ENERGY DEMAND MODEL FOR ROAD TRANSPORT OF PETROLEUM PRODUCTS BETWEEN NAIROBI AND MOMBASA IN KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature…….. …………………………………………Date…………………………….

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This thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

I dedicate this thesis to my creator, the Almighty God who gave me the physical and mental strength to undertake and accomplish this work.

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ABBREVIATIONS

AC	Alternating Current
EC	European Commission
ED	Energy Demand
MJ	Mega Joules
HDNP	Highway Network Development Plan
HP	Horse Power
KPC	Kenya Pipeline Corporation
KRB	Kenya Roads Board
LCV	Light Commercial Vehicle
MOE	Ministry of Energy
NA	Not Applicable
NT	Number of Trips
NTK	Net Tonnage Kilometres
PIEA	Petroleum Institute of Eastern Africa
SPSS	Statistical Package for Social Sciences
TED	Total Energy Demand
TRL	Transport Research Laboratory
UK	United Kingdom

ABSTRACT

The issue of analyzing and predicting transport energy demand is crucial for the government and industry stakeholders. Planners and decision-makers use models to determine local conformity and areas of development. However not much has been done to estimate the transport energy demand and expected demand trends in the coming years of enhanced economic growth leading to the Kenya Vision 2030. This was largely due to lack of necessary data, appropriate models, qualified personnel and required institutions. The goal of this research is to develop an energy demand model for estimating energy demand for road cargo transport for the distribution of petroleum products between Nairobi and Mombasa in Kenya. The model can be used to play a powerful role in shaping policy by identifying emerging problems, pinpointing areas for energy savings and providing a context within which to judge alternative policy option. To achieve this goal the study used a number of methodologies including: a field survey where data was collected using structured random questionnaires, observations, face to face interviews and focal group discussions. The secondary data were obtained from government departments. Both were analyzed using SPSS11.5 while C++ was used built the functions on Excel spread sheet and presented inform of graphs and simulation. This research used the data obtained from field survey to determine the amount of fuel consumed annually for distribution of petroleum products. Three models were developed namely fuel consumption model, trip production model and energy demand model. The models established that if the trucks can be driven at an average speed of 70 to 75 kilometres per hour in Kenya maximum energy savings can be achieved. Finally the study recommends other models to be developed in the other roads and towns.

1.0 CHAPTER ONE: INTRODUCTION

The primary energy source for the transport sector is petroleum. The transport sector consumes nearly two-thirds of the petroleum used in the United States. Highway traffic is responsible for nearly three-fourths of the total transportation energy use, with about 80 percent from automobiles, light trucks, motorcycles, and about 20 percent from heavy trucks and buses (Davis, 2002). Petroleum fuels are the most important source of commercial energy in Kenya and are mainly used in the transport, commercial and industrial sectors. The consumption of energy in the transport sector in the period 2005-2009 range from 49.5% to 57.7% of the total petroleum energy consumed (KNBS, 2010).

The issue of analyzing and predicting energy demand is crucial for the government and stakeholders and there is substantial body of literature for estimating its determinant. Two major approaches to energy demand analysis are macro and sectorial demand analysis. Macro demand analysis considers demand as a function of population, income and prices while sectorial demand analysis examines the structure of sector and subsector and their energy consuming activities (Koomey, 2002).

Uncertainties play a key role in projecting future developments of the energy system. At least two factors contribute to this: the energy system is determined by complex interactions of a wide range of drivers and there is a lack of empirical data. Factors that influence future energy demand and supply include economic activity, developments in economic structure, lifestyle changes and technology development. Our understanding of the interaction of these factors is still limited and they may range over a wide range of possible outcomes. In addition, lack of empirical data complicates the development and calibration of models, especially for developing regions (Armstrong, 2005). Despite limitations in theory and data availability, a wide range of models have been developed to explore trends at global, regional and national scales. These include multiple linear regression models, fuzzy theory, times series analysis, neural network, grey theory, genetic algorithm and input-output framework.

