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****

VEHICLE OPERATING COSTS

NTRC-150

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SUMMARY

The main benefits which can be quantified from road improvements are; savings in Vehicle Operating Costs, savings in journey time, reduction of road accidents and the social benefits. Since the savings Costs (VOC) is the major benefit. The investment in road improvements can be justified by savings in VOC.

A study on Vehicle Operating Costs was carried out by NTRC in 1985 which became out-dated due to the inflation in prices, deterioration of roads and the variation in volume and composition of traffic on road. Therefore, it was felt that the VOC should be updated for planning and appraisal purposes.

The study was launched with the aim to work out the Vehicle Operating Costs of the conventional classes of motor vehicles on paved and un-paved roads under the conditions prevailing in the country. Only 6 types of vehicles i.e. Car, Wagon, Mini Bus, Bus, Medium Truck and Heavy Truck have been covered in the study. The VOC have been calculated by using two different methods i.e. theoretical as well as empirical. For theoretical calculation the conventional models RTIM2 developed by the TRRL, U.K. have been used. However, the equation to workout the fuel consumption for Suzuki

1000 c.c. and 800 c.c. Cars has slightly been modified. Whereas, to calculate the empirical VOC on paved as well as un-paved roads the results of the experimental studies "Vehicle Operating Costs" carried out by Mr. Abdul Majeed of NTRC in 1985 and "Road Freight Industry Survey" based on the road side interviews conducted in Pakistan by Mr. John L. Hine of TRRL in 1987 have been used.

However, the empirical costs calculations are partly based on the assumption which have been used for the empirical data. Therefore, the empirical VOC calculated in this report are not being recommended for use in the palnning and appraising of projects.

According to the theoretical calculations the VOC rupees per kilometer on paved as well as un-paved roads are estimated as under:

Vehicle Class	Paved	Un-paved
Car Toyota	2.68	3.51
Car Suzuki 1000 cc	1.73	2.30
Car Suzuki 800 cc	1.47	1.97
Wagon - Ford	2.31	2.70
Mini Bus - Mazda	2.68	3.17
Bus - Bedford	3.58	5.11
Medium Truck - Bedford	2.68	3.59
Heavy Truck - Nissan	3.71	4.85

The study would be updated after every 6 months or whenever there is substantial costs variation in any input. In this connection a Computer Programme has been developed to continuous monitoring and readily updating the VOC. The current operating costs would be available on the network Computer system. The compiled information will be updated bi-annually and supplied to all planning agencies and appraising organizations.

CHAPTER - 1

1. Introduction

The rapid increase in the number of motor vehicles all over the world over the last few decades has led to greater demand for more and better roads requiring more resources. This has brought into sharp focus the need for proper appraisal of investments on construction and improvements of roads.

The investment in any development sector can only be justified by saving in Vehicle Operating Costs. Any investment in improving the surface, evaluation, curvature and reducing the distance based on the exclusive idea to save the Vehicle Operating Costs. For such type of road planning, the road planners need information, not only on Vehicle Operating costs as such, but also on variations inVehicle Operating Costs in response to changes in road characteristics, such as surface smoothness, elevation, curvature, distance as well as climate. Because Vehicle Operating Costs are maintained, if any, by road users, according to main costs componenets, like price of the vehicle and parts, fuel, oil, labour, wages of crew, tyres etc.

The Vehicle Operating Costs, which consist of three possible components; (a) the direct running costs which vary with kilometer run and sppeds and include items such as fuel, oil, lubricants tyres, maintenance and repair; (b) the indirect running costs, including vehicle depreciation and crew costs, which vary with vehicle working time and utilisation; (c) the fixed costs including overheads and interest charges. Differences in road conditions affect these categories in different ways. The rougher the road is the higher the direct vehicle running costs, as bad road conditions are associated with lower speed and increases crew hours and higher vehicle depreciation. Bad road conditions also affect the fixed costs per tone/kilometer through prolonged journey time and consequently reduces vehicle utilisation.

The main components of Vehicle Operating Costs are listed below:-

- Fuel consumption
- Oil consumption
- Spare parts consumption
- Maintenance labour hours
- Tyre wear
- Vehicle depreciation
- Crew costs

On the other hand, the variables which influenced the Vehicle Operating Costs are: road characteristics, vehicle characteristics, environmental conditions and the volume and composition of the traffic on the road. the information required to work out the Vehicle Operating Costs are as under:-

Road Characteristics

Rise (m/km)

Fall (m/km)

Surface roughness (mm/km)

Degree of curvature (o/km)

Road width (meters)

Surface moisture content (%)

Rut depth (mm)

Vehicle Characteristics

Environmental free speed

Vehicle weight

Power to weight ratio (BHP/tone)

Vehicle age in km

Annual vehicle hours

Vehicle age spectrum

Vehicle price

Tyre price

Crew costs (per hour)

Fuel price (per litre)

Oil price (per litre)

Maintenance labour costs (per hour)

Climatic condition

Rain fall rate (mm)

Temperature (degree centigrade)

Volume and composition

Number of vehicles on road

Vehicle type

In the costs and benefits analysis of the transport projects, the reduction in Vehicle Operating Costs is by far the most important and easily identifiable benefit especially in developing countries. It is generally large in these countries since the initial transport conditions are normally very bad, and therefore very costly. Differnet types of road have different impacts on these costs.

The reduction in operating costs benefits occur to normal as well as divert traffic that uses the facility under consideration. Normal traffic usually gets the full benefits which are measured according to with and without criterion, i.e. the difference between costs before and after the road improvement. As regards benefits to the diverted traffic, it is a bit more complicated. If the diversion from one route to another of the same mode, then the benefit will be the difference in operating costs between the old route and the new one. But when comparing two modes it is different.

As this report is concerned only with road Vehicle Operating costs so the diverted benefits (difference in costs from one mode to another, i.e. road and rail) is not likely to be considered in depth. The emphasis will, therefore, only be to work out the, Vehicle Operating Costs under the condition prevailing in the country. The four developing countries namely Kenya, India, Brazil and the Caribean will be reviewed in this report, who have used RTIM, RTIM2 and HDMII models to work out VOC. The Vehicle Operating Costs will be worked out by using RTIM2 model and the results will be compared with empirical evidence in pakistan.

Further details about the scope and coverage are discussed under the sub-headings `Backgroud' and `Objectives' in this chapter.

1.1 Background

The users, operators and public agencies responsible for economic planning, development and control of transport services are all interested in Vehicle Operating costs. The interest of users as well as operators is in fact as old as the motor vehicle itself. The information is needed by various agencies for a variety of purposes. For example, the agencies concerned with planning and development of infrastructure and transport servies need the information for appraisal of road investment projects. The agencies concerned with construction and maintenance of roads need the information for design of raod and bridge structures and maintenance; the agencies concerned with operation of transport services, need the information for estimating Vehicle Operating Costs. In addition to these the enforcement agencies need the information about sppeed limits for road safety. The information related to estimating the Vehicle Opeating costs also provides an important input for transport models of various types and is of general interest to traffic enginners and transport economists.

Various agencies and experts had done notable work in this field. As far as developing countries are concerned, the major work has been done in four countries: Kenya, India, Brazil and the Caribbean. In these four major study regions they have used differnt models and formula to work out as well as to compile the Vehicle Operating Costs according to their environment and climatic conditions. All these countries have considered different makes and characteristics of vehicles.

The road characteristics, vehicle characteristics and other input information used in the above-mentioned four study regions vary. In these studies the models used for estimating the costs of each component are also different.

It is true that the exact Vehicle Operating Costs cannot be predicted because of changes in road characteristics and prices of relevant items over the time span. In fact it is out of human reach to know what exactly would happen in the future. Similarly, it is impossible to predict the exact future Vehicle Operating Cost. But with a certain degree of accuracy, the future physical as well as financial costs can be predicted depending upon relevant factors, but it is not a simple problem. Many factors correlate with each other and different factors influence in different ways in different areas of the world.

The relationship between speed and Vehicle Operating costs is of particular improtance. Various cost components behave differently with change in speed. For example, the fuel consumption is high both at very low and high speeds and is lowest at optimum speeds. Other physical cost components like, oil consumption, wear and tear of tyres, breakes, parts etc., increases with speed. On the other hand, time based costs, like interest, depreciation, wages, decrease with increase in speed.

However, both physical and time based cost components vary with speed, therefore, the operating speeds provide an important input in estimating the Vehicle Operating costs.

In the results of the above mentioned four major studies it seems that the theoratical estiamtes vary with experimental results which is also a debatable point.

An ideal and standard model for Vehicle Operating costs shoud be transferable across countries and also over time within the given country, such models may locally be adopted by correcting the values of the necessary regional factors.

The details about the models used in the for major studies will be discussed under the literature review in chapter-II.

No attempt has so far been made in context with Pakistan to develop a model for estimating the Vehicle Operating Costs. Nevertheless in assessing the benefits of road project investments, its improtance cannot be ignored. However, the national Transport Research Centre, pakistan, has calculated Vehicle Operating costs which are based on the experimental data.

There is therefore, a need to either adopt a model which has been used in one of the four above mentioned studies or develop a suitable model for Pakistan. The main purpose of this report is to estimate the Vehicle Operating Costs by using an appropriate model and these estimation which whill be collected by conducting a small scale road'side user's survey.

1.2 Study objectives

The Principal aim of this study was to work out the Vehicle Operating Costs of the following classes of motor vehicles on paved and unpaved roads under the conditions prevailing in the country.

- Cars
- Coaches
- Wagons
- Rickshaws
- Motor Cycles
- Mini Buses
- Buses
- Vans
- Jeeps
- Trucks
  - 2 axles
  - multi axles

But due to non-availability of primary data the VOC regarding Motor Cycles, Rickshaws, Jeeps and Vans could not be worked out.

The study would be updated after every six months or whenever there is substantial cost variation in any input. The compiled information will be updated bi-annually and supplied to all planning agencies and appraising organizations.

CHAPTER - 2

2. Literature Review

2.1 International

Low and Kinnear-Clark: the first report on Vehicle Operating Costs for animal drawn vehicles was published in 1981. Agg (1923): after the first world war, in North America Attention was given to estimating the motor Vehicle Operating costs. The staff of lowa State College Engineering Station initiated a series of Vehicle Operating costs studies under the Agg's directorship. By 1935 they found the effect of road characteristics on Vehicle Operating Costs.

One of the earliest surveys of Vehicle Operating costs was carried out by the research associate Professors, Moyer and Winfrey (1939) of the Civil Engineering Department of lowa State College. In this survey they reported the cost of operating rural mail carrier. They examined the fuel, oil, maintenance and tyre costs on paved, gravel and earth roads in this report. By 1960 the work was further extended through several experiments and models were developed to work out the results of speed and fuel experiments, including vehicle and road characteristics.

In 1952 the American Association of States Highway (AASHO) produced the first road user costs manual. But the data provided in this manual was only for cars in rural areas. Some information however, was also reported about truck costs.

In 1963 Winfrey compiled all part survey data and analysed the available experiments relevant to the operating costs and produced a publication for road planning for the following fifteen years. But this data was based on the inforamtion regarding American vehicles.

For the highway project appraisal in the developing countries, the World Bank (de Weili, 1966) compiled the vehicle cost tables and published 'Quantification of Road User Savings'. Most of the data were obtained from Winfrey reports, which were according to American environment and vehicles.

In 1969 the World Bank initiated a program of research to develop models for the road project appraisal in the developing countries. the model for estimating Vehicle Operating Costs is a part of this program.

In phase-I of the program the research was carried out by the Massachusetts Institute of Technology, the World Bank and the Transport and road Research Laboratory (TRRL), U.K. The conclusion of the report under phase-I of the program predicted highway deterioration and economic relationship in developing countries were inadequate. The phase-II of this program was designed to remedy these deficiencies.

Besides other works done by various agencies and experts, the following four major studies have been carried out:

1. Kenyan study
2. The Caribbean study
3. Indian study
4. Brazilian study

The above mentioned studies were conducted between 1975 to 1982. Because of different environmental condition, road and vehicle characteristics the estimated costs varied in each study region. The brief description of each study is reported in the following paragraphs.

2.1.1 The Kenyan Study

The team of the Transport and Road Research Laboratory (TRRL), U.K., carried out 'the Kenyan Road Transport cost Study' in 1975.

As mentioned in chapter-1, the climatic conditions of a particular region influence the deterioration of roads, affect vehicle speed and subsequently the operating costs of vehicles. The average weather conditions of the above mentioned four study regions may be seen in table-1.

The Kenyan study was carried out in the Kenyan highlands, which are moderate rainfall areas (kisumu and nairobi). The peak period of the rainfall is from March to May. This is the most productive agricultural land so is a densely populated area. The temperature is very low in this area. The survey to collect the user data from vehicle operators was carried out by two parts, i.e. (1) an experimental study of vehicle speed and fuel consumption; (2) a road user survey. The survey data were obtained from 289 vehicles (43 cars, 74 light goods vehicles, 78 medium / heavy trucks -5 to 26 tonnes payload and 121 buses of more than 30 seats).

The Kenyan study was carried out before 1975 when fuel was relatively cheap and vehicles observed were purchased at that time. The vehicle designed then used the technology of the 1960s and as such were not fuel efficient.

The roughness was measured using a car mounted bump integrator. The Road Transport and Investment Model (RTIM) was used to estimate the costs so different components of Vehicle Operating Costs were obtained from the experiments and road user/operators data.

