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THE COSTS OF MAINTAINING AND REPAIRING VEHICLES IN DEVELOPING COUNTRIES

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EXECUTIVE SUMMARY

To assist with the economic appraisal of road investment and maintenance expenditure the World Bank's Highway Design and Maintenance Standards Model (HDM) and the Transport and Road Research Laboratory's Road Transport Investment Model (RTIM) were developed to estimate changes in transport costs associated with improvements in road condition, such as reduced road roughness. Within developing countries (where passenger time savings are usually ascribed little value) changes in vehicle maintenance costs represent an important component of the benefits of reduced transport costs resulting from improvements in road condition. These models were based on the results of large scale field surveys carried out in Brazil, Kenya, India and the Caribbean.

The results of these surveys indicate a wide range of sensitivity of vehicle maintenance costs to road surface roughness. For example, within the HDM-III model the user is able to select vehicle operating costs (VOCs) based on relationships derived from one of the four field surveys mentioned above. In order to examine this matter further this report analyzes data collected from four new field studies (two in Botswana, one in St Helena and one in Pakistan) and compares the results with HDM and RTIM.

The first Botswana study was based on the records held by the Central Transport Organisation of the Government of Botswana. It uses maintenance records from 46 passenger cars, 45 utility vehicles and 49 medium trucks. In total 360 vehicle years of data were analyzed. The second Botswana study was based on the maintenance (parts) records of a private transport company covering 16 articulated Mercedes trucks over a three year period. Most of the journeys were along the Francistown-Orapa road which was gradually improved over the period. Because precise data on road roughness was collected during this period it was possible to relate changes in road surface roughness directly to vehicle maintenance costs.

The St Helena study was based on maintenance data collected from the Public Works and Services Department, it covers 250 vehicle years of data relating to passenger cars, utilities and trucks. The Pakistan study relates to data collected from a roadside survey of 3500 truck drivers. Most drivers worked for private transport operators and were able to make reasonable estimates of their maintenance expenditure.

Vehicle maintenance costs are usually expressed in terms of parts consumption and maintenance labour. For three of the new studies (ie. excluding the study of the Botswana articulated trucks) it was only possible to compare parts consumption with an overall average level of road roughness although the effects of different vehicle ages could be explored.

The analyses of the different data sets confirmed that the different VOC models give quite different estimates and that the results from the field surveys do not support any one model. For example, the Pakistan truck maintenance parts costs appear to be well below the VOC models. In contrast, the Botswana Government cars parts costs appear to be higher than VOC models.

Because of the different forms of equation used comparisons between the VOC models can be difficult, especially when there is more than one independent variable. Furthermore, given the differences both between the models and between the field data, complex equations are difficult to justify.

The following simplified parts consumption model is proposed:

$$P = (a + b \times RI) \times (CKM/100{,}000)^{KP}$$

where

P is the cost of spare parts expressed in terms of the value of new vehicles per million km

CKM is vehicle age in km

RI is roughness on the IRI scale

a, *b* and KP are constants.

The appropriate coefficients for this simplified model are given in Tables 1 and 2 (see page 2).

TABLE 1

Coefficients for simplified equation derived from HDM, RTIM and Botswana articulated trucks

Vehicle type	*a*	*b*	KP
Brazil			
Cars and Utilities	0.15	0.56	0.31
Trucks Lt & Med	0.11	0.35	0.37
Trucks Heavy	0.62	0.28	0.37
Trucks Artic	1.00	0.20	0.37
India			
Cars & Utilities	-0.05	0.25	0.00
Trucks Light	-0.12	0.09	0.34
Trucks Medium	-0.18	0.13	0.34
Trucks Heavy	-0.38	0.28	0.34
Kenya			
Cars & Utilities	-5.19	2.38	1.00
Trucks Medium	0.16	0.43	1.00
Caribbean			
Cars & Utilities	-8.64	2.70	1.00
Trucks Medium	-2.39	1.01	1.00
Botswana field study			
Trucks Artic	-0.70	0.29	0.36

The simplified model form fits the data from the Botswana study of articulated trucks well; it can be seen from Table 1 that two coefficients are close to those derived from Brazilian and Indian data used in HDM.

TABLE 2

Coefficients for simplified equation derived from other field studies

Vehicle type	RI	($a + b$RI)	KP
Botswana			
Cars	4.7	8.31	0.65
Utilities	8.4	2.59	0.50
Trucks Medium	6.8	3.12	0.20
St Helena			
Cars	8.9	0.90	0.40
Utilities	8.9	1.86	0.50
Trucks Medium	8.9	2.42	0.31
Pakistan			
Trucks Medium	6.5	0.34	0.28

(Note. Because only one roughness value was used in the field studies referred to in Table 2 it was not possible to derive separate *a* and *b* coefficients.)

THE COSTS OF MAINTAINING AND REPAIRING VEHICLES IN DEVELOPING COUNTRIES

ABSTRACT

To assist with the economic appraisal of road investment and maintenance expenditure the Highway Design and Maintenance Standards Model (HDM) and the Road Transport Investment Model (RTIM) were developed to estimate changes in transport costs associated with improvements in road condition, such as reduced road roughness. Within developing countries (where passenger time savings are usually ascribed little value) changes in vehicle maintenance costs represent an important component of the benefits of reduced transport costs resulting from improvements in road condition. In order to improve the modelling of vehicle maintenance costs this report examines field data collected from Botswana, St Helena, and Pakistan and compares the results with HDM and RTIM. Large differences are shown to exist in the vehicle maintenance cost relationships (expressed in terms of parts consumption and maintenance labour input) between the different model formulations and the field data; Pakistan's vehicle maintenance costs are particularly low. A simplified parts consumption model is proposed using three coefficients to relate parts consumption to vehicle age and road roughness. The results from a survey of articulated trucks in Botswana fit the simple model well; two of the coefficients are close to those derived from Brazilian and Indian data used in HDM. However with the other field surveys there is little consistency in the coefficients that are derived.

1. INTRODUCTION

Expenditure on road construction, improvement and maintenance is normally justified by economic analysis in which the costs of the proposed works are compared with the benefits they will generate by reducing travel costs. Standard models such as HDM, the Highway Design and Maintenance Standards Model (Watanatada et al, Vol 1 and Vol 2, 1987) and RTIM, the Road Transport Investment Model (Cundill, 1993) have been developed to carry out these assessments. They are based on the results of large field surveys carried out in Brazil, Kenya, India and the Caribbean.

In developing countries, where the value of time is usually ascribed relatively little value, travel costs are mainly vehicle operating costs. These can be broken down into a number of components: fuel, tyres, lubricants, maintenance and repair, crew wages, etc. According to the models, where roads have very poor riding surfaces, much of the benefit from road improvement arises because of reductions in vehicle maintenance and repair costs. This includes both the cost of the parts used and the cost for a mechanic to carry out the work.

The field studies which were used to provide data on vehicle operating costs were carried out a number of years ago and gave a range of answers. Because of this and their importance in economic assessments, the Overseas Centre of the Transport Research Laboratory has, for a number of years, been carrying out small studies on vehicle operating costs in different locations. The aim has been to see if the model relationships are applicable in other locations and for more modern vehicle types.

This report describes the results from four of those studies: two in Botswana, one in St Helena and one in Pakistan. These locations were chosen partly through opportunism (contacts had been established for other work and it was known that suitable data was available) and partly because they were similar to countries previously studied: Botswana and Kenya, St Helena and the Caribbean, Pakistan and India.

2. MODELLING PROCEDURES

Within the HDM-III model, the user is able to select vehicle operating costs based on Brazil, India, Kenya or the Caribbean, while in RTIM3, the user can only use a cost model which is based on both Kenya and the Caribbean. Appendix 1 lists these relationships for HDM-Brazil, HDM-India and RTIM3.

In the models, the cost of parts is related chiefly to road roughness and vehicle age, expressed as cumulative travel to date. To deal with vehicles of different prices, parts costs are usually standardised by expressing them as a fraction of the new vehicle price. To make this fraction a convenient number, in this report, standardised parts costs are expressed in terms of new vehicles per million kilometres of travel. The cost of repairs due to accidents is not included and refinements such as excluding from the new vehicle price the cost of a new set of tyres and an element to cover the value of the vehicle warranty have not been considered. Tax costs have been ignored on the assumption that they are present to the same degree in both the cost of parts and the new vehicle price.

Labour costs are often less important than parts costs. In the models, they are calculated chiefly as a function of standardised parts cost but they are also sometimes dependent on road roughness.

3. BOTSWANA - GOVERNMENT VEHICLES

3.1 DATA

The data source for this study was the maintenance records held by the Central Transport Organisation (CTO) of the Government of Botswana. This organisation supplied and maintained vehicles operated by all government departments throughout the country and at any one time was responsible for around 5,000 vehicles. The CTO's fleet included a wide range of vehicle types, sizes, makes and models. However, the vehicles were relatively young as most of them were disposed of ('boarded') after four or five years, typically after travelling between 75,000 and 125,000 kilometres.

The CTO had workshops and fuel points throughout the country. All work carried out at CTO workshops was recorded in detail and the records were sent periodically from the outstations to the headquarters in Gaborone, where a file was maintained on each vehicle.

For this study, maintenance costs were collected on vehicles in three classes: passenger cars, utilities and trucks. Four vehicle models were studied over the three year period 1985-1987. The sample was drawn from four government departments whose activities were well spread throughout the country: Roads, Water Affairs, Police and Health.

Forty six passenger cars were selected for study, consisting of 27 Opel Rekords and 19 Opel Commodores, all of which had been purchased in 1985. Both of the models are four-door saloons; the Rekord (see Plate 1) is the smaller, with a two litre, four-cylinder engine, while the Commodore has a three litre, six-cylinder engine. Most of the cars were based in Gaborone.