These models are partly developed from different scientific paradigms, which may lead to different interpretations of the past and different expectations of the future (Löschel, 2002).However little effort has been put in specializing on transport energy model and statistical data related to transport is more deficient. The perception that a complex model with extensive input data produces more accurate results might not be always true. Simple models can sometimes yield results as accurate as more complicated techniques (Armstrong, 2005). As (Koomey, 2002) pointed out, energy demand modelers should ask whether the modeling tool drives or supports the process of developing a coherent scenario and credence to deal with uncertainties.

1.1 PROBLEM STATEMENT

The transportation of petroleum products in Kenya was carried out using pipeline 72.74% and roads 27.26% in year 2005 to 2009 (KNBS,2010) while railway remained unutilized. The use of road for transportation of petroleum products between Mombasa port and Nairobi continued to increase due to economic and population growth, and inefficient pipeline services whereby the pipeline between Mombasa and Nairobi was carrying 4 billion litres annually instead of 6.4 billion litres per year (Ministry of Roads, 2009).

The petroleum products transportation demand continued to grow drastically due to opening up of borders between Kenya and her neighbours, and the creation of East African common market with enlarged membership (Kenya, Tanzania, Uganda, Rwanda and Burundi). The implication of this road cargo transportation was high demand for energy, accompanied by high costs of transport, road maintenance, increased air pollution, road accidents and loss of property.

Not much has been done to estimate the energy demand and expected demand trends in the coming years of enhanced economic growth leading to the Kenya Vision 2030. This was largely due to lack of necessary data, appropriate models, qualified personnel and required institutions. Despite limitations in theory and data availability, a wide range of models have been developed to explore trends at global scales and in developed countries. These models are partly developed from different scientific paradigms, which may lead to different interpretations of the past and different expectations of the future (Löschel, A., 2002). However little effort has been put in specializing on transport energy model in developing countries and statistical data related to transport is more deficient .This study thus proposes a model to estimate the energy (fuel) consumption for distribution of petroleum products in Kenya.

1.2 MAIN OBJECTIVE

The main objective of this study was to develop a model for estimating energy demand for road cargo transport for the distribution of petroleum products in Kenya.

1.3 SPECIFIC OBJECTIVES

1. To determine annual fuel consumption for road cargo transport for the distribution of petroleum products between Nairobi and Mombasa.
2. To develop a model to predict number of trips for road cargo transport for the distribution of petroleum products between Nairobi and Mombasa.
3. To develop a model to predict energy demand for road cargo transport for the distribution of petroleum products between Nairobi and Mombasa.

1.4 CONCEPTUAL FRAMEWORK OF THE STUDY

The study focused on analysis of the historical and existing petroleum products data and future petroleum demand as well as the energy consumption of distribution of petroleum products in Kenya. The following tasks formed the main part of the transport and energy investigations and projections:

- Reviews of existing data available from related authorities were undertaken.
- Data collected by field survey on distribution of petroleum in Kenya.
- Consideration of relationship between speed and energy consumption.
- Consideration of relationship between transportation trips productions and petroleum products sales.
- Consideration of relationship between number of vehicles, travel demand and energy demand.
- Formulation of a model for forecasting energy demand by road for distribution of petroleum in Kenya.
- Model validation that takes into consideration the correlation coefficient.
- Use of model to analyze energy demand by road for distribution of petroleum in Kenya.

1.5 SIGNIFICANCE OF THE STUDY

This study provides both academic and policy significance on following areas; first the study bridged the gap in knowledge of transport energy demand studies for oil products distribution in Kenya. Secondly, the study provided a basis of undertaking projections of future transportation energy demand which can play a powerful role in shaping policy by identifying emerging problems, pinpointing areas for energy savings and providing a context within which to judge alternative policy option.

Therefore, this study developed a tool to be used in estimating energy demand and accessing energy efficiency of road cargo transport.