2.1.2 <u>The Caribbean Study</u>

The Caribbean study was also conducted by the Transport and road Research Laboratory (TRRL), UK. It covered Barbados and Windward islands of St Vincent, St Lucia and Dominica. The study was launched in 1977 and

Table 1: Average Daily Temperatures (T : ^{o}C, Max and Min) and Average Monthly Rainfall (R : mm)

MONTH	KENYA									BRAZIL								
	Kisumu			Mombasa			Nairobi			Goiás			Paraná			Rio de Janeiro		
	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R
J	29	18	48	31	24	25	25	12	38	30	17	317	32	14	287	29	23	125
F	29	19	81	31	24	18	26	13	64	32	17	251	32	15	236	29	23	122
M	28	19	140	31	25	64	25	14	125	32	17	259	32	15	239	28	22	130
A	28	18	191	30	24	196	24	14	211	33	17	117	32	14	102	27	21	107
M	27	18	155	28	23	320	22	13	158	33	16	10	33	12	13	25	19	79
J	27	17	84	28	23	119	21	12	46	32	13	0	33	9	0	24	18	53
J	27	17	58	27	22	89	21	11	15	32	13	0	33	9	3	24	17	41
A	27	17	76	27	22	64	21	11	23	34	15	8	34	10	5	24	18	43
S	28	17	64	28	22	64	24	11	31	34	18	58	35	13	28	24	18	66
O	29	18	56	29	23	86	24	13	53	34	17	135	34	14	127	25	19	79
N	29	18	86	29	24	97	23	13	109	32	17	239	33	14	231	26	20	104
D	29	18	102	30	24	61	23	13	86	31	17	241	32	14	310	28	22	137

MONTH	BARBADOS			ST. LUCIA			INDIA											
	Bridgetown			Soufrière			Hyderabad			Srinagar			Delhi			Bombay		
	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R	T max	T min	R
J	28	21	66	28	21	135	29	16	8	5	-2	74	21	7	23	28	19	3
F	28	21	28	28	21	91	32	18	10	7	-1	71	24	9	18	28	19	3
M	29	21	33	29	21	97	36	21	13	14	3	91	31	14	13	30	22	3
A	30	22	36	31	22	86	38	24	31	19	7	94	36	20	8	32	24	0
M	31	23	58	31	23	150	40	27	28	24	11	61	41	26	13	33	27	18
J	31	23	42	31	23	218	35	24	112	29	14	36	39	28	74	32	26	405
J	30	23	147	31	23	236	31	23	152	31	18	58	36	27	180	29	25	617
A	31	23	147	31	23	269	31	23	135	31	18	61	34	26	173	29	24	340
S	31	23	170	31	23	252	31	22	165	28	12	38	34	24	117	29	24	264
O	30	23	178	31	22	236	31	21	64	22	5	31	34	18	10	32	24	64
N	29	23	206	29	22	231	29	17	28	16	-1	10	29	11	3	32	23	13
D	28	22	97	28	21	198	28	15	8	9	-2	33	33	8	10	31	21	3

Source: The World Weather Guide, (Pearce and Smith, 1984) the findings were finally published in 1982. The data were analysed over a period of 12 months.

Barbados comprises flat to rolling areas with small hilly parts, whereas the other island consists of mountainous areas.

A test fleet of three instrumented vehilces were used to measure fuel consumption. Free speeds were obtained for three types of vehicles viz. cars, light goods vehicles and trucks. The total vehicle operating Costs in monetary units per 1000 kilometers at different speed levels and road characteristics by using vehicle age (VA) methods.

2.1.3 The Indian Study

the Indian study "Road User Cost Study in India" was conducted (1977-82) by the Indian Central Road Research Institute based at New Delhi and finally published in 1982. The vehicle used for fuel experiments were locally manufactured.

2.1.4 The Brazilian Study

The work on Brazilian costs study was started in 1975 and the final report was published in 1982. This report was conducted by the Ministry of Transport, Brazil. the Brazilian costs sutdy is more comprehensive than the other three studies both types of surveys, i.e. road side survey and road user survey were carried out for this study.

A fleet of ten different types of vehicles were used to conduct the fuel experiments at different conditions.

2.2 National

The NTRC is responsible for research, planning of development and efficient operation of facilities at national level. The Centre has so far completed more than 100 research studies, most of them are in the area of road and road transport. The NTRC is the only organization which is responsible for such types of work at national level.

Out of the above mentioned activities the following three research studies related to this report are briefly described as below.

2.2.1 Highway Speed Survey

The NTRC report No.51 was carried out in 1980 by Mr. Abdul Majeed, of the Centre. The report comprises the mean speeds of vehicles on different types of roads. The method used to measure the speed was 'single observe method'. Under this method the speed was recorded manually by using a stop watch. The roads covered in the survey were undivided, paved and level tangent.

It is evident that the road surface roughness, gradient (rise plus fall) and degree of curvature are the main factors which influence the vehicle speed. In addition, this survey was carried out only in the day time, whereas in the night time the composition of vehicles differs from the day. For example, most of the freight movements are during the night. Therefore, this speed cannot be used confidently in assessing the VOC unless this is corrected by using ratio of effects of each factor. The model used to estimate the speed is based on the simple linear function of width of the road and volume and proportion of slow moving vehicles.

However, the results reported in the study are checked and compared with other sources and found closer to other countries speed data.

2.2.2 Fuel Consumption Study

This NTRC report No.54 was also carried out by Mr. Abdul Majeed in 1981. This study is mainly concerned with fuel consumption by individual vehicles in different operating conditions, particularly at varying speeds. The results reported in this study have been combined with the results derived from 'Highway Speed Survey' discussed in section of this chapter, to provide more realistic estimates of fuel consumption at varying speeds. In the experimental survey the fuel consumption has been predicted on the basis of speed of vehicle. Another variable like road characteristics, viz. surface roughness, rise plus fall and degree of curvature, which influence the vehicle speeds and subsequently the fuel consumption have not been incorporated. The characteristics of vehicles used in the experiments are shown in table-2.

It is reported in the study that most of the road section selected for experiments were level tangent paved, whereas the road section around Islamabad federal capital, which is mostly rolling and gradient area. However, few tests were made at average rise plus fall 0.4 and 2.9%.

The results derived from the experiments reported in the study are in the form of average fuel consumption at per km on level tangent roads by different classes of vehicles and characterisitcs versus different levels of speeds.

2.2.3 Vehicle Operating Costs Study

This report No.79 was also carried out by Mr. Abdul Majeed, in 1985 of the Centre. The results of the highway speed survey and the fuel consumption study have been used in this study to estimate the VOC. The other basic data have been derived from the studies carried out in different countries and other agencies in Pakistan. In the report the Vehicle Operating Costs have been compiled for three types of road viz. paved, un-paved and shingle. The costs of different components have been compiled by given road characteristics and quantity unit costs were multiplied with prices of each component.

In the study the correction values have been provided for different costs components at varying road characteristics i.e. surface roughness, rise and fall, degree of curvature.

Table-2

Physical characteristics of Representative Vehicles

Sl. No.	Type of Vehicle and make		Gross Weight, tonnes	No of axles	No of tyres excluding spare
1	2		3	4	5
1.	Car 1000-1300 cc	- Toyota	1.0	2	4
2.	Wagon/mini bus	- Ford - Transit	2.7	2	4
3.	Bus - 52 seater	- Bedford	10.0	2	6
4.	Truck	- Bedford	14.0	2	6

The given road characteristics for three types of roads to estimate the VOC were as follows:

Table-3

Specifications of Roads Types

Type of road	Gradient m/km	Curvature degrees/km	Roughness m/km
1	2	3	4
Improved	10	100	1.5
Un-improved	20	200	3.5
Shingle	20	200	5.5

The estimated VOC physical as well as financial as reported in the study will be discussed in chapter for the purpose of comparison.

In spite of all these efforts no attempt has so far been made to estimate the theoretical VOC, neighter has any model for this purpose been developed nor adopted from any other study. In the report mentioned above, it seems that primary data have been obtained from other countries and sources which may vary from Pakistan's conditions because each component behaves differently with the cahnges in any other variable. It is true that many factors correlate with each other and different factors influence in different ways in different areas of the world.

2.2.4 Road Freight Industry Survey

The study was carried out is pakistan by Mr. John L. Hine of TRRL. In this report Mr. Hine has estimated the operating costs of freight transport as a part of the study. The estimated operating costs in this report are based on field surveys and road side interviews of drivers and operators. The results of this report will be used to calculate the empirical operating costs of goods vehicles.

CHAPTER-3

3. Assessment of Vehicle Operating Costs

3.1 Geographical and Climatic Condition

Pakistan is lying between the latitudes of 23 45 north and between the longitudes of 61 and 75 31 east. Pakistan stretches over 1600 km north to south and about 885 km broad east to west covering a total area of 796,095 square km. It comprises of four provinces: The North-West Frontier Province (NWFP), Punjab, Baluchistan and Sind, of these, Baluchistan is the largest province, with an area of 347,190 square km, followed by Punjab , 205,344 square km, Sind, 140,914 square km, the NWFP, 74,521 square km. The Federally Administered Tribal Area (FATA) covers 27,220 square km and the Federal Capital (Islamabad) area is 906 square km. The Punjab is the largest province in population. Whereas the Karachi is the most densely populated city, followed by Lahore city of Punjab and so on. In addition to these the Azad Jamu and Kashmir (AJK) is also the part of Pakistan, which is in the north part of the country.

Pakistan is a land of diversified relief. In the north it is bonded by the Himalayan ranges; the Karakoram range and the Hindukash beyond it. The Himalayas have an average elevation of 6100 metres with some of the highest peaks in the world. K-2, 8111 metres is the highet peak of the Karakoram range and second highest in the world. Tirich Mir, 7736 metres is the highest peak of the Hindukash. Below the Karakorams is the parallel range of the Himalayas extending far to the east and on the west, ending up at the Nanga Parbat peak, 8068 metres standing eighth in the world rating.

Out of the total 796,095 square, km about 475,884 square km is in the north-west and west from a highly differentiated mountainous terrain. The remaining 320,211 square km is a flat and gradational surface. Pakistan comprises the following six major physical diversions or regions: (1) northern mountains, (2) Western off-shoots of the Himalayans, (3) Baluchistan plateau, (4) potwar plateau and the salt range, (5) upper and lower Indus plains, (6) the Thar desert.

Pakistan is located in the north of the tropic of cancer and possesses a great range of climatic diversity, from some of the hottest in the world in Jacobabad and Sibi districts (Baluchistan) to the coldest in the world in Skardu, Hunza in the northern area. Along the coastal belt, the climate is modified by sea breezes. Pakistan is on the margin of the monsoon climate. In the plain, the temperature in the month of January varies from 0 to 28 and in June/July from 21 to 46 whereas in the mountainous are, the temperature in the months of January/February varies from - 11 to 4 and in the months of June/July from 11-20 .

The rainfall in the plains varies from 12.7 cm in upper Sind to 125 cm in the Himalayan sub mountain area, while in the lee of these mountains, in the gilgit Agency and Baluchistan, it is hardly 15 cm. It usually takes place during July to September due to its monsoon origin. In the hot weather, occasionally high rains follow the dust storms.

Apart from above the water logg also influences the road deterioration but the exact information about the water logg is not available. But it is generally known that in most of the plains area the water logg exists.

3.2 Volume and Composition

The information about the volume and composition of traffic on the raod is needed to determine the speed at which vehicles will move. If the road is congested the speeds slows down. In both conditions at very low and very high speed, the fuel consumption is high and is lowest at optimal speeds. The traffic volume is both very low or high, according to the road capacity and is affected by the vehicle speed, fuel consumption and subsequently the VOC. The composition of f

ast and slow moving vehicles on the roads also influence the speed.

the number of vehicles on roads or in the country in 1989 stood at 1,695,500 of which 86,534 were trucks, 48,298 buses, 26,320 delivery vans, 33,609 taxis, 50,677 auto rickshaws, 237,966 tractors, 35,041 wagons, 27,745 jeeps, 331,451 cars, 745,921 motor cycles and scooters and 71,938 others.

3.3 Application of Models

In order to develop the models to predict the VOC and the research efforts which are being made for the past fifteen years by the numerous experts this can be divided into two categories, viz. aggregate-correlative approach and micro-mechanistic approach. These approaches are briefly described below.

3.3.1 Aggregate-Correlative Approach

Under this approach the models produced are expressed in simple algebraic forms. Aggregate-correlative models have been developed in the major studies conducted in Kenya, the Caribbean, India and Brazil. The Kenyan and the Caribbean studies conducted by TRRL, to predict and calculate the VOCs, the Road Transport Investment Model (RTIM) have whereas for the Brazilian study the work was implemented by the Brazilian transport Planning Agency (GEIPOT) and by the taxes Research and Development Foundation (TRDF) as the contractor of the World Bank, which served as the executing agency for UNDP. A separate computer model to predict speed and fuel consumption has been developed for the study. The Indian study was carried out by the Central Raod Research Institute of India (CRRI) joints sponsored by World Bank and the Indian government. The Highway Design Model (HDM) has been used to predict the VOC. For this approach less data base from users is required.

In fact every model is supplemented by the following models. The TRRL has now develped an advanced version of TRIM model named RTIM2. Similarly, the World Bank has improved their model HDM and named it HDMIII.