The utility vehicles selected were all Toyota Landcruisers purchased in 1984 and 1985. The Landcruiser is a two-axle vehicle with single-tyred rear wheels, four-wheel drive and powered by a six-cylinder, four litre engine (see Plate 2). Altogether, there were 45 of these vehicles which were based all over Botswana and were used mostly on rough terrain.

Finally, in the truck category, 49 Bedford trucks, model TJ1090, were chosen which were purchased by the CTO in 1985. Powered by a 5.4 litre diesel engine these are two-axled, flat decks with the unusual feature of single-tyred rear wheels due to the deep rutting on the sandy unpaved roads (see Plate 3). The trucks in the sample were based throughout Botswana and used on a variety of road types.

Plate 1. Botswana CTO — Opel Rekord

Plate 2. Botswana CTO — Toyota Landcruiser

Plate 3. Botswana CTO — Bedford

The maintenance records covered:

- 360 vehicle years
- 10 million kilometres of travel
- £140,000 of maintenance expenditure

The characteristics of each model type are summarised in Table 1.

TABLE 1

Vehicle characteristics, Botswana Government

	Opel Rekord	Opel Commodore	Toyoto Landcruiser	Bedford TJ1090
Engine size (litres)	2.0	3.0	4.0	5.4
Fuel type	Petrol	Petrol	Diesel	Diesel
Unladen weight (kg)	1,140	1,337	1,800	3,160
Max gross weight (kg)	-	-	3,035	10,920

To compare the observed cost of spare parts with model predictions, it was necessary to estimate vehicle age and road roughness. Estimating vehicle age for most of the vehicles was quite straightforward since they were monitored from new. The only exceptions were Landcruisers purchased in 1984 since no survey data were available before 1985. The first year travel for these vehicles was assumed to be the same as the observed first-year travel for Landcruisers purchased in 1985.

It was not possible to obtain a detailed record of the roads on which the vehicles had been operating but each vehicle type had a general pattern of use. On the basis of this and engineering judgement about road condition, average road roughness could be estimated. The values (on the IRI scale) were 4.7 m/km for the Opel cars, 8.4 m/km for the Toyota Landcruisers and 6.8 m/km for the Bedford trucks. The figures were broad estimates but it was felt that they were probably accurate to within 25 per cent.

In addition, other less important variables are needed by some of the model equations. Since Botswana is a flat country with few gradients and straight, wide roads, average rise and fall per kilometre and average horizontal curvature per kilometre were both set to zero in the calculations, while pavement width was assumed to be eight metres. Average gross weight of the trucks is also needed. It was assumed that the Bedford trucks ran empty for one third of their trips and were loaded to about half their capacity for the remainder, giving an average gross weight of six tonnes.

Since government-owned vehicles are not subject to tax, all the prices used in the study were net of customs duties and import taxes. In order to have convenient units with which to compare results, parts consumption is expressed as the ratio of parts costs (per million kilometres of travel) to the price of a new vehicle, i.e. in units of new vehicles per million kilometres of travel.

Table 2 illustrates the average vehicle prices between 1985 and 1987. All of the vehicles in the study were imported and therefore vehicle prices were dependent upon the exchange rate between the Pula and the currency of the exporting country. The Opels were imported from the Republic of South Africa, the Landcruisers from Japan, and the Bedford trucks from the United Kingdom. No Opels were purchased during 1987, and so their prices have been estimated on the basis of the annual inflation rate in Botswana, and the devaluation of the Rand relative to the Pula.

It should be noted that for both new vehicles and spare parts, all prices were from tender to CTO and as such were considerably lower than available to smaller customers.

As can be seen, there were very rapid price increases in Landcruisers and Bedford trucks over the survey period. These were largely attributable to the devaluation of the Pula relative to Sterling and the Yen. Relating the cost of spare parts to the price of the new vehicles implies that movements in the price of new vehicles in a given year will be matched by movements in the price of spares. When vehicle price increases are modest, this is a reasonable assumption but when there are very rapid changes, there is a danger that the price of spares will lag behind new vehicle prices, especially if spares are costed at historic prices and there are significant stock holdings. The extent of this problem could not be determined from the data files but the possible implications on the analyses are considered below.

TABLE 2

Average new vehicle prices in Botswana (Pula). (Year on year price increase)

Vehicle	1985	1986	1987
Rekord	9,970	10,330 (4%)	11,210 (9%)
Commodore	12,750	13,200 (4%)	14,350 (9%)
Landcruiser	13,110	18,555(42%)	21,020(13%)
Bedford	20,750	31,000(49%)	36,640(18%)

3.2 ANALYSIS OF PARTS CONSUMPTION

The results for the three vehicle classes are shown in Figures 1 to 3, where cost is plotted against vehicle age (in kilometres) for a given road roughness. The values for very new vehicles (age less than 20,000 km) are unimportant for most applications.

Figure 1 shows the results for cars, the three points giving the average values for each of the three survey years. Both the RTIM and HDM-Brazil models predict an increase in parts consumption with age, whereas the HDM-India model predicts a constant level independent of age. As vehicles become older, so the model predictions diverge, with RTIM predicting the highest values and HDM-India the lowest.

The observed levels of parts consumption for both types of car increase with age but over the range of vehicle ages examined, the rate of increase is higher even than for RTIM. At an age of 50,000 km, the value for the Opel Rekord is almost twice that of RTIM. To get reasonable agreement between observed and predicted values, it would be necessary to assume roughness levels of 6.5 m/km for RTIM and 8.5 m/km for HDM-Brazil, well outside the estimated 25 per cent limits of uncertainty.

The results for utilities are shown in Figure 2. The form of the model predictions are similar to Figure 1. As expected, observed parts consumption increases with vehicle age but the values are well below those of the two models which predict an increase with age - RTIM and HDM-Brazil - and the best agreement appears to be with HDM-India. To obtain good agreement with HDM-Brazil, roughness would have to be only 4.5 m/km and to obtain good agreement with RTIM, it would have to be only 3.0 m/km.

It was shown in Table 2 that the price of new Landcruisers rose rapidly during the period of the study and this might have given rise to distortion if the price of spares had lagged. However, even if the unit price of spares had remained constant over the whole survey period, the observed costs would still have remained below HDM-Brazil, especially for the first three years, and much lower than RTIM.

Finally, the results for trucks are shown in Figure 3. Here, all three models predict that consumption will rise with vehicle age but the HDM-India model predicts values well below those of the other two models. The values for gross weight and road width used are just outside the recommended ranges for HDM-India but the effects are small and have been ignored.