1.6 SCOPE, LIMITATIONS AND ASSUMPTIONS OF THE STUDY

The scope of the study was restricted to the heavy duty vehicles used for the distribution of petroleum products between Nairobi and Mombasa in Kenya as shown in figure1. The limitation of study was qualification of the results due to uncertainty in forecasting, upheaval in global oil supply, economic disruptions and unforeseen technology changes which could push demand higher or lower.

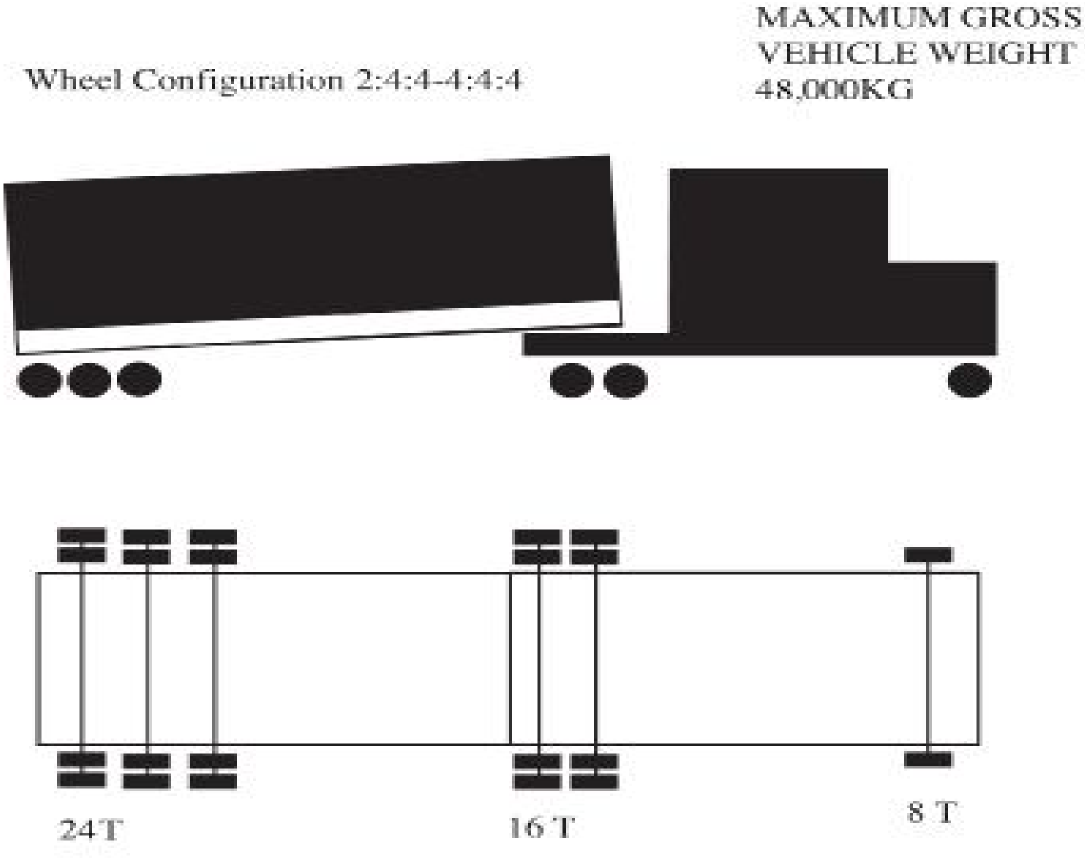

Figure 1 Numbers of Axles

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 FACTORS AFFECTING ENERGY CONSUMPTION

Passenger transport over land is the largest consumer of energy followed by land freight. Road transport is a larger sub-sector than rail and air. Energy intensities are high in this sector due to an ageing vehicle fleet, low occupancy rates and poor maintenance of vehicles. Historically segregated residential patterns result in large commuter communities which increases fuel consumption and resultant emissions. Loading and maintenance regulations are poorly enforced and public transport systems. This leads to high smog levels, road damage, increased road fatalities and reduced productivity as people spend more time and money on commuting Haw and Hughes (2007).