The aggregate algebraic functions are easy to use and locally adaptable providing the values of the necessary regional factors. Under this approach the poineering kenyan models have been implemented in Road Investment Analysis Model (RIAM), the first version of Road Transport Investment Model (RTIM) and an early version of the Highway Design Model (HDM). The caribbean models have been incorporated in the latest version of the RTIM model (RTIM2), and the kenya, India and some of the Brazilian models have been included in the new version of the HDM model (HDMIII).

3.3.2 Micro - Mechanistic Approach

This approach has a genral tendency to depend less on a large data base of a single field study than the aggegate-correlative approach. In this approach comprehansive details of independent variables of each road section are required. This approach is particularly based on theory and has an inherent tendency to transfer in other conditions. This model has less provision for empirical quantification than aggregate-correlative. In this model no provision for road surface roughness is the main variable which influences the vehicle speed and subsequently fuel consumption.

Most of the models used in the major VOC studies are based on the aggregate-correltaive approach.

Due to non-aviability of details, road characteristics and some other limtations our own equations cannot be checked from the above mentioned models.

therefore, to estimate the VOCs the methodology will be to use the RTIM2 model. The equations for each component will be used on computers by given ranges of road characteristics. The average rise plus fall for paved road will be from 5 to 20 m/km, average surface roughness from 2000 to 4000 mm/km (bump integrator) and the average degree of curvature will be from 50 to 200 /km. Whereas for unpaved roads the rise plus full will be from 5-20 m/km, average surface roughness from 6000-8000 mm/km (BI) and the average degree of curvature will be from 100 to 250 /km.

3.4 Vehicle Characteristics

Most of the common vehicles which are operating in the country have been taken to work out the VOC. The detail characteristics may be seen in table-4.

Pakistan is assembling Suzuki-800 cc, and recently has started the assembly of Suzuki-1000 cc. Therefore, Suzuki-800 cc has become the most common car in the country. However, it is rather small to be taken as a typical car, the typical car is some what larger. The Toyota Corolla has also been considered in this analysis as a typical car with a 1300 cc engine. This is a popular vehicle and almost similar to other popular cars viz. the Honda, Nissan, Mazda and Lancer.

Table 4
Vehicle Characteristics

Vehicle Class	Make & Model	Fuel Type	BHP (SAE) RPM	No. of Tyres	Tyre Size	No. of Axles	GVW (K.G)	Seating Capacity
CARS	Toyota Corolla AE 80-R	Petrol	1295 C.C	4	6.15x13	2	910	4
	Suzuki 800 C.C	Petrol	39.5/5500	4	5.65x12	2	620	4
	Suzuki 1000 CC	Petrol	50/5800	4	5.95x12	2	690	4
WAGON	Ford BDV-ZEA	Diesel	24 H.P.	4	6.15x14	2	1547	12
MINI BUSES	Mazda T3500	Diesel	90PS/3000	6	7.00x16	2	6115	30
BUSES	Bedford NJM2BZO	Diesel	98/2600	6	825x20	2	10920	52
TRUCKS	Bedford CJP3ZO	Diesel	98/2600	6	900x20	2	10920	-
	Nissan TK20GT	Diesel	190/2300	6	1100x20	2	14175	-

3.5 Road Characteristics

As reported earlier in this chapter the road characteristics viz. surface roughness, rise plus fall and degree of curvature of any region or average are not available therefore, differnt ranges of such variables ahave been assumed to use in the equations. The ranges of raod characteristics which have been used to estimate the VOC are shown below in table-5.

Table-5

Road Characteristics

Type	Rise and Fall (m/km)	Roughness BI (mm/km)	Curvature (/km)	Pavement Width (m)
1	2	3	4	5
Paved	5-20	2000-4000	50-200	8
Un-Paved	5-30	6000-8000	100-250	4

In the following chapter the theoretical estimates of the main components of Vehicle Operating Costs as well as models used to derive the results have been reportd.

CHAPTER-4

4. Vehicle Operating Costs

It is evident from all of the exercises done in the past that theoretical costs vary with the empirical cost. Assuming that this due to the reason that in the theoretical equations no provision has been provided for the different makes of a vehicle class. Similarly in the vehicle estimation the road characteristics, vehicle cahracteristics and volume and composition of the vehicle on road of the region have been taken as an averages. Because the theoretical models have been used to predict the Vehicle Operating Costs at country level instead of a particular road section or a vehicle class and its make. It is also established from the results of the major studies discussed in chapter-2 that in the theoretical estimation the over heads are not included. Accordingly it may be assumed that the theoretical costs should be less than empirical. In order to check the differences in the theoretical and the experimental unit costs of each component as well as total Vehicle Operating Costs, in the Running chapter the theoretical as well as empirical costs have been calculated.

4.1 Theoretical Costs

In the following section the theoretical unit costs have been derived by using the RTIM and RTIM2 models. The equations used to derive the costs of each component on paved and unpaved roads are as under.

Paved Roads

Cars

$V = 102.6-372RS-0.076FL-0.111C-0.0049A$

$F = (53.4+499/V+0.0058V^2+1.594RS-0.854F)\times 1.08$

$TC = (-.0601+0.0000764R)\times 10^{-3}$

$PC = (-5.50+0.00262R)\times 10^{-10}\times VP\times K$

$LH = (851-0.078R)\times PC/VP$

$DP = 0.25+0.078Y$

Wagons

$V = 86.9-0.418RS-0.050FL-0.074C-0.0028A$

$F = (74.7+1151/V+0.0131V^2+2.906RS-1.277FL)\times 1.08$

$TC = (-83+0.058R)\times 10^{-6}$

$PC = (-5.50+0.00262R)\times 10^{-11}$

$LH = (851-0.078R)\times PC/VP$

$DP = 0.25+0.078Y$

Buses

$V = 72.5-0.526RS+0.067FL-0.066C-0.0042A$

$F = (-48.6+69.2\sqrt{(VW)}+903/V+0.0143V^2+4.362RS-1.834FL-2.40PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (-0.67+0.0006R)\times 10^{-9}\times VP\times K$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

Medium Trucks

$V = 51.9-0.222RS-122FL-0.017C-0.00106R+.559PW$

$F = (105.4+903/V+0.0143V^2+4.362RS-1.834FL-2.40PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (0.48+0.00037R)\times 10^{-11}\times VP\times K$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

Heavy Trucks

$V = 68.1-.519RS+0.030FL-0.058C-0.0004A$

$F = (-48.6+69.2\sqrt{(VW)}+903/V+0.0143V^2+4.362RS-1.834FL-2.40PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (0.48+0.00037R)\times 10^{-11}\times VP\times K$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

Unpaved Roads

Cars

$V = 84.2-0.210RS-0.070FL-0.118C-0.00089R-0.13M-0.19RD$

$F = (-46.9+614/V+0.0079V^2+1.723RS-1.066FL+0.00113R+0.82L)\times 1.08$

$TC = (-0.060+0.0000764R).10^{-3}$

$PC = (-5.50+0.00262R)\times 10^{-10}$

$LH = (851-0.078R)\times PC/VP$

$DP = 0.25+0.078Y$

Wagons

$V = 81.2-0.317RS-0.059FL-0.097C-0.00095R-0.29M-0.20RD$

$F = (72.8+844/V+0.0137V^2+2.828RS-1.306FL+0.00110R+1.76L)\times 1.08$

$TC = (-83+0.058R).10^{-6}$

$PC = (-5.50+0.00262R)\times 10^{-11}$

$LH = (851-0.078R)\times PC/VP$

$DP = 0.25+0.078Y$

Buses

$V = 62.6-0.492RS+0.010FL-0.046C-0.00036R-0.16M-0.09RD$

$F = (-32.0+69.2\sqrt{GVW}+796/V+0.0150V^2+4.176RS-2.216FL+0.00145R+1.97L-2.62PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (-0.67+0.0006R)\times 10^{-9}\times VP\times K^{\frac{1}{2}}$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

Medium Trucks

$V = 69.3-0.433RS+0.004FL-0.061C-0.00060R-0.22M-0.27RD$

$F = (122.0+796/V+0.0150V^2+4.176RS-2.216FL+0.00145R+1.97L-2.62PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (0.48+0.00037R)\times 10^{-11}\times VP\times K$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

Heavy Trucks

$V = 69.3-0.433RS+0.004F-0.061C-0.00060R-0.22M-0.27RD$

$F = (-32.0+69.2\sqrt{GVW}+796/V+0.0150V^2+4.176RS-2.216FL+0.00145R+1.97L-2.62PW)\times 1.13$

$TC = (83+0.0112R).L.10^{-7}$

$PC = (0.48+0.00037R)\times 10^{-11}\times VP\times K$

$LH = PC\times 0.45$

$DP = -0.317+0.625Y^{1/3}$

The notations used in the equations are as follows.

NOTATIONS

V = Vehicle speed km/hr

F = Fuel consumption ($1/10^3$ km)

O = Oil consumption per 10^3 km

TC = Tyre consumption per 10^3 km

PC = Maintenance parts cost per 10^3 km

LH = Maintenance labour hours per 10^3 km

DP = Depreciation percentage of new vehicle price

RS = Rise (m/km)

FL = Fall (m/km)

R = Surface Roughness (mm/km)

C = Degree of Curvature (^{o}/km)

A = Altitude (meter)

PW = Power to gross vehicle weight ratio (bhp/tonnes)

GVW = Gross vehicle weight (tonnes/kg)

K = Age of vehicle ($km/10^3$)

Y = Age of vehicle (years)

W = Road width

RD = Rut depth

M = Moisture contents (%)

VP = Vehicle price (Rupees)

4.1.1 Vehicle Speed

In the Vehicle Operating Costs the vehicle speed prediction need to determine the crew costs, interest and depreciation. The fuel consumption is a major component in the Vehicle Operating Costs which influence the vehicle speed. The model used to predict vehicle speed is a simple linear function of highway characteristics viz average rise plus fall, average degree of curvature and surface roughness.

The results derived from the linear equations are reported in the table 6-7.

4.1.2 Fuel Consumption

Fuel cost is the main component of Vehicle Operating Costs. The models ued to predict the fuel conumption took into consideration the speed, road characteristics i.e. gradient and in some models, roughness, but not curvature except where curvature affects speed. The model applied for fuel consumption related directly to the vehicle speed and highway characteristics. It is evident that at constant speed, other than steep grades, the relationship between fuel consumption and vehicle speed is U-shaped. the fuel consumption models shown below have this U-shaped form. Fuel consumption being minimum when vehicle speed is equal to (b/2c) 1/3 (assuming b, c positive).

The graphs plotted from the equations are placed in figure 1. Hide et (1975) derives a relationship between fuel consumption and gross vehicle weight (tonnes) using user survey fuel consumption data and adds this to the medium truck fuel consumption equations given above to allow predictions to be made for heavy goods vehicles and buses. To incorporate this adjustment add (-154+69.2 (GVW) to the medium truck fuel consumption equations. To convert the fuel consumption predictions use the equations mentioned above to predict fuel consumption under normal operating conditions. The equations are mentioned after converting coefficients on the power to weight ratio so that they may apply to power to weight ratio in kilowatts per ton.

It is also mentioned here that during the analysis it has been observed that to workout the fuel consumption for different type of cars, no provision is available in the equations of RTIM2 model. Therefore the equation has slightly been modified to workout the fuel consumption by using a correction factor. This correction factor is based on the empirical results derived by conducting a small scale road side interview survey. Accordingly for Suzuki 1000 c.c. and 800 c.c. the correction factors are -0.020 and -0.033 respectively. These factors have been incorporated in the original equation used for Toyota 1300 c.c. car.

The predict fuel consumption at diff rent speeds and road characteristics are reported in the table 6 & 7.