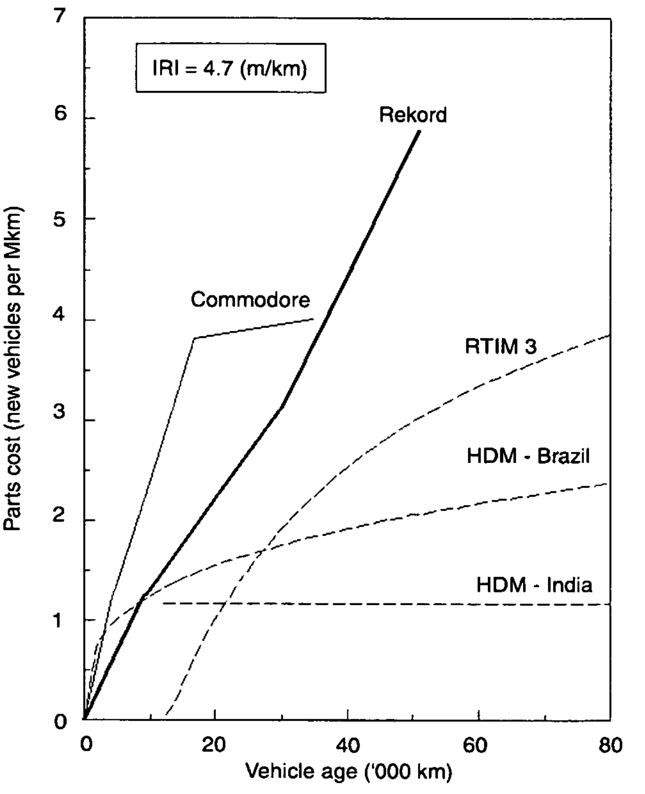

Fig.1 Observed and predicted parts cost - cars in Botswana

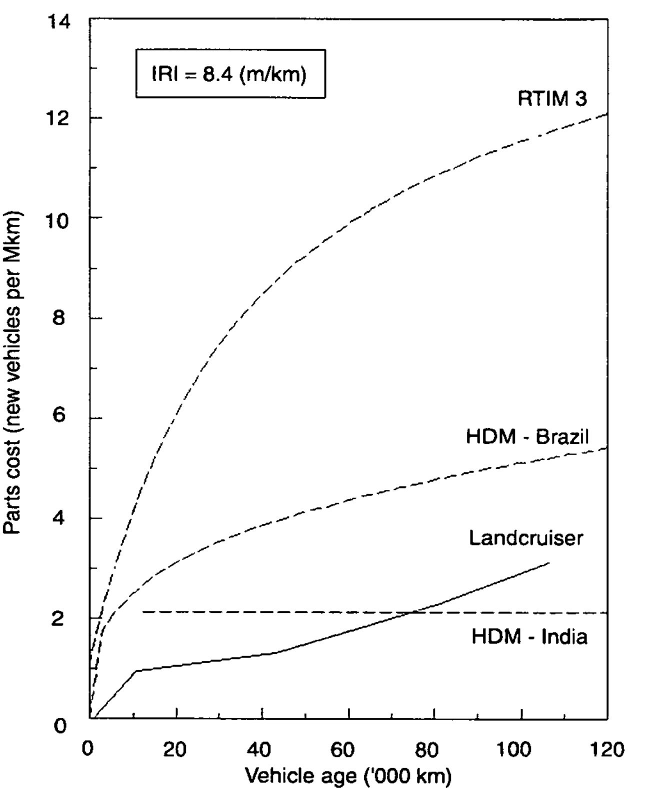

Fig.2 Observed and predicted parts cost - utilities in Botswana

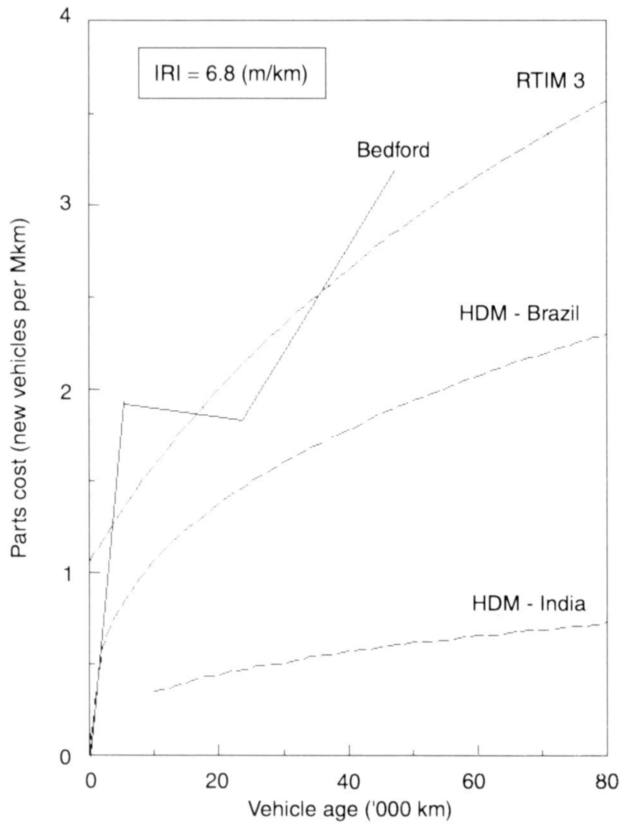

Fig.3 Observed and predicted parts cost - trucks in Botswana

The observed levels of parts consumption for the Bedford trucks are very similar to those predicted by RTIM (which is also based on Bedford trucks) but well above the predictions of the other two models. At 40,000 km for example, observed consumption is around sixty per cent higher than predicted by HDM-Brazil and almost five times higher than HDM-India. If the price of spares had lagged behind those of new vehicles, then the corrected levels would be higher than all three models. To get good agreement with HDM-Brazil, roughness would have to be around 10 m/km which is well above the upper limit of 6.8 plus 25 per cent. No sensible roughness level would give agreement with HDM-India.

4. BOTSWANA - PRIVATELY OPERATED TRUCKS

4.1 DATA

In addition to the CTO survey, a second survey of maintenance costs was carried out in Botswana in the mid-eighties, this one being a study of costs for a private haulage company based in Francistown. The company's operation covered most of the major routes in Botswana and the neighbouring countries of Malawi, Namibia, South Africa and Zambia. During the period of the study, however, much of the company's business was with the diamond mine at Orapa (in Botswana) which it supplied with fuel and other commodities from depots at Francistown.

The survey was carried out over the three-year period 1984 to 1986 and during this time, careful records were kept of the routes and the cost of spare parts for 16 articulated Mercedes trucks operated by the company. (See Plates 4 and 5). Table 3 lists the principal vehicle characteristics. The parts consumed by each vehicle were recorded on summary sheets each month and the cost of each part was obtained from the component suppliers. The information was collected in regular visits to the company by technicians from the Botswana Roads Department. Unfortunately, corresponding information on the amount of maintenance labour used was not available.

Information was collected on both tractors and trailers, with tractor parts costing, on average, about five times more than trailer parts. However, analysis of trailer costs was difficult because trailers were occasionally switched between different tractors. In this analysis, therefore, as with the Brazil study, costs have been confined to tractor units only.

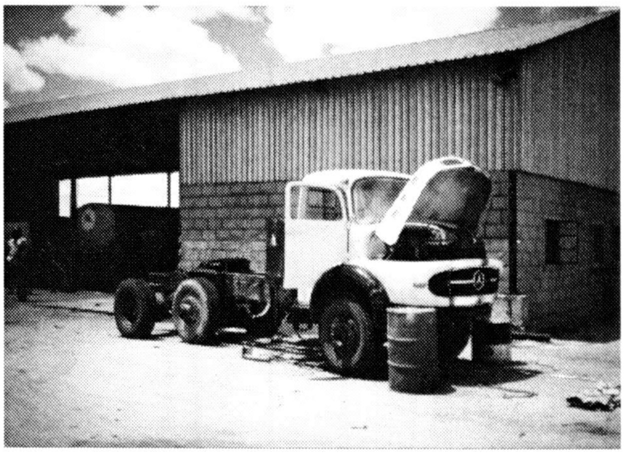

Plate 4. Botswana Private Operator —Mercedes Truck

Plate 5. Botswana Private Operator —Mercedes Truck

TABLE 3

Vehicle characteristics, Botswana private operator

Make Size (litres)	Model Weight (t)	Class Weight (t)	Engine	Unladen	Max Gross
Mercedes	2624	Articulated	11.0 - 11.6	9.2 - 9.7	44.2 - 45.7

Despite the considerable effort that went into collecting costs, it was necessary to make coarse adjustments to allow for factors such as:

- repairs carried out in the field, the costs of which were not recorded by the workshops
- the use of second-hand parts from cannibalised company vehicles
- mark-up on price costs (suppliers quoted South African, rather than local, prices)
- changes in exchange rates (the problem of obtaining correct prices at this time was discussed earlier in the context of the CTO study).

On the basis of discussions with the transport manager, costs were increased by up to 87 per cent to allow for the above factors.

Roughness on the routes included in the study was measured by a vehicle-mounted bump integrator which was calibrated using either a TRL Profile Beam or a TRL Merlin calibration device. Estimating roughness along the various routes was facilitated by the fact that most of the journeys were along the Francistown-Orapa road. Moreover, many of the gravel roads used in Botswana and Namibia were similar to the gravel sections of the Francistown-Orapa road and so they were assumed to have the same roughness. Paved roads in Northern Botswana and Southern Africa were mostly in good condition with low roughness (IRI = 3.5 m/km).

At the start of the study in 1984, the roughness of the Francistown-Orapa road was very high but it fell over the following years. This was partly because of the bitumenization of a section of the road and partly because of an increase in the frequency of maintenance on both this road and other unpaved roads in the area following an increase in the allocation of resources for maintenance activities.

By monitoring roughness along the Francistown-Orapa road regularly and taking occasional measurements along the other routes, it was possible to derive for each year an approximate relationship between average roughness and the percentage of unpaved road travelled. With this information and the route log, the average roughness could then be derived for each vehicle for each year.

4.2 ANALYSIS OF PARTS CONSUMPTION

For each year, the average vehicle age, road roughness and cost of parts consumption were calculated and are shown in Table 4.

As can be seen, over the survey period the average vehicle age rose, road roughness fell and so did average parts consumption. To compare these values with the model predictions it was assumed that:

- gradient = 0 m/km
- horizontal curvature = 0 degrees/km
- road width = 8 m
- average vehicle gross weight = 28 tonnes.

(The first three of these are the same as in the CTO study.)

Figure 4 shows the observed yearly level of parts consumption compared with the model predictions. The RTIM3 and India models give very similar results but they are much

TABLE 4

Year by year summary, Botswana private operator

Year	No of Vehicles	Vehicle Price (Pula)	Ave Age ('000 km)	Total Travel ('000 km)	Roughness (m/km)	Parts (Veh/Mkm)
1984	15	74,100	333	909	12.1	4.0
1985	15	85,200	389	775	8.7	2.8
1986	16	106,500	418	936	8.0	2.0

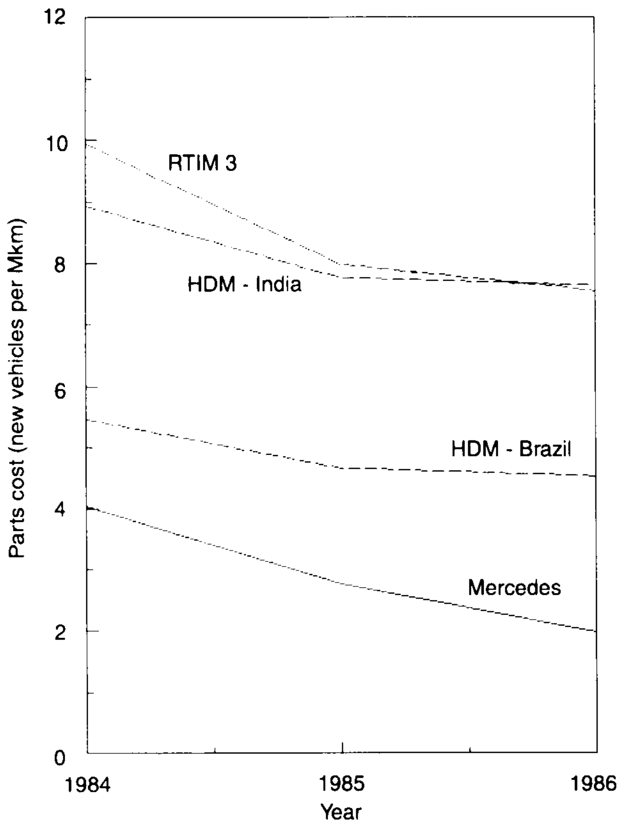

Fig.4 Observed and predicted parts cost - articulated trucks in Botswana

higher than the Brazil model. The observed values, however, are lower still; in 1986 they were less than half the Brazil values and this was despite the considerable allowances that had been made for under-recording of parts costs. Analysis of this data is considered further in Section 7.

5. ST HELENA - GOVERNMENT VEHICLES

5.1 DATA

Information on vehicle operating costs was provided by the Public Works and Services Department (PWSD) of the Government of St Helena. The PWSD operated a fleet of vehicles on the island and provided detailed records of maintenance costs at six-month intervals over the period 1986 to 1989.

For this study, maintenance costs were analyzed for six different makes and models of vehicle, three passenger cars, two utilities and one truck. A summary of the data is given in Table 5.

Plates 6 to 8 show three of the vehicle types. The data contained maintenance records for:

- 250 vehicle years
- 2.8 million kilometres of travel
- £39,000 of parts costs (at 1986 prices).

It is interesting to note that the two Ford cars were both diesel powered while the Landrovers were split almost equally between diesel and petrol engines. During the survey period, there was the normal level of fleet turnover with vehicles being scrapped, new vehicles acquired and some vehicles being followed for the whole of the four years.

All the vehicles had been operated by the PWSD from new and their age (in kilometres) was accurately known. Because of the small size of St Helena, annual travel was only in the range 7,000 to 16,000 km for the different vehicle types.

TABLE 5

Vehicle characteristics and sample size, St Helena

Make & Model	Vehicle Class	Vehicle Price (£ 1986)	Fuel & Engine Size (litres)	Average Age ('000 km)	Sample Size (Veh Yr)
Rover Mini	Passenger Car	5,600	Petrol 1.0	57	13.5
Ford Escort	Passenger Car	5,600	Diesel 1.6	15	23.5
Ford Fiesta	Passenger Car	5,600	Diesel 1.6	12	26.5
Ford Transit	Utility	8,700	Diesel 2.5	50	63
Landrover	Utility	10,000	Petrol & Diesel 2.2 - 2.5	62	53.5
Bedford	Truck	13,900	Diesel 5.4	43	68.5

Plate 6. St Helena — Ford Escort

Plate 7. St Helena — Landrover

Plate 8. St Helena — Bedford

The limited road network and the similarity of the roads made it relatively easy to estimate representative road characteristics. Roads on the island tend to be narrow, steep, twisting and rough. Road roughness was measured using a TRL Merlin on a series of typical road sections. Although the roads were sealed, their condition was poor and average roughness was estimated as 8.9 m/km.

Gradient, curvature and road width were measured directly for a number of test sections and in addition, gradient and curvature were estimated from measurements on large-scale maps.

Hence, it was estimated that on average:

- gradient = 80 m/km
- horizontal curvature = 500 degrees/km.
- road width = 4.6 m

As with the CTO vehicles in Botswana, average gross weight of the trucks was estimated as 6 tonnes.

All the prices used exclude taxes, import duties and shipping costs. The vehicles and spares were imported from England and so all prices were converted to 1986 levels using the UK retail price index (see Table 6).

These price changes are modest and any distortions due to inflation should be small.

TABLE 6

Retail price index, St Helena

1986	1987	1988	1989
1.00	1.04	1.09	1.18

5.2 ANALYSIS OF PARTS CONSUMPTION

The analysis of parts consumption is similar to that for the Botswana CTO data but in this case the data does not consist of records covering the first three or four years of a vehicle's life but six-month summaries for vehicles of a variety of ages. A feature of the data is the skewness of the parts costs and the effect that this might have on the analysis. For example, for the Transits, the six-month parts costs at 1986 prices have the following features:

- average of £91
- median of £35 (38 % of the average)
- 12 per cent of records at zero
- maximum of £1,540 (17 times the average).

The equivalent statistics for the Landrovers are:

- average of £73
- median of £25 (34 % of the average)
- 10 per cent of records at zero
- maximum of £1185 (16 times the average).

Given the small number of these outliers, it is very unlikely that they were distributed in a representative way with respect to vehicle age and so, to reduce distortion of the graphical presentations, the following procedure was adopted. For each vehicle type, the records for each six-month period were ordered by increasing parts cost and the top three per cent of the records (containing the outliers) were set to one side. The remaining records were then ordered by increasing vehicle age and divided into sequential groups of approximately 10 records per group. For each group, the average vehicle age and average parts consumption were calculated. These averages were then scaled by a factor which made up for those records which had been set aside.

It is possible that this procedure has itself introduced some bias, for the average age of the outliers was usually, though not always, above that of the remaining data. However, inspection of the graphs with and without the separate treatment for outliers showed no obvious induced bias. Nevertheless, in the analyses presented later in the report, simple regression procedures were used with no special treatment of the outliers.

Figures 5 to 7 show the measured parts costs plotted against vehicle age together with the RTIM and HDM model predictions. Consider first the passenger cars in Figure 5. The Escort and Fiesta costs are very similar to each other and much lower than any of the model costs. The Mini costs are much higher, however, and fall between those of Brazil and India. Compared with Botswana (Figure 1), roughness is much higher and this is reflected in the higher model predictions, whereas the observed parts costs are mostly lower.

Figure 6 presents results for the two utilities, the Land Rover and the Transit. They are very similar to each other and increase with vehicle age. They agree best with India, although the India model shows no change with vehicle age, and are only about one third of the Brazil values. Comparing with Botswana (Figure 2), roughness is very similar and there is very good agreement with the Landcruiser.

Finally, Figure 7 shows the results for the Bedford trucks. The measured values fall between Brazil and India and are about 25 per cent less than the Brazil values. As with the other two vehicle categories, estimates from the RTIM model are very high. Comparison with Botswana is particularly interesting since the CTO also maintained Bedford trucks. The comparison is disappointing, however, since although roughness was higher in St Helena, the parts costs were about 30 per cent lower.

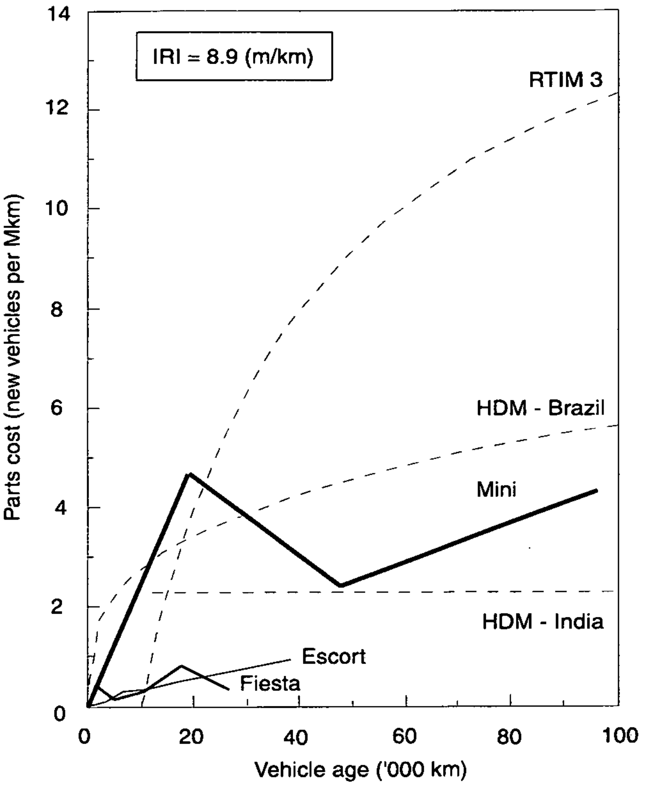

Fig.5 Observed and predicted parts cost - cars in St Helena

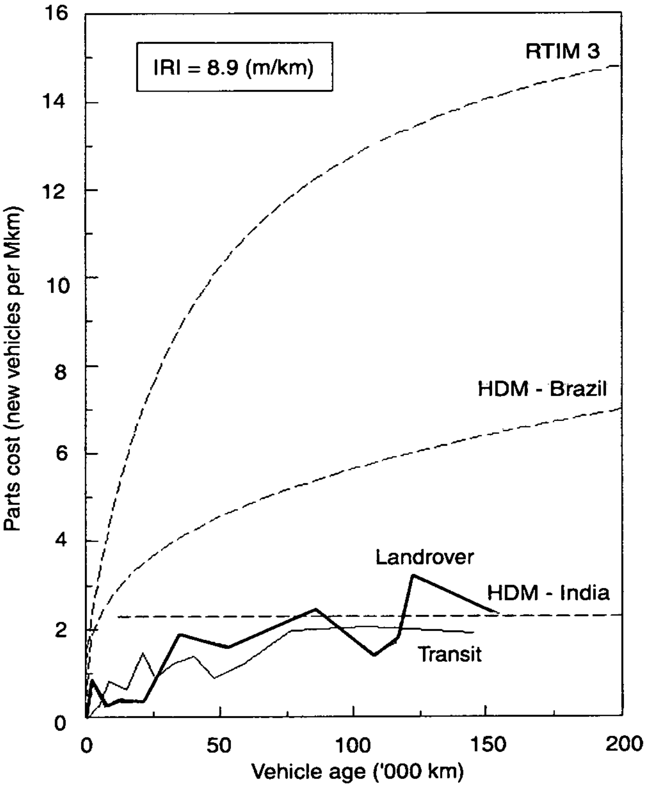

Fig.6 Observed and predicted parts cost - utilities in St Helena

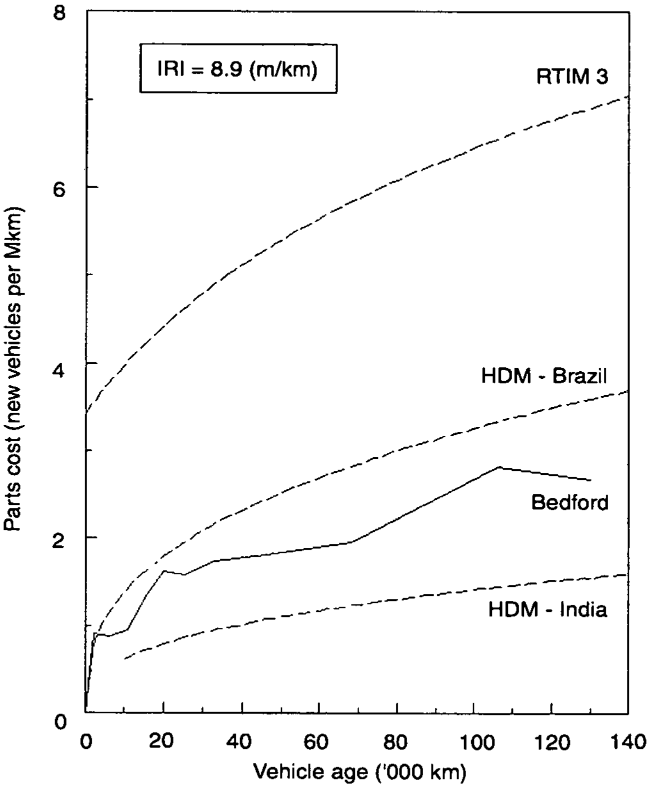

Fig.7 Observed and predicted parts cost - trucks in St Helena

5.3 ANALYSIS OF MAINTENANCE LABOUR

In addition to information on the cost of spare parts, three quarters of the maintenance records provided by the PWSD also included data on the amount of time spent by mechanics in carrying out the work. A total of almost 4,500 labour hours were recorded. The cost of labour (plus overheads) for the PWSD mechanics was £2.2 per hour and hence the total labour cost was just under £10,000; the corresponding parts cost was £30,000.

Within the models, labour hours are considered to be dependent on parts cost (expressed as a fraction of the new vehicle price) and, in some cases, road roughness. To compare the data with model predictions, therefore, a similar procedure was adopted to that for parts. For each vehicle type, records were ordered by increasing parts cost and they were then put into sequential groups of about 10 records per group. Average parts cost and labour hours were calculated for each group. Unlike the parts analysis, there was no need for a special treatment of outliers.

Figures 8 to 10 show the results together with the model prediction. The main points to note are:

In each case the India model predictions are far higher than the Brazil and RTIM models and the observed values. They cannot easily be shown on the same graph.

The Brazil model gives labour increasing approximately with the square root of parts consumption, whereas the RTIM model has a linear dependence.

For cars, only the Mini records have a high level of parts consumption. All three car types give best agreement with the Brazil model.

For utilities, the Brazil and RTIM models are the same as for cars. Again the best overall agreement is probably with the Brazil model.

For trucks, the Brazil and RTIM models are very similar. Best agreement is probably with RTIM.

The low cost of labour in India has led to very high labour hours which are not appropriate to conditions in St Helena. For example, for a car at an age of 60,000 km, the India model predicts 33 hours of labour per 1000 km of travel. If average running speed is assumed to be 50 kph, then this implies 1.7 hours of labour for each hour of vehicle travel. The equivalent figure derived from the Brazil model is only 0.2 hours.

It is very encouraging to find that the Brazil and RTIM models give similar predictions and on the whole there is quite a fair agreement between these and the observed values. Unfortunately, the labour hours predictions are themselves based on predicted parts costs and so will be subject to any errors in estimating parts costs.

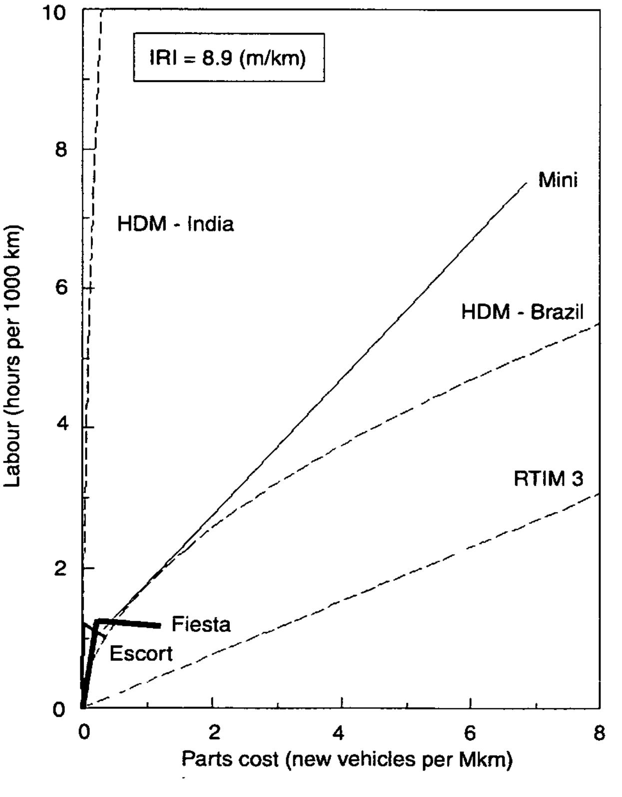

Fig.8 Observed and predicted labour hours - cars in St Helena

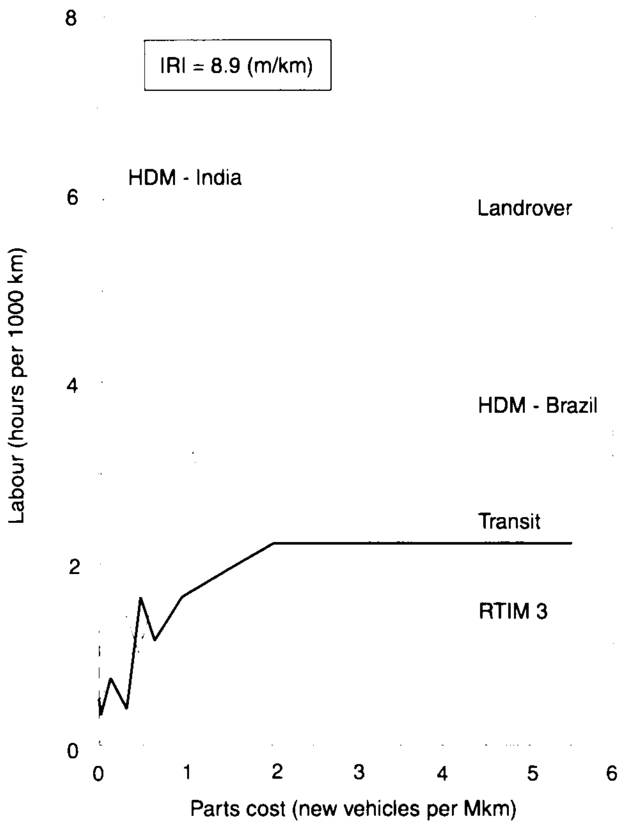

Fig.9 Observed and predicted labour hours - utilities in St Helena

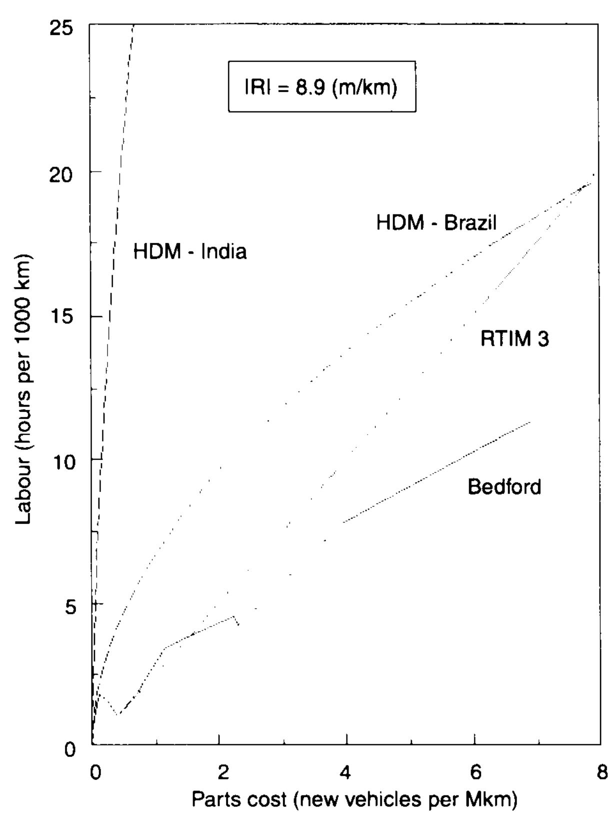

Fig.10 Observed and predicted labour hours - trucks in St Helena

6. PAKISTAN - PRIVATELY OPERATED TRUCKS

6.1 DATA

In 1986, the Overseas Unit of the Transport and Road Research Laboratory and the National Transport Research Centre, Islamabad carried out a major study of the road freight industry in Pakistan (Hine & Chilver 1991, Hine 1991, Hine & Chilver 1994). As part of this work, a large roadside survey was conducted in which 3,500 truck drivers were interviewed at 39 sites around the country.

At the time of the survey, the vehicle fleet was dominated by 2-axle Bedford trucks and they accounted for three quarters of the vehicles surveyed. Of the remainder, most were Japanese (Isuzu, Hino and Nissan). Plates 9, 10 and 11 show typical vehicles. Eighty per cent of the surveyed vehicles were open high-sided, 10 per cent were tankers and the rest were mostly open low-sided or flat.

The Bedford trucks were imported in "completely knocked down" form (CKD) with a local component which had progressively increased over the years and, by the time of the survey, accounted for over 50 per cent by value of the vehicle. Most of the Japanese vehicles were also assembled in Pakistan, although the local component at the time of the survey was less than 20 per cent. Most trucks in Pakistan, including the newer Japanese vehicles, are strengthened to take heavier loads.

The large majority of trucks, especially the smaller ones, were operated by hauliers, most of whom owned only one vehicle (90 per cent of the Bedfords and 57 per cent of the articulated vehicles belonged to one-vehicle operators). Vehicles were often away from base for periods of up to three weeks at a time travelling around the country and the drivers took responsibility for looking for loads and maintaining the vehicle. They kept careful records of their activities and expenses and for this reason were able to provide good information at the roadside interview.

During the survey, drivers were asked a range of questions about their activities and costs, including vehicle age, distance travelled and expenditure on vehicle maintenance. The survey did not distinguish between expenditure on parts and the cost of labour but it did provide information on the total maintenance cost per kilometre and how it varied with vehicle age. Because the survey data concerned current costs rather than costs collected over a number of years, there was no need to apply corrections for inflation.

Four classes of vehicle were considered: Bedford trucks, 2-axle Japanese trucks, 3-axle Japanese truck and articulated Japanese trucks. Table 7 summarises the data.

TABLE 7

Vehicle characteristics and sample size, Pakistan

Make & Model	Vehicle Type	Vehicle Price (Rps 1986)	Gross Weight (Tonnes)	Average Age (Years)	Average Age ('000 km)	Sample Size (Records)
Bedford	2-axle	325,000	13	10.6	1377	2512
Japanese	2-axle	406,000	15	3.1	467	387
Japanese	3-axle	508,000	24	3.0	451	106
Japanese	Articulated	700,000	28	4.2	592	94

Plate 9. Pakistan — Bedford

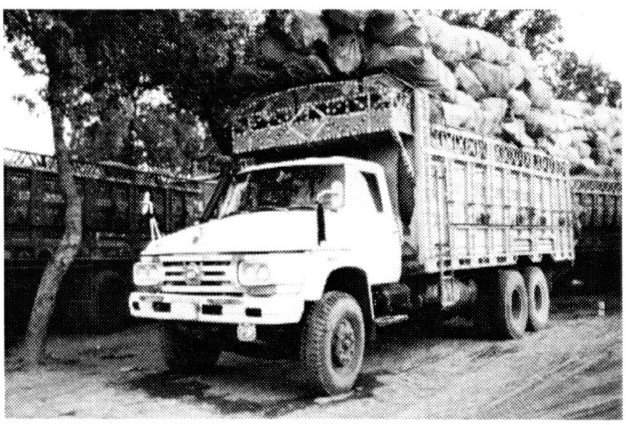

Plate 10. Pakistan — 3-axle Japanese truck

Plate 11. Pakistan — articulated truck

The Bedford trucks were the oldest vehicles, averaging just over 10 years of age and vehicles up to 29 years old were surveyed. The Japanese trucks were much younger and averaged 3 to 4 years of age but even so, vehicles up to 14 years old were recorded. Despite very low running speeds, typically around 50 km/h, annual vehicle travel was very high, averaging between 130,000 and 150,000 km for the different vehicle types. This was because of the very long haul distances in Pakistan and the fact that most vehicles had two drivers and were driven day and night. Vehicle ages, expressed in kilometres, were correspondingly high. Bedford trucks, for example, were recorded which had travelled well over 3 million kilometres and Japanese vehicles were observed which had travelled over 1.5 million kilometres. These figures are far higher than the other surveys in this report and exceed the upper limits for the India and Brazil VOC models.

6.2 ANALYSIS

Road conditions are quite similar throughout much of Pakistan and for the VOC models, the following average values were estimated:

- gradient = 0 m/km
- horizontal curvature = 0 degrees/km
- road width = 6.5 m
- roughness = 6.5 m/km

The cost of labour was estimated to be 9.4 Rupees per hour and gross weight is as shown in Table 7.

Unfortunately, it is not possible to compare the different vehicle types with the model predictions on the same graph and so Figures 11 to 14 show four separate graphs of observed and predicted maintenance costs versus vehicle age. The costs include both parts and labour and are expressed in units of new vehicles per million kilometres of travel. All the surveyed costs were paid by the private sector and so included taxes but it is assumed that the taxation element is sufficiently uniform to have little effect on costs when expressed in terms of the new vehicle price.

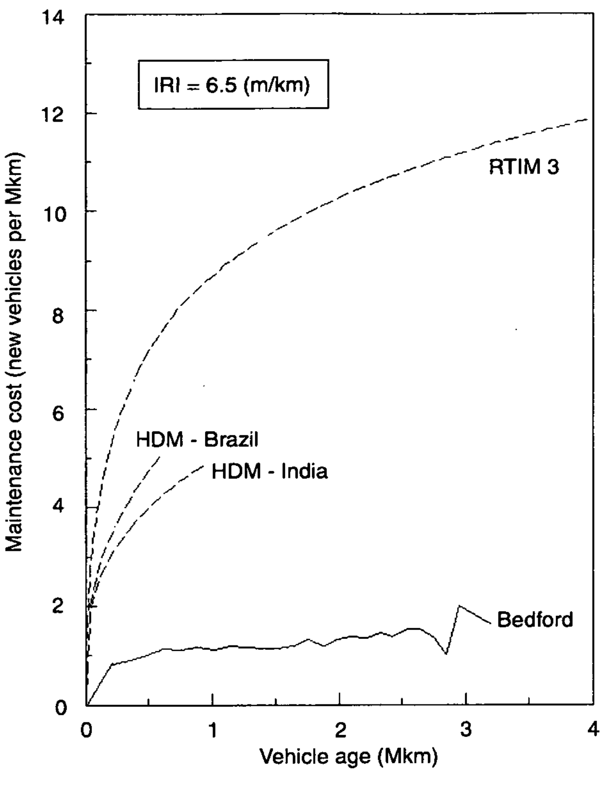

Fig.11 Observed and predicted maintenance costs - Bedford trucks in Pakistan

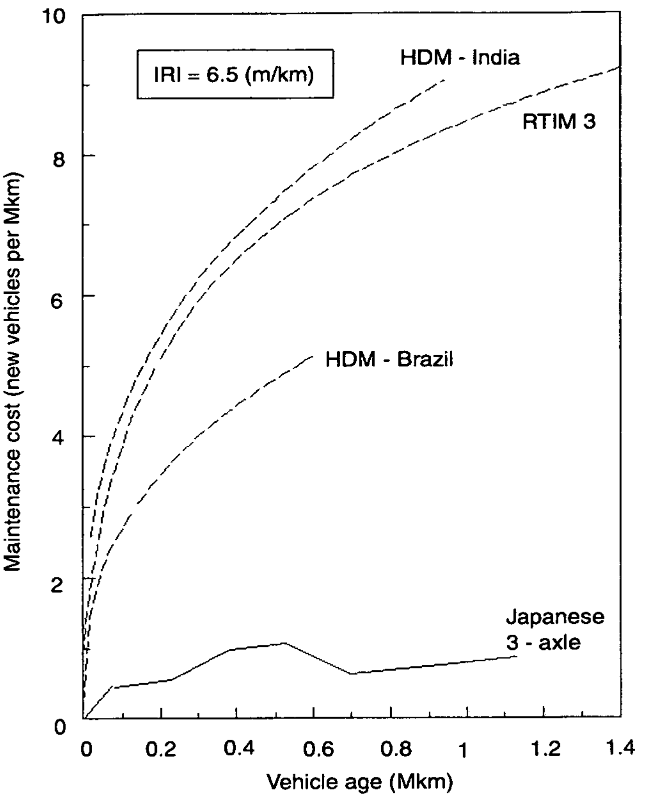

Fig.13 Observed and predicted maintenance costs - Japanese 3-axle trucks in Pakistan

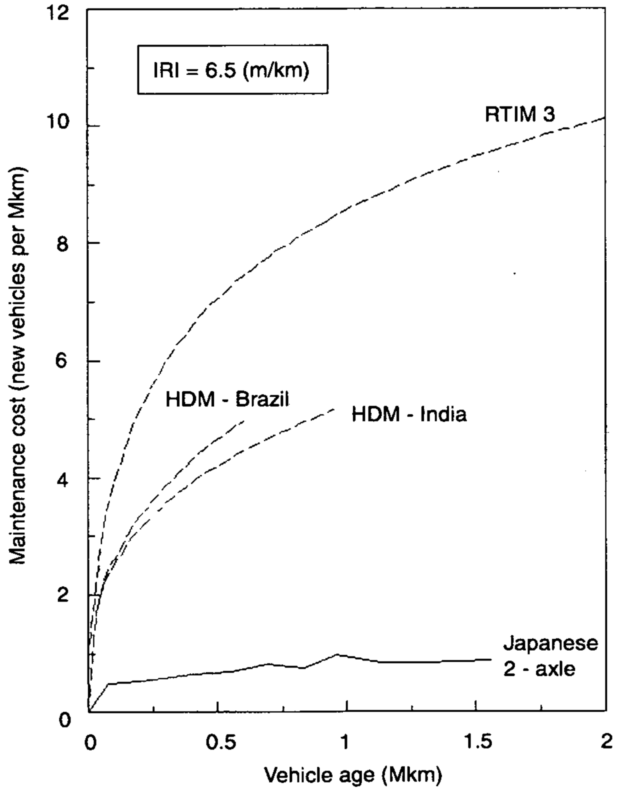

Fig.12 Observed and predicted maintenance costs - Japanese 2-axle trucks in Pakistan

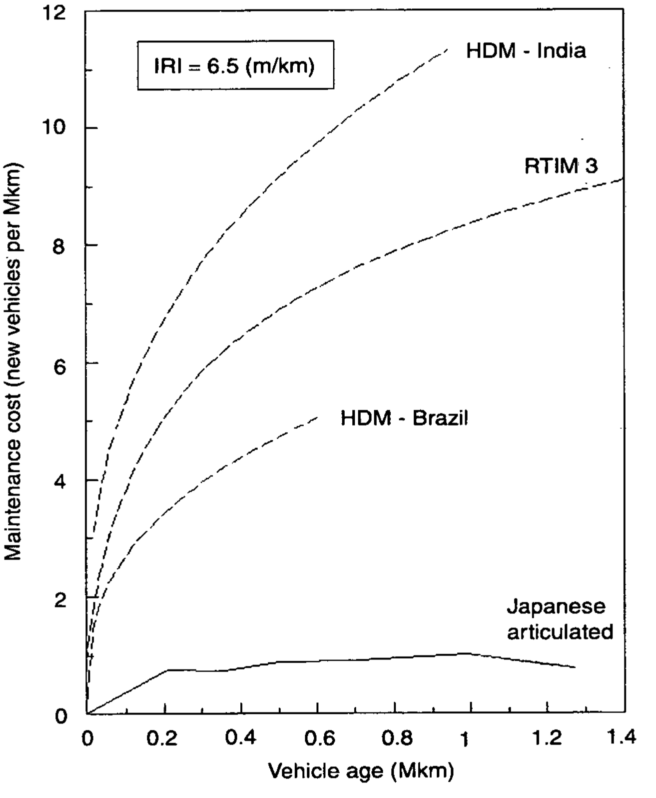

Fig.14 Observed and predicted maintenance costs - Japanese articulated trucks in Pakistan

The observed values for all four vehicle types are very similar and they are far lower than the model predictions. Even the HDM-India model, which was derived in an operating environment similar to Pakistan, gave higher costs. It is also interesting to note that the observed costs for Bedford trucks are lower than those recorded for Bedford trucks in Botswana and St Helena.

As a cross-check on these very low maintenance costs, it was possible to use information collected in another survey from the freight study. Truck drivers in Pakistan kept detailed diaries recording their work and costs and a number of the drivers were prepared to hand over their diaries for analysis. In all, 50 years of vehicle operating data was collected in this fashion. It was found that the mean estimates of maintenance costs from the diaries were lower, not higher, than the roadside data, although some of the difference could be explained by the lower vehicle age. The check gave no suggestion that the roadside data underestimated costs.

It is interesting to consider the split between parts and labour costs in the model predictions shown in Figures 11 to 14. For both the RTIM and Brazil models, labour costs account typically for about 10 per cent of the total whereas in the India model they account for around 50 per cent. The estimate of labour costs from the India model is more appropriate than in St Helena because of the much lower unit cost of labour. In St Helena, the price of a new Bedford truck was equivalent to about 6,000 hours of garage labour whereas in Pakistan, the equivalent figure was 35,000 hours. Since, in Pakistan, there was also considerable emphasis on the use of reconditioned parts for vehicle repairs (ie a substitution of labour for parts). The split between parts and labour may be more similar to the India model than the Brazil or RTIM models.

7. SIMPLE PARTS MODEL

From the parts cost analyses presented in this report, two important conclusions emerge: that the different VOC models can give quite different estimates and that the results from the field surveys do not support any one model. Because of the different forms of equation used, comparison between the VOC models can be very difficult, especially when there is more than one independent variable. Moreover, given the differences between the models and between the models and the field data, complex equations are difficult to justify.

As an alternative, the following simple parts model could be used which incorporates constants that can be easily interpreted:

$$P = (a + b \times RI) \times (CKM/100{,}000)^{KP} \quad .... (1)$$

where

P is the cost of spare parts expressed in terms of the value of new vehicles per million km

CKM is vehicle age in km

RI is roughness on the IRI scale (minimum value IRI_{MIN})

a, b and KP are constants.

This is a variant on the second HDM-Brazil equation shown in the Appendix (Section 11.1). (In HDM-Brazil, it applies at all roughness levels if RPo is set to zero). It can be thought of as being in two parts:

- the roughness term ($a + b \times RI$), which gives the parts cost per unit travel along a road of roughness RI for a vehicle of age 100,000 km. It is assumed that when RI is at IRI_{MIN} or less, the effects of road surface irregularities are completely absorbed by the suspension and flexing of the tyres and roughness has no effect on parts cost. In an economic appraisal, the key factor will often be the value of *b*
- the age term $(CKM/100{,}000)^{KP}$, which reflects the effect of vehicle age on parts consumption. Because of the similarity to HDM-Brazil, the same constant name, KP, has been adopted. The age term becomes unity at 100,000 km, regardless of the value of KP. A doubling of vehicle age will increase parts consumption by 2^{KP}.

To explore this approach further, the VOC models were turned into the above form, in some cases simply by algebraic manipulation while in others it was necessary to fit linear regressions. Because of difficulties in converting the RTIM model, the HDM Kenya and Caribbean models were used. For the same reason, the India truck model was based on Chesher's analysis (1987) rather than HDM. The coefficients derived are shown in Table 8.

The table shows the constants *a* and *b* and the roughness term (a+bRI) for roughness values of RI=3 and RI=6. As expected, since *a* is an extrapolation, it varies more than the other terms. Note that for larger vehicles, IRI_{MIN} might be greater than 3 and so (a+3b) would be an under-estimate of the roughness term. The table also shows the constant KP and the age-doubling term 2^{KP}.

There are some clear trends but also considerable differences between the models. The Brazil results seem to show the most consistent patterns. As size increases, *a* tends to increase, *b* tends to decrease and 2^{KP} varies little.

The parts costs for the privately-operated articulated trucks in Botswana were measured for a variety of vehicle ages and

TABLE 8

Coefficients for the simplified equation derived from the VOC models

Vehicle Type	*a*	*b*	(*a* + 3 *b*)	(*a* + 6 *b*)	KP	2^{KP}
Brazil						
Cars & Utils	0.15	0.56	1.82	3.49	0.31	1.24
Trucks Lt & Med	0.11	0.35	1.15	2.20	0.37	1.29
Trucks Heavy	0.62	0.28	1.47	2.31	0.37	1.29
Trucks Artic	1.00	0.20	1.61	2.22	0.37	1.29
India						
Cars & Utils	-0.05	0.25	0.71	1.47	0.00	1.00
Trucks Lt	-0.12	0.09	0.15	0.43	0.34	1.27
Trucks Med	-0.18	0.13	0.22	0.62	0.34	1.27
Trucks Heavy	-0.38	0.28	0.47	1.32	0.34	1.27
Kenya						
Cars & Utils	-5.19	2.38	1.94	9.06	1.00	2.00
Trucks Med	0.16	0.43	1.46	2.77	1.00	2.00
Caribbean						
Cars & Utils	-8.64	2.70	-0.55	7.54	1.00	2.00
Trucks Med	-2.39	1.01	0.63	3.65	1.00	2.00

road roughnesses. Equation (1) can be turned into the form:

$$P/ (CKM/100{,}000)^{KP} = (a + b \times RI) \quad ....(2)$$

where the term on the left is the parts cost adjusted for vehicle age (cost when age = 100,000 km). Using the Botswana data, the adjusted parts cost were plotted against RI using different values for KP. It was found that the best correlation ($R^2 = 0.47$) occurred at KP = 0.36 and this value was then adopted. The 46 data records, each one corresponding to one year's use, were then ordered by increasing roughness and put into 9 separate consecutive groups. The mean age-adjusted parts cost and roughness were derived for each group and these are shown plotted in Figure 15.

Over the range of roughnesses observed, the data supports the use of a linear relationship between parts and roughness and the gradient, *b*, is similar to Brazil and India (heavy trucks). However, the levels of parts consumption at RI = 3 and RI = 6 are much lower than Brazil and even lower than India (see Table 9).

Results from the other field surveys have been turned into the same form insofar as it is possible. Parts costs were recorded over a range of vehicle ages and so the age constant, KP, could be derived directly. However, because each vehicle type was surveyed only on roads of one roughness value, the results could not be used to determine both *a* and *b*.

In the case of the Pakistan data, only total maintenance costs (parts plus labour) were surveyed. These increased with vehicle age raised to the power KP′, where KP′ was found to be 0.21 for Bedford trucks and 0.22 for the Japanese vehicles. The power term for parts alone, KP, is likely to be higher than KP′ since most of the studies agree that, as total maintenance cost increases, the proportion of labour cost falls. For the Bedford trucks, parts costs were estimated by assuming that, as with the India model, at an age of 100,000 km, maintenance costs would be split equally between parts and labour and that labour costs increase with parts cost raised to the power 0.6. The results are shown in Table 10.

For the smaller vehicles, the constant, KP, seems to be higher than Brazil or India, though not as high as found in Kenya or the Caribbean. Although in Table 9, the value of *b* agreed with the VOC models, adopting values of *b* for the other field studies appeared to give variable and unsatisfactory results. Since *b* is the important term for most economic analyses, this underlines the uncertainties of using the existing VOC relationships.

TABLE 9

Coefficients for the simplified equation derived from Botswana

Vehicle Type	*a*	*b*	(*a* + 3 *b*)	(*a* + 6 *b*)	KP	2^{KP}
Trucks Artic	-0.70	0.29	0.18	1.06	0.36	1.28

TABLE 10

Coefficients for the simplified equation derived from the other field studies

Vehicle Type (1)		RI	($a + b$ RI)	KP	2^{KP}
Botswana					
	Cars(2)	4.7	8.31	0.65	1.57
	Utilities	8.4	2.59	0.50	1.41
	Trucks Med	6.8	3.12	0.20	1.15
St Helena					
	Cars Small(3)	8.9	5.00	-	-
	Cars(4)	8.9	0.90	0.40	1.32
	Utilities(5)	8.9	1.86	0.50	1.41
	Trucks Med	8.9	2.42	0.31	1.24
Pakistan					
	Trucks Med	6.5	0.34	0.28	1.22

(1) Where results for different vehicle types were very similar, they have been amalgamated as shown
(2) Opel Rekord and Opel Commodore
(3) Rover Mini
(4) Ford Escort and Ford Fiesta
(5) Landrover and Ford Transit

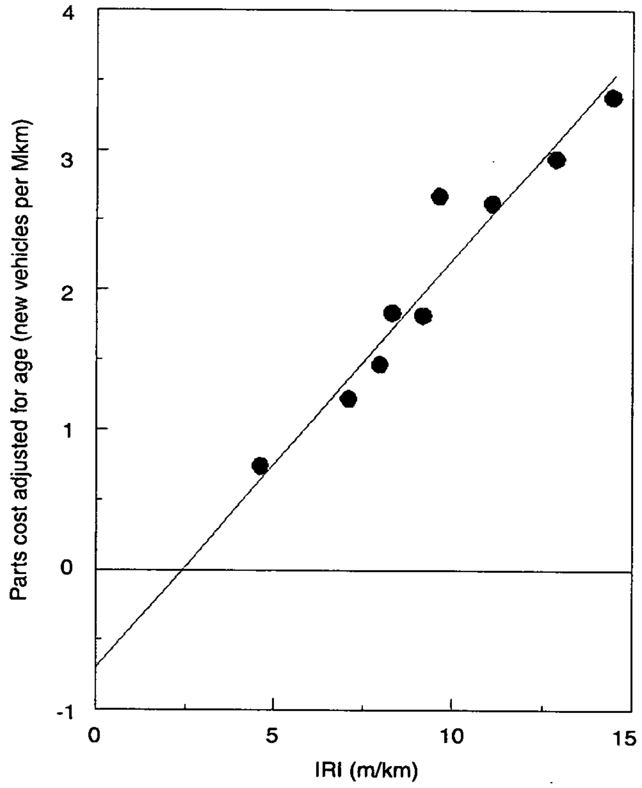

Fig.15 Fitting a simple parts model - articulated trucks in Botswana

8. DISCUSSION AND CONCLUSIONS

Table 11 summarises the different field studies covered in this report and from them, the following conclusions can be drawn:

1) Collecting data on the cost of vehicle maintenance and repairs requires excellent co-operation from well-organised vehicle operators or maintenance depots. It is important to check that adequate allowance is made for repairs carried out in the field, re-use of parts from old vehicles, etc.

2) If economic inflation is high, or has been high in the recent past, problems may arise in knowing the current value of the spares consumed.

3) Because of their sporadic nature, repair costs can be very variable and so for analysis, large amounts of data are required and careful interpretation may be necessary.

4) According to existing VOC models, the two principal factors affecting the consumption of spare parts are vehicle age and road roughness. The sensitivity to road roughness is usually the key factor in an economic analysis but it is much easier to survey vehicle operating costs as a function of vehicle age than road roughness.

5) Predicted spare parts costs can vary considerably between the different existing VOC models. The HDM-India model usually gave the lowest estimates, although in practice this would be compensated for to some degree by higher estimates for the cost of labour. None of the models gave consistently better predictions of the field study results and despite their spread, the model predictions did not always encompass the observed values. This was especially true

TABLE 11

Summary of the field studies

Country	Botswana	Botswana	Botswana	Botswana	St Helena	St Helena	St Helena	Pakistan
Vehicle Type	Cars Medium	Utilities Artic	Trucks Medium	Trucks Various	Cars	Utilities	Trucks	Trucks
Operator Type	Govt.	Govt.	Govt.	Private	Govt.	Govt.	Govt.	Private
Survey Type	Workshop	Workshop	Workshop	Workshop	Workshop	Workshop	Workshop	Roadside
Parts	X	X	X	X	X	X	X	(1)
Labour	-	-	-	-	X	X	X	(1)
Sample Size (Vehicle Years)	120	120	120	130	60	120	70	(2)
Max Vehicle Age ('000 km)	50	110	50	640	80	150	130	3,500
Road Roughness (m/km)	4.7	8.4	6.8	4 - 13	8.9	8.9	8.9	6.5

(1) Parts and labour combined
(2) 3,500 Vehicle drivers interviewed

for the results from Pakistan. Despite the difficulties in carrying out these studies, it seems unlikely that the differences can be attributed to errors in data collection or analysis.

6) A simple model using just three coefficients has been proposed to relate parts consumption to age and roughness. The existing VOC models have been expressed in this simple form and the coefficients derived. Results from a survey of articulated trucks in Botswana appear to fit the simple model quite well and two of the coefficients are similar to those from the VOC models. However, with the other field surveys, there is relatively little consistency in the coefficients that are derived.

7) Labour costs were available from only one of the studies. There was fair agreement between the observed values and the estimates from the HDM-Brazil and RTIM3 relationships. Unfortunately, the labour hours predictions are themselves based on predicted parts costs and so will be subject to any errors in estimating parts costs. Moreover, the labour relationships are unsatisfactory in that there are large differences between the HDM-India model on the one hand and HDM-Brazil and RTIM3 on the other.

8) To make further progress in this area, it is recommended that the influence of other factors on parts consumption be examined more carefully, particularly the effects of vehicle speed and standard of maintenance. Also, the concept of combining parts and labour to produce an overall maintenance cost is worth considering.

9. ACKNOWLEDGEMENTS

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11 APPENDIX 1: VEHICLE OPERATING COST RELATIONSHIPS

11.1 HDM BRAZIL

The costs of spare parts, P, in new vehicles per million km, for cars, utilities and trucks are related to vehicle age in kilometres (CKM) and road roughness on the IRI scale (RI)

by the expressions:

For RI <= RPo

$$P = 1000 \text{ CPo CKM}^{KP} \exp(\text{CPr RI})$$

For RI > RPo

$$P = 1000 \text{ CPo CKM}^{KP} (d0 + d1 \text{ RI})$$

where

$$d0 = \exp(\text{CPr RPo}) (1 - \text{CPr RPo})$$

$$d1 = \text{CPr} \exp(\text{CPr RPo})$$

The amount of maintenance labour, LH, in hours per thousand km, is given by:

$$LH = \text{CLo} (P/1000)^{CLp}$$

The coefficients are as follows (see Table A1.1):

The recommended range for the input variables are given in Table A1.2.

TABLE A1.2

Recommended range for the Brazilian model input variables

	CKM (km)	RI (m/km)
Cars and Utils	0 - 300,000	1.9 - 9.2
Trucks	0 - 600,000	1.9 - 9.2

11.2 HDM INDIA

The costs of spare parts, P, in new vehicles per million km, for cars and utilities are related to road roughness on the BI scale (BI) by the expression:

$$P = 42.0 \times \exp(0.000{,}169 \text{ BI}) / 64.8$$

For trucks, parts are given by the expression:

$$P = \{0.924 \times (\text{CKM})^{0.359} \times \exp[(61.8 \times 10^{-6} \times \text{BI}) + (686 \times 10^{-6} \times C) + (545 \times 10^{-6} \times G) + (0.853/W) + (0.0765 \text{ GVW})]\}/180.7$$

where

CKM is vehicle age in km

C is curvature in degrees/km

G is gradient in m/km

W is road width in metres

GVW is gross weight of vehicle in tons.

The amount of maintenance labour, LH, in hours per thousand km, is given by:

$$LH = a \times (b \times P)^c \times \exp(d \times \text{BI})$$

where the constants a,b,c and d are given in Table A1.3

TABLE A1.1

Brazil model coefficients

	KP	CPo 10^{-6}	CPr 10^{-3}	RPo	CLo	CLp
Cars & Utils	0.308	32.49	178.1	9.23	77.14	0.547
Trucks Lt & Med	0.371	1.49	3,273.3	0.00	242.03	0.519
Trucks Heavy	0.371	8.61	459.0	0.00	301.46	0.519
Trucks Artic	0.371	13.94	203.5	0.00	652.51	0.519

(Note that in the standard HDM nomenclature where roughness is expressed in QI units rather than IRI, $CPo = Co_{sp}$, $CPr = 13\ CP_{spqi}$, $RPo = QIo_{sp}/13$, $CLo = Co_{lh}$, $CLp = C_{lhqi}$)

TABLE A1.3

India model coefficients

	a	b	c	d 10^{-6}
Cars	1.799	64.8	0.584	0
Utilities	4.42	64.8	0.445	0
Trucks	0.898	180.7	0.654	25

The recommended range for input variables are given in Table A1.4.

TABLE A1.4

Recommended range for the Indian model input variables

	CKM (km)	C (deg/km)	G (m/km)	W (m)	GVW (tons)
Cars & Utils	12,000 - 250,000	0 - 700	0 - 40	-	-
Trucks	9,000 - 950,000	0 - 1,200	0 - 60	3.5 - 7.5	7.0 - 28.0

11.3 RTIM3

For cars and utilities, the cost of spare parts, P, in new vehicles per million km, is related to vehicle age in kilometres (CKM) and road roughness on the BI scale (BI) by the expression:

$$P = (2.319\ BI' \times CKM' - 9.87\ BI' - 841) \times 10^{-3}$$

[Minimum value of P = 0]

where

$$BI' = (500 + 14{,}500\ e^{W})/(1 + e^{W})$$

$$W = 415\ BI \times 10^{-6} - 2.9$$

and

$$CKM' = (5.301\ e^{Y})/\ (1 + e^{Y})$$

$$Y = 1.579\ Log_{10}(CKM + HY) - 5.332$$

for cars, HY = 10,000

for utilities, HY = 22,500

For trucks, the relationship is:

$$P = (4.484 + 106\ BI' \times 10^{-6})\ Log_{10}\ (CKM + HY) + 24.86\ G \times C \times 10^{-6} - 22.07$$

[Minimum value of P = 0]

HY = 37,500

where CKM′ is as defined above, G is the gradient in m/km and C is the curvature in degrees/km.

The amount of maintenance labour, LH, in hours per thousand km, is given by:

for cars and utilities

$$LH = [\ (695 + 383\ e^{Z})/\ (1 + e^{Z})\ ] \times P \times 10^{-3}$$

for trucks

$$LH = [\ (2{,}819 + 2{,}507\ e^{Z})/\ (1 + e^{Z})\ ] \times P \times 10^{-3}$$

where

$$z = 0.00159\ BI - 6.373$$

The recommended range for input variables are given in Table A1.5.

TABLE A1.5

Recommended range for the input variables for RTIM3

	BI (mm/km)	C (degrees/km)	G (m/km)
All Vehicles	0 - 20,000	0 - 1,200	0 - 140

MORE INFORMATION

The Transport Research Laboratory has published the following other reports on this area of research:

LR1057 The TRRL road investment model for developing countries (RTIM2). L L Parsley and R Robinson. Price code OS_A.

LR1031 Vehicle operating costs in the Caribbean: results of a survey of vehicle operators. H Hide. Price code OS_A.

LR672 The Kenya road transport cost study: research on vehicle operating costs. H Hide, S W Abaynayaka, I Sayer and R J Wyatt. Price code OS_A.

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