William (1977) reported the factors affecting the fuel consumption of heavy commercial vehicles .The factors were categorized according to their relative impact on fuel consumption. Essenligh *et al* (1979) studied the variation of automobile fuel consumption with respect to vehicle size and engine displacement. The study concluded that the effect of weight on fuel consumption is much more complex than a simple linear correlation between specific fuel consumption and weight would imply. However Ghogel and Watson (1995) gave two separate relationships (one for an urban cycle and other for a highway cycle), describing the linear variation of specific fuel consumption of heavy vehicles with respect to vehicles mass. Those relations were reported to have correlation coefficient of 0.936 and 0.938 respectively.

The relationship developed by Thoresen (1993) did not provide such a good fit and was developed from the freight vehicle operating cost survey which contained a small number of heavy commercial vehicles. Similarly, Houghton and McRobert (1998), in comparative study of resource consumption, assumed the linear variation in fuel consumption with respect to gross vehicle mass. Other studies such as Biggs (1988), Bowyer *et al* (1985) and Post *et al* (1984) categorized the fuel consumption influencing factors as rolling resistance, aerodynamic resistance, inertial forces and grade force, cornering resistance, drive-train efficiency and power required for vehicle accessory.

Greenwood and Bennett (2001) argued that only 18% of the total energy in fuel is available to propel the vehicle along road under urban driving conditions. BT (1995) noted major fuel consumption influencing parameters as the age and type of vehicles in operation, condition of the equipment and standards for maintenance and repair, technologies used, terrain traveled and drivers' skills. Ahn *et al* (2002), in a study on energy consumption patterns of cars and light commercial vehicles categorized the variables influencing vehicle energy rates into six broad groups. Travel category these include distance between two terminals and number of trips. Weather category these are temperature, humidity and wind effects. Vehicle category these are engine size, the condition of engine, equipments in the vehicles such as AC and catalytic converter. Roadway category these are road grade and surface roughness. Traffic category these are vehicle to vehicle interaction and vehicle to control interaction. Finally driver category these are drive behavior and aggressiveness.

2.2TRAVEL-RELATED FACTORS

Fuel consumption is highly dependent on many different traffic characteristics. Speed and acceleration are significant factors affecting fuel consumption rates. Generally, fuel consumption rates increase as speed and acceleration increases. Also, fuel economy is somewhat poor at lower average trip speeds due to frequent accelerations and stops. Also, fuel consumption rates are reduced by engine friction, tires and accessories such as power steering and air conditioning at low speeds and are dominated by the effect of aerodynamic drag on fuel efficiency at high speeds (Ross, 1993a).The operation of the vehicle also affects fuel consumption. Engines typically take several minutes to reach their normal operation. The cold-start fuel consumption experienced during the initial stages of the trip result in lower fuel efficiency than when the engines are fully warmed up (Baker, 1994).

2.3HIGHWAY-RELATED FACTORS

The highway related factors such as steep upgrades and poor road surface conditions also reduce fuel efficiency. On steep upgrades, vehicles require a heavy power output from their engines, consuming more fuel than under normal conditions. Also, rough roads can lead to significant incremental increases in fuel consumption by influencing the rolling resistance and aerodynamic drag generated. At typical highway speeds, vehicles tested on a rough road increased their fuel consumption by five percent over a vehicle tested on a normal quality road (Baker, 1994).

2.4 VEHICLE-RELATED FACTORS

Vehicle characteristics such as weights, engine sizes, and technologies are the primary factors affecting fuel economy. Generally, larger and heavier vehicles, vehicles with automatic transmissions, and vehicles with more power accessories (e.g., power seats and windows, power brakes and steering, and air conditioning) require more fuel than vehicles lacking these systems (Murrell, 1980). Without proper vehicle maintenance, fuel consumption can increase by as much as 40 percent (Baker, 1994). According to research, improper engine tuning can increase average fuel consumption by about 10 percent and wheel misalignment as small as 2 mm can cause an increase of fuel consumption by about 3 percent due to tire rolling resistance (Baker, 1994). Finally, the influence of weather conditions contributes to fuel economy.