Table-6

Vehicle Speed V/S Fuel Consumption on Paved Road

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (0/Km): 50 Speed	50 Fuel	100 Speed	100 Fuel	150 Speed	150 Fuel	200 Speed	200 Fuel
1	2	3	4	5	6	7	8	9	10	11
5	2000-4000	Car Toyota	92.00	120.54	86.50	114.77	80.90	109.33	75.35	104.38
		Car Suzuki 1000	92.00	100.54	86.50	94.77	80.90	89.33	75.35	84.38
		Car Suzuki 800	92.00	87.54	86.50	81.77	80.90	76.33	75.35	71.38
		Wagon	79.25	194.01	75.55	183.66	71.85	179.81	68.15	175.58
		Mini Buses	64.49	195.60	61.19	189.76	57.87	184.36	54.89	179.42
		Buses	64.49	276.10	61.19	273.65	57.87	264.86	54.59	259.92
		Medium Trucks	62.53	186.30	59.63	181.38	56.73	176.30	53.83	172.60
		Heavy Trucks	62.53	299.87	59.63	294.94	56.73	290.36	53.83	286.76
10	2000-4000	Car Toyota	89.76	122.14	84.21	116.49	78.66	111.16	73.11	106.41
		Car Suzuki 1000	89.76	102.14	84.21	96.49	78.66	91.16	73.11	86.41
		Car Suzuki 800	89.76	89.14	84.21	83.49	78.66	78.16	73.11	73.41
		Wagon	76.91	198.13	73.21	191.07	69.51	184.51	65.81	178.44
		Mini Buses	62.20	205.78	58.90	200.24	55.60	195.17	52.30	190.57
		Buses	62.20	286.29	58.90	280.74	55.60	275.67	52.30	271.88
		Medium Trucks	60.08	196.41	57.18	191.76	54.28	187.27	51.38	103.60
		Heavy Trucks	60.08	309.96	57.18	305.33	54.20	301.07	51.32	297.07
15	2000-4000	Car Toyota	87.53	123.81	81.98	118.34	76.43	113.30	70.88	108.73
		Car Suzuki 1000	87.53	103.81	81.98	98.34	76.43	93.30	70.88	88.73
		Car Suzuki 800	87.53	90.81	81.98	85.34	76.43	80.30	70.88	75.73
		Wagons	72.23	206.88	68.53	200.45	64.83	194.50	61.13	189.06
		Mini Buses	57.61	307.27	54.31	302.39	51.01	217.48	47.71	294.11
		Buses	57.61	307.27	54.31	302.39	51.01	297.98	47.71	294.11
		Medium Trucks	55.19	217.48	52.29	213.36	49.39	209.84	46.49	206.53
		Heavy Trucks	55.19	330.93	52.29	326.92	49.39	323.29	46.49	320.10
20	2000-4000	Car Toyota	85.29	125.54	79.74	120.25	74.19	115.40	68.64	111.02
		Car Suzuki 1000	85.29	105.54	79.74	100.25	74.19	95.40	68.64	91.02
		Car Suzuki 800	85.29	92.54	79.74	87.25	74.19	82.40	68.64	78.02
		Wagons	67.55	216.42	63.85	210.61	60.13	205.28	56.43	200.53
		Mini Buses	53.02	329.17	49.72	244.46	46.42	240.79	43.12	237.71
		Buses	53.02	329.17	49.72	324.96	46.42	321.29	43.12	318.21
		Medium Trucks	50.30	239.39	47.40	236.06	44.50	233.15	41.60	230.71
		Heavy Trucks	50.30	352.96	47.40	349.62	44.50	346.72	41.60	344.30

Table-7

Vehicle Speed V/S Fuel Consumption
on Un-Paved Road

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (D/Km)							
			100		150		200		250	
			Speed	Fuel	Speed	Fuel	Speed	Fuel	Speed	Fuel
1	2	3	4	5	6	7	8	9	10	11
5	6000	Car Toyota	56.50	109.35	50.6	105.32	44.7	102.27	38.8	100.31
		Car Suzuki 1000	56.50	89.35	50.6	85.32	44.7	82.27	38.8	80.31
		Car Suzuki 800	56.50	75.35	50.60	71.32	44.7	68.27	38.85	66.31
		Wagon	52.44	171.04	47.59	165.64	42.74	161.34	37.89	158.27
		Mini Buses	47.91	214.46	45.61	211.77	43.31	209.35	41.01	207.23
		Buses	47.91	296.52	45.61	293.83	43.31	291.41	41.01	289.29
		Medium Trucks	44.02	205.28	40.97	202.41	37.92	200.10	34.87	198.42
		Heavy Trucks	44.02	317.27	40.97	314.40	37.92	312.08	34.87	310.39
	6500	Car Toyota	56.06	109.63	50.16	105.67	44.26	102.68	38.36	100.83
		Car Suzuki 1000	56.06	89.63	50.16	85.67	44.26	82.68	38.36	80.83
		Car Suzuki 800	56.06	75.63	50.16	71.67	44.26	68.68	38.36	66.83
		Wagon	51.97	171.07	47.16	165.81	42.27	161.58	37.42	158.64
		Mini Buses	47.73	215.07	45.43	212.39	43.13	209.99	40.83	207.89
		Buses	47.73	297.14	45.43	294.45	43.13	292.06	40.83	289.95
		Medium Trucks	43.72	205.80	40.67	202.98	37.62	200.73	34.57	199.11
		Heavy Trucks	43.72	317.79	40.67	314.96	37.62	312.71	34.57	311.09
	7000	Car Toyota	55.61	110.20	49.71	106.02	43.81	103.12	37.91	101.36
		Car Suzuki 1000	55.61	90.20	49.71	86.02	43.81	83.12	37.91	81.36
		Car Suzuki 800	55.61	76.20	49.71	72.02	43.81	69.12	37.91	67.36
		Wagons	51.49	171.09	46.64	165.90	41.79	161.82	36.94	159.03
		Mini Buses	47.55	215.67	45.25	213.01	42.95	210.63	40.65	208.56
		Buses	47.55	297.73	45.25	295.07	42.95	292.69	40.65	257.19
		Medium Trucks	43.42	206.31	40.37	203.55	37.32	201.36	34.27	199.80
		Heavy Trucks	43.42	318.29	40.37	315.54	37.32	313.34	34.27	311.78
	7500	Car Toyota	55.17	110.20	49.27	106.38	43.37	103.55	37.47	101.89
		Car Suzuki 1000	55.17	90.20	49.27	86.38	43.37	83.55	37.47	81.89
		Car Suzuki 800	55.17	76.20	49.27	72.38	43.37	69.55	37.47	67.89
		Wagons	51.02	171.14	46.17	166.04	41.32	162.08	36.47	159.43
		Mini Buses	47.37	216.26	45.07	213.63	42.77	211.28	40.47	209.23
		Buses	47.37	298.32	45.07	295.69	42.77	293.34	40.47	291.29
		Medium Trucks	43.12	206.84	40.07	204.12	37.02	201.99	33.97	200.50
		Heavy Trucks	43.12	318.82	40.07	316.11	37.02	313.97	33.97	312.48

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (D/Km)							
			100		150		200		250	
			Speed	Fuel	Speed	Fuel	Speed	Fuel	Speed	Fuel
1	2	3	4	5	6	7	8	9	10	11
	8000	Car Toyota	54.72	110.48	48.82	106.72	42.92	103.99	37.02	102.43
		Car Suzuki 1000	54.72	90.48	48.82	86.74	42.92	83.97	37.02	82.43
		Car Suzuki 800	54.72	76.48	48.82	72.74	42.92	69.99	37.02	68.43
		Wagons	50.54	171.18	45.69	166.19	40.84	162.36	35.99	159.84
		Mini Buses	47.19	216.87	44.89	214.26	42.59	211.93	40.29	209.91
		Buses	47.19	298,93	44.89	296.32	42,59	293,99	40.29	291.97
		Medium Trucks	42.82	207.37	39.77	204.72	36.72	202.64	33.67	201.21
		Heavy Trucks	42.82	319,35	39.77	316.70	36.72	314.62	33.67	313.19
10	6000	Car Toyota	55.1	111.86	49.2	108.06	43.30	105.24	37.40	103.59
		Car Suzuki 1000	55.1	91.86	49.2	88.06	43.30	85.24	37.40	83.59
		Car Suzuki 800	55.1	77.86	49.2	74.06	43.30	71.24	37.40	69.59
		Wagon	50.56	177.05	45.71	172.05	40.86	168.20	36.01	165.70
		Mini Buses	45.50	222.72	43.20	220.40	40.90	218.21	38.6	216.42
		Buses	45.50	304.78	43.20	302.37	40.90	300.27	38.6	298.48
		Medium Trucks	41.87	214.28	38.82	211.79	35.77	209.91	32.7	208.72
		Heavy Trucks	41.87	326.26	38.82	323.77	35.77	321.89	32.7	320.70
	6500	Car Toyota	54.66	112.16	46.76	107.38	42.86	105.69	36.96	104.14
		Car Suzuki 1000	54.66	92.16	46.76	87.38	42.86	85.69	36.96	84.14
		Car Suzuki 800	54.66	78.16	46.76	73.38	42.86	71.69	36.96	70.14
		Wagon	50.09	177.11	45.24	172.23	40.39	168.50	33.54	166.13
		Mini Buses	45.32	223.34	43.02	220.96	40.72	218.88	38.42	217.11
		Buses	45.32	305.40	43.02	303.02	40.82	300.94	38.42	299.17
		Medium Trucks	41.57	214.83	38.52	212.40	35.47	210.58	32.42	209.46
		Heavy Trucks	41.57	326.81	38.52	324.38	35.47	322.57	32.42	321.44
	7000	Car Toyota	54.21	112.46	48.31	108.78	42.41	106.13	36.51	104.68
		Car Suzuki 1000	54.21	92.46	48.31	88.78	42.41	86.13	36.51	84.68
		Car Suzuki 800	54.21	78.46	48.31	74.78	42.41	72.13	36.51	70.68
		Wagons	49.61	177.17	44.76	172.40	39.91	168.79	35.06	166.57
		Mini Buses	45.14	223.96	42.84	221.60	40.54	219.54	38.24	217.81
		Buses	45.14	306.02	42.84	303.66	40.54	301.60	38.24	299.87
		Medium Trucks	41.27	215.39	38.22	213.02	35.17	211.26	32.12	210.21
		Heavy Trucks	41.27	327.37	38.22	325.00	35.17	323.24	32.12	322.19

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (D/Km) 100 Speed	100 Fuel	150 Speed	150 Fuel	200 Speed	200 Fuel	250 Speed	250 Fuel
1	2	3	4	5	6	7	8	9	10	11
	7500	Car Toyota	53.77	112.76	47.87	109.16	41.97	106.58	36.07	105.24
		Car Suzuki 1000	53.77	92.76	47.87	89.16	41.97	86.58	36.07	85.24
		Car Suzuki 800	53.77	78.76	47.87	75.16	41.97	72.58	36.07	71.24
		Wagons	49.14	177.25	44.29	172.59	39.44	169.11	34.59	167.03
		Mini Buses	44.96	224.58	42.66	222.25	40.36	220.21	38.06	218.50
		Buses	44.96	306.64	42.66	304.31	40.36	302.27	38.06	300.56
		Medium Trucks	40.97	215.95	37.92	213.63	34.87	211.95	31.82	210.97
		Heavy Trucks	40.97	327.97	37.92	325.61	34.87	323.93	31.82	322.96
	8000	Car Toyota	53.32	113.06	47.42	109.54	41.52	107.05	35.62	105.81
		Car Suzuki 1000	53.32	93.06	47.42	89.54	41.52	87.05	35.62	85.81
		Car Suzuki 800	53.32	79.06	47.42	75.54	41.52	73.05	35.62	71.81
		Wagons	48.66	177.33	43.81	172.77	38.96	169.42	34.11	167.51
		Mini Buses	44.78	225.21	42.48	222.90	40.18	220.89	37.88	219.20
		Buses	44.78	307.27	42.48	304.96	40.18	302.95	37.88	301.26
		Medium Trucks	40.67	216.51	37.62	214.26	34.57	212.64	31.52	211.77
		Heavy Trucks	40.67	328.49	37.62	326.24	34.57	324.62	31.52	323.71
20	6000	Car Toyota	52.30	117.04	46.40	113.68	40.50	111.39	34.60	110.41
		Car Suzuki 1000	52.30	97.04	46.40	93.68	40.50	91.39	34.60	90.41
		Car Suzuki 800	52.30	73.04	40.40	97.68	40.50	77.39	34.60	76.41
		Wagon	46.80	189.52	41.95	185.40	37.10	182.57	32.25	181.29
		Mini Buses	40.68	240.17	38.38	238.41	36.08	237.00	33.78	235.97
		Buses	40.68	322.23	38.38	320.47	36.08	319.06	33.78	318.03
		Medium Trucks	37.58	233.10	34.53	231.48	31.48	230.59	28.43	230.57
		Heavy Trucks	37.58	345.08	34.53	343.47	31.48	342.58	28.43	342.55
	6500	Car Toyota	51.86	117.37	45.96	114.08	40.08	111.88	34.16	110.99
		Car Suzuki 1000	51.86	97.37	45.96	94.08	40.08	91.88	34.16	90.99
		Car Suzuki 800	51.86	83.37	45.96	80.08	40.08	77.88	34.16	76.99
		Wagon	46.33	189.66	41.48	185.66	36.63	182.96	31.78	181.86
		Mini Buses	40.50	240.83	38.20	239.11	35.90	237.73	33.60	236.73
		Buses	40.50	322.90	38.20	321.17	35.90	319.79	33.60	318.79
		Medium Trucks	37.28	233.73	34.23	232.18	31.18	231.38	28.13	231.43
		Heavy Trucks	37.28	345.71	34.23	344.16	31.18	343.36	28.13	343.42

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (0/Km) 100 Speed	100 Fuel	150 Speed	150 Fuel	200 Speed	200 Fuel	250 Speed	250 Fuel
1	2	3	4	5	6	7	8	9	10	11
	7000	Car Toyota	51.41	117.69	45.51	114.48	39.61	112.37	33.71	111.60
		Car Suzuki 1000	51.41	97.69	45.51	94.48	39.61	92.37	33.71	91.60
		Car Suzuki 800	51.41	83.69	45.51	80.48	39.61	78.37	33.71	77.60
		Wagons	45.85	189.81	41.00	185.92	36.15	183.38	31.30	182.43
		Mini Buses	40.32	241.51	38.02	237.81	35.72	238.45	33.42	237.49
		Buses	40.32	323.57	38.02	321.87	35.72	320.51	33.42	319.56
		Medium Trucks	36.98	234.36	33.93	232.89	30.88	232.16	27.83	232.31
		Heavy Trucks	36.98	346.35	33.93	344.87	30.88	344.15	27.83	344.29
	7500	Car Toyota	50.97	118.03	45.07	114.89	39.17	112.87	33.27	112.23
		Car Suzuki 1000	50.97	98.03	45.07	94.89	39.17	92.87	33.27	92.23
		Car Suzuki 800	50.97	84.03	45.07	80.89	39.17	78.87	33.27	78.23
		Wagons	45.38	189.97	40.53	186.21	35.68	183.79	30.83	183.04
		Mini Buses	40.14	242.18	37.84	240.50	35.54	239.19	33.24	238.26
		Buses	40.14	324.24	37.84	322.56	35.54	321.25	33.24	320.32
		Medium Trucks	36.68	235.01	33.63	233.60	30.58	232.64	27.53	233.20
		Heavy Trucks	36.68	346.99	33.63	345.59	30.58	344.93	27.53	345.18
	8000	Car Toyota	50.52	118.36	44.62	115.31	38.72	113.38	32.82	112.86
		Car Suzuki 1000	50.52	98.36	44.62	95.31	38.72	93.38	32.82	92.86
		Car Suzuki 800	50.52	84.36	44.62	81.31	38.72	79.38	32.82	78.86
		Wagons	44.90	190.14	40.05	186.50	35.20	184.24	30.35	183.67
		Mini Buses	39.96	242.86	37.66	241.21	35.36	239.92	33.06	239.02
		Buses	39.96	324.92	37.66	323.27	35.36	321.98	33.06	321.08
		Medium Trucks	36.38	235.66	33.33	234.32	30.28	233.76	27.23	234.10
		Heavy Trucks	36.38	347.65	33.33	346.30	30.28	345.74	27.23	346.09
30	6000	Car Toyota	49.50	122.41	48.94	122.09	37.70	117.84	37.14	117.74
		Car Suzuki 1000	49.50	102.41	48.94	102.09	37.70	97.84	37.14	97.74
		Car Suzuki 800	49.50	88.41	48.94	88.09	37.70	83.84	37.14	83.74
		Wagon	43.04	202.66	38.19	199.52	33.34	197.86	28.49	198.07
		Mini Buses	35.86	259.04	33.56	258.05	31.26	257.49	31.12	257.48
		Buses	35.86	341.09	33.56	340.11	31.26	339.55	31.12	339.35
		Medium Trucks	33.29	253.18	30.24	252.62	27.19	252.98	24.14	254.51
		Heavy Trucks	33.29	365.16	30.24	364.60	27.19	364.97	24.14	366.49

Average rise and fall (m/km)	Average roughness (mm/km)	Vehicle Type	Average degree of curvature (D/Km)							
			100		150		200		250	
			Speed	Fuel	Speed	Fuel	Speed	Fuel	Speed	Fuel
1	2	3	4	5	6	7	8	9	10	11
	6500	Car Toyota	49.06	122.77	48.49	122.46	37.26	118.37	36.69	118.28
		Car Suzuki 1000	49.06	102.77	48.49	102.46	37.26	98.37	36.69	98.28
		Car Suzuki 800	49.06	88.77	48.49	88.46	37.26	84.37	36.69	84.28
		Wagon	42.57	202.90	37.72	199.88	32.87	198.39	28.02	198.81
		Mini Buses	35.68	259.77	33.38	258.81	31.08	258.29	30.94	258.28
		Buses	35.68	341.83	33.38	340.87	31.08	340.35	30.94	340.34
		Medium Trucks	32.99	253.91	29.94	253.44	26.89	253.90	23.84	255.56
		Heavy Trucks	32.99	365.89	29.94	365.42	26.89	365.88	23.84	367.54
	7000	Car Toyota	48.61	123.14	48.05	122.84	36.81	118.91	36.25	118.84
		Car Suzuki 1000	48.61	103.14	48.05	102.84	36.81	98.91	36.25	98.84
		Car Suzuki 800	48.61	89.14	48.05	88.84	36.81	84.91	36.25	84.84
		Wagons	42.09	203.13	37.24	200.25	32.39	198.93	27.54	199.58
		Mini Buses	35.50	260.49	33.20	259.56	30.90	259.09	30.76	259.08
		Buses	35.50	342.55	33.20	341.58	30.90	341.15	30.76	341.14
		Medium Trucks	32.69	254.64	29.64	254.25	26.59	254.83	23.54	256.61
		Heavy Trucks	32.69	366.63	29.64	366.24	26.59	366.81	23.54	368.59
	7500	Car Toyota	48.17	123.51	47.61	123.22	36.37	119.46	35.81	119.41
		Car Suzuki 1000	48.17	103.51	47.61	103.22	36.37	99.46	35.81	99.41
		Car Suzuki 800	48.17	89.51	47.61	89.22	36.37	85.46	35.81	85.41
		Wagons	41.62	203.39	36.77	200.65	31.92	199.48	27.07	200.37
		Mini Buses	35.32	261.23	33.02	260.34	30.72	259.89	30.58	259.88
		Buses	35.32	343.29	33.02	342.40	30.72	341.95	30.58	341.94
		Medium Trucks	32.39	255.38	29.34	255.08	26.29	255.77	23.24	257.69
		Heavy Trucks	32.39	367.36	29.34	367.07	26.29	367.75	23.24	369.67
	8000	Car Toyota	47.72	123.89	47.16	123.59	35.92	120.02	35.36	119.97
		Car Suzuki 1000	47.72	103.89	47.16	103.59	35.92	100.02	35.36	99.97
		Car Suzuki 800	47.72	89.89	47.16	89.59	35.92	86.02	35.36	85.97
		Wagons	41.14	203.65	36.29	201.06	31.44	200.06	26.59	201.19
		Mini Buses	35.14	261.96	32.84	261.11	30.54	260.69	30.40	260.68
		Buses	35.14	344.02	32.84	343.17	30.54	342.75	30.40	342.74
		Medium Trucks	32.09	256.13	29.04	255.92	25.99	256.72	22.94	258.78
		Heavy Trucks	32.09	368.12	29.04	367.09	25.99	368.70	22.94	370.77

4.1.3 Lubricant Consumption

It is evident that in the Vehilce Operating Costs lubricant costs are a minor component but difficult to examine. Lubricants include, engine oil, other oil and grease. In these three lubricant items, engine oil is the most important one in the VOC. No equation has been reported in neither RTIM2 nor the HDMIII models.

The results derived from the user survey data in the Kenyan and Carribean at different conditions of roads are assumed to be the same for Pakistan. The details of oil consumption, litre per 1000 km, are estimated in table 8.

Table-8

Engine Oil Consumption Litre Per 1000 Km.

Vehicle Type	Type of Road			
	Paved Road		Un-paved Road	
	Surface Roughness BI (mm/km		Surface Roughness	
	200	4000	600	8000
1	2	3	4	5
Car	1.2	1.2	2.4	2.4
Wagon	1.8	1.8	3.6	3.6
Mini Bus	4.0	4.0	8.0	8.0
Bus	4.0	4.0	8.0	8.0
Medium Truck	4.0	4.0	8.0	8.0
Heavy Truck	4.0	4.0	8.0	8.0

It is found that there is a 100% increase in oil consumption when vehicles are moved from paved to un-paved roads.

4.1.4 Tyre Consumption

Tyre costs are also an important component of Vehicle Operating Costs, particularly for heavy vehicles and in deveoping countries. Tyre wear is mainly related to road characteristics. It is evidnet that in developed countries the expected tyre life is more than 1000,000 km. On the other hand in the developing countries it is hardly half on paved roads costs increase linearity with highway characterisitcs. The dependent variable for tyre cost equation is T which is equivalent to new tyres per kilometer vehicle defined as T = TCV.

The tyre consumption predictions for various type of vehicle on paved and un-paved roads are reported in table 9.

4.1.5 Maintenance Parts Costs

The maintenance parts costs are directly related to the road characteristics, vehicle age and driver's behaviour. The maintenance costs also influence the way of utilisation of the vehicle. For example, control of speed, loads and preventive maintenance of the vehicle. The maintenance parts costs have been estimated as the percentage of new vehicle prices. The vehicle age also affects the maintenance costs, because the maintenance parts costs of an old vehicle is relatively higher than for a new one.

Table-9
Tyre Costs Per Kilometer Against Surface Roughness

Vehicle Tyre	TYRE COST — Paved Road — Surface Roughness BI (mm/km)				
	2000	2500	3000	3500	4000
1	2	3	4	5	6
Car	0.0000927	0.0001300	0.0001619	0.0002000	0:0002460
Wagon	0.0000330	0.0000620	0.0000910	0.0001200	0.0001490
Mini Bus	0.0000645	0.0000679	0.0000713	0.0000747	0.0000782
Bus	0.0001151	0.0001212	0.0001273	0.0001334	0.0001396
Medium Truck	0.0001054	0.0001110	0.0001166	0.0001222	0.0001278
Heavy Truck	0.0001494	0.0001573	0.0001653	0.0001732	0.0001812

Vehicle Tyre	Un-Paved Road — Surface Roughness BI (mm/km)				
	6000	6500	7000	7500	8000
1	2	3	4	5	6
Car	0.00039830	0.00043650	0.00047470	0.0005129	0.0005511
Wagon	0.00026500	0.00029400	0.00032300	0.0003520	0.0003810
Mini Bus	0.00009190	0.00009530	0.00009870	0.0001021	0.0001055
Bus	0.00016402	0.00017010	0.00017620	0.0001824	0.0001885
Medium Truck	0.00015020	0.00015580	0.00016140	0.0001670	0.0001726
Heavy Truck	0.00021290	0.00022080	0.00022880	0.0002367	0.0002447

Before deriving the results of maintenance costs it is necessary to explain that the age of the vehicle in km has been estimated as: average vehicle driven hours per year, multiplied by total vehicle age in years since the first registration. The total vehicle kilometerage depends upon the highway conditions and highway characteristics influences the vehicle speed. The vehicle kilometerage per year against vehicle age in years and surface roughness may be seen in table 12.

The predicted maintenance parts costs against vehicle age are shown in table 10.

Table-10

Maintenance Parts Costs Per Km Against Vehicle Age (PC % VP)

Vehicle Type	(000) Average Kilometerage		(PC % VP)	
	Paved	Un-paved	Paved Road	Un-Paved Road
1	2	3	4	5
Car (Toyota)	184	138	0.00004210	0.0000981
Car (Suzuki 1000)	184	138	0.00001470	0.0000341
Car (Suzuki 800)	184	138	0.00001040	0.0000241
Wagon	691	553	0.00000482	0.0000119
Mini Bus	864	691	0.00002246	0.0000581
Bus	1728	1382	0.00004576	0.0000977
Medium Truck	1382	1037	0.00001118	0.0000147
Heavy Truck	1728	1382	0.00002171	0.0000305

4.1.6 Maintenance Labour Costs

The results derived are shown in table 11.

Table-11
Average Maintenance Labour Hour Per Km

Vehicle Type	Average Kilometerage (000)		LH	
	Paved	Un-paved	Paved Road	Un-Paved Road
1	2	3	4	5
Car (Toyota)	184	138	0.0227130	0.02227
Car (Suzuki 1000)	184	138	0.0079233	0.00774
Car (Suzuki 800)	184	138	0.0056056	0.00547
Wagon	691	553	0.0037104	0.00270
Mini Bus	864	691	0.0087975	0.01319
Bus	1728	1382	0.2058300	0.04390
Medium Truck	1382	1037	0.0050310	0.00662
Heavy Truck	1728	1382	0.0097690	0.01373

4.1.7 Depreciation Costs

The depreciation costs can be calculated by using two methods viz. value-age (VA) method or optimal life (OL) menthod. Under the OL method the depreciation costs work out with the relationship of hours driven per year and derivation of a vehicle age invariant annual utilisation. Whereas, the VA method is the relationship of value and age of the vehicle. For this report the VA method has been used to estimate the depreciation costs.

The ages of all vehicles have been taken from the date of first registration details may be seen in table 12. The vehicle depreciation is also influenced by the driver behaviour and road conditions. The results of depreciation coss which have been derived by multiplying the depreciation percentage with the new vehicle price and divided by the vehicle age in 1000 km, have been reported in table 13.

Table 12
Average Vehicle Kilometerage

Vehicle Class	Average Daily Kilometerage		Average Kilometerage Per Year		Vehicle Age	Average Vehicle Kilometerage(000)	
	Paved	Un-paved	Paved	Un-paved	(years)	Paved	Un-paved
1	2	3	4	5	6	7	8
Car	80	60	23040	17280	8	184	138
Wagon	200	160	57600	46080	12	691	553
Mini Bus	250	200	72000	57600	12	864	691
Bus	500	400	144000	115200	12	1728	1382
Medium Truck	400	300	115200	86400	12	1382	1037
Heavy Truck	500	400	144000	115200	12	1728	1382

The depreciation costs are related to the total km driven at a given age and the total km driven depends upon the highway condition. If the highway condition is good then the vehicle kilometerage will be high due to the increase in speed. The 288 working day's year has been assumed to calculate the annual kilometerage.

Table-13
Average Vehicle Depreciation Per Km

Sl.No.	Type of Vehicle	Depreciation	
		Paved	Un-Paved
1	2	3	4
1.	Car	0.000037900	0.00005058
2.	Wagon	0.000335080	0.00026430
3.	Mini Bus	0.000137300	0.00016470
4.	Bus	0.000077380	0.00009670
5.	Medium Truck	0.000096700	0.00012890
6.	Heavy Truck	0.000077400	0.00009670

4.1.8 <u>Summary of Theoretical Unit Costs</u>

The theoretical unit costs of each components in terms of quantity has been summarised in table-14.

Table-14
Vehicle Operating Costs Per Kilometer
(Theoratical)

Vehicle Type	Paved						
	V	F	O	T	P	L	D
1	2	3	4	5	6	7	8
Car Toyota	86.50	0.115	0.0012	0.0000927	0.00004210	0.0227130	0.00003790
Car Suzuki 1000	86.50	0.095	0.0012	0.0000927	0.00001470	0.0079233	0.00003790
Car Suzuki 800	86.50	0.082	0.0012	0.0000927	0.00001040	0.0056056	0.00003790
Wagon	75.55	0.184	0.0018	0.0000330	0.00000482	0.0037104	0.00033508
Mini Bus	61.19	0.190	0.0040	0.0000645	0.00002246	0.0087975	0.00013730
Bus	61.19	0.274	0.0040	0.0001151	0.00004576	0.0205830	0.00007738
Medium Truck	59.63	0.181	0.0040	0.0001054	0.00001118	0.0050310	0.00009670
Heavy Truck	59.63	0.295	0.0040	0.0001494	0.00002171	0.0097690	0.00007740

Vehicle Type	Un-Paved						
	V	F	O	T	P	L	D
1	2	3	4	5	6	7	8
Car Toyota	54.72	0.110	0.0024	0.0005510	0.0000981	0.02227	0.00005058
Car Suzuki 1000	54.72	0.090	0.0024	0.0005510	0.0000341	0.00774	0.00005058
Car Suzuki 800	54.72	0.076	0.0024	0.0005510	0.0000241	0.00547	0.00005058
Wagon	50.54	0.171	0.0036	0.0003810	0.0000119	0.00270	0.00026430
Mini Bus	47.19	0.217	0.0080	0.0001055	0.0000581	0.01319	0.00016470
Bus	47.19	0.299	0.0080	0.0001885	0.0000977	0.04390	0.00009670
Medium Truck	42.82	0.207	0.0080	0.0001726	0.0000147	0.00662	0.00012890
Heavy Truck	42.82	0.319	0.0080	0.0002447	0.0000305	0.01373	0.00009670

Units:

V= Speed km/h
F= Fuel lit/km
O= Oil lit/km
T= Tyre Cost % of new tyre/km
P= Parts Cost % VP/km
L= Labour Cost Labour hour/km
D= Depreciation % of VP/km

4.2 Empirical Costs

For the comparison of theoretically estimated VOC, the results of research report `Vehicle Operating Costs´ carried out by Mr. Abdul Majeed, National Transport Research Centre (NTRC) which is based on two field surveys viz. Highway Safety Survey and Fuel Consumption study will be taken as empirical evidence. The brief introduction has already been reported in chapter-3. The results of the study in terms of quantity have been taken to calculate the empirical VOC.

Another tudy `Road Freight Industry Survey´ carried out by Mr. John L. Hine, Consultant of Transport and Road Research Laboratory (TRRL). In this report Mr. Hine has estimated the operating costs of the report are based on field surveys and road side interviews of teh drivers and operating costs of goods vehicles.

In addition to the above evidences a small scale survey has also been carried out to calculate the empirical operating costs of the vehicles which are not included in the above mentioned two studies. For this survey a simple questionnaire was designed to collect the requisit information from the drivers/operators. The specimen questionnaire is placed at Appendix A (1).

The empirical unit costs in terms of quantity derived from the above mentioned evidences have been summarised in table-15.

Table-15

Vehicle Operating Costs Per Kilometer
(Empirical)

Vehicle Type	Paved					
	F	O	T	P	L	D
1	2	3	4	5	6	7
Car Toyota	0.089	0.00144	0.0000240	0.000026	0.0026	0.000660
Suzuki 800	0.061	0.00144	0.0000163	0.000073	0.0026	0.000360
Wagon	0.147	0.00205	0.0000304	0.000337	0.0040	0.000347
Mini Bus	0.100	0.00216	0.0000240	0.000061	0.0170	0.002600
Bus	0.216	0.00550	0.0000770	0.000098	0.0196	0.000240
Medium Truck	0.278	0.00553	0.0000770	0.000094	0.0189	0.000260
Heavy Truck	0.405	0.00702	0.0001430	0.000087	0.0473	0.000260

Vehicle Type	Un-Paved					
	F	O	T	P	L	D
1	2	3	4	5	6	7
Car Toyota	0.109	0.00144	0.0000940	0.000276	0.00499	0.00066
Suzuki 800	0.075	0.00144	0.0000635	0.000276	0.00499	0.00036
Wagon	0.179	0.00205	0.0001413	0.003580	0.00768	0.00035
Mini Bus	0.134	0.00216	0.0001120	0.000284	0.01950	0.00026
Bus	0.270	0.00553	0.0001090	0.000266	0.02414	0.00024
Medium Truck	0.333	0.00553	0.0001090	0.000275	0.02409	0.00026
Heavy Truck	0.485	0.00702	0.0002260	0.000167	0.06093	0.00026

Units:

V= Speed km/h
F= Fuel lit/km
O= Oil lit/km
T= Tyre Cost % of new tyre/km
P= Parts Cost % VP/km
L= Labour Cost Labour hour/km
D= Depreciation % of VP/km

4.3 Financial Costs Calculations

The unit costs of each component has been multiplied with the prices of July, 1991. The details are shown in Annex-A(2).

The basis of price calculations of the necesary components are briefly mentioned in the following paragraphs.

4.3.1 Tyre

Two types of tyres are available in Pakistan, one is locally manufactured by the General Tyre Company and the other is imported. Market prices of imported and locally manufactured tyres do not vary widely. General Tyre Company estimated that the total market for tyres for four or more wheel vehicles in Pakistan is about 1.2 million units. According to 1989 statistics, the General Tyre Company have about 50% of the market (700,000 units).

The import duty on tyres is 100% other surcharges and sales tax. The retail prices are obtained from the local market.

4.3.2 Labour Charges

The average maintenance labour charges in Pakistan are obtained from 'Survey of Mechanised Road Transport' in which they have reported labour maintenance charges for different categories of vehicles for each provincial headquarter. In this survey the data were collected for annual employment costs of motor mechanics. As the results reported are of 1981-82, therefore, the inflation rate, i.e. 10%, has been used to estimated the maintenance labour charges.

4.3.3 Crew Costs

The costs of the crew of a bus, truck or car, is part of the economic and financial operating costs of the vehicle. For buses the calculation is based on one driver and a conductor. Wages for a driver are in a range round about Rs.1500 per month and for conductors Rs.1000 per month which is taken as a median. In addition drivers and conductors recieve a commission of 10% on the fare of each passenger. Fares for ordinary stage carriage services are based on Rs.0.01. For large and mini buses the average occupancy is 40 and average annual utilisation is 55,000 km. Therefore, the crew commission is on the average 40 x 0.10 x 55,000 x 10/1000 =22,000/12 =1833. This 10% commission is equally divided between the driver and the conductor. Therefore, the total monthly costs of a bus crew are estimated at Rs.4333.

For trucks the calculation is based on two drivers and a cleaner, responsible for the cleaning of the windscreen, to check the air in tyres, re-filling the radiator etc. Since this is by far the most common arrangement on long distance travel average wages for a driver are in the range of about Rs.1500 and Rs.1000 for cleaners per month. In addition drivers and cleaners receive an extra daily allowance for food etc. which is about Rs.15 for drivers and Rs.10 for cleaners. Therefore, the total monthly cost of a truck crew is estimated at Rs.5200 including allowance for food.

For Cars, the crew cost is calculated only for a driver and is Rs.1500 per month. The wages for car drivers are relatively higher than others because no extra allowance is admissible to them.

Assuming eight working hours per day for all categories of crew, finally the crew cost is calculated as mentioned in the price list. The annual wage rate has been divided by annual kilometerage for per km crew costs.

4.3.4 Interest Costs

The interest costs per km have been derived by assuming an interest rate of 12% per year on the capital costs (equivalent to the new vehicle price). The interest costs have been estimated on the basis of vehicle driven hours. The interest cost have been added in the total financial Vehicle Operating Costs in table-16.

The vehicle age (VA) method has been used to calculate notations have been used for total operating costs for each vehicle class.

V= Vehicle speed (km/hr)

F= Fuel costs

O= Engine oil costs

T= Tyre costs

P= Maintenance parts costs

L= Maintenance labour cost

C= Crew costs

D= Depreciation costs

I= Interet cost

4.3.5 Summary

The summary of Vehicle Operating Costs rupees per km for different class of vehicle on paved and un-paved roads are reported in table-16. Whereas the empirical operating costs rupees per km for different type of vehicles on paved and un-paved roads is shown in table-17.

Table-16

Vehicle Operating Costs Rupees Per Kilometer (Theoretical)

Vehicle Type	Paved									
	V	F	O	T	P	L	D	C	I	Total
1	2	3	4	5	6	7	8	9	10	11
Car Toyota	86.50	1.3559	0.0324	0.1112	0.193660	0.358638	0.174340	0.159	0.299	2.68414
Car Suzuki 1000	86.50	1.1201	0.0324	0.0834	0.026370	0.125109	0.067993	0.159	0.117	1.73137
Car Suzuki 800	86.50	0.9668	0.0324	0.0788	0.012830	0.088512	0.046769	0.159	0.080	1.46511
Wagon	75.55	0.9292	0.0486	0.0512	0.013496	0.060331	0.938210	0.182	0.083	2.30604
Mini Bus	61.19	0.9595	0.1080	0.1355	0.290500	0.147885	0.618537	0.361	0.063	2.68190
Bus	61.19	1.3837	0.1080	0.5335	0.296800	0.346000	0.502249	0.361	0.045	3.57625
Medium Truck	59.63	0.9141	0.1080	0.5059	0.060640	0.092269	0.523534	0.433	0.047	2.68444
Heavy Truck	59.61	1.4897	0.1080	0.8217	0.139161	0.179163	0.496134	0.433	0.045	3.71186

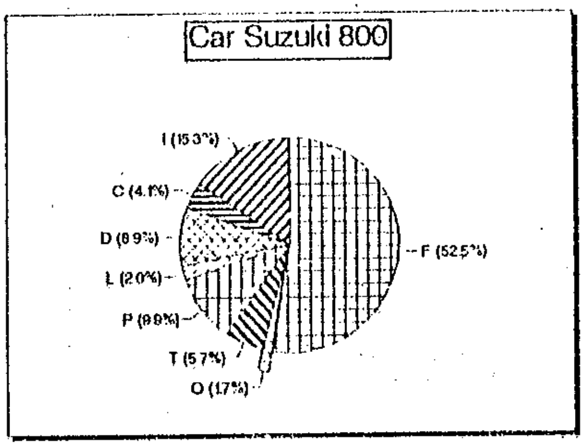
Vehicle Type	Un-Paved									
	V	F	O	T	P	L	D	C	I	Total
1	2	3	4	5	6	7	8	9	10	11
Car Toyota	54.72	1.2969	0.0648	0.6613	0.451260	0.351643	0.232760	0.2514	0.20000	3.51006
Car Suzuki 1000	54.72	1.0611	0.0648	0.4960	0.061180	0.122215	0.090776	0.2514	0.15570	2.30320
Car Suzuki 800	54.72	0.8960	0.0648	0.4684	0.029739	0.086371	0.062440	0.2514	0.10710	1.96625
Wagon	50.54	0.8636	0.0972	0.5906	0.033320	0.043902	0.740050	0.2270	0.10417	2.69984
Mini Bus	47.19	1.0958	0.0972	0.2216	0.261741	0.221724	0.741974	0.4510	0.07821	3.16925
Bus	47.19	1.5099	0.2160	0.8737	0.633975	0.737959	0.627485	0.4510	0.05633	5.10635
Medium Truck	42.82	1.0454	0.2160	0.8285	0.079586	0.121411	0.697865	0.5420	0.06266	3.59342
Heavy Truck	42.82	1.6109	0.2160	1.3459	0.195505	0.251801	0.619847	0.5420	0.06680	4.84875

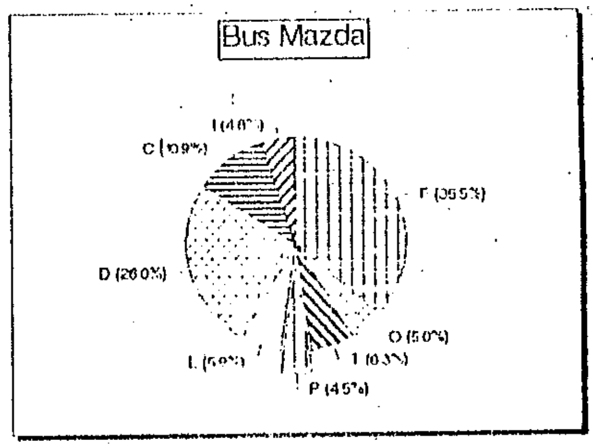
Units:

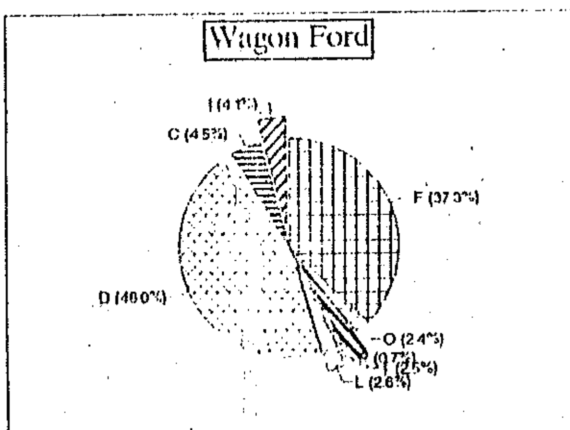
V= Speed
O= Oil lit/km
F= Fuel lit/km
T= Tyre cost % of new tyre/km
P= Part cost % VP/km
L= Labour cost Labour hour/km
D= Depreciation % of VP/km
C= Crew cost/km

Vehicle Operating Cost on Paved Roads

(Theoretical)







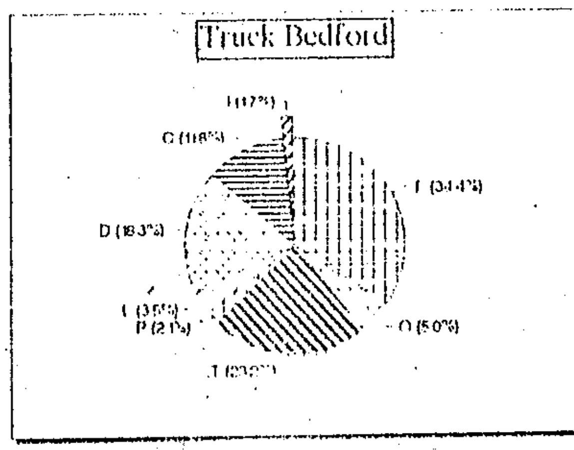


Table-17

Vehicle Operating Costs Rupees Per Kilometer

(Empirical)

Vehicle Type	Paved								
	F	O	T	P	L	D	C	I	Total
1	2	3	4	5	6	7	8	9	10
Car Toyota	1.0493	0.03890	0.0290	0.1196	0.0411	0.25290	0.159	0.299	1.9888
Car Suzuki 800	0.7192	0.03890	0.0140	0.0901	0.0411	0.44424	0.159	0.080	1.5865
Wagon	0.7424	0.05540	0.0470	0.9436	0.0650	0.97160	0.182	0.083	3.0900
Mini Bus	0.5050	0.05832	0.0500	0.2748	0.2858	1.17130	0.361	0.063	2.7692
Bus	1.0908	0.14850	0.3570	0.6359	0.3295	1.55736	0.361	0.045	4.5251
Medium Truck	1.4039	0.14931	0.3700	0.5089	0.3466	1.40764	0.433	0.047	4.6663
Heavy Truck	2.0453	0.18950	0.7865	0.5577	0.8675	1.68480	0.433	0.045	5.6093

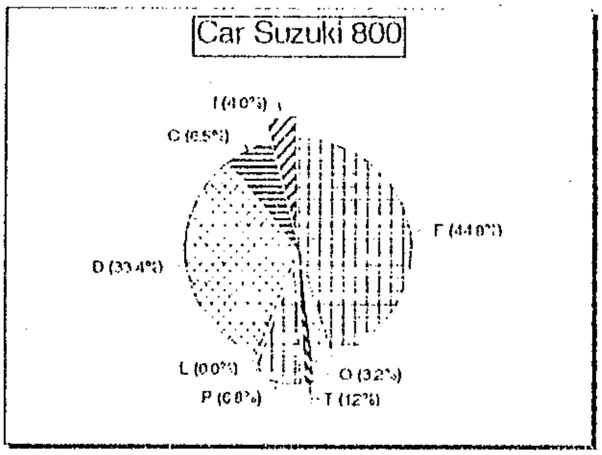
Vehicle Type	Un-Paved								
	F	O	T	P	L	D	C	I	Total
1	2	3	4	5	6	7	8	9	10
Car Toyota	1.2851	0.03890	0.1130	1.2696	0.07879	0.25290	0.2515	0.20000	3.4897
Car Suzuki 800	0.8843	0.03890	0.0540	0.3406	0.07879	0.44424	0.2514	0.10710	2.1993
Wagon	0.9040	0.01020	0.2190	1.0102	0.12487	0.97160	0.2270	0.10417	3.6162
Mini Bus	0.6767	0.05830	0.2350	1.2794	0.32779	1.17130	0.4510	0.07821	4.2777
Bus	1.3635	0.14931	0.5050	1.7261	0.40579	1.55736	0.4510	0.05633	6.2144
Medium Truck	1.6817	0.14931	0.5230	1.4888	0.44181	1.40764	0.5420	0.06266	6.2969
Heavy Truck	2.4493	0.18954	1.2430	1.0822	0.56726	1.68480	0.5420	0.06680	7.8249

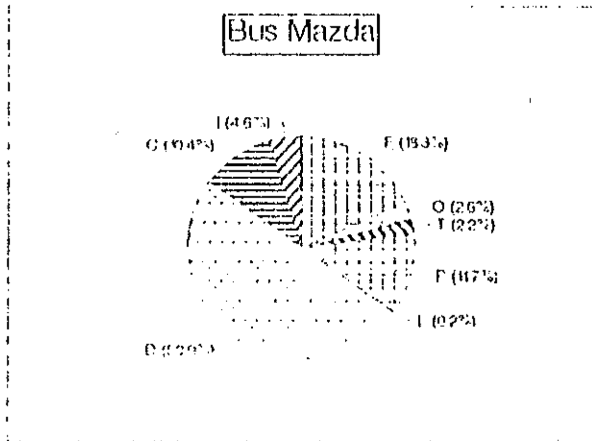
Units:

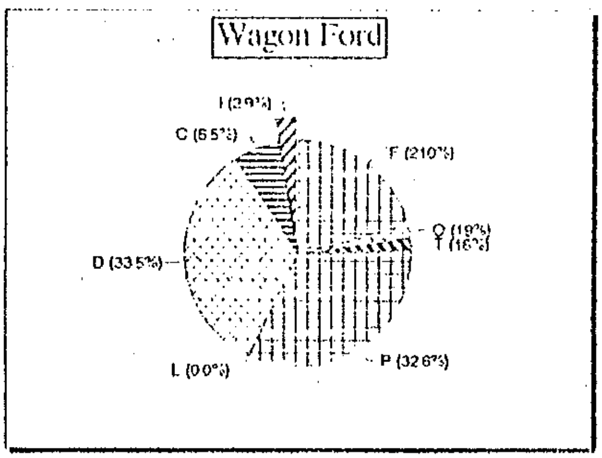
V= Speed
O= Oil lit/km
F= Fuel lit/km
T= Tyre cost % of new tyre/km
P= Part cost % VP/km
L= Labour cost Labour hour/km
D= Depreciation % of VP/km
C= Crew cost/km

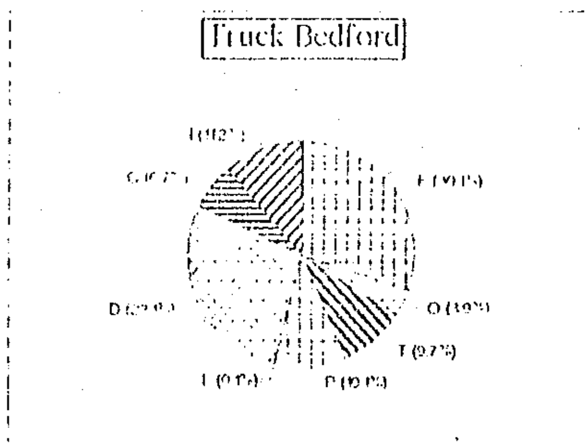
Vehicle Operating Cost on Paved Roads

(Empirical)









5. Comparison

Theoretical Verses Empirical Operating Costs

The principal aim of this chapter is to outline the differences in theoretical and empirical unit cost of each component as well as total Vehicle Operating Costs. The theoretical operating costs is based on RTIM and RTIM2 models whereas empirical costs is based on the field survey's data conducted by the NTRC. The reports considered to derive the empirical costs are described in sections 2.2 & 4.2. The assumption made are also reported in Chapter-3. The theoretical as well as empirical operating costs rupees per kilometer as reported in table 16 and 17 are summarised in table 18 and 19. It is evident from the result that the theoretical costs vary with empirical operating costs. For the purpose of comparison only matching vehicle classes have been taken and the suzuki car 1000 CC has not been incorporated in the comparison. The toyota car, bus and wagon have been taken from the report 'Vehicle Operating Costs' carried out by Mr. Abdul Majeed of NTRC and the medium and heavy truck have been extracted from the report "Road Freight Industries Survey" conducted in Pakistan by Mr. John L. Hine of TRRL. The problem in the comparison of financial Vehicle Operating Costs was that the prices used in the NTRC report of 1985 and in the TRRL report are of 1986, whereas in the current report the prices of July, 1991 have been used i.e. after the announcement of finanical budget 1991-1992. To over-come this problem, only unit costs in terms of quantity have been taken from the previous reports and the current prices have been used to derive the empirical financial VOC. It may also be noted here that the crew costs have not been included in the VOC report of NTRC (1985). To bring the similarity for the sack of comparison the crew costs have also been included in the comparative statement (placed at table-19).

In the VOC report (1985) the parts costs are based on the assumption and have been taken as a percentage of new vehicle price. In the road freight industry survey's report the costs of all component of VOC have not been included and some are missing, for example, depreciation costs, interest costs. However, some relevant information is available for the estimation of depreciation and interest costs.

The VOC estimated in current reprot are found less than the empirical costs which is calculated in the previous two studies, specially in case of buses, medium and heavy trucks. On the paved roads the costs rupees per kilometer in case of cars and light vehicles are slightly higher than empirical costs. However, on unpaved roads the VOC rupees per kilometer in case of all vehicle types are less than the empirical costs. The theoretical costs rupees per km on paved roads which is found slightly higher than empirical costs for cars are due to fuel and tyre costs. These two components seems slightly under etimated empirical calculation.

Table 18

<u>Theoretical V/S Empirical Vehicle Operating Costs Per Km</u>

Vehicle Type	Theoretical - Paved Road						Empirical - Paved Road					
	F	O	T	P	L	D	F	O	T	P	L	D
1	2	3	4	5	6	7	8	9	10	11	12	13
Car Toyota	0.115	0.0012	0.0000927	0.00004210	0.0029190	0.00003790	0.089	0.00144	0.0000240	0.000026	0.0026	0.000660
Car Suzuki 800	0.082	0.0012	0.0000927	0.00001040	0.0072250	0.00003790	0.061	0.00144	0.0000163	0.000073	0.0026	0.000360
Wagon	0.184	0.0018	0.0000330	0.00000482	0.0037104	0.00033508	0.147	0.00205	0.0000304	0.000337	0.0040	0.000347
Mini Bus	0.190	0.0040	0.0000645	0.00002246	0.0156375	0.00013730	0.100	0.00216	0.0000240	0.000061	0.0170	0.002600
Bus	0.274	0.0040	0.0001151	0.00004574	0.0205830	0.00007740	0.216	0.00550	0.0000770	0.000098	0.0196	0.000240
Medium Truck	0.181	0.0040	0.0001054	0.00001118	0.0050310	0.00009670	0.278	0.00553	0.0000770	0.000094	0.0187	0.000260
Heavy Truck	0.295	0.0040	0.0001494	0.00002171	0.0097690	0.00007740	0.405	0.00702	0.0001430	0.000087	0.0473	0.000260
	Un-paved Roads						Un-paved Roads					
Car Toyota	0.109	0.0024	0.0003980	0.00006490	0.0248600	0.00005058	0.109	0.00144	0.0000940	0.000276	0.00499	0.00066
Car Suzuki 800	0.075	0.0024	0.0003980	0.00001590	0.0060900	0.00005058	0.075	0.00144	0.0000635	0.000276	0.00499	0.00036
Wagon	0.171	0.0036	0.0002650	0.00000790	0.0030300	0.00026430	0.179	0.00205	0.0001413	0.003580	0.00768	0.00035
Mini Bus	0.314	0.0080	0.0000920	0.00003640	0.0147100	0.00016470	0.134	0.00216	0.0001120	0.000284	0.01950	0.00026
Bus	0.297	0.0080	0.0001640	0.00006930	0.0311900	0.00009670	0.270	0.00553	0.0001090	0.000266	0.02414	0.00024
Medium Truck	0.205	0.0080	0.0001500	0.00001160	0.0052200	0.00012890	0.333	0.00553	0.0001090	0.000275	0.02409	0.00026
Heavy Truck	0.317	0.0080	0.0002130	0.00002390	0.0107600	0.00009670	0.485	0.00702	0.0002260	0.000167	0.06093	0.00026

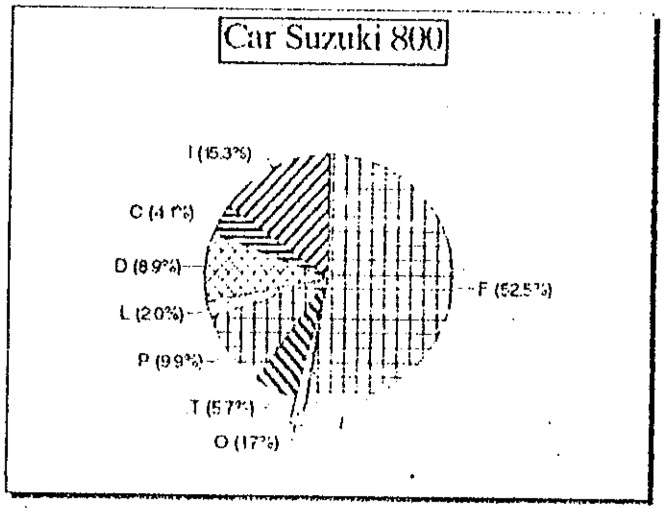
Table 19
Theoretical V/S Empirical Vehicle Operating Costs

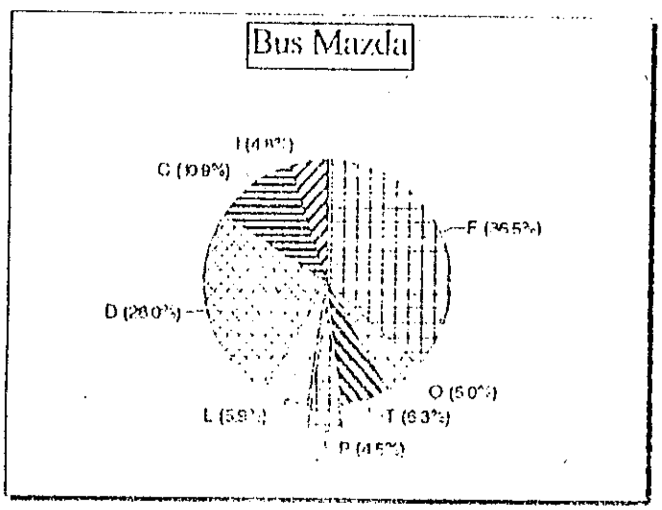
Rupees Per Km

Vehicle Type	Theoretical Paved Road										Empirical Paved Road								
	V	F	B	T	P	L	D	C	I	Total	F	B	T	P	L	D	C	I	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Car Toyota	86.50	1.3559	0.0324	0.1112	0.193660	0.358638	0.174340	0.159	0.299	2.68414	1.0493	0.03890	0.0290	0.1196	0.0411	0.25290	0.159	0.299	1.9888
Car Suzuki 800	86.50	0.9668	0.0324	0.0788	0.012830	0.088512	0.046769	0.159	0.080	1.46511	0.7192	0.03890	0.0140	0.0901	0.0411	0.44424	0.159	0.080	1.5865
Wagon	75.55	0.9292	0.0486	0.0512	0.013496	0.060331	0.938210	0.182	0.083	2.30604	0.7424	0.05540	0.0470	0.9436	0.0650	0.97160	0.182	0.083	3.0900
Mini Bus	61.19	0.7595	0.1080	0.1355	0.290500	0.147886	0.618537	0.361	0.063	2.68190	0.5050	0.05832	0.0500	0.2748	0.2858	1.17130	0.361	0.063	2.7692
Bus	61.19	1.3337	0.1080	0.5335	0.296800	0.346000	0.502249	0.361	0.045	3.57625	1.0908	0.14850	0.3570	0.6359	0.3295	1.55736	0.361	0.045	4.5251
Medium Truck	59.63	0.9141	0.1080	0.5059	0.060640	0.092269	0.523534	0.433	0.047	2.68444	1.4039	0.14931	0.3700	0.5089	0.3466	1.40764	0.433	0.047	4.6663
Heavy Truck	59.61	1.4897	0.1080	0.8217	0.139161	0.179163	0.496134	0.433	0.045	3.71186	2.0453	0.18950	0.7865	0.5577	0.8675	1.68480	0.433	0.045	5.6093
	Un-Paved										Un-Paved								
Car Toyota	54.72	1.2969	0.0648	0.6613	0.451260	0.351643	0.232760	0.2514	0.20000	3.51006	1.2851	0.03890	0.1130	1.2696	0.07879	0.25290	0.2515	0.20000	3.4897
Car Suzuki 800	54.72	0.8960	0.0648	0.4684	0.029739	0.086371	0.062440	0.2514	0.10710	1.96625	0.8843	0.03890	0.0540	0.3406	0.07879	0.44424	0.2514	0.10710	2.1993
Wagon	50.54	0.8636	0.0972	0.5906	0.033320	0.043902	0.740050	0.2270	0.10417	2.69984	0.9040	0.01020	0.2190	1.0102	0.12487	0.97160	0.2270	0.10417	3.6162
Mini Bus	47.19	1.0958	0.0972	0.2216	0.261741	0.221724	0.741974	0.4510	0.07821	3.16925	0.6767	0.05830	0.2350	1.2794	0.32779	1.17130	0.4510	0.07821	4.2777
Bus	47.19	1.5099	0.2160	0.8737	0.533975	0.737959	0.627486	0.4510	0.05633	5.10635	1.3635	0.14931	0.5050	1.7261	0.40579	1.55736	0.4510	0.05633	6.2144
Medium Truck	42.82	1.0454	0.2160	0.8255	0.079586	0.121411	0.697865	0.5420	0.06266	3.59342	1.6817	0.14931	0.5230	1.4888	0.44181	1.40764	0.5420	0.06266	6.2969
Heavy Truck	42.82	1.6109	0.2160	1.3459	0.195505	0.251801	0.619847	0.5420	0.06680	4.84875	2.4493	0.18954	1.2430	1.0822	0.56726	1.68480	0.5420	0.06680	7.8249

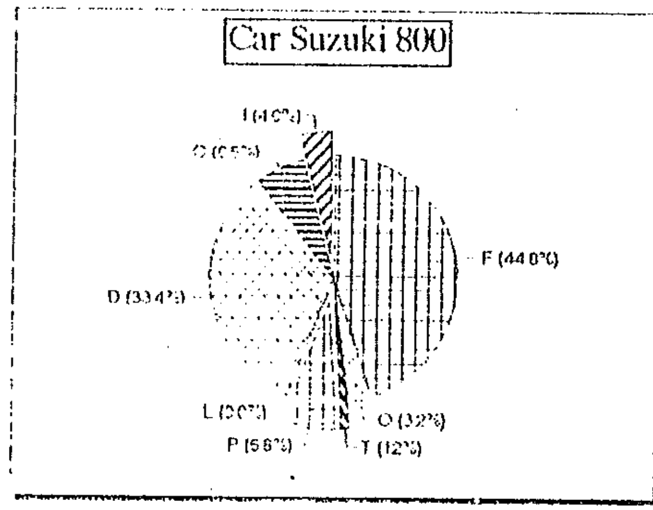
Comparison

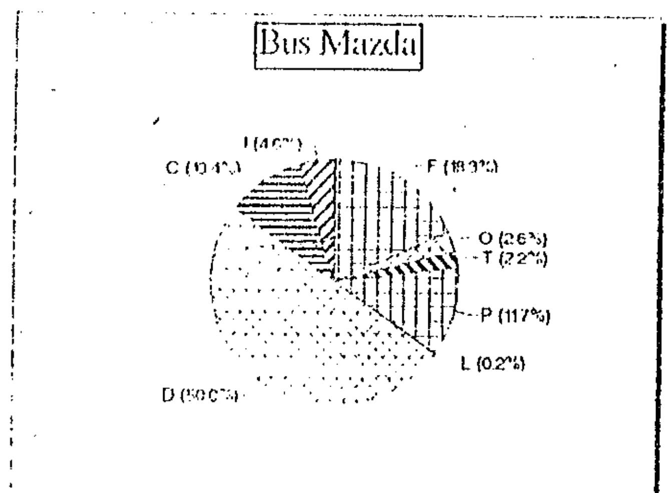
Theoretical





Empirical





Over all in the comparison the results of this report on paved and unpaved roads seems logical and show that the total VOC estimated for this report are more or less equal in case of cars and light vehicles whereas for the heavy vehicles viz. buses and trucks are slightly higher than empirical costs. It is established that the theoretical costs should be less than empirical costs because in the theoretical estimation the unforeseen expenses could not been incorporated which occure in the practical movement of the vehicles. The detailed comparative statement of theoretical versus empirical VOC rupees per km may be seen at table-19.

6. Conclusion

In order to work out the Vehicle Operating Costs rupees per kilometer the conventional models RTIM and RTIM2 developed by ;the Transport and Road Research Laboratory)TRRL), U.K. have been used. During the analysis it was found that in the models no provision has been provided to derive the costs for different makes of vehicles. While, it is evident that maintenance costs, fuel consumption etc, varies with the make of a vehicle. To overcome this deficiency the models have been slightly modified according to the condition prevailing in the country.

According to the theoretical calculation the VOC rupees per kilometer on paved as well as un-paved roads for different vehicle classes is as follows:

Vehicle Class	Paved	Un-Paved
Toyota Car	2.68	3.51
Suzuki Car 1000 CC	1.73	2.30
Suzuki Car 800 CC	1.47	1.97
Wagon	2.31	2.70
Mini Bus	2.68	3.17
Bus	3.58	5.11
Medium Truck	2.68	3.59
Heavy Truck	3.71	4.85

Similarly the empirical VOC which is based on survey's data have been derived and found VOC rupees per kilometer on paved and un-paved roads as under:

Vehicle Class	Empirical VOC Rs.Km Paved	Empirical VOC Rs.Km Un-Paved
Toyota Car	1.99	3.49
Suzuki Car 800	1.59	2.20
Wagon	3.09	3.62
Mini Bus	2.77	4.28
Bus	4.53	6.21
Medium Truck	4.67	6.30
Heavy Truck	5.61	7.82

It is established from the literature review, analysis and comparison made in this report that the theoretical costs are less than the observed and empirical operating costs. However, in case of car and light vehicles the unit costs of two components viz. fuel and tyre are slightly higher than the empirical costs.

6.1 Recommendations

In the research area the slot of an improvement always exists and no one can say that this is the end of the research in this area. The models used in this study are still in the developing stage. The HDMIII model could not be tested in this report due to non-availability of basic data. During the analysis it has been found that none of the models have a provision of transferability in case of different makes of vehicles. It is evident the maintenance costs and fuel consumption are less in the case of Japanese Vehicles, apart from the similarity in engine capabity and gross vehicle weight. Therefore, such type of provision may be incorporated into the model.

For VOC analysis in the models the climatic condition is included, because the temperature and rain fall influence the road deterioration. In addition, in tropical countries it is observed that the wind also effect the vehicle speed, fuel consumption and subsequently the VOC. Specially in the tropical countries like Pakistan and India, the speed of wind which follows the dust storms is often very high in both seasons, viz. summer and winter. Therefore, if the average wind speed as a variable may be included in the models it may increase the rate of accuracy of prediction of the VOC.

It is recommended that the experimental surveys to work out the vehicle speed, fuel consumption in the different environmental areas of Pakistan may be conducted. To estimate the unit costs of other components a comprehensive road side interview survey of the Operators/Road users may also be conducted so that the reliable empirical VOC at regional level could be calculated.

As discussed earlier that the empirical costs is partly based on the assumptions which have been used for the theoretical calculations. Therefore, the empirical costs calculations are not reliable to use as empirical operating costs. In view, it is recommended that the theoretical VOC calculated in this report may be used for the planning and appraising agencies.

However, in future an attempt would be made to work out the empirical Vehicle Operating Costs by conducting field survey's and experiments.

It is also recommended that NTRC may take a step further and an attempt should be made to develop a theoretical model according to the regional and environmental conditions of Pakistan.

Appendix A(1)

VEHICLE OPERATING COSTS

Place:______________________________ Date______________

1. Type of Vehicle:______________________
2. Make:______________
3. Year of First Registration:______________
4. Weight:
   i) Laden : ______________
   ii) Un-Laden: ______________
5. Seating Capacity:______________
6. Fuel type: ________________
7. Estimated Kms performed during a day:______________
8. Average Fuel Consumption Kms per litre:____________
9. No. of working days:______________
10. Route Information:
    Urban, rural, Both:______________
11. No. of Staff:__________________
12. Crew:
    i) Bassic Pay: Rs.___________
    ii) Allowances: Rs.___________
13. Total maintenance and repair expenditure for the last one year: Rs.____________
14. Tyre replaced interval:
    Kilometers:______________
    Years: ______________
15. No. of Tyres:________________
16. Battery replaced interval:
    Kilometers:______________
    Years: ______________

Apendix A(2)

Prices Rupees - July, 1991

Items	Quantity		Price
Fuel: Petrol (Super)	1 Litre		11.79
Petrol (Regular)	1 Litre		10.80
Diesel	1 Litre		5.05
Engine Oil	1 Litre		27.00
Vehicle and Tyres:		Vehicle	Tyre
Car-Toyota Crolla	One	460,000	1,200
Car-Suzuki 800 CC	One	123,400	850
Car-Suzuki Swift (Std)	One	179,400	900
Wagon-Ford	One	280,000	1,550
Mini Bus-Mazda	One	450,500	2,100
Busess-Bedford NJM2B20	One	648,900	4,635
Truck-Bedford	One	541,400	4,800
Truck-Nissan TK20GT	One	641,000	5,500
Labour Costs:			
Cars	Per hour		15.79
Light Goods Vehicles			16.26
Buses			16.81
Trucks			18.34
Crew Costs:			
Cars	Per hour		9.62
Light Goods Vehicles			22.12
Buses			22.12
Trucks			22.12

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