	34-55	43	18-30	24	0.06
Springs	50	40-100	68	28-46	40	0.06
Fuel pump	50	44-64	52	12-20	15	0.03
Oil pump	50	92-138	109	16-28	21	0.02
Radiator	50	66-96	76	10-25	16	0.02
Fan belt	1050	40-68	51	3-6	4	0.01
Total						1.15

[1] Based on responses to an inquiry submitted to the chief engineers of the highway departments of each of the 50 states, and to each of the division engineers of the Bureau of Public Roads, US.

3.4.2 The Swedish VETO Model

The Swedish Road and Traffic Research Institute (VTI) has for some years been developing a vehicle operating costs model, called the VETO model, that is intended to be fully mechanistic (Hammarström & Karlsson 1991). At the time of the literature review recorded in this present report (1993) the researchers had been successful only in describing brake wear in a physical way where wear was taken to be in direct proportion to the work done. For treatment of the wear of other components they used statistical descriptions similar to that of the HDM III model.

The description of this research includes a moderately complex representation of the vehicle as a two dimensional spring/ mass/ damper system under excitation from vertical and horizontal loadings imposed through the wheels and suspension, and from horizontal forces of traction, braking and aerodynamic resistance.

Drive train and frictional losses were modelled using mathematical relationships for most mechanical components, i.e. suspension; tyres; engine; clutch; gearbox; driveshaft; rear axle; steering linkages; brakes.

R&M costs were treated as a base cost and a roughness-related cost. The base cost was derived as a fixed proportion of overall average R&M costs (which came from a Swedish Consumer Council report) and the remainder was assumed to be roughness related. The basis for this division appeared to be an early paper by Both & Bayley (1976) from Australia.

Having developed fairly complex relationships between parts wear, speed and roughness, VTI was able to apply the model to four mechanical components (shock absorbers, wheel bearings, springs, and steering linkages). The model related the dynamic forces normal to the road surface with wear coefficients against standard stress cycling of components. The model was therefore responsive to the road shape, which induces the vertical movement and transient normal forces, the axle loads and the vehicle speed.

However, they concluded that

> *... it would probably be virtually impossible to develop a model which could be used for calculating the relationship between total repair costs and road unevenness, component by component.*

Instead Hammarström & Karlsson suggested that the costs and wheel loads could be monitored for a number of vehicles, so that a more aggregate but still mechanistic relationship could be determined empirically between vehicle "wear" and the root mean square value of the wheel load raised to the sixth power.

Although the VETO research was incomplete at the time of review, for these four mechanical components over 90% of roughness-related wear was predicted to occur on less than 10% of roads and for 6% of vehicle travel. This was a much steeper relationship than displayed by HDM III but could be explained by the fact that the components modelled were those which experience the greatest cyclical stresses from road roughness.

3.4.3 North America

3.4.3.1 Texas Research and Development Foundation (TRDF) Model

This model was critically reviewed in Bein & Biggs (1993). The model addressed four elements of vehicle operation, i.e. constant speed running on flat or grade sections, speed changes, negotiating horizontal curves, and stopped engine at idle. Data collection was limited to truck operating costs covering 15 line-haul operators and nearly 12,500 vehicles. For light vehicles, pre-1980 data sources were used. The TRDF also used preliminary results from the GEIPOT Brazil studies to assist in the research.

The parts and maintenance labour consumption was broadly categorised into general maintenance, brakes and drive train, and the total R&M costs were allocated in proportions using data from Ullman (1980) for light vehicles and from the user cost survey for trucks. These costs were then employed to calculate correction factors to

Winfrey's (1969) costs for constant speed on level road. For other operating conditions, excess costs were calculated from a regression analysis linking horsepower and constant speed costs. A roughness adjustment was made using Brazil data.

Bein & Biggs (1993) pointed out many methodological assumptions in the TRDF work, as well as reliance on some rather old data sources. They noted that the predictive ability of the model compared with the Canadian HUBAM model was not good.

3.4.3.2 Bein (1993a)

In a general critique of vehicle operating costs models, Bein (1993a) noted that several North American models relied directly or indirectly on the TRDF methods noted above. These included the HIAPS, HPMS and MicroBENCOST computer modelling packages. The AASHTO Red Book was found to be even more dated again, relying primarily on Winfrey (1969) and Claffey (1971). Bein noted that allocation of R&M costs to different operating conditions in both the TRDF and Winfrey work was largely judgmental and based on old vehicle technology.

4. SELECTION OF A MODELLING APPROACH

4.1 Hierarchy of Modelling Approaches

The review of the available literature showed the following hierarchy of models for vehicle R&M costs, progressing from the most general to the highly mechanistic and detailed.

- **Average costs** - all repairs and maintenance are aggregated over the vehicle life or a substantial operating period, and averaged over the total distance run.

- **Constituent components costing** - individual components are costed and estimates of their life span obtained from users or servicing agents. The average maintenance costs can then be estimated by aggregating the per kilometre costs for each component.

- **Allocated constituent components costing** - individual components are costed and life spans are estimated or obtained from surveys. However, the costs are then allocated to elements of the driving profile, i.e. speed change cycle-related (braking and steering system), cruise-related, cold-start related (proportion of engine and drivetrain wear). This allows some differentiation of costs according to vehicle duty and could be used to differentiate urban and rural running.

- **Regression modelling against principal factors such as road roughness, vehicle age** (accumulated kilometres) and, less likely, highway geometric and climatic factors. This is the HDM III approach and requires user data which will provide maximum differentiation between road conditions while controlling all operator variables as far as possible.

- **Aggregate mechanistic model** - as suggested by VTI. Parts consumption is modelled against the stress cycling applied to the vehicle by the road profile. As suggested in the VETO model, this would be proportional to the root mean square of applied vertical loading at the wheels raised to the sixth power. To calibrate such a model would require fairly precise information on vehicle axle loading, distance travelled, operating speeds, and road surface profile, for a sample of vehicle types over a protracted period of time.

- **Disaggregate mechanistic model** - as attempted by VTI, of similar form but expressing parts consumption for each component. This is regarded by VTI as a probably unattainable goal.

Each of the modelling approaches described above rely on an analysis of data obtained from actual vehicle operation. The demands of each differ in the detail of information which has to be obtained, from merely the aggregate cost of R&M over a period of time to details of individual component wear, replacement and unit costs.

The two ways in which vehicle operational data can be obtained are by:
- a retrospective analysis of individual vehicle or fleet records; or
- monitoring future individual vehicle or fleet operating costs as they are incurred.

The first approach has the advantages of requiring less data acquisition effort, and the prospect of being able to carry out the surveys within a short time span, say within a 6-month period. However, it relies on such records being available in a suitable form and it is likely that only more organised and probably better managed organisations would be the focus of study. The second approach allows a more controlled form of data acquisition, with less likelihood of missing information, and better prospects of capturing data from less well managed enterprises. However, it requires a sufficiently long period to gain the necessary length of records, and we would suggest at the very minimum one year and probably longer.

The extent to which the research project could progress up this scale of modelling detail would depend on the quality of available user data and the degree of discrimination that could be detected between operating conditions. Table 4.1 illustrates the different approaches and the factors involved in each approach.

Table 4.1 The Two Modelling Approaches.

Survey/ Modelling Approach	**Time for Study (months)**	**Cost**	**Required Data Type**	**Required Data Quality**	**Likely Data Availability**	**Prospects of Successful Outcome**
RETROSPECTIVE DATA ANALYSIS:						
Average R&M Costs	6	Low	Aggregate	Good	Good	Good
Unallocated Constituent Component Costs					Good	Fair
Allocated Constituent Component Costs					Poor	Fair
Regression Model v. Age, Roughness, etc.	9	Moderate			Fair	Fair
Aggregate Mechanistic Model					Poor	Poor
Disaggregate Mechanistic Model	18	High	Disaggregate	Excellent	Poor	Poor
MONITORING FUTURE OPERATING COSTS:						
Average R&M Costs	18	Moderate	Aggregate	Good	Very Good	Very Good
Unallocated Constituent Component Costs					Very Good	Good
Allocated Constituent Component Costs					Fair	Fair
Regression Model v. Age, Roughness,etc.	27	High			Good	Good
Aggregate Mechanistic Model					Fair	Fair
Disaggregate Mechanistic Model	48	Very High	Disaggregate	Excellent	Poor	Poor

4.2 Reliability of Existing Data and Prospects for Improvement

Where data already exists, the NZVOC model is of limited reliability for R&M costs, in both the average R&M cost per kilometre for each vehicle class and for the variation in R&M cost with road condition. For project evaluation purposes, reasonable accuracy is required in each case. Any route shortening or traffic diversion makes use of average cost data, while smoothing requires good data on the relationship of R&M costs against road roughness. In the latter case, the cost differences involved between unsealed and sealed roads are important for all seal extension work. Thus the information sought is both the roughness effect and other cost differences arising from a loose metal surface compared to a sealed surface. There is also considerable uncertainty regarding the slope of the R&M cost curve at low levels of roughness.

A user survey which provided reliable average cost information would be a substantial improvement on the present situation, but desirably the project would aim to obtain a reliable relationship between maintenance costs, and road roughness and surface type. This second objective would be considerably more difficult and it was difficult to gauge the likelihood of success of a retrospective cost survey until it had been attempted.

4.3 Selection of a Modelling Approach

The project brief envisaged that a constituent component approach would be the basis of the cost model. This was later modified in the contract with Transit New Zealand to an approach similar to that used in HDM, based on a regression analysis approach.

The enquiries of operators indicated that relatively few recorded their R&M costs in a disaggregate form. Most treated such costs as a single item.

Those that did record costs in more detail generally adhered to a similar form of classification into: engine and drive train; suspension, steering and braking; electrical systems; body and chassis. Below this level of detail, sub-categories were sometimes used which are also generally similar.

Of all the operators and asset managers contacted, NAFA Asset Management Ltd, Auckland, appeared to offer the most rigorous and detailed breakdown of maintenance items covering a large number of vehicles. NAFA's categorisation of costs was rational and as detailed as any, so it was adopted as a model for classifying cost data collected from other operators.

The prospects for detecting systematic differences in maintenance cost items with respect to road condition and/or geographical location, using NAFA records supplemented by other selected user data, appeared promising. There was already anecdotal evidence of differences between regions, and possibly between sealed/unsealed surface and topography.

Accordingly, the second objective, beyond obtaining average maintenance cost data, was to determine the degree of difference in costs between contrasting road conditions using the following grid.

Location/Terrain		**Sealed**	**Unsealed**
Urban	Flat		
	Hilly		
Rural	Flat		
	Hilly		

Level 1 objective: In distinguishing between urban and rural costs, the allocated constituent component approach, whereby certain maintenance items are attributed to such factors as stop/start operation and cold starting, would be used to build up a model of R&M costs for each vehicle type. The output from the exercise would be compared against average maintenance costs for operators engaged in mainly urban use versus mainly line-haul rural-highway operators, to determine whether the modelled differences are detectable in practice.

Level 2 objective: The output from this stage of analysis, assuming it were successful, would then allow a coarse relationship between roughness and R&M costs to be obtained, comparing average sealed road roughness with average unsealed road roughness.

Level 3 objective: The third level objective would be to calibrate a model of parts cost against road roughness and vehicle age, similar to that used in the HDM. This would demand more detail on the measured roughness values on roads each vehicle travels, which should be available for most of the rural road system, and sufficient data should also be available to generalise a roughness value for urban roads.

4.4 Scope of Stage 2 Work

The extent of work contracted to the end of Stage 2, was to conduct a user cost survey, including the NAFA fleet data, to determine the mean R&M costs for each of the six vehicle classifications, and to undertake some regional statistical analyses. The brief was extended in November 1995 to add the following analysis tasks:

- Normalise the mean R&M costs from the user surveys as a percentage of vehicle replacement cost, and make a comparison with the modelled NZVOC R&M costs;
- Indicate, in addition to the mean values obtained from the user surveys, the range, standard deviation and standard error statistics;
- Separate the costs of prime movers and trailers for the HCVII class of vehicle;

- Make a comparison of urban and rural bus R&M costs from the user surveys;
- Provide a commentary and, where possible, numerical comparisons for R&M costs over a range of MCV sizes, types and costs;
- Analyse the NAFA data for any relationship between R&M costs and vehicle age and/or accumulated kilometres;
- Analyse the NAFA data and, where possible, other survey data for relationships between routine servicing costs versus other R&M costs;
- Determine the relationship between labour cost and parts cost by vehicle type and, if possible, by vehicle age and utilisation.

5. INVESTIGATION OF DATA SOURCES

A total of 55 fleet operators throughout New Zealand were contacted. By and large, the request for assistance was well received, with 36 organisations indicating their willingness to co-operate in the research. Of the remainder, 14 either indicated they would not assist or held information that was unsuitable.

Ideally, detailed disaggregate data on R&M costs for individual vehicles, and accurate indications of the road surfaces that are normally traversed, coupled with detailed information on company maintenance policies, would allow progression to a model of parts cost against road roughness and vehicle age, similar to that of HDM. However, only a few of the operators contacted recorded their R&M costs in a disaggregated form, and only when the survey was underway was it possible to accurately judge the likely overall level of detail available. It was encouraging that some operators grouped their maintenance costs in broad categories with the aid of vehicle operating costs computer programs offered by organisations such as Mobil Oil New Zealand Limited. This level of detail, coupled with a knowledge of the running conditions, could assist the progress of an allocated constituent component approach.

5.1 Wide Area Databases

A number of wide area database owners indicated their willingness to assist with the supply of information for the study.

The Motor Vehicle Registration Centre, operated at the time by New Zealand Post, was asked to give a quotation for the supply of multiple relicensing data for a 10% sample of vehicles. Similar information had previously been provided to Transit New Zealand free of charge in 1991. From this data it was expected that information on fleets of the designated vehicle classes could be obtained so that approaches could be made to relevant potential user groups. Although willing to assist, the cost of data extraction was too high for the project budget in relation to the likely value of the data that could be released without breaching commercial confidentiality.

The MOT TASS (Transport Automotive Safety System) database was made available by the MOT Automotive Section for a charge of $250. This identified all fleet vehicles requiring a Certificate of Fitness including rental cars, and was updated on a fortnightly basis. Each fleet operator was identified, with the file giving the total number of vehicles owned by the operator and the axle configuration. From this the vehicle type and use could be inferred. The database was helpful in identifying fleet operators who could later be approached to participate in the user survey.

The New Zealand Customs Department has a tariff history dating from 1988 and an approach was made to determine whether data held by the Department would be useful to the study. For each tariff code (an eleven digit number) a report could be generated that listed the value of items imported under each code. Each report, with a maximum length of 1000 lines, would have cost $5 and, because of the number of codes covering vehicle components, the total cost would have been of the order of $600. A problem with this database was that it did not cover items manufactured in New Zealand. Overall, it was concluded that this database would not be sufficiently useful to warrant the costs involved in data acquisition and interpretation.

Fleetcard is a service from which a database covering 40,000 vehicles comprising mainly company-owned passenger cars can be compiled. Data were sourced from two Fleetcard services - the "Fuel and Oil" card and the "All Services" card. The second of these covered fuel, oil, and repairs and maintenance. However, there were only two categories of R&M in the database. Individual vehicle data with a 12-month history and life-to-date statistics were available. The cost of acquiring the data in relation to the level of detail was judged to be too high, particularly as a more detailed database had been identified at lower cost from NAFA Asset Management Ltd.

An extremely comprehensive database was available from NAFA Asset Management Ltd. The company carried out active management and cost recording for over 5,000 car and light commercial fleet vehicles in 1996 and had a history of all R&M costs for up to five years, giving a total database of over 10,000 active and retired vehicles. Information from this database was available as the main data source for car and light commercial vehicle R&M cost information. The organisation had a sufficiently widely spread fleet that investigating variations in vehicle R&M costs by geographic area was possible. The computerised management system also allowed sorting of records to be undertaken on rural and urban usage based on repairer location, on selected company clients (e.g. stock and station agents), and on up to 24 vehicle component categories.

5.2 Vehicle Fleet Operator Records

The vehicle operators were sampled, based on the general knowledge of the researchers, on the TASS database, and through business directories. An effort was made to contact as wide a variety of fleet operators as possible. The list of operators contacted is not reproduced here for reasons of confidentiality. Almost without exception the operators offered to make their data available free of charge.

The information held by the operators obviously varied in quality and quantity and it was anticipated that some data would not be entirely suitable for use in the project. The stated availability of data from vehicle operators needed to be treated with some caution, as past experience has indicated that fleet managers either do not have as much data in an accessible form as they claim, or are less forthcoming with their time to access the data when an approach is actually made.

The types of user groups contacted included:

- Oil companies
- Line-haul transport operators
- Local bodies
- Provincially based trucking companies

- Urban and tour bus operators
- Vehicle parts distributors

A number of the organisations that were contacted operated fleets of trucks ranging from medium commercial class (MCV) to heavy commercial vehicle (HCVII) in size. Local authorities tended to operate trucks in the MCV class and on comparatively short-haul work. Most of the road transport companies contacted tended to be provincial firms carrying stock, farm supplies and regional intercity freight, and operated on medium-haul work. Long-haul trucking companies usually employed owner-drivers and were therefore not concerned with the maintenance of the trucks, which made it more difficult to obtain data for the heavy commercial classes.

5.3 Vehicles in Private Ownership

Obtaining useful data for the privately owned vehicle fleet is the most difficult area, and yet private cars make up a substantial proportion of the New Zealand vehicle fleet. Private car owners tend not to be good record keepers and those who are may be atypical. It was not possible to make progress with this sector of the vehicle fleet in Stage 2 of the study.

The AA publishes data annually on the operating costs of four classes of car based on engine capacity. When the Auckland AA engineers responsible for producing the car operating costs were approached, the sample size was discovered to be 10 to 14 cars per class. This number would therefore probably not provide a large enough pool of privately owned vehicles for R&M cost analysis.

5.3.1 Retrospective Survey of Private Car Owners

A possible way of obtaining data on privately owned motor vehicles data may be to advertise in the national newspapers for people who have an active interest in the cost of running their car and have historic records available for inspection. The difficulty with this sort of sampling is that those who have an active interest in costs of vehicle operation may incur lower unscheduled maintenance costs than the average motorist, but have higher routine maintenance costs.

Private motorists who purchase new vehicles, and have these serviced according to the manufacturer's recommended service schedule, would be another source of data. However, confidentiality may prevent servicing agents from providing owner names for this purpose and the data would provide coverage only of comparatively new vehicles, whereas the mean age of a privately owned car in New Zealand is over 10 years old.

5.3.2 Future Survey of Randomly Selected Private Car Owners

An alternative solution to the problem of private vehicle ownership would be to conduct a survey over a period of one year or more of a sample of motorists selected according to geographic location, vehicle size, vehicle age, and the road surfaces normally used.

To obtain a manageable sample of the private car fleet it is estimated that a random selection of 1,000 number plates issued over the last 15 years would be needed. It would also be necessary to obtain identifying owner information from the Motor Vehicle Register. From this survey, potential participants would be selected, based on the selection criteria listed in the paragraph above, to ensure an appropriate spread across the identified groupings. Some sort of incentive would probably be needed for the participants, such as inclusion in a draw for a prize at the completion of the one year term. Otherwise it may not be possible to hold their interest. The survey would require monthly returns on R&M expenditure to be made from each owner over the survey period, in an effort to monitor their continued participation. To establish a sample group, conduct the survey and analyse the results is expected to take 1½ years, at a minimum estimated cost of $50,000.

5.4 Conclusions on Data Availability

From the degree of response received, the transport industry showed a definite willingness to assist with the user survey. It was hard to gauge from the relatively brief contact made with some of the potential providers how much detail would be available in their records. Nevertheless, because of the number of sources, the amount of data was considered likely to be sufficient to provide accurate estimates of aggregated R&M costs for each vehicle type. The geographical spread of organisations contacted was also thought to be sufficient to provide an indication of variation of R&M costs with respect to urban and rural running.

Some of the operators had also indicated that they held detailed breakdowns of R&M cost data which could provide information for determining constituent component costs related to the running conditions.

6. PREPARATION OF RESEARCH PLAN

6.1 Data Acquisition Plan (Stage 2)

6.1.1 Survey Questionnaires

Consideration was given to the desirability of employing the services of an outside survey agency to execute the user survey. However, this option was rejected because of the previous experience of the researchers in conducting surveys of vehicle fleet operators. The person making the survey approach needed to have a reasonable knowledge of automotive engineering, to be able to deal with a variety of people in the companies, from those in senior management to the automotive mechanics, and to be able to change the approach on the spot to obtain the best degree of co-operation and data access, knowing what the ultimate objectives of the project are. These qualities could not be readily found in the general market research industry.

Obtaining data on vehicle and equipment costs is, in the experience of the researchers, not so much a matter of administering a tightly structured questionnaire, but rather of gaining the survey subject's interest and co-operation, and then deciding on-the-spot how best to acquire data which may be presented in a variety of forms. This may require visiting different personnel within the organisation, from vehicle drivers to the company secretary, each of whom requires a different approach. The survey forms (Appendix 1) were prepared with this in mind.

Effective data collection required questions on the maintenance policy of the firm for routine items, what maintenance was undertaken in-house, and what was done by outside organisations, and whether discounting arrangements existed for procurement of parts. In vehicle fleet management, there is believed to be a trade-off between robust vehicle construction (at greater initial cost) and lower recurrent maintenance cost. The survey therefore needed to capture information such as vehicle capital cost, so that the opportunity was retained to investigate any relationships that might exist between initial cost and R&M costs.

The questionnaires were structured to gather basic data for determination of overall R&M costs and to provide relevant information for the possible later development of the allocated constituent component model, as defined in Section 4.1 of this report.

Two survey forms were prepared. The first of these, the **company survey** (Appendix 1a), was designed to collect data on:

- Fleet statistical details (e.g. numbers of each vehicle classification);
- Predominant service provided by the company (e.g. line haul or delivery, rural or urban running);
- Operational Data (e.g. road surface operated on);
- Company policy on:
  - replacement of plant;
  - maintenance of routine items;
  - maintenance undertaken in-house or by outside organisations;

- labour charging; and
- discounting arrangements for procurement of parts.

To provide data for constituent component modelling, a list of maintenance categories was included against which operators were asked to provide life estimates for specified parts for a range of road types.

The second survey form, the **individual vehicle survey** (Appendix 1b), was structured to obtain:

- Capital cost and age details;
- Information on utilisation;
- Details on body construction and special equipment; and
- Bulk and specific information on maintenance costs related to the vehicle life, for in-house and outwork.

The opportunity was also taken to gather data on fuel and tyre usage where this was readily available so that checks could be made on these other components of the NZVOC model if desired.

The survey forms were trialled on a small selection of vehicle fleet operators as a pilot exercise and subsequently were modified. The forms shown in Appendix 1 are the final forms used in the main survey, after several revisions.

6.1.2 Interviewer Requirements

The expected variation in the data records kept by different user groups necessitated the use of one-on-one interviews to ensure that the greatest amount of information of benefit to the study could be obtained. The interviewers had to have sufficient knowledge of the subject in order to know whether extra questions, not contained on the questionnaire form, might be required, especially if the organisation had organised their data in a manner that was not readily compatible with the survey form.

Ideally the user group surveys would have been best conducted by the principal researchers. However, as the cost of this option would be well beyond the available budget for this project, intermediate level technical staff were used, with a background or interest in road transport.

The need to provide training for the selected interviewers before commencement of the interview phase was identified. This training provided the interviewers with a clear understanding of the purpose and the importance of their work so that quality data could be gathered. Two staff were engaged to undertake the interview work, one working from a base in Auckland and another from Wellington.

6.1.3 Sample Size

A wide geographic spread of vehicle fleet operators was obtained through the North and South Islands. To ensure that geographic variability was taken into account but, at the same time, that a proportional spread of information through the six vehicle classes was maintained, a target number of vehicles in each category was required.

Variability in the fleet age was also anticipated. An aim of the survey was to obtain data from an initial 1% sample of each of the six vehicle classes. This equated to a total sample size of approximately 20,000 vehicles. It was recognised that some of the potential sources would be unsuitable and would have to be discarded during the course of the survey, and that decisions would need to be made at the time as to whether alternative sources of data would be needed.

6.2 Manipulation of Acquired Data to Derive Mean R&M Costs

Data from the vehicle operators were to be entered onto a central database, allowing sorting operations to be undertaken on significant variables.

Initially the data were to be separated according to regions: into a Northern region for the areas north of and including Hamilton; with a subdivision for urban Auckland considered; a Central region for the rest of the North Island; and a Southern region for the South Island. Subdivisions separating major centres from other areas might be made in the other regions if this was considered to be beneficial.

In each of these subdivisions, for the six vehicle classes, the mean R&M costs per kilometre would be determined, along with the standard deviations for the sample vehicles. The R&M costs would also be analysed by vehicle class for the country as a whole. A comparison would then be made between the regional results and the national mean to determine if there would be any significant regional differences in the mean R&M costs by region. A further comparison would be made between the national mean determined in this survey with that currently implied by the NZVOC model.

As this degree of analysis was expected to be all that could be achieved within a budget only slightly more than that allocated, the resulting models for cost variation against operating conditions would only provide coarse relationships.

6.3 Further Model Development

The course of the continuing work programme would be dependent on the correlation obtained between the figures for mean R&M costs derived from the user survey and those implied by the NZVOC model.

If the correlation was good then the development of a new model might not be continued. However, if the correlation was poor, as was expected, then further work to develop an improved model would be recommended.

6.3.1 Constituent Component Cost Analysis Study

If the decision was made to develop a new model, then the next step would be to conduct a constituent component cost analysis utilising the data gathered from the vehicle operator survey and the NAFA database. The cost and frequency of replacement of the individual components for each class would be established and discounted, as done by Pienaar (1981), over the life of the vehicles. This would yield a non-routine maintenance cost per kilometre. Scheduled routine maintenance would be treated in the same manner to provide a cost per kilometre.

These two costs (of non-routine and routine maintenance) would then be combined to derive the overall maintenance cost per kilometre for each vehicle class, which would be calibrated against the figures derived from the user survey.

6.3.2 Mechanistic Model

Going a step further, the constituent component costs would be allocated to the elements of the driving profile (i.e. braking, cold starting, etc.) so that it could be determined whether a difference in costs can be determined between urban and rural running. A comparison could be made between the average maintenance costs for operators working in urban or rural areas to determine whether the modelled differences are detectable in practice.

If successful, the comparison would show a coarse relationship existing between R&M costs and roughness. Assuming that detailed roughness information for the roads, on which each vehicle travels, was available in both the urban and rural environments, then progress in the calibration of a model of parts cost against road roughness and vehicle age, similar to that in HDM, should be possible.

7. VEHICLE OPERATOR COST SURVEY

7.1 Survey of Commercial Vehicle Operators

The surveys of commercial vehicle fleet operators were conducted over the period January to May 1994. The forms used for the survey are shown as Appendix 1. The design of the forms was to accommodate as many variations as possible in data availability and degrees of aggregation. It was envisaged that not all data items would be completed for any one operator or vehicle. In most cases only aggregate R&M costs were available, and any breakdown into classes of work was quite rare. In most cases only a mean cents/km R&M cost was provided, with a breakdown into parts and labour for about half of the returns. The information returned on parts replacement periods and lifetimes was answered by a few operators, and in all cases the responses were from experience without recourse to records.

As expected, the outcome of the operator survey was less in fact than in promise. This was for several reasons: the low priority given to answering the survey questionnaire in relation to the business of day-to-day operations; records which were either difficult or time-consuming to access; insufficient staff to devote to the task, coupled with a reluctance to allow access by the researchers' own staff to commercially sensitive information; and over-optimistic assessments of how much detailed information was in fact recorded by the operators. In some cases, while data were available on costs, data on kilometres run were inadequate.

7.2 NAFA Data Acquisition

Discussions with NAFA, the company that could provide a comprehensive database, began in May 1992 about the information that they would be able to provide from their vehicle database. In June 1992, NAFA provided a report outlining the data sources and general methodology that they would use in the analysis. After Stage 1 of the project there was a hiatus while Transit New Zealand considered the report and decided on ongoing work. It was not until November 1993 that continuation with the NAFA analysis was approved, and December before funds were allocated.

A two stage approach was taken for this part of the work. NAFA undertook first to produce a trial output of the analysis of a sample of vehicle records. After this had been verified by BCHF a full analysis was to be undertaken. At this point, NAFA was in the process of revising its computer system and a trial analysis was not ready until May 1994. Several trial runs were undertaken and it was August 1994 before all the uncertainties had been resolved. These uncertainties mainly involved the period over which the R&M costs applied and the corresponding mileage driven over that period. Although a full analysis run was received, the analysis did not provide a breakdown into labour and parts costs. At this point NAFA's analyst left his position in the company and there was a further delay as the job was re-assigned to new staff. The final analysis of the NAFA data was not received until the end of February 1995.

The form of the data at this point was a total of some 11,500 records in text format, each record corresponding to a single vehicle. In fact, three files were provided of the same data sorted into: urban/rural vehicle location; engine size; and region - north/central/south. Labour and parts data were provided separately, making six data files in all. The files were supplied in ASCII text format.

7.3 Data Manipulation

For the operator surveys, the data were entered into database (dBASE IV) files. However, because of the gaps in information, and the number of responses that could be handled on a spreadsheet, the analysis of the commercial operator survey was transferred to a Lotus 123 spreadsheet.

For the NAFA data, the next step was to amalgamate the data into a single database file (dBASE IV) for further analysis. A number of additional data fields were also created to assist in subsequent processing. The structure of the database file is shown in Appendix 2.

The NAFA data provide dollar costs for parts and labour for R&M costs classified into a number of categories. Because it was evident that "Routine Servicing" accounted for quite a large proportion of total R&M cost, costs were totalled with and without this component.

After some initial analysis of the NAFA data, vehicle histories of less than 12 months were removed because these periods were too short to give reliable results. This had the effect of eliminating most of the outlying very large and very small cents/km costs. However, it also reduced the useful data set from 11,500 to about 7,500.

For further analysis, the few MCVs were removed from the NAFA database file and added to the other Lotus dataset from the operator survey. For cars and LCVs, the reverse was done, adding the data on these vehicles from the operator survey to the NAFA data set. A data field "source" was created so that NAFA and non-NAFA data could be distinguished. Also the company code from the operator survey was added as a data field (though no company identifiers were available in the NAFA data).

8. RESULTS OF VEHICLE R&M COST SURVEY

8.1 Total R&M Costs by Vehicle Class and Size

Table 8.1 shows the main results of vehicle R&M costs in cents per kilometre for the vehicle classes and subdivisions into either engine size (for light vehicles) or gross vehicle weight (GVW for heavy vehicles).

Table 8.1 Breakdown of R&M Costs by Vehicle Class, and by Gross Vehicle Weight.

Vehicle Class	No. in total screened sample	No. in screened NAFA Database	Mean R&M Costs (cents/km)			Standard Deviation - Total Sample	Standard Error - Total Sample
			NAFA Leased	Other Sample	Total Sample		
Cars							
small	604	573	2.26	3.55	2.33	1.44	0.06
medium	2119	2104	2.26	4.31	2.28	1.51	0.03
large	2959	2953	2.51	3.28	2.51	1.51	0.03
very large	870	854	2.84	4.19	2.87	1.65	0.06
Cars: Total	*6552*	*6484*	*2.45*	*3.84*	*2.47*	*1.53*	*0.02*
Range, max/min			*42.3/0.02*	*17.8/0.35*	*42.2/0.02*		
LCVs							
small	160	152	3.69	7.36	3.87	3.75	0.30
medium	545	520	2.80	4.01	2.85	2.40	0.10
large	288	274	3.26	4.41	3.32	4.65	0.27
very large	27	27	3.40	-	3.40	2.13	0.41
LCVs: Total	*1020*	*973*	*3.08*	*4.70*	*3.16*	*3.41*	*0.11*
Range, max/min			*50.6/0.28*	*24.1/1.45*	*50.6/0.28*		
MCVs, by GVW							
3.5-7.5 t	188	90	4.45	18.31	11.67	21.17	1.54
7.6-12.5t	84	9	3.81	20.87	19.04	19.51	2.13
12.6-17.5t	69	2	4.74	29.87	29.14	26.06	3.14
17.6-22.5t *	3	-	-	*	*	*	*
MCVs: Total	*346*				*16.96*	*22.75*	*1.22*
Range, max/min					*257.5/0.0*		
Bus							
inter-urban / tour	167	-	-	33.03	33.03	23.63	1.83
urban bus	46	-	-	23.33	23.33	-	-
Bus: Total	*213*	-	-	*30.93*	*30.93*	*n.a.*	*n.a.*
HCVs							
I powered	417	-	-	20.86	20.86	34.33	1.68
II trailer	467	-	-	8.81	8.81	10.67	0.49

* Note - values for small samples are not shown
GVW - gross vehicle weight

8.1.1 Functional Form of the Distribution of R&M Costs

In Tables 8.1 to 8.9, the mean values, standard deviations and standard error of the mean relate to the sample data and, apart from the mean, should not be taken as estimates of these statistics for the population.

The standard deviation of sample data is calculated as

$$s' = (\Sigma(x - xi)^2/N))^{1/2} \text{ where x is the sample mean.}$$

An estimate of the population standard deviation would be given by

$$s = (\Sigma(x - xi)^2/(N-1))^{1/2}.$$

As N is large for most of the samples, the difference between these two statistics is small.

At this preliminary analysis stage of analysis, no systematic investigation of the shape of the distribution or the best representative functional form was made. However, the size of the sample standard deviations relative to the mean indicate that the distribution of R&M costs is unlikely to conform to a normal distribution. Frequency distributions of R&M costs for the sample cars and LCVs are shown in Figure 8.1. The shape of the histograms indicate that a lognormal distribution is likely to provide a better fit to the data.

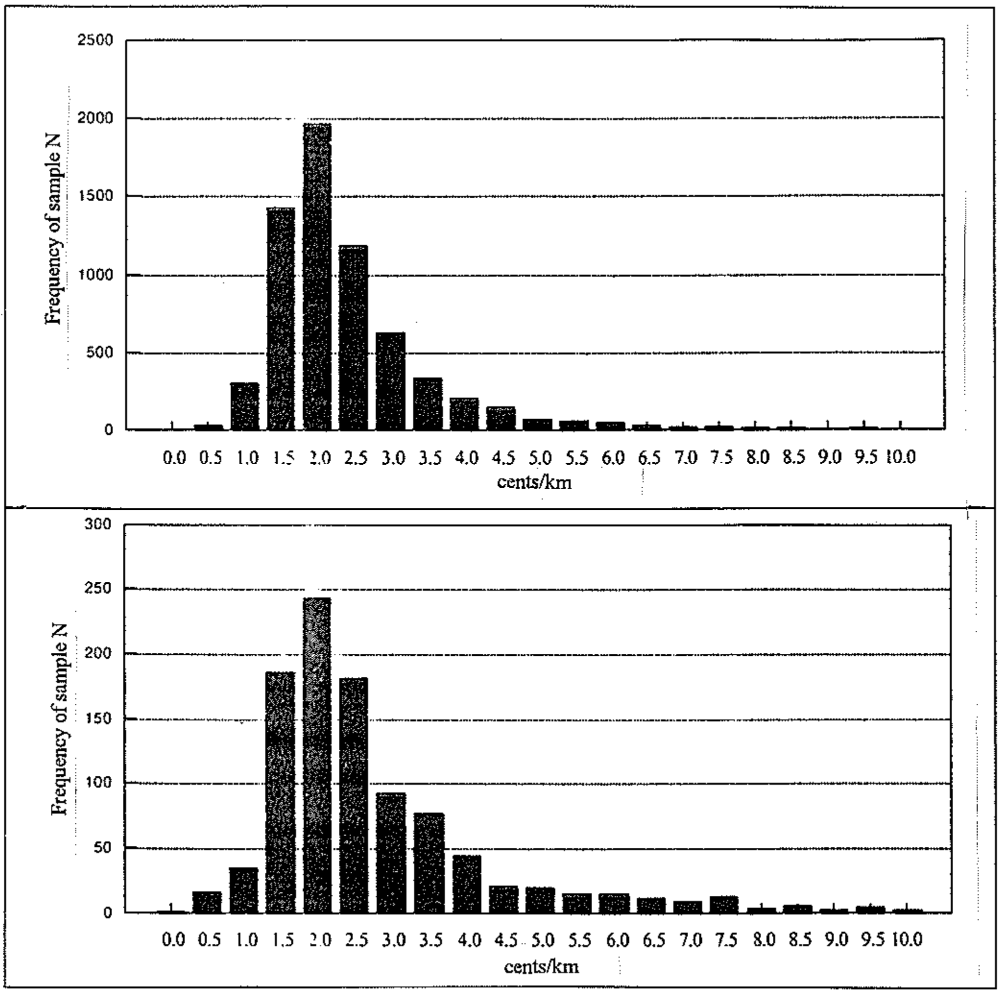


Figure 8.1 Distribution of R&M costs (cents/km) for all cars (upper histogram) and for all LCVs (lower histogram).

8.1.2 NAFA Data and Other Sample Data

For cars and LCVs, the NAFA database provided the main source of information. These were generally newer vehicles than those collected through the other user surveys, and the reasons for the difference in R&M cost between the data sets became evident once an analysis was made on either vehicle age or accumulated kilometres (see Section 8.4). For MCVs similar numbers were available in both the NAFA data and the user surveys, while for HCVs and buses the data were almost exclusively from the commercial operator surveys.

8.1.3 Cars

The size categories used for cars are:

small	1600 cc and under
medium	1601 - 2000 cc
large	2001 - 3500 cc
extra large	over 3500 cc

The choice of these four size categories was to suit the distribution of sizes in the database. Because the NAFA source dominates, there is a greater representation of large engine sizes than in the New Zealand vehicle fleet overall. The categories used here differ somewhat from the underlying sub-categories used in NZVOC and HDM III. In NZVOC and HDM for R&M purposes, cars are in two classes: a small class up to 2000 cc; and large cars over 2000 cc. For the purposes of fuel consumption modelling, however, NZVOC has used three categories: under 1300 cc, 1301 to 1600 cc, 1601 to 2000 cc, and over 2000 cc.

The amount of variation in R&M cost per km with vehicle size is quite modest, of a range of only 11% between the highest (extra large cars) and the lowest (medium cars). Of interest is that R&M costs appear to be higher for vehicles in the under 1600 cc category to those in the 1601 to 2000 cc category. When these figures are normalised by vehicle replacement cost, the comparison between these groups becomes more extreme.

8.1.4 Light Commercial Vehicles

For LCVs, NZVOC has adopted four sub-classes which are based on fuel type, body style, and a combination of gross weight and wheelbase. The data to form this classification in the NAFA data set are not readily available as there are no data on gross vehicle weight (GVW). Also the model description data are not always detailed enough to identify the particular sub-model from which manufacturers' technical data could then be used to identify gross weight. So a simple classification by engine size has been used for LCVs at this stage of analysis. This is sufficient to demonstrate the range of difference in R&M cost by vehicle size. Further work could possibly produce a sub-classification of R&M data by GVW or wheelbase.

While LCVs as a class show a higher R&M cost than cars, being about 28% higher overall, there is little evidence of any increase in R&M cost with engine size across the LCV sub-classes. However, as with cars, the smallest engine size group presents a higher R&M cost compared to the next larger size.

8.1.5 Medium Commercial Vehicles

MCVs are almost equally represented in the NAFA database and the other fleet operator surveys. The MCV class has been subdivided into four size categories based on GVW as follows:

3.5 to 7.5 tonnes	"5 tonne"
7.6 to 12.5 tonnes	"10 tonne"
12.6 to 17.5 tonnes	"15 tonne"
>17.5 tonnes	

Only a few vehicles were indicated to be heavier than 17.5 tonnes. This appears to be rather high for a two axle vehicle and the data should be disregarded. There is a clear increase in R&M cost with increased size, the 15-tonne category showing a mean R&M cost that is 2.5 times the 5-tonne category. This leads to one conclusion that the present method of subdividing MCVs in the NZVOC model into two categories "6 tonne" and "8 tonne" (load capacity) is probably inadequate and that a division into three sub-categories, as carried out for this analysis, may be preferable. However, some care is needed in defining the lower boundary of this group because of the adoption of wheelbase as a defining factor for traffic counting purposes.

Quite a substantial difference (i.e. threefold) exists between the mean R&M cost for the smallest category MCV (5 tonne) and the largest LCV.

8.1.6 Heavy Commercial Vehicles

For HCVs, the separation is into powered and unpowered units (trailers). An analysis of both powered units and trailers by axle number (2,3,4 axle) has been made but has not been presented because of the variability in the data, and of the lack of any distinction in R&M costs between the different sub-groups on the basis of axle numbers.

Whether a realistic distinction can be made between HCVI and HCVII vehicles for the purposes of R&M cost modelling is uncertain. It is difficult to clearly separate single unit trucks from tractor units of articulated combinations in some of the data. Many of the single unit trucks are being used as part of HCVII combinations, but are probably indistinguishable in R&M cost from an HCVI when the powered unit is considered on its own. It would be reasonable to expect that the powered units represent the HCVI mean cost, while the powered + unpowered represent the HCVII mean cost.

8.1.7 Buses

For buses, urban services have been separated from inter-urban and tour buses. As all the urban bus data are from a single fleet and provide a fleet average rather than an analysis of individual vehicle records, the representativeness of this section of the vehicle fleet is uncertain. For inter-urban and tour buses the sample is much larger, being from three vehicle fleets and records of individual vehicles. The difference in R&M cost between inter-urban/tour buses and urban buses appears to be quite marked. Without conducting a specific analysis, items such as air conditioning are likely to add to the R&M costs for the route/tour buses, and possibly explain their higher operating costs. Buses in this class also tend to be larger, even though passenger capacity is lower.

8.2 Regional Variations in R&M Costs

The data have been analysed to investigate any evident regional variations in R&M costs (Table 8.2). A segmentation into three regions has been used: north of the North Island (Northern region); south of the North Island (Central); and the South Island (Southern region). This segmentation was agreed with NAFA as the limit of what could be reliably provided, taking account of the relatively fewer vehicles in the NAFA database from regions other than the north of the North Island.

There was no clear evidence of regional variation (see Tables 8.2, 8.3). For cars, with the exception of large cars, the mean R&M cost is slightly lower for the South Island vehicles than those from the two North Island regions. For commercial vehicles the mean age and unit cost of repairs and maintenance is quite uniform over the three regions. Differences between mean cents/km, which are apparent for medium and heavy vehicles, can be attributed to regional differences in vehicle mean age for the sample. This does not imply that these differences in mean age are representative of the population - they may merely be a characteristic of the datasets. Also, vehicles of less than one year in age were removed from the analysis, so the mean age of the reduced dataset does not reflect the mean age of the total sample.

This preliminary analysis is insufficient to conclude whether there is a statistically significant difference in R&M costs by region, in particular between the North and South Islands. If there is such a difference then it will be relatively small as a proportion of the mean R&M cost, the preliminary analysis indicating in the order of 10% for cars. In the case of LCVs, differences in vehicle age may contribute part of the difference in mean R&M costs.

Table 8.2 R&M Costs Analysis by Region for Cars and LCVs.

Vehicle Class Region	**Mean Total R&M Cost (cents/km)**	**Standard Deviation**	**Number of Vehicles**	**Standard Error**	**Mean Age (months)**
All Cars					
North	2.51	1.68	2613	0.03	32.7
Central	2.45	1.34	3240	0.02	33.1
South	2.27	1.49	631	0.06	32.7
Small Cars					
North	2.22	1.01	226	0.07	34.2
Central	2.36	1.68	309	0.10	35.2
South	1.70	0.59	38	0.10	33.8
Medium Cars					
North	2.33	1.96	776	0.07	32.2
Central	2.27	1.09	1129	0.03	33.5
South	1.98	0.82	199	0.06	33.2
Large Cars					
North	2.54	1.60	1216	0.05	32.5
Central	2.51	1.35	1418	0.04	33.2
South	2.38	1.78	319	0.10	32.7
Extra Large Cars					
North	2.90	1.56	395	0.08	33.5
Central	2.78	1.57	384	0.08	30.3
South	2.85	1.62	75	0.19	31.1
All LCVs					
North	2.88	3.07	415	0.15	40.5
Central	3.40	3.88	439	0.19	42.3
South	2.65	2.25	119	0.21	36.8
Small LCVs					
North	4.12	4.78	41	0.75	62.2
Central	3.77	3.85	93	0.40	48.3
South	2.28	1.31	18	0.31	39.1
Medium LCVs					
North	2.64	2.19	226	0.15	40.3
Central	3.03	2.76	229	0.18	43.6
South	2.64	2.19	226	0.15	40.3
Large LCVs					
North	2.93	3.67	133	0.32	35.0
Central	3.76	6.03	108	0.58	34.7
South	2.95	3.56	33	0.62	38.0
Extra Large LCVs					
North	2.60	0.99	15	0.26	15.0
Central	4.72	3.00	9	1.00	38.3
South	3.47	0.61	3	0.35	21.0

Table 8.3 R&M Costs Analysis by Region for Heavy Trucks and Buses.

Vehicle Class Region	Mean Total R&M Cost (cents/km)	Standard Deviation	Number of Vehicles	Standard Error	Mean Age (months)
All MCVs					
North	5.2	31.3	68	3.8	50.6
Central	17.5	33.5	190	2.4	73.6
South	24.6	64.5	90	6.8	92.6
Medium CV <5t					
North	4.0	26.7	47	3.9	43.9
Central	13.1	33.6	100	3.4	67.2
South	16.7	53.0	43	8.1	74.3
Medium CV 5-10t					
North	9.3	29.5	14	7.9	69.1
Central	20.7	33.1	62	4.2	79.3
South	22.9	55.1	8	19.5	106.8
Medium CV 10-15t					
North	5.1	44.2	7	16.7	58.0
Central	27.1	27.6	26	5.4	83.1
South	35.3	74.1	36	12.4	112.7
Large Bus					
North	33.9	41.9	84	4.6	41.9
Central	25.8	48.2	43	7.3	48.2
South	29.8	55.8	124	5.0	55.8
Heavy Truck/ Driving Unit					
North	21.7	40.9	168	3.2	51.7
Central	16.5	46.0	180	3.4	77.7
South	20.3	112.5	165	8.8	92.8
Heavy Trailer					
North	7.9	60.4	217	4.1	69.5
Central	7.4	65.2	199	4.6	124.2
South	10.4	110.4	135	9.5	176.0

8.3 Urban/Rural Variations in R&M Costs

For the NAFA data, vehicles were classified into predominantly urban or predominantly rural operations. This was a broad and somewhat subjective categorisation made by NAFA on their knowledge of the companies involved and the place of domicile of the vehicles. The comparison between urban and rural R&M costs is shown in Table 8.4 of this report. For cars, urban vehicle R&M costs appear to be slightly lower per kilometre travelled than rural vehicle R&M costs. Over the range of car sizes, urban costs range between 86.3% and 91.5% of rural car R&M costs. However urban cars are also, on average, older vehicles by about 2 months than are rural cars, and this will account for part of the difference. For LCVs R&M costs show no evident difference between urban and rural domicile, although urban LCVs are on average 3.5 months older than their rural counterparts.

Table 8.4 R&M Costs Analysis by Urban/Rural Location for Cars and LCVs.

Vehicle Class Urban/Rural	Mean Total R&M Cost (cents/km)	Standard Deviation	Number of Vehicles	Standard Error	Mean Age (months)
All Cars					
Urban	2.54	1.62	5019	0.02	33.5
Rural	2.23	1.17	1533	0.03	31.6
Small Cars					
Urban	2.36	1.47	498	0.07	36.5
Rural	2.16	1.26	106	0.12	34.1
Medium Cars					
Urban	2.35	1.60	1636	0.04	33.0
Rural	2.04	1.13	483	0.05	32.5
Large Cars					
Urban	2.59	1.61	2269	0.03	33.2
Rural	2.25	1.06	690	0.04	31.5
Extra Large Cars					
Urban	2.99	1.73	616	0.07	32.9
Rural	2.58	1.37	254	0.09	29.1
All LCVs					
Urban	3.18	3.53	713	0.13	42.5
Rural	3.12	3.11	307	0.18	38.9
Small LCVs					
Urban	3.71	3.88	124	0.34	51.4
Rural	4.43	3.18	36	0.53	46.6
Medium LCVs					
Urban	2.59	2.67	390	0.14	43.1
Rural	2.96	1.47	155	0.12	40.2
Large LCVs					
Urban	3.23	4.74	183	0.35	36.1
Rural	3.47	4.49	105	0.44	34.8
Extra Large LCVs					
Urban	3.73	2.20	16	0.55	31.4
Rural	2.93	1.93	11	0.58	34.3

8.4 R&M Cost Relationships with Vehicle Age and Use

8.4.1 R&M Cost and Vehicle Age

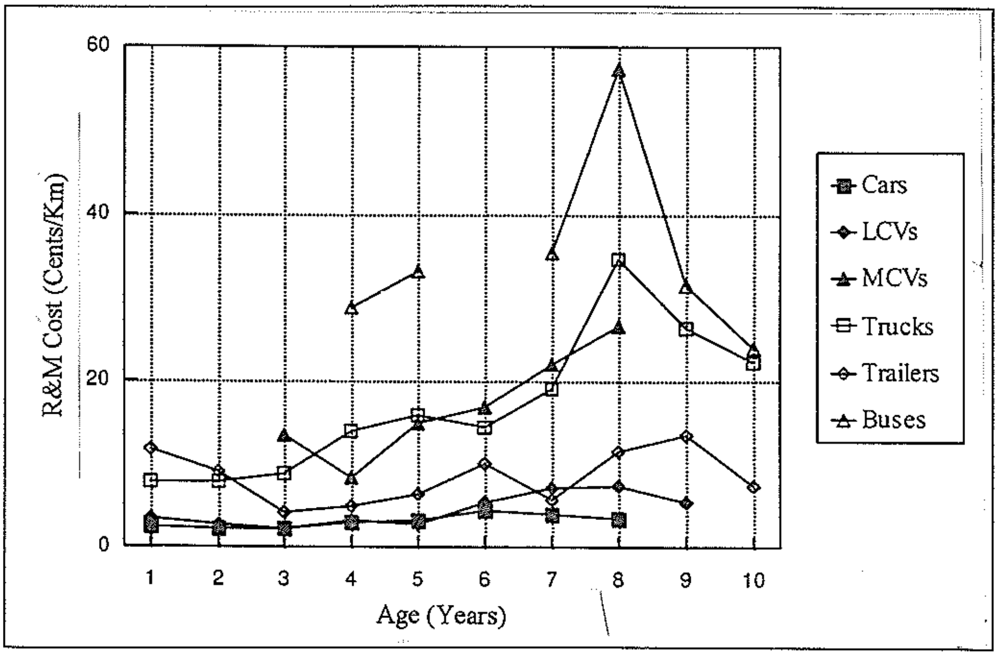
An analysis has been made of R&M cost variation with age and with accumulated kilometres of use. The results, presented in Table 8.5 and Figure 8.2 in this report, show that there is a systematic relationship between R&M cost and age. For cars, LCVs, and MCVs over the first 3 to 4 years of vehicle life, the R&M cost does not increase with age. However, after that period the R&M cost/km starts to rise. Unfortunately, because the data are almost exclusively from company fleets, the age spectrum tends to be heavily biased to the "young" end of the vehicle fleet. Very few vehicles in the sample were over 7 or 8 years of age.

Table 8.5 Variation of Mean R&M Cost (cents/km) with Vehicle Age in Years.

Age (Years)	Cars		LCV		MCV (5t)		HCV - powered		HCV - trailers		Buses - Interurban	
	N	mean	N	mean	N	mean	N	Mean	N	mean	N	mean
1	378	246	50	3.44			7	7.79	5	11.66		
2	2003	2.22	213	2.75			21	7.85	7	9.14		
3	3060	2.40	401	2.39	8	13.56	40	8.96	13	4.32		
4	876	2.98	201	3.20	13	8.47	61	14.05	57	5.03	10	28.7
5	143	3.34	44	2.83	14	14.91	49	15.89	20	6.45	10	33.1
6	37	4.50	16	5.43	17	16.90	25	14.31	16	10.17		
7	14	4.10	13	7.24	10	22.05	18	19.13	13	5.78	5	35.2
8	19	3.53	44	7.28	9	26.55	24	34.35	17	11.55	14	57.4
9			28	5.38			11	26.38	9	13.42	21	31.4
10					8	13.08	25	22.29	20	7.48	16	23.8

N = sample size

Figure 8.2 R&M cost variation with vehicle age.



8.4.2 R&M Cost and Accumulated Kilometres Travelled

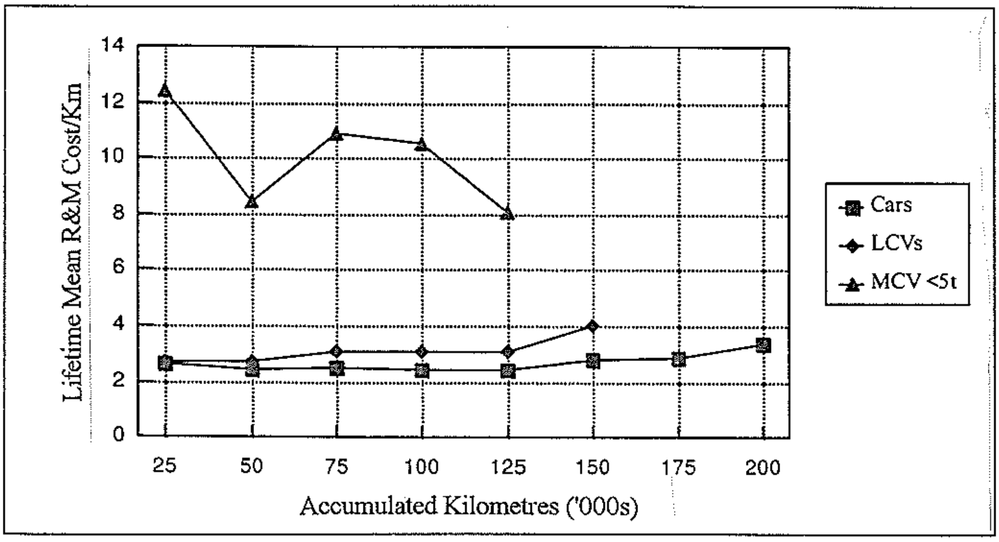
The variation between R&M cost and vehicle accumulated kilometres travelled, given in Table 8.6 and Figure 8.3, shows a similar pattern for cars and LCVs. However, because of the wide range in accumulated annual kilometres at higher levels of utilisation, the upper end of the graph cannot be extended beyond 200,000 km. (In making this comparison, utilisation has been rounded to the nearest 25,000 km.) For MCVs and HCVs, no evident relationship exists between R&M cost and vehicle total utilisation.

Table 8.6 Variation of Mean R&M Cost (cents/km) with Vehicle Accumulated Lifetime Kilometres.

Accumulated kilometres (km x 10^3)	**Cars**				**LCVs**			
	N	mean	s.d.	s.e.	N	mean	s.d.	s.e.
25	288	2.65	2.26	0.13	47	2.68	2.34	0.34
50	1506	2.40	1.40	0.04	197	2.71	1.94	0.14
75	2333	2.46	1.39	0.03	301	3.07	3.67	0.21
100	1815	2.43	1.17	0.03	295	3.09	2.82	0.16
125	506	2.44	1.32	0.06	131	3.04	2.22	0.19
150	69	2.78	1.21	0.15	29	4.03	3.74	0.69
175	16	2.82	1.56	0.39	8	9.47	10.09	3.57
200	10	3.36	1.72	0.54				

N = sample size; s.d. = standard deviation; s.e. = standard error

Figure 8.3 Variation of R&M cost per kilometre with accumulated kilometres.

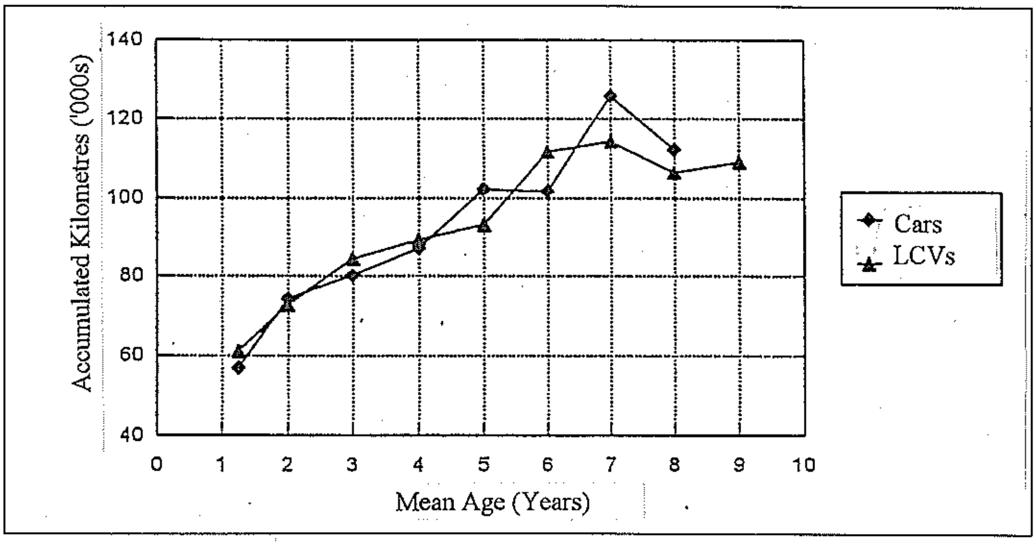


8.4.3 Vehicle Age and Accumulated Travel Relationships

The relationship between vehicle age and mean accumulated kilometres of travel obtained from odometer readings for the survey vehicles is shown in Table 8.7 for cars and LCVs. There is a wide spread of odometer readings at any particular year of age. Some uncharacteristically low readings for the older aged vehicles (7 to 9 years) may be indicative of incorrect odometer readings which had been stopped, wound back, or were "round the clock", but not recorded as such. In Figure 8.4, which shows the mean odometer reading against age, a tailing off in additional kilometres for older vehicles occurs, which again may be symptomatic of a proportion of incorrect readings.

An alternative explanation is that vehicles which are retained in commercial fleets for more than 4 to 5 years have an uncharacteristically low annual utilisation compared with most vehicles, which are retired at the age of 4 to 5 years. It may be this low annual utilisation which leads to their retention.

Figure 8.4 Vehicle Age versus Accumulated Kilometres Travel for Cars and LCVs.



8.5 Labour and Parts Costs Relationships

The proportion of labour cost to parts cost in the R&M cost total is available for all of the NAFA data and for most of the other user data. For the NAFA data, R&M costs are coded as either attributable to various categories of work required (electrics, suspension, etc.) or to "servicing", i.e. routine work usually done at periodic intervals by kilometres run over the first few years of vehicle life. The other (non-NAFA) data are not sufficiently disaggregated to identify differences between routine servicing costs and other R&M costs.

Table 8.7 Annual Utilisation of Vehicles (in accumulated kilometres travelled) versus Age of Cars and LCVs (excluding vehicles under 1 year age).

(a) Cars

Odometer km x 10^3	**Age (years)**									
	1¼	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
25	84	141	58	7	-	-	-	-	-	290
50	157	579	651	101	10	3	-	-	-	1501
75	79	607	1233	356	37	12	2	3	-	2329
100	41	516	883	300	56	9	3	5	-	1813
125	13	151	217	83	18	7	5	6	1	501
150	-	5	21	16	15	5	2	4	1	69
175	-	-	-	9	5	1	-	-	-	15
200	-	-	1	4	2	-	2	-	1	10
Total	374	1999	3064	876	143	37	14	18	3	6528

(b) Light Commercial Vehicles

Odometer km x 10^3	**Age (years)**									
	1¼	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
25	12	22	9	3	1	-	-	-	-	47
50	14	60	82	29	4	1	3	-	-	193
75	11	63	130	63	12	5	2	8	7	301
100	7	46	122	64	20	4	1	20	8	292
125	4	17	51	32	5	3	1	8	9	130
150	-	3	7	6	1	-	4	6	1	28
175	-	1	-	2	-	-	2	-	1	7
200	-	-	-	1	1	-	-	1	-	3
Total	48	212	401	200	44	14	13	43	26	1001

Table 8.8 Parts Costs as Percentage of Total R&M Cost and Contributions of Routine Servicing to Total R&M Cost.

(a) Cars and LCVs (NAFA Data)

Age (years)	Cars				LCVs			
	% of Cost in Parts			% of Cost in Routine Servicing	% of Cost in Parts			% of Cost in Routine Servicing
	Routine Servicing	Other	Total		Routine Servicing	Other	Total	
1	50.0	70.3	57.0	75.3	44.4	59.1	52.5	61.1
2	49.3	73.3	57.6	72.6	47.9	68.5	55.6	69.3
3	51.9	70.1	59.6	70.8	51.9	70.0	59.2	70.5
4	52.2	69.0	61.3	61.1	45.9	66.2	58.0	57.8
5	53.5	65.2	63.1	52.0	4443.5	62.8	58.6	44.2
6	28.7	51.0	49.2	23.0	38.3	53.2	54.8	24.9
7	31.4	57.7	56.2	17.5	17.2	46.7	50.4	16.4
8	19.3	44.4	45.4	14.7	31.5	64.1	60.0	15.3
9					27.4	58.0	57.5	13.6
All	70.6	50.8	59.0	69.3	46.8	66.8	57.7	60.3

(b) All vehicle classes with % parts cost of total R&M costs.

Vehicle Class	Number	Mean	Std Dev
Car: small	573	58.65	18.93
medium	2119	56.88	15.70
large	2959	60.28	15.69
extra large	870	60.19	12.36
Cars	*6521*	*59.02*	*15.71*
LCV: small	160	60.42	20.24
medium	545	56.74	16.22
large	288	56.93	14.39
extra large	27	69.72	13.84
LCVs	*1020*	*57.71*	*16.55*
MCVs: 5 t	157	54.52	20.37
10 t	57	49.42	20.19
15 t	26	47.61	15.01
MCVs	*240*	*52.56*	*20.01*
Bus	105	44.01	12.29
HCV:			
powered	92	53.04	9.08
trailer	144	48.03	11.28

Table 8.8 shows the percentage of R&M costs attributable to parts for each vehicle class and against vehicle age in the case of cars and LCVs. The proportion of cost in parts shows a slight but perceptible decline with vehicle age for routine servicing service costs for both cars and LCVs. However, for the other R&M components, charged against specific items of work, the proportion of parts costs is similar for all vehicle ages.

For different types of vehicle, the proportion of costs in parts lies in the range 45% to 60% with a tendency for a higher proportion of parts costs in light vehicles.

The main result from this analysis is that routine servicing as a proportion of total R&M cost shows a very marked decrease over time, after the first three years of vehicle life. This conclusion can only be drawn for light vehicles as insufficient numbers of any other category in the NAFA database were available.

8.6 Analysis of R&M Costs by Vehicle Body Type

Further analysis was made of R&M cost variation with vehicle body type. Body type is often an indicator of a particular form of vehicle duty such as bulk materials haulage, tanker liquids haulage, etc.

LCVs were grouped into four body type categories for analysis:

1. light truck (cab/chassis vehicles fitted with tray or deck),
2. van bodies,
3. station wagons (full cab 4x4 vehicles, e.g. Nissan Patrol),
4. utilities.

Table 8.9 shows the mean R&M cost per kilometre, age, and accumulated travel for each of these body types.

For the LCV body types, the light trucks stand out as having a significantly greater R&M cost per kilometre than other body types. This body type shows a slightly higher accumulated utilisation and age but this is not sufficient to account for the difference in R&M cost. To identify any differences in gross vehicle weight would be worth exploring further. Unfortunately the NAFA data do not contain GVW, although this could be added by cross-referencing vehicle model against manufacturers' technical data.

MCVs did not have sufficient identifying data to allow an analysis against body style. A disaggregation into three weight groups as discussed in Section 8.1 of this report appears to provide the degree of discrimination needed to deal with this MCV vehicle class.

Table 8.9 R&M Costs by Vehicle Body Type.

(a) Light Commercial Vehicles

Body Type	Number in Sample	Mean R&M (cents/km)	Std Dev.	Std Error	Mean Engine Size (cc)	Mean Acc. Km(x10^3)	Mean Age (months)
Light Truck	106	4.53	6.95	0.68	2233	93.7	44.75
Van	553	3.02	2.78	0.12	1878	82.6	41.60
Station Wagon	9	2.82	0.90	0.30	2256	73.7	45.89
Utility	352	2.98	2.52	0.13	2297	86.8	39.93

(b) Heavy Trucks

Body Type	Number in Sample	Mean R&M (cents/km)	Std Dev.	Std Error	Mean Acc. Km (x 10^3)	Mean Age (months)
Tanker	177	19.19	42.12	3.2	386.0	81.6
Bulk Materials	64	11.34	9.46	1.2	344.4	90.4

(c) Heavy Trailers

Body Type	Number in Sample	Mean R&M (cents/km)	Std Dev.	Std Error	Mean Acc. Km (x 10^3)	Mean Age (months)
Tanker	429	8.52	10.18	0.49	380.9	122.1
Bulk Materials	233	9.70	10.88	0.71	192.4	165.2

For heavy trucks, the data set includes a large number of tanker and bulk materials vehicles, allowing a comparison to be made between these two types, both for the driving units and the trailers. Trailers show little difference in R&M costs but the driving units of tanker vehicles (the sample is a mixture of milk, beer and fuel tankers) have a significantly greater R&M cost than those used for bulk materials haulage (the sample vehicles carried mainly aggregates and other building materials).

9. COMPARISON OF RESULTS WITH THE PROJECT EVALUATION MANUAL

9.1 Normalisation of R&M Costs by Vehicle Replacement Cost

As discussed in Section 3.3 of this report, the present relationships used in the NZ Vehicle Operating Cost Model (NZVOC) have their basis in the World Bank HDM model. R&M costs are modelled as separate parts and labour components. The parts costs is modelled as a parameter "parts consumption" which is the ratio of parts cost per kilometre to vehicle replacement cost. Labour hours and costs are then related to parts costs.

To compare the results of the operator surveys with the values derived from HDM relationships for use in the NZVOC model, first the parts and labour cost data must be "normalised" by dividing the parts cost by vehicle replacement cost. This has been done in Table 9.1 in this section of the report.

9.2 NZVOC Parts Costs Model

9.2.1 NZVOC V3.0 (1986), V3.1(1989)

Relevant data from the NZVOC model, as first used in the NRB Economic Appraisal Manual (RRU Technical Recommendation No. TR9, Bone 1986), have been assembled for comparison. The form of the model is given in Section 3.3.2 of this report. The parameter values for V3.1(1989) of the model (Bennett 1989a) are shown in Table 9.2 and are basically the same as for the earlier V3.0 (1986) in respect of R&M costs.

The parameter CFPART (Correction Factor for parts) was "calibrated" so that the value of parts consumption (PC) would equate with values estimated by the Ministry of Transport at that time, assuming a 55:45 parts:labour cost ratio, and an average roughness of 100 NAASRA counts (45 to 50 QI depending on the method of correlation). There was discussion at the time of the relative merits of adjusting the values of Cosp rather than adding the additional CFPART term, i.e. adjusting the slope of the curve against roughness rather than translating the curve. It was decided that the integrity of the model would be best preserved by adding the CFPART term rather than by adjusting Cosp.

Table 9.1 Normalised Parts Costs Derived from Operator Surveys.

<table>
<tr><th rowspan="2">Vehicle Sub-class</th><th rowspan="2">Vehicle Size (1)</th><th colspan="2">Replacement Cost ($NZ 1994) (4)</th><th colspan="2">R&M Parts Cost/km (cents/km)(4)</th><th colspan="2">Parts Consumption PC% / 1000 km(3)</th></tr>
<tr><th>Vehicle</th><th>Trailer</th><th>Vehicle</th><th>Trailer</th><th>Vehicle</th><th>Trailer</th></tr>
<tr><td>Car</td><td><1300</td><td>21,300</td><td></td><td>2.33</td><td></td><td>0.109</td><td></td></tr>
<tr><td>Car</td><td>1301-1600</td><td>28,200</td><td></td><td>2.33</td><td></td><td>0.082</td><td></td></tr>
<tr><td>Car</td><td>1601-2000</td><td>31,700</td><td></td><td>2.28</td><td></td><td>0.072</td><td></td></tr>
<tr><td>Car</td><td>> 2000</td><td>37,000</td><td></td><td>2.51</td><td></td><td>0.067</td><td></td></tr>
<tr><td>LCV</td><td>1.9t GVW</td><td>20,000</td><td></td><td>2.85</td><td></td><td>0.143</td><td></td></tr>
<tr><td>LCV</td><td>2.6t GVW</td><td>29,400</td><td></td><td>3.32</td><td></td><td>0.113</td><td></td></tr>
<tr><td>LCV</td><td>2.9t GVW</td><td>4,300</td><td></td><td>3.32</td><td></td><td>0.097</td><td></td></tr>
<tr><td>LCV</td><td>3.4t GVW</td><td>39,900</td><td></td><td>3.40</td><td></td><td>0.085</td><td></td></tr>
<tr><td>MCV</td><td>9.8t GVW</td><td>57,700</td><td></td><td>19.04</td><td></td><td>0.330</td><td></td></tr>
<tr><td>MCV</td><td>13.0t GVW</td><td>72,600</td><td></td><td>29.14</td><td></td><td>0.401</td><td></td></tr>
<tr><td>HCVI</td><td>3 axle</td><td>152,000</td><td></td><td rowspan="6">20.86</td><td></td><td rowspan="6">0.120 to 0.160</td><td></td></tr>
<tr><td>HCVI</td><td>4 axle (2)</td><td>135,000</td><td>34,500</td><td rowspan="5">8.81</td><td rowspan="5">c. 0.22</td></tr>
<tr><td>HCVII</td><td>5 axle</td><td>152,000</td><td>26,200</td></tr>
<tr><td>HCVII</td><td>6 axle</td><td>133,000</td><td>53,400</td></tr>
<tr><td>HCVII</td><td>7 axle</td><td>173,500</td><td>57,000</td></tr>
<tr><td>HCVII</td><td>8 axle</td><td>176,700</td><td>84,500</td></tr>
<tr><td>Bus</td><td>2 axle</td><td>269,000</td><td></td><td>23.33</td><td></td><td>0.090</td><td></td></tr>
<tr><td>Bus</td><td>3 axle</td><td>383,000</td><td></td><td>33.03</td><td></td><td></td><td></td></tr>
</table>

Notes: (1) Size : cc for cars; gross weight (GVW) in tonnes (t) for MCVs; number of axles for HCVs.

(2) Trailer only for 2 axle truck towing 2 axle trailer; otherwise the total is for 4 axle twinsteer.

(3) The units of Parts Consumption (PC) are the proportion of new Vehicle Cost (VC) in dollars per 1000 km in the NZVOC model; units for PC:VC are dollars/1000 km, converted to cents/km (c/km) by dividing by a factor of 10.

(4) Units of R&M Parts Cost are cents/km (c/km); Replacement costs are in $NZ 1994.

Differences from the 1986 version are highlighted in italics.

Table 9.2 Parameter Values Used in NZVOC Parts Cost Model V3.0 (1986).

Vehicle Sub-class	Vehicle Size (1)	Fuel	AKM ($x10^3$)	Life (yr)	CKM ($x10^4$)	K	Cosp	Cspqi ($x10^{-3}$)	CFPART	PC % at 50 QI (2)
Car	< 2000	p	14	18	85	0.308	32.49	13.70	+0.151	0.36
Car	> 2000	p	14	18	85	0.308	32.49	13.70	+0.068	0.28
LCV	1.8t GVW	p	20	18	120	0.308	32.49	13.70	+0.113	0.35
LCV	2.5t GVW	p	20	18	120	0.308	32.49	13.70	+0.078	0.31
LCV	2.6t GVW	p	20	18	120	0.308	32.49	13.70	+0.110	0.35
LCV	3.5t GVW	d	20	18	120	0.308	32.49	13.70	+0.072	0.31
MCV	5.0t GVW	d	25	22	180	0.371	1.49	251.79	+0.107	0.29
MCV	5.6t GVW	d	25	22	180	0.371	1.49	251.79	+0.89	0.27
MCV	9.2t GVW	d	25	22	180	0.371	1.49	251.79	+0.80	0.26
MCV	12.5t GVW	d	25	22	180	0.371	1.49	251.79	+0.073	0.25
HCVI	3 axle	d	35	18	315	0.371	8.61	35.31	-0.119	0.14
HCVII	3 axle towing	d	40	16	320	0.371	13.94	15.65	-0.188	0.09
HCVII	artic towing	d	40	16	320	0.371	13.94	15.65	-0.188	0.09
unused										
unused										
unused										
Bus	2 axle	d	80	24	620	0.4483	1.77	3.56	-0.084	0.05
Bus	3 axle	d	80	24	620	0.483	1.77	3.56	-0.084	0.05

Notes: (1) See Table 9.1 footnotes for explanation of vehicle sizes

(2) QI = roughness (in NAASRA Counts)

p petrol; d diesel
AKM Average kilometres of travel / year
CKM Average accumulated kilometres of travel / year
Cosp Coefficient in HDM parts consumption model
Cspqi Coefficient in HDM parts consumption model

Differences from 1986 V3.0 are italicised.

9.2.2 Project Evaluation Manual 1991, NZVOC V3.2b

In 1991, TR9 was extensively revised and issued as the Project Evaluation Manual (PEM, Transit New Zealand 1991). At this time some work was carried out to update the vehicle parameter values and to modify the vehicle sub-classes used in the modelling (Bone 1991). Table 9.3 shows the parameter values corresponding to those in Table 9.2 and used in the 1991 issue of the PEM. The values of PC% at 100 NAASRA counts are calculated. Differences from the 1986 version are highlighted in italics.

The effect of the changes on PC was nil because no changes were made to CKM (even though some small changes were made to AKM and LIFE), and other parameters such as K, Cosp, Cpsqi and QIosp were also unchanged for the vehicle classes concerned. (Note: there is an inconsistency as HCVI, 4 axle, twinsteer trucks are attributed with parameters for the HCVII class.)

Table 9.3 Vehicle Parameter Values Used in NZVOC Parts Cost Model V3.2b (May 1991).

Vehicle Sub-class	Vehicle Size (1)	Fuel	AKM ($x10^3$)	Life (yr)	CKM ($x10^3$)	K	Cosp	Cspqi ($x 10^{-3}$)	CFPART	PC % at 50 QI (2)
Car	<2000	p	*12*	18	85	0.308	32.49	13.70	+0.151	0.36
Car	>2000	p	*11*	*20*	85	0.308	32.49	13.70	+0.068	0.28
LCV	1.8t GVW	p	*14*	*20*	120	0.308	32.49	13.70	+0.113	0.35
LCV	*2.6t GVW*	p	*15*	*20*	120	0.308	32.49	13.70	+0.078	0.31
LCV	*2.7t GVW*	*d*	*17*	*20*	120	0.308	32.49	13.70	+0.110	0.35
LCV	*3.3t GVW*	d	*18.3*	*20*	120	0.308	32.49	13.70	+0.072	0.31
unused										
unused										
MCV	*10.0t GVW*	d	*18.7*	*22*	180	0.371	1.49	251.79	+0.080	0.26
MCV	*13.0t GVW*	d	*19*	*22*	180	0.371	1.49	251.79	+0.073	0.25
HCVI	3 axle	d	*30*	*20*	315	0.371	8.61	35.31	-0.119	0.14
HCVI	*4 axle*	d	*40*	*20*	320	0.371	13.94	15.65	-0.188	0.09
HCVII	*5 axle*	d	*45*	*18*	320	0.371	13.94	15.65	-0.188	0.09
HCVII	*6 axle*	*d*	*50*	*16*	*320*	*0.371*	*13.94*	*15.65*	*-0.188*	*0.09*
HCVII	*7 axle*	*d*	*60*	*14*	*320*	*0.371*	*13.94*	*15.65*	*-0.188*	*0.09*
HCVII	*8 axle*	*d*	*60*	*14*	*320*	*0.371*	*13.94*	*15.65*	*-0.188*	*0.09*
Bus	2 axle	d	*35*	24	620	0.483	1.77	3.56	-0.084	0.05
Bus	3 axle	d	*45*	24	620	0.483	1.77	3.56	-0.084	0.05

Notes: (1) See Table 9.1 footnotes for explanation of vehicle sizes

(2) QI = roughness (in NAASRA Counts)

p petrol; d diesel
AKM Average kilometres of travel / year
CKM Average accumulated kilometres of travel / year
Cosp Coefficient in HDM parts consumption model
Cspqi Coefficient in HDM parts consumption model

Differences from 1986 V3.0 are italicised.

9.2.3 Project Evaluation Manual, NZVOC V3.3h (1995)

The latest issue of vehicle operating costs tables and charts was made in mid-1995 as amendments to the PEM. This update used Version 3.3h of the NZVOC model. Some further changes were made in vehicle classification to add a further two car subtypes, thus using up all of the available "slots" for vehicle sub-classes in the program in its present form. The corresponding parameter values and the changes from 1991 are shown in Table 9.4 in this section of the report.

Table 9.4 Vehicle Parameter Values Used in NZVOC Parts Cost Model V3.2h (April 1995).

Vehicle Sub-class	Vehicle Size [1]	Fuel	AKM ($x10^3$)	Life (yr)	CKM ($x10^3$)	K	Cosp	Cspqi ($x 10^{-3}$)	CFPART	PC% at 50 QI [2]
Car	*<1300*	*p*	*11*	*18*	*85*	*0.308*	*32.49*	*13.70*	*+0.151*	*0.36*
Car	*1301-1600*	*p*	*12.9*	*20*	*85*	*0.308*	*32.49*	*13.70*	*+0.068*	*0.28*
Car	*1601-2000*	p	*14.3*	*22*	85	0.308	32.49	13.70	+0.151	0.36
Car	>2000	p	*15.3*	*22*	85	0.308	32.49	13.70	+0.068	0.28
LCV	1.8t GVW	p	*13.3*	20	120	0.308	32.49	13.70	+0.113	0.35
LCV	2.6t GVW	p	16	20	120	0.308	32.49	13.70	+0.078	0.31
LCV	*2.9t GVW*	d	17	20	120	0.308	32.49	13.70	+0.110	0.35
LCV	*3.4t GVW*	d	18.3	20	120	0.308	32.49	13.70	+0.072	0.31
MCV	*9.8t GVW*	d	18.7	22	180	0.371	1.49	251.79	+0.080	0.26
MCV	13.0t GVW	d	19	22	180	0.371	1.49	251.79	+0.073	0.25
HCVI	3 axle	d	30	20	315	0.371	8.61	35.31	-0.119	0.14
HCVI	*4 axle*	d	40	20	320	0.371	13.94	15.65	-0.118	0.09
HCVII	4 axle	d	45	18	320	0.371	13.94	15.65	-0.118	0.09
HCVII	6 axle	d	50	16	320	0.371	13.94	15.65	-0.118	0.09
HCVII	7 axle	d	60	14	320	0.371	13.94	15.65	-0.118	0.09
HCVII	8 axle	d	60	14	320	0.371	13.94	15.65	-0.118	0.09
Bus	2 axle	d	35	24	620	0.483	1.77	3.56	-0.084	0.05
Bus	3 axle	d	45	24	620	0.483	1.77	3.56	-0.084	0.05

Notes: (1) See Table 9.1 footnotes for explanation of vehicle sizes

(2) QI = roughness (in NAASRA Counts)

p petrol; d diesel
AKM Average kilometres of travel / year
CKM Average accumulated kilometres of travel / year
Cosp Coefficient in HDM parts consumption model
Cspqi Coefficient in HDM parts consumption model

Differences from 1986 V3.0 are italicised.

9.3 Comparison of Operator Survey and NZVOC

9.3.1 Parts Costs

The parts cost (PC) output has remained fixed through the various amendments to the NZVOC model as the underlying parameters of CKM, K, Cosp, Cspqi and QIosp have remained unchanged. This means that R&M costs (in cents/km) from the model have risen in direct proportion to vehicle replacement cost.

Comparing the percentage parts consumption per 1000 km between the user survey and NZVOC, the user surveys indicate an R&M cost for cars and LCVs that is approximately ⅓ that in the NZVOC model. For MCVs however, the NZVOC model values are marginally lower than the operator survey. For HCVs, the NZVOC model values are about ¾ of those from the operator survey.

However, the comparison may not be as straightforward as this. The NZVOC model, and the HDM model on which it is based, attempt to provide R&M costs that are representative of the vehicle fleet as a whole. The operator surveys, particularly the NAFA source for light vehicles, give values for vehicles mainly in the 1 to 4 year age group (whereas the mean age for cars is about 10 years).

If an average lifetime of 20 years is taken for cars, with a mean age of 10 years, and with R&M costs per kilometre showing no rise over the first 3 to 4 years and thereafter rising linearly at 20% per year until year 10, after which it remains level for the rest of the vehicle life (as there is no evidence to indicate whether R&M costs continue to rise beyond 10 years), an average R&M cost for the fleet as a whole can be very roughly estimated. For cars this average R&M cost works out to be approximately 5.0 cents/km, or about double the value obtained from the operator surveys. For LCVs a similar calculation gives 5.6 cents/km, i.e. 78% greater than the user surveys. For MCVs and HCVs the sample is likely to be more representative of the age spectrum of the fleet at large, as it is drawn wholly (for HCVs and buses) from the non-NAFA sources. With these corrections, the comparison shows the values listed in Table 9.5.

Table 9.5 Comparison of Parts Consumption in the Vehicle Operator Surveys with NZVOC Model.

Vehicle Class	**Parts Consumption, PC% /1000km**		**Ratio of**
	Surveys	**NZVOC v. HDM**	**Survey:Model**
Cars	0.13 to 0.22	0.28 to 0.36	0.55
LCVs	0.15 to 0.25	0.31 to 0.35	0.60
MCVs	0.33 to 0.40	0.25 to 0.29	1.37
HCVs	0.12 to 0.16	0.09 to 0.14	1.25
Buses	0.09	0.05	1.80

Thus, it appears that the NZVOC model is over-estimating parts costs for cars and LCVs by a factor of 2, and is under-estimating parts costs for MCVs, HCV trucks and buses by between 25% and 80%. While these may appear to be significant differences, they are not really surprising in view of the very limited information base that is supporting current New Zealand practice. Also, responsibility for the differences should not be laid necessarily with the HDM model, as the NZVOC values have been "locally calibrated" to give agreement with the earlier MOT VOC tables. If the local calibration is removed the effect is that listed in Table 9.6.

Table 9.6 Comparison of Parts Consumption in the Vehicle Operator Surveys with HDM Model.

Vehicle Class	Parts Consumption, PC% /1000km			Ratio of Survey:Model
	Surveys	NZVOC v. HDM Models		without CF PART
		With CFPART	Without CFPART	
Cars	0.13 to 0.22	0.28 to 0.36	0.21	0.83
LCVs	0.15 to 0.25	0.31 to 0.35	0.24	0.83
MCVs	0.33 to 0.40	0.25 to 0.29	0.18	2.00
HCVs	0.12 to 0.16	0.09 to 0.14	0.27	0.50
Buses	0.09	0.05	0.13	0.70

The HDM model, unaltered, would appear to be a better predictor of mean R&M costs for cars and LCVs than the "calibrated" NZVOC model. However, the prediction for MCVs is poor and, for heavy trucks and buses, removal of the calibration factor moves the model from over-estimating to under-estimating.

9.3.2 Labour Costs

The NZVOC model treatment of labour costs (by hours) is a simple addition in the ratio of 55% parts : 45% labour (L COST = 0.8182 P COST). The HDM model is more complex (see Section 3.2.2 Equation (5) in this report) and incorporates road roughness for treating buses. The labour costs (hours) are related to a power function of parts consumption.

The user surveys indicate that parts:labour cost ratio lies in the range 56:44 to 61:39 for cars and LCVs, depending on vehicle size, although this should be qualified by the possible need to adjust for the different age structure between the sample and the vehicle population. For MCVs, the ratio is in the range 47:53 to 55:45 depending on size. The ratios from the surveys are for buses 44:56, for heavy trucks 53:47, and for trailers 48:52.

Overall, the present treatment of labour costs as being directly proportional to parts costs does not appear to be introducing any major error, although there may be scope for "fine tuning".

10. CONCLUSIONS & RECOMMENDATIONS

10.1 Achievement of Objectives

The project has substantially achieved the objectives set to the end of Stage 2 of the project, which was the limit of approved funding, having obtained mean values of R&M costs per kilometre for each vehicle type, with a breakdown into parts and labour components. This has allowed a comparison with the treatment of R&M costs in the NZVOC model at average levels of roughness.

A substantial number of vehicle records have been obtained and analysed through the user surveys. The acquisition of the NAFA data source was critical to the success of the project as this source provided a large bank of data at a considerable level of detail.

However, the amount of useful data obtained, particularly from the individual operator surveys, was not as large or as comprehensive as targeted (about 8,500 vehicle records were used in the final analysis compared with the initial target sample size of 20,000 or 1% of the New Zealand vehicle fleet). Unfortunately, in surveys involving data capture from existing records, the level of co-operation always falls well short of promise, because the output of such research is not of critical importance to the operators' businesses and no real incentives can be offered to participants. In some cases much more data was known to be available, but the amount of time that respondents were prepared to give the task limited the amount that could be acquired. In other cases, while operators believed that their records were detailed and comprehensive, this was either not true in practice or the records were not in a form where data could be readily extracted.

The analysis carried out on the operator survey responses for this project has provided some interesting results on matters which were not anticipated. These include the relationship between R&M costs and vehicle age, and the relationship between routine servicing and other R&M costs with vehicle age. There is also variation in R&M costs between vehicle subtypes which has not been previously identified.

10.2 Requirements for Further User Surveys

In view of the shortfall in data received, supplementary user surveys aimed to achieve better coverage of certain industry sectors, and forms of vehicle duty, may be worthwhile considering. No attempt to address the household sector has (consciously) been made, which limits the confidence that can be placed in the R&M costs for light vehicles, particularly cars.

For a household survey to be successful, the R&M costs of a sample of vehicles will probably need to be tracked for a period of time by recruiting a number of owners to supply data. This need not be as costly a task as it may sound, but would certainly take some time to bear results. A period of at least 18 months and possibly 30 months would be needed.

A number of operators were approached who are known to have good records, but were unable to assist at the time or could only supply data for a few vehicles from their fleet. It would be worthwhile re-visiting these operators.

However, further analysis of the data acquired so far and, in particular, an exploration of the "constituent component" approach to R&M cost estimation, should be made before timing and designing further surveys.

10.3 Prospects for Achieving Relationships with Road Roughness

The user surveys have not shown any significant variation in vehicle R&M costs which can be directly attributed to road roughness. Regional differences are not evident, and the information obtained on amount of travel on sealed/unsealed roads and in urban/rural conditions does not assist in making any distinction between road surface condition. While these findings are negative, they are still significant. They indicate that any relationships between R&M costs and road surfaces which do exist are unlikely to be identified through the methods currently being employed in the project.

Insofar as R&M costs rise with vehicle age and accumulated travel, obviously long-term effects on vehicle wear with use occur, and it is possible that smoother roads will either delay the onset of higher costs or reduce the slope of the upward growth in costs/km against age. However, part of these costs will be associated with mechanical wear which is unaffected by road surfaces, and some deterioration in materials which occurs with time when vehicles are exposed to the elements, irrespective of operation.

The user surveys have not revealed any vehicle fleets which satisfied the conditions for identifying systematic differences in R&M costs by road condition. These costs are:

- Common fleet management and servicing/repair regime;
- Distinct sections of the fleet running on roads with significant and measurable differences in surface condition, particularly roughness; and
- Comprehensive and accessible servicing records.

The expectation of finding operators who can satisfy these conditions is not great at this point in time (1996). Without a user survey basis for obtaining relationships between road surface condition and R&M costs, other methods should be explored, in particular the allocated constituent component approach. Some information on component replacement periods has been obtained from the operator surveys which will assist in developing this method. Also the NAFA record contains a large and so far untapped source of data, which allocates R&M costs to different component groups.

10.4 Recommendations for Further Action

The two main areas where further action is recommended are:

1. Adjustments required to the NZVOC Model to take account of findings from the R&M study; and

2. Follow-up work on the R&M project, in particular progression of work on the constituent component modelling approach utilising data obtained in the operator surveys but not so far analysed. Following this, the desirability of carrying out supplementary operator surveys should be reviewed.

11. BIBLIOGRAPHY

Abaynayaka, S.W., Hide, H., Morosiuk, G., Robinson, R. 1976. Tables for estimating vehicle operating costs on rural roads in developing countries. *TRRL Laboratory Report LR723,* Transport and Road ResearchReseach Laboratory, Crowthorne, UK.

Al-Balbissi, A.H. 1991. Economics of pavement condition, axle load, and vehicle operating costs. *ITE Journal, May 1991.*

AASHTO (American Association of State Highway and Transportation Officials). 1978. *Manual of road user benefit analysis for highways and bus transit improvements.* Washington DC.

Andreassen, D.C. 1992. Vehicle repair costs. *ARRB Research Report ARR 218.*

Anon. 1981. Containing vehicle maintenance costs. *Transport, July/August 1981.*

Aplin, W.N. 1983. Analysis of maintenance and repair costs for log vehicles. *8th Australian Transport Research Forum.* Canberra ACT.

Arthur Young, 1988. Financial performance of truck operators - 1987 survey results for the New Zealand Road Transport Association.

ARRB (Australian Road Research Board). 1993. Review and enhancement of vehicle operating cost models: assessment of existing models, draft report. *Austroads Project BE.3A.40.*

Automobile Association. 1991. How much does it cost to operate your car? Car operating costs. *Directions, July 1991.*

BCHF (Beca Carter Hollings & Ferner Ltd). 1990. Strategy and proposals for vehicle operating cost research. Report to Transit New Zealand.

Bein, P. 1990. Review of the HDM III User Cost Model for suitability to Canadian heavy vehicles. *Transportation Research Record 1262.*

Bein, P. 1993a. *Evaluation of VOC models.* Ministry of Transportation and Highways, British Columbia.

Bein, P. 1993b. *VOC model needs of a Highways Department.* Ministry of Transportation and Highways, British Columbia.

Bein, P., Biggs, D.C. 1993. *Critique of TRDF vehicle operating cost model.* Ministry of Transportation and Highways, Sypher:Mueller International, British Columbia.

Bennett, C.R. 1985. A highway economic evaluation model for New Zealand. *University of Auckland, Department of Civil Engineering, Report No. 368.*

Bennett, C.R. 1986. The New Zealand vehicle operating costs model, final report. Report to the Administration Committee, RRU, August 1986.

Bennett, C.R. 1987a. The New Zealand operating costs model. *Transportation Research Record 1106.*

Bennett, C.R. 1987b. Vehicle operating costs for use in economic appraisals. *Proceedings of NZ Roading Symposium, 1987:* 4.

Bennett, C.R. 1988. The New Zealand operating cost model, Release 3.0, October 1988.

Bennett, C.R. 1989a. The New Zealand vehicle operating cost model, Release 3.1. *NRB RRU Bulletin 82.*

Bennett, C.R. 1989b. Estimation of per kilometre operating costs. Inter-Departmental Study on Road Pricing (unpublished).

Bennett, C.R. 1989c. The depreciation of motor vehicles in New Zealand. *NRB RRU Occasional Paper, August 1989,* Transit New Zealand, Wellington.

Bester, C.J. 1974. Die Invloed van Geometriese Padontwerp op Suid-Afrikaanse Voertuigbedryfskoste. Unpublished dissertation for the Degree of M.Eng., University of Stellenbosch.

Bishop, H.K. 1939. Report of Committee on Maintenance Costs. *Highway Research Board Proceedings 19.*

Bone, I.H. 1985. The economic appraisal of road improvement projects. *RRU Technical Recommendation No. TR9.* National Roads Board, Wellington.

Bone, I.H. 1986. A comment on : Vehicle Operating Costs and Road Roughness - A Southland Perspective. *Proceedings of NZ Roading Symposium, 1986.*

Bone, I.H. 1990. Notes on the VETO Computer Program Manual.

Bone, I.H. 1991. Transit New Zealand Project Evaluation Model, NZ Operating Costs Model Inputs, Working Paper 3, April 1991.

Bonney, R.S.P., Stevens, N.F. 1967. Vehicle operating costs on bituminous, gravel and earth roads in East and Central Africa. *Ministry of Transport, Road Research Laboratory Technical Paper No. 76,* HMSO London.

Both, G.J., Bayley, C. 1976. Evaluation procedures for rural road and structure projects. *ARRB Conference Proceedings 8, 1976.*

Brown, T.J., Troon, J.J. 1986. Vehicle operating costs and road roughness issues: A Southland Perspective. *Proceedings of NZ Roading Symposium, 1986.*

Butler, B.C., de Carvalho, J.T., Hudson, W.R. 1979. Relating vehicle operating costs to low volume road parameters in Brazil. *Transportation Research Record 702.* Transportation Research Board, Washington DC.

Carlsson, G. 1986. Vejstandard og Transport Omkostninger (VETO). *VTI Rapport 307* (English Translation). Swedish Road and Traffic Research Institute (VTI), Linkoping, Sweden.

Caudill, R.J., Kaplan, R.A., Taylor-Harris, A. 1983. Developing bus operating cost models : a methodology. *Journal of Transportation Engineering 109 (2).*

CRRI (Central Road Research Institute). 1982. *Road user cost study in India: Final Report.* CRRI, New Dehli, India.

Chesher, A. 1987. Road roughness related to vehicle operating costs. *Proceedings of NZ Roading Symposium, 1987,* invited paper.

Chesher, A., Harrison, R. 1987. *Vehicle operating costs : evidence from developing countries.* World Bank Publication, The Highway Design and Maintenance Standards Series. 377pp. John Hopkins University Press, Baltimore.

Claffey, P.J. 1960. Motor vehicle operating and accident costs and benefits arising from their reduction through road improvement. *Highway Research Board Special Report 56.* Washington DC.

Claffey, P.J. & Associates 1971. Running costs of motor vehicles as affected by road design and traffic. *NCHRP Program Report 111,* Highway Research Board, Washington DC.

Clouston, P.B. 1983. The effects of road roughness and seal extension on the costs of road vehicle operation. Unpublished report.

Cox, J.B., Bein, P., Lea, N.D. Undated. *Adapting the Brazil and World Bank research on user costs and pavement deterioration to Canadian needs and conditions.* ND Lea Associates, Vancouver, Canada.

Curtayne, P.C., Visser, A.T., du Plessis, H.W., Harrison, R. 1987. Calibrating the relation between operating costs of buses and road roughness on low-volume roads. *Transportation Research Record 1106.* Transportation Research Board, Washington DC.

Daniels, C. 1974. Vehicle Operating Costs in Transport Studies with Special Reference to the Work of the EIU in Africa. The Economist Intelligence Unit Ltd, *EIU Technical Series No.1.*

de Weille, J. 1966. *Quantification of road user savings.* International Bank for Reconstruction and Development.

du Plessis, H.W. (Ed.). 1989. An investigation of vehicle operating cost relationships for use in South Africa. *CSIR Research Report DPVT-C96.1.* CSIR, Pretoria, South Africa.

du Plessis, H.W., Meadows, J.F. 1990. A pilot study to determine the operating costs of passenger cars as affected by road roughness. *CSIR Research Report DPVT-142.* CSIR, Pretoria, South Africa.

du Plessis, H.W., Schutte, I.C. 1991. Road roughness effects on vehicle operating costs: Southern Africa relations for use in economic analyses and in road management systems. South African Roads Board, Research & Development Advisory Committee, Project Report 88/070/3. Unpublished report.

du Plessis, H.W., Visser, A.T., Harrison, R. 1987. The effects of road condition on the operating costs of buses. *Proceedings of ATC '87, Paper 2A/VIII.* Pretoria, South Africa.

Edwards, S.L., Bayliss, B.T. 1971. Operating costs in road freight transport. Department of the Environment, UK.

Ekholm, T. 1986. A guide to the use of the program NZVOC2. April 1986.

Finlayson, A.M., du Plessis, H.W. 1991. Operating costs of medium to heavy trucks as affected by road roughness. *RDAC Project PR 88/070/3.* South African Roads Board, Department of Transport, Pretoria, South Africa.

Fox, T.B. 1980. The operator's role in the determination of bus whole life costs. *Impact of Vehicle Design on Whole Life Costing* : Conference sponsored by the Automobile Division of the Institute of Mechanical Engineers, London, 21-23 October 1980.

GEIPOT (Brazil Ministry of Transport: Empresa Brasileria de Palnejamento de Transportes). 1981. Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilisation, Final Report. *Volume 5 - Study of Road User Costs.*

Gephart, R. 1985. Development of a bus operating cost model based on disaggregate data. *Transportation Research Record 1011.* Transportation Research Board, Washington DC.

Gregson, R.D. 1983. An examination of bus operating costs in New Zealand. Economics Division of Ministry of Transport.

Hammarström, U., Karlsson, B. 1991. *VETO - A computer program for calculation of transport costs as a function of road standard.* Swedish Road and Traffic Research Institute (VTI), Linkoping, Sweden. (English translation with annotations by Hammarström.)

Harrison, R., Chesher, A.D. 1983. Vehicle operating costs in Brazil : Results of a road user survey. *Transportation Research Record 898.* 378pp. Transport Research Board, Washington DC.

Hide, H. 1982, Vehicle operating costs in the Caribbean: Results of a survey of vehicle operators. *TRRL Report 1031.* Transport and Road Research Laboratory, Crowthorne, UK.

Hide, H., Keith, D. 1979a. Effect of simple road improvement measures on vehicle operating costs in the Eastern Caribbean. *Transportation Research Record 702.* Transport Research Board, Washington DC.

Hide, H., Keith, D. 1979b. Effect of simple road improvement measures on vehicle operating costs in the Eastern Caribbean. *TRRL Supplementary Report SR527.* Transport and Road Research Laboratory, Crowthorne, UK.

Hide, H., Abaynayaka, S.W., Sayer, I., Wyatt, R.J. 1975. The Kenya road transport cost study : research on vehicle operating costs. *TRRL Report 672.* 70pp. Transport and Road Research Laboratory, Department of the Environment.

Hide, H., Morosiuk, G., Abaynayaka, S.W. 1983. Vehicle operating costs in the Caribbean. *Transportation Research Record 898,* paper presented at the Low Volume Roads Third International Conference. Transport Research Board, Washington DC.

Hopkins, D.A. 1973. Computer-monitored preventative maintenance pays off. *Public Works November 1973.*

Jackson, G.C., Maze, T.H. 1983. Vehicle life-cycle costing with probabalistic part replacement and repair options. *Transportation Research Record 912.* Transportation Research Board, Washington DC.

Ker, I.R. 1977. Research into road vehicle operating costs and its application in Australian conditions. *ARRB Research Report ARR No. 77.*

Lang, A.S., Robbins, D.H. 1962. A new technique for predicting vehicle operating cost. *Highway Research Board Bulletin 308.*

Lawson, A.J, W D Scott & Co. 1971. *Motor Vehicle Operating Costs, Project EX/3.* Road Research Unit Technical Committee No. 3, National Roads Board, Wellington, New Zealand.

Liu Peiyu. 1986. The predictive models of speed and fuel consumption of the log trucks in New Zealand. Thesis for Master of Forestry Science, University of Canterbury.

Lowen, M.G. 1977. The suitability of the diesel engine for milk tanker operations. *NZ Journal of Dairy Science and Technology 12(2).* A44-A45.

Maloney, P.G. 1982. *Vehicle repairs and maintenance costs : a methodology and literature review.* New Zealand Ministry of Transport, February 1982.

Memmott, J.L., Dudek, C.L. 1982. A model to calculate the road user costs at work zones. *Texas Transportation Institute Research Report 292-1* for FHA.

Ministry of Transport, N.Z. 1988. Truck operating costs, Annual to 1987/88. MOT, Wellington, New Zealand.

Noettl, J., Belanger, R. 1980. Analysis of typical vehicle repair costs - Phase II.

Parsley, L.L., Robinson, R. 1982. The road transport investment model for developing countries (RTIM2). *TRRL Laboratory Report LR1057,* Transport and Road Research Laboratory, Crowthorne, UK.

Pienaar, W.J. 1981. Cost of car travel in South African cities. *NITRR Technical Report RT/1/81.* National Institute for Transport and Road Research (NITRR), CSIR, South Africa.

Potter D.W. 1982. Road deterioration increases vehicle operating costs. *Proceedings of 19th ARRB Regional Symposium,* Wagga Wagga, NSW.

Robinson, R., Hide, H., Hodges, J.W., Rolt, J., Abaynayaka S.W. 1975. A Road transport investment model for developing countries. *TRRL Laboratory Report LR674.* Transport and Road Research Laboratory, Crowthorne, UK.

Roess, R.P. 1974. Operating cost models for urban public transportation systems and their use in analysis. *Transportation Research Record 490.* Transportation Research Board, Washington DC.

Schutte, I.C. 1979. Estimating the costs of maintenance and depreciation as elements of vehicle running costs. *NITRR Technical Report RT/44/79.* National Institute for Transport and Road Research, CSIR, South Africa.

Soberman, R.M., Clark, G.A. 1970. A General-purpose model for motor vehicle operating costs. *Highway Research Record No. 314.*

Speedy, R. 1984. *A set route truck operating cost programme.* Economics Division, Ministry of Transport, Wellington, New Zealand.

Stopher, P.R., Brandrup, L., Lee, B., Parry, S.T. 1987. Development of a bus operating cost allocation model compatible with UMTA Urban Transportation Planning System Models. *Transportation Research Record 1108.* Transportation Research Board, Washington DC.

Stulen, J.A. 1985. Log truck axle layouts - 1985. *Logging Industry Research Association (LIRA) Report 10 (8).* 4pp.

Stulen, J.A., Goldsack, R.W. 1985. Log truck axle layouts - 1985. *Logging Industry Research Association (LIRA) Report 10 (11).* 4pp.

Sweatman, P., Potter, D.W. 1980. Road condition measurement related to vehicle operating factors.

Thoresen, T. 1993. *Survey of freight vehicle costs 1991.* Report to ARRB. 19pp.

Thoresen, T., Evans, S. 1983. Updating freight vehicle operating costs. *ARRB Internal Report AIR 253-2.*

Transit New Zealand, 1991. *Project Evaluation Manual, Volumes I and II.* Transit New Zealand, Wellington, New Zealand.

Trimac Consulting Services Ltd. 1990. *Operating costs of trucks in Canada.* Prepared for the Motor Carrier Policy and Programs, Transport Canada, Government of Canada.

Ullman, J.E. 1980. *Cost of owning and operating automobiles and vans.* US Department of Transportation, FHWA. 20pp.

US Department of Transportation. 1979. *The Highway Performance Monitoring System Analytical Process (HIAPS): field implementation manual.* 150pp. FHWA.

Visser, A.T. c.1990. Warrants for upgrading gravel roads to bituminous standard. *CSIR Report RR370.*

Watanatada, T., Dhareshwar, A.M., Lima, P.R.S.R. 1987. Vehicle speeds and operating costs: models for road planning and management. *The Highway Design and Maintenance Standards Series,* World Bank publication. John Hopkins University Press, Baltimore.

W.D. Scott, D.H. & S. (NZ). 1986. The New Zealand Vehicle Operating Cost Model, April 1986. Prepared for Road Research Unit, New Zealand.

Wightman, L.J. 1987. Calibration of vehicle operating costs in New Zealand. *Road Research Unit Administration Committee Memo No. 743, 62/593/AD44.*

Winfrey, R. 1969. *Economic analysis for highways.* International Textbook Company, Scranton, Pennsylvania.

Wyatt, R.J., Harrison, R., Moser, B.K., de Quadros, L.A.P. 1979. The effect of road design and maintenance on vehicle operating costs - field research in Brazil. *Transportation Research Record 702.* Transportation Research Board, Washington DC.

Zaniewskie, J.P., Butler, B.C., Cunningham, G., Elkins, G.E., Paggi, M.S., Machemal, R. 1982. Vehicle operating costs, fuel consumption and pavement type and condition factors. *Texas Research and Development Foundation, Federal Highway Administration Report FHWA-PL-82-001.* US Department of Transportation, Washington DC.

APPENDIX 1
SURVEY FORMS

VEHICLE REPAIR AND MAINTENANCE COSTS

a. COMPANY SURVEY

Survey Date: . . . .

1. Preliminary

Company Name: . . . .
Address: . . . .
. . . .
. . . .
Postal Address: . . . . (if different)
Contact Person: . . . .

2. Fleet Data

Total Number of Vehicles in Fleet: . . . .

Distribution of Vehicles:	Number
Cars	. . . .
Vans/utes	. . . .
2 axle trucks	. . . .
>2 axle trucks	. . . .
>2 axle towing	. . . .
Buses	. . . .
Trailers >1 axle	. . . .

3. Predominant Service Provided by Company (tick)

Private car . . . .
Local deliveries . . . .
Line haul operation . . . .
Rental cars/vans . . . .
Rural collection/delivery . . . .
Buses - urban/suburband . . . .
- long distance . . . .
Other (state) . . . .

4. Operational Data of the Fleet

Predominant Road Surface Operated On: (tick)

- Urban ....
- Urban/rural ....
- Rural highway ....
- Local rural - sealed ....
- Local rural - unsealed ....

5. Company Policy on Servicing/Replacing

What proportion of the fleet vehicles have been bought new? .... %

When do you decide to sell vehicles, and for what reasons?

Which parts are serviced or replaced according to:

(a) A time schedule?

(b) Vehicle distance travelled?

(c) As necessary?

6. Maintenance Arrangements

What repairs and maintenance are conducted in-house? (tick)

	Routine Servicing	**Unscheduled Repairs**	**Scheduled Repairs**
Body/Cab			
Brakes			
Chassis			
Electrical			
Engine			
Power train			

In-house, how are the labour hours on repairs and maintenance charged? (tick)

Directly against the plant item . . . .

Against a general maintenance budget . . . .

Other (specify) . . . .

What is the charge rate for maintenance labour? $ . . . . / hr

Is an overhead factor added to (. . . .) or included in (. . . .) the rate? (tick)

If added to the rate, what is the percentage? . . . . %

Does the company have parts supply arrangements that allow purchasing at discounted rates? Yes / No

If so, what is the average discount? . . . . %

(If this varies between components but is known, what are the individual discount rates?) (list)

7. Parts Life Estimates

For each of the road surfaces specified, give an estimate of the expected life:

	Urban		**Urban/Rural**		**Rural Highway**		**Local Rural - Sealed**		**Local Rural - Unsealed**	
	km or months		**km or months**		**km or months**		**km or months**		**km or months**	
Air filter elements										
Wheel alignment										
Brake pads/shoes										
Wheel cylinders										
Exhausts										
Steering components										
Shock absorbers										
Wiper blades										
Battery										
Springs										
Radiators										
Fan belts										
Windscreens										
Engines										
Cylinder heads/gaskets										
Clutches										
Gearboxes										
Differentials										
Carburettor										
Body adjustments										

8. Standby Plant

How many vehicles are held on standby to cover breakdowns? . . . .

9. Fuel Supply

Is fuel supplied to the company at a discounted rate? Yes / No

If yes, what is the % discount? . . . . %

10. Tyre Policy

Does the company use new or retread tyres? . . . .

What is the average number of retreads available on a tyre? . . . .

11. Other Details

VEHICLE REPAIR AND MAINTENANCE COSTS

b. INDIVIDUAL VEHICLE SURVEY

Company: . . . . Survey Date: . . . .

1. Vehicle Specification

Identification (Reg No./Fleet No.) . . . .
Make . . . .
Model . . . .
Horsepower rating . . . .
Year of manufacture . . . .
Motive power (petrol, diesel, none, other) . . . .
Purchased new or secondhand . . . .
Purchase price - cab and chassis $ . . . .
- body $ . . . .
Mileage at Purchase Date . . . . km
Mileage at Survey Date . . . . km
If sold prior to survey date, selling price: $ . . . .
If the vehicle - prime mover (tractor unit)? . . . .
- trailer? . . . .
- combination? . . . .
What is the axle configuration of the vehicle? . . . .
(Choose code(s) from attached list)

2. Running Details

Total km travelled since new: (a) Vehicle . . . . km
(b) Engine . . . . km

Weight of vehicle cab and chassis: . . . . kg
Tare weight (including body): . . . . kg
Gross weight (fully laden): . . . . kg

What percentage of running time is spent:
(a) Fully laden . . . . %
(b) Partly laden . . . . %
(c) Unladen . . . . %

For units capable of towing, what percentage of time is spent towing? . . . . %

2. Running Details (cont'd)

What percentage of time of spent running on:

(a) Urban roads? .... %
(b) Urban/rural roads? .... %
(c) Rural highway (line haul)? .... %
(d) Rural local roads - sealed? .... %
(e) Rural local roads - unsealed? .... %

Annual utilisation: .... km or .... hrs

Approximately how many cold starts does the vehicle have each day? ....

Approximately how many stops are made each day? ....

3. Body Details

Body Construction: (tick)

- Flat deck/tray ....
- Fixed sides - dumper/tipper ....
- Tanker ....
- Van ....
- Curtain sided/tautliner ....
- Stock crate ....
- Logging rig ....
- Other (specify) ....

Body Materials: (tick)

- Timber ....
- Steel ....
- Stainless steel ....
- Aluminium ....
- Fabric ....
- Combination of (specify) ....

4. Special Equipment

Are any of the following items incorporated in the rig?

- Container lifter Yes / No
- Hiab hoist Yes / No
- Deck hoist Yes / No
- Refrigeration unit Yes / No

5. Maintenance Details

Are tyres included under repairs and maintenance?	Yes / No
Life-to-date repairs and maintenance cost:	$ . . . .
Does this cost cover the whole of the vehicle life?	Yes / No
If not, what period does it cover?	. . . . . . km or yrs
Has the vehicle been involved in any accidents?	Yes / No
If yes, are the repair costs included in the life-to-date repairs and maintenance cost?	Yes / No
What were the repair costs?	$ . . . .

5.1 In-House Maintenance

What has been the total cost of parts over the life of the vehicle?	$ . . . .
What is the cost of parts in ¢/km over its life?	. . . . ¢/km
What has been the total maintenance labour cost over the life of the vehicle?	$ . . . .
What is the cost of maintenance labour in ¢/km over its life?	. . . . ¢/km
How many labour hours have been spent on maintenance over the life of the vehicle?	. . . . hrs
Can the total maintenance expenditure on parts be broken down into component areas?	Yes / No

If yes, indicate the cost in each of the following categories:

	Cost $
Engine	. . . .
- Block	. . . .
- Crank shaft	. . . .
- Pistons/rings	. . . .
- Cylinder heads/gaskets	. . . .
- Exhausts	. . . .
Fuel System	. . . .
- Carburettor	. . . .
- Air filter elements	. . . .
Cooling System	. . . .
- Radiator	. . . .
- Fan belts	. . . .

Electrical System . . . .
- Battery . . . .
- Alternators/generators . . . .

Drive Train . . . .
- Clutches . . . .
- Gearboxes . . . .
- Differentials . . . .

Brakes . . . .
- Pads/shoes . . . .
- Wheel cylinders . . . .
- Air system . . . .

Steering Components . . . .

Wheel Alignments . . . .

Suspension . . . .
- Shock absorbers . . . .
- Springs/shackles . . . .

Body/Chassis . . . .
- Wiper blades . . . .
- Windscreens . . . .
- Body adjustments . . . .

5.2 Outwork

What has been the cost of outwork over the life of the vehicle? $ . . . .

6. Fuel Consumption

What has been the average cost of fuel consumption over the life of the vehicle? . . . . ¢/km

7. Tyre Consumption

How many tyres does the vehicle have? . . . .
Does the vehicle operate on radial ply tyres? Yes / No
Are retreaded tyres fitted? Yes / No
What is the tyre size? . . . .
What is the normal life of a new tyre on this vehicle? . . . . km
What is the normal life of a retreaded tyre on this vehicle? . . . . km

8. Other Information

APPENDIX 2
NAFA DATA FILE STRUCTURE

NAFA DATA FILE STRUCTURE

Field	FieldName	Type	Width	Decimal	Contents Description
1	SOURCE	Character	1		NAFA or other data source
2	COMPANY	Character	3		Code identifying the company (non-NAFA data)
3	POPMOD	Character	1		
4	FREQ	Numeric	5		Frequency count (1 in each field)
5	FREQRS	Numeric	5		Frequency for selected records (1 each field)
6	U_R	Character	1		Urban or Rural (U or R)
7	REG	Character	3		Region
8	TYP	Character	3		Vehicle Main Type
9	TYP2	Character	3		Vehicle Sub-Type
10	BODY	Character	3		Vehicle Body Style
11	MAKE	Character	4		Vehicle Make
12	MOD	Character	10		Vehicle Model
13	MODEL	Character	28		Vehicle Mode/lSubmodel (NAFA description)
14	CC	Character	5		Engine Size in cc
15	CC_GROUP	Character	2		Engine Size Group
16	CC_GRP2	Character	2		Engine Size SubGroup
17	TRN_TYP	Character	1		Auto or Manual Transmission
18	AGE_MON	Numeric	8		Vehicle Age in Months
19	AGE_YRS	Character	1		Vehicle Age, years
20	ODOMETER	Numeric	10		Last Odometer Reading
21	ACC_KM	Character	3		Accumulated kilometres Group
22	KM_PER_MO	Numeric	9		Mean Kilometres per Month
23	CAB_PC	Numeric	10	2	Parts Cost, dollars - Cab and Body
24	CAB_LB	Numeric	10	2	Labour Cost, dollars - Cab and Body
25	CAB	Numeric	10	2	Total Cost, dollars - Cab and Body
26	CHS_PC	Numeric	10	2	Parts Cost, dollars - Chassis, Suspension, Steering
27	CHS_LB	Numeric	10	2	Labour Cost,dollars-Chassis, Suspension, Steering
28	CHS	Numeric	10	2	Total Cost, dollars- Chassis, Suspension, Steering
29	BRK_PC	Numeric	10	2	Parts Cost, dollars - Brakes
30	BRK_LB	Numeric	10	2	Labour Cost, dollars - Brakes
31	BRK	Numeric	10	2	Total Cost, dollars - Brakes
32	TRN_PC	Numeric	10	2	Parts Cost, dollars - Transmission
33	TRN_LB	Numeric	10	2	Labour Cost, dollars - Transmission
34	TRN	Numeric	10	2	Total Cost, dollars - Transmission
35	CLU_PC	Numeric	10	2	Parts Cost, dollars - Clutch
36	CLU_LB	Numeric	10	2	Labour Cost, dollars - Clutch
37	CLU	Numeric	10	2	Total Cost, dollars - Clutch
38	ELE_PC	Numeric	10	2	Parts Cost, dollars - Electrics
39	ELE_LB	Numeric	10	2	Labour Cost, dollars - Electrics
40	ELE	Numeric	10	2	Total Cost, dollars - Electrics
41	ENG_PC	Numeric	10	2	Parts Cost, dollars - Engine
42	ENG_LB	Numeric	10	2	Labour Cost, dollars - Engine
43	ENG	Numeric	10	2	Total Cost, dollars - Engine
44	FUL_PC	Numeric	10	2	Parts Cost, dollars - Fuel System
45	FUL_LB	Numeric	10	2	Labour Cost, dollars -Fuel System
46	FUL	Numeric	10	2	Total Cost, dollars - Fuel System

47	ACC_PC	Numeric	10	2	Parts Cost, dollars - Accident Damage
48	ACC_LB	Numeric	10	2	Labour Cost, dollars -Accident Damage
49	ACC	Numeric	10	2	Total Cost, dollars - Accident Damage
50	TOT_PC	Numeric	11	2	Parts Cost, dollars - SubTotal Parts Cost
51	TOT_LB	Numeric	11	2	Labour Cost, dollars - SubTotal Labour Cost
52	TOT	Numeric	11	2	Total Cost, dollars - SubTotal Total Cost
53	TOT_PCPC	Numeric	10	2	Percentage Parts Cost - Routine Servicing
54	CPK_PC	Numeric	10	2	Cents/km, Parts - SubTotal
55	CPK_LB	Numeric	10	2	Cents/km, Labour - SubTotal
56	CPK	Numeric	10	2	Cents/km, Total - SubTotal
57	SER_PC	Numeric	10	2	Parts Cost, dollars - Routine Servicing
58	SER_LB	Numeric	10	2	Labour Cost, dollars - Routine Servicing
59	SER	Numeric	10	2	Total Cost, dollars - Routine Servicing
60	SER_PCPC	Numeric	10	2	Percentage Parts Cost- Routine Servicing
61	CPK_PCS	Numeric	10	2	Cents/km - Parts Costs, Routine Servicing
62	CPK_LBS	Numeric	10	2	Cents/km - Labour Costs, Routine Servicing
63	CPKS	Numeric	10	2	Cents/km - Total Costs, Routine Servicing
64	TOT_PCA	Numeric	11	2	Parts Cost, dollars - Total Costs inc Servicing
65	TOT_LBA	Numeric	11	2	Labour Cost, dollars - Total Costs inc Servicing
66	TOTA	Numeric	11	2	Total Cost, dollars - Total Costs inc Servicing
67	TOTA_PCPC	Numeric	11	2	Percentage Parts Costs, Total Costs inc Servcing
68	PC_SER	Numeric	11	2	Percentage of Costs in Routine Servicing
69	CPK_PCA	Numeric	10	2	Cents/km, Parts Costs - Total Costs inc Servicing
70	CPK_LBA	Numeric	10	2	Cents/km, Labour Costs-Total Costs inc Servicing
71	CPKA	Numeric	10	2	Cents/km, Total Costs - Total Costs inc Servicing
72	TYR_PC	Numeric	10	2	Parts Cost, dollars - Tyres and Tubes
73	TYR_LB	Numeric	10	2	Labour Cost, dollars - Tyres and Tubes
74	TYR	Numeric	10	2	Total Cost, dollars - Tyres and Tubes
75	GRT_PC	Numeric	11	2	Parts Cost, dollars - Grand Total Cost (inc tyres)
76	GRT_LB	Numeric	11	2	Labour Cost, dollars - Grand Total (inc tyres)
77	GRT	Numeric	11	2	Total Cost, dollars - Grand Total (inc tyres)
78	CPM_PC	Numeric	10	2	Parts Cost, Cents/month
79	CPM_LB	Numeric	10	2	Labour Cost, Cents/month
80	CPM	Numeric	10	2	Total Cost, Cents/month
81	ANN_KMS	Numeric	10		Mean Annual Kilometres
82	DISTANCE	Numeric	10		Distance Run in Period, kms
83	LST_REP	Character	8		Date of Last Reported R&M Cost
84	FST_REP	Character	8		Date of First R&M Cost
85	FST_ODO	Numeric	10		Odometer Reading, Start of Period
86	PER_MON	Numeric	6		Period between First and LastDdates, Months