Fuel consumption rates worsen at low temperatures and with high winds, which result in aerodynamic losses (Murrell, 1980). For example, in Europe, fuel consumption in winter is worse than in summer by about 15 to 20 percent (Baker, 1994) There are various small additional fuel consumption needs to be considered such as those due to evaporation (EC, 1999), cold start (Chang *et al*, 1976), tire pressure variation increasing the rolling resistance and small fluctuations of speed (Biggs, 1988) and (BT, 1995).Table 1 shows the summary of the factors affecting energy consumption.

TABLE 1: FACTORS AFFECTING ENERGY CONSUMPTION

CATEGORY	**FACTORS**
Travel related	Trip distance, number of trips, stops, average speed, acceleration, driver behaviour and aggressiveness, temperature, humidity, wind effects
Vehicle related	Engine size, condition of engine, equipment in the vehicle such as AC and catalytic converter, number of wheels, number of axles, tire weight, loading capacity
Roadway related	Road grade, surface roughness, traffic congestion ,vehicle to vehicle interaction, traffic lights

2.5 ENERGY CONSUMPTION MODELS

During the 1970's, the energy consumption of cars and LCVs were estimated using regression models using speed as the single most important independent variable. Chang *et al* (1976) used distance between links and travel time for fuel consumption estimation. This type of average speed model continues to be used due to its simplicity and acceptable accuracy. Bowyer *et al* (1985) and Biggs (1988) also used the average speed formulation along with other models. To better describe the fuel estimation, the terms such as rise, fall and roughness were introduced in regression (empirical) models.

Post *et al* (1984) compared the results of a more complex power demand model with simple average speed model and concluded that both give similar results and accuracy for longer distance trips. Bowyer *et al* (1985) stated satisfactory performance of the average speed model on a long distance provided that average travel speeds are not high. In the 1980's, advances in fuel consumption modeling lead to the incorporation of various other parameters. Post *et al (*1984) developed a relationship between fuel consumption and power developed at the vehicle's tail shaft. Ferreira (1985) developed an empirical relation for estimating urban fuel consumption using data from Leeds, the UK. The fuel consumption influencing factors such as stop/start and slowing down was incorporated in that model. Bowyer *et al* (1985) classified different types of models into four groups, namely: average speed model, running speed model, four mode elemental model and instantaneous model.

The shortcomings of average speed models, such as its inability to differentiate fuel consumption during the running and idle phase, led to the development of running speed model. Running speed fuel consumption model incorporates the average effect of grade, effect of difference in fuel consumption while running and idle. Bowyer *et al* (1985) reported that this model could underestimate the fuel consumption over a trip and the error was related to the grade term. Further moves towards accurately estimating the energy consumptions led to the development of the four mode elemental model. Bowyer *et al* (1985) presented a refined form of the same model which estimates fuel consumption by classifying a vehicle operation into four phases, namely: idle, cruise, acceleration and deceleration. Average speed and running models cannot estimate energy consumption well for short section less than 5km whereas four mode elemental models could be used. The use of instantaneous model on long road section is likely to improve the energy estimation result and it only increases the complexity of calculation Post *et al* (1984). Bowyer *et al* (1985) and Post *et al* (1984) suggested the good performance of previously mentioned simpler (average speed and regression) model over instantaneous and four mode elemental models when it comes to longer trip distances. Table 2 shows the summary of energy consumption models.

TABLE 2 SUMMARY OF ENERGY CONSUMPTION MODEL

Model Name	**Comments**	**Limitation**
Running speed model	Divide the operations of a vehicle into two phases namely run and idle.	High chance of under estimating the effect of grade on a long trip.
Four mode elemental model	Divide the vehicles operation into four phases namely idle, cruise, acceleration and deceleration.	Could only be used for short trips.
Instantaneous model	Estimate the fuel consumption for a small increment in time and length.	It has many set of input parameters.
Average speed model	This model is simple and accurate.	It can only be used for moving vehicles.

2.6 ENERGY DEMAND

A number of possible demand indicators may be considered as drivers of the demand for energy services in the transportation sector. None of these indicators is universally applicable to all transport modes: Population growth is indicative of the demand for personal or household vehicles, and indirectly for nonresidential vehicles to support the economy. Number of persons working may serve as a good indicator of the demand for business travel, either commuting daily by car, bus or rail, or extended business trips by rail or air. Number of vehicles in each mode is useful for within modes perhaps, but not across modes. It severely restricts analysis of high-density vehicles (i.e., buses, trains, and planes carrying more people per vehicle) .Growth in personal income is an important indicator because in the residential transportation sector, higher incomes are more likely to result in the purchase of a second or third car.

Number, frequency, and duration of trips made by passenger vehicles vary significantly. Fuel cost is considered to be a key determinant of transportation demand--the low price of gasoline, which contributes to low overall vehicle operating costs, currently does not appear to be as influential in consumers' choice of vehicle purchases in comparison with the 1970's and early 1980's. Vehicle-miles traveled mask differences in vehicle occupancy across passenger transport modes and changes in occupancy over time. In 1991, automobiles carried on average 1.6 passengers per mile while buses and air carriers transported 16.4 and 87.7 passengers; respectively. Passenger-miles traveled reflect vehicle occupancy within each passenger mode. In 1991 mass transit rail and buses traveled more than 12 billion vehicle-miles, compared with 153 billion passenger-miles over the same period Urban *et al* (2007).

According to Craig *et al*. (2002), energy demand forecasts in the United States show that most of the forecasts overestimated the demand by 100%. The models employed suffer from a long list of limitations. They often bury analytical assumptions in “black boxes” which are difficult to evaluate and reproduce the results. There could be several reasons why results coming out of energy demand modeling exercises are far from the actual demands. Some of them, according to (Laitner *et al* 2003), are inaccurate characterization of the behavior of economic agents – most models group consumers into a few representative agents to represent the “millions of decisions made by millions of individuals," and provide relatively stylized descriptions of their decision making, incomplete coverage of social and environmental impacts, lack of adequate technological detail and finally unrealistic economic assumptions such as fully employed and efficiently allocated resources, rational individuals, optimizing firms and perfectly functioning markets.

In the past energy economists have put a lot of time and effort into searching for the most appropriate specification of energy demand functions. However, there is no unique approach for modeling energy demand and no generally accepted consensus on the correct way to proceed. Therefore, there is still some debate over the relative advantages of different econometric techniques over others and as stated by Watkins (1992) "there is no one 'technique for all seasons' " adding that it "is a matter of selecting the methodology whose strengths best match the task at hand''.

The importance of developing countries in the world energy scene has grown significantly in the past thirty years. Although energy models have considered developing countries, the basic assumption was that they follow the same features of industrialized countries but with a different time lag (Urban *et al* 2007). However, this has not turned out to be true. For example, China has sustained a high level of economic growth for decades and has emerged as a major global player. Such global players have now changed the focus of energy sector development from the developed countries to developing countries. At the same time, within these fast growing economies as well as in many lower income countries, access to clean and affordable energy remains a major development issue.

(Armenia *et al* 2010) proposed a detailed systems dynamics model, to represent the demand for mobility and energy consumption of passenger transport. The model includes a number of the drivers and interactions which define energy consumption in passenger transport and illustrates the complex interactions and extensive data needs required to effectively model this sector. Road freight transport would be very similar but for instance where environmental policies drive vehicle occupancy in the passenger, environmental and safety policies would drive maximum vehicle load in freight. The major economic and policy drivers are however similar for both the road and rail transport modes and the outcome of the system, fuel consumption, is still the direct result of vehicle km travelled and vehicle fuel efficiency.

Several elements are included in the calibrated vehicle model these are the distance travelled per vehicle, the total kilometres travelled, fuel consumption, fuel efficiency, the total vehicle fleet, and the average age of vehicles. Certain factors affecting the vehicle km travelled and fuel efficiency, for instance traffic congestion, are difficult to quantify as they are not well understood due to the limited availability of data. To accommodate the unknown influences the model is calibrated by adjusting the variables until the output matches the known fuel sales data. Once calibrated, we can be reasonably sure that the model returns realistic estimates of the number of operating vehicles and their annual distance travelled. By making an informed assumption regarding the average occupancies of different vehicle types we can then estimate total private travel demand.

The last century has seen exceptionally rapid growth in the human population and its demand for resources, particularly energy. It might be argued that this rate of change results from the availability of cheap and accessible energy. Clearly, predicting future consumption patterns, particularly in the context of climate change and the diminishing abundance of oil, is a very challenging task. In building up the components of a model, the developer will typically look for patterns or consistencies in the behaviour of the critical aspects of the system to which the outcomes are most sensitive. Table 3 shows the summary of the energy demand indicators for road transport sector models.

TABLE 3: ENERGY DEMAND INDICATORS FOR TRANSPORT SECTOR

Indicator	**Application**
Population growth	Personal vehicles, passenger vehicles and freight
Number of vehicles	Personal vehicles, passenger vehicles and freight
Personal income	Personal vehicles and passenger vehicles
Fuel cost	Personal vehicles and passenger vehicles
Vehicle-miles traveled	Personal vehicles, passenger vehicles and freight
Number of trips	Personal vehicles, passenger vehicles and freight

3.0 CHAPTER THREE: MATERIALS AND FIELD SURVEY

This study develops three models namely: fuel consumption estimation, trip production estimation and estimation of energy demand. In order to develop the three models both primary and secondary data was utilized. Secondary data were obtained from official statistical publications including Statistical Abstracts, Economic Survey 2010, and publication from PIEA (Petroleum Institute of Eastern Africa). In addition, primary data was collected using interviews and questionnaires.

3.1 STUDY AREA

Research concentrated mainly on the road between Nairobi (1^0 South, 36^0 East) and Mombasa (4^0 South, 39^0 East) which covers a distance of 485 kilometres. The road was suitable for this study because it connect Mombasa port to the biggest urban area of the region, Nairobi. The area was also served by railway and pipeline network. The study also involved visiting the offices of transportation companies located in Nairobi and Mombasa. The Figure 2 below shows vehicle transporting petroleum products on the road between Nairobi and Mombasa at Athi River.

Figure 2 Nairobi to Mombasa road at Athi River

3.2 SAMPLE SIZE

Samples of ninety drivers were given questionnaires while ten transport managers and four truck owners were interviewed. This was necessary to capture the diversity of the population and their opinion. The research found this sample size adequate bearing in mind that they have a varied work experience, education and occupation.

$$n = \frac{(P(1-P)}{\frac{\frac{A^2}{Z^2} + \frac{P(1-P)}{N}}{R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .1$$

Where	n	Sample size
	N	Population size
	P	Estimated variance in population
	A	Precision desired
	Z	Confidence level
	R	Estimated response rate

In this study the population size was taken as 37,249 total freight transport vehicles issued with road transport licenses in year 2009 (KNBS,2010).The confidence level is taken as 95%.Estimated variance in the population is taken as 0.5 and estimated response rate was expected to be 100%.

$$n = \frac{(0.5(1-0.5)}{\frac{\frac{0.1^2}{1.96^2} + \frac{(0.5(1-0.5)}{37249}}{1}} = 96 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2$$

3.3 RESEARCH INSTRUMENT AND EQUIPMENTS.

The study used structured random questionnaires, observations, face to face interviews and focal group discussions to acquire primary data which was then analyzed using SPSS11.5 and Microsoft Excel. Interviews were conducted to collect qualitative data from four truck owners and ten transport managers while questionnaire were distributed to the drivers. The study utilized survey research design. The research design was selected because it enabled collection of data for the study variables at specified timescales. Simple random sampling of 90 questionnaires was distributed to drivers at Changamwe loading point, Mariakani weighbridge, Mlolongo weighbridge and industrial area Nairobi.

Questionnaires were used to collect data on first, personal characteristics which include respondent’s age, gender and education level. Secondly, truck designs which include the type of fuel truck used, engine size, number of wheels, number of axles, type of the vehicle, tire weight, loading capacity and gross weight and lastly truck operating factors which were average speed, number of trips, trip distance, number of times the vehicle undergoes service annually, the distance traveled before a vehicle undergoes service, distance traveled using 1 litre of fuel when loaded and unloaded, and the amount of fuel consumed in a trip. Face to face interview and focal group discussion was used to establish the accuracy of the data regarding average speed, fuel consumption per trip and total gross weight which was done with transport managers and truck owners. An observation was also used to establish the average speed with drivers.

Finally measuring, observation and review of manufacturers specifications was used to establish the frontal area and aerodynamic drag. Two research assistants were used to collect data for duration of 6 months. The SPSS 11.5 was also used to develop models and together with Excel presented the results while C++ was used to code the models. The mathematical formulas developed were coded in the Excel spread sheet using C++ program. Then excel was used to present the results in form of tables, graphs and simulations. Three models were coded using the C++ which was fuel consumption model, trip production model and the energy demand model. The first two models were used to input the data to the energy demand. The first model fuel consumption had one input of average speed per trip which has an output of fuel consumption. This fuel consumption is divided by the trip distance which resulted to the fuel economy of a vehicle. The second trip production model is used to generate number of trips which are then divided by number of trips per year a truck can make to produce number of vehicles used for transportation. The other input were vehicle kilometres travelled per vehicle and energy converting factor which converted fuel used into energy.

3.4 FUEL CONSUMPTION ESTIMATION

There are several factors that influence the fuel consumption. First the fuel consumption is influenced by the energy content of the fuel. Secondly from Newton's second law, it can be demonstrated that the net force on a vehicle in the direction of motion is proportional to its acceleration and is required to overcome the aerodynamic, rolling resistance and grade resistance. Therefore the fuel consumption is also influenced by engine size, number of wheels, number of axles, distance, weight, carriage, average speed, road grade and surface roughness. Thirdly driver personal characteristics which are age, education and gender. And finally the Thoresen (2003) lookup tables (see appendix 5) were used to calculate the coefficients of the basic fuel consumption equation which are A, B and C.

The average speed model in equation 1 was used.

$$FC = \left(A + \frac{B}{V} + CV^2\right) * [CF] \quad \ldots\ldots\ldots\ldots\ldots 3 \ldots\ldots\ldots\ldots \text{Thoresen (2003)}$$

Where FC is fuel consumption

V is the average speed measured over a distance, including stops and speed changes

A is parameter associated with fuel consumed to overcome rolling resistance, approximately proportional to vehicle weight.

B is parameter approximately proportional to fuel consumption while idling.

C is the parameter associated with acceleration

CF is the correction factors due to road roughness

3.5 TRIP PRODUCTION ESTIMATION

The trip production is defined as the process of estimating the total trip generated within the study area. Trips are usually thought of being two-way excursions originating at the trips-makers home. Trips are normally stratified by purpose: for each trip type, the number produced in a particular zone is assumed to depend on the size and characteristics of the zone. Therefore the following data was required in order to determine number of trips annually. It includes loading capacity per trip, mode of transportation used and petroleum products sales historical data. This was done by first classifying different petroleum products with different densities that were regular, premium, kerosene, aviation gas, diesel and industrial diesel. Secondly using Traffic acts (1993) chapter 403 (revised edition 2009), twelfth and thirteenth Schedules guide on the maximum allowable volume (see appendix 6) and the weight a vehicle carry in Kenyan roads and loading capacity per trip, the number of trips was established. And finally trip production model was modified from the linear regression model developed by (HDNP, 1991).

$$NT = a + b\,TED \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4$$

Where TED is the petroleum product sales

NT is the total number of trips

a is parameter associated with other petroleum products transport activities.

b is parameter associated with sales of petroleum products.

3.6 ENERGY DEMAND ESTIMATION

In order to analyze energy use patterns in the transportation sector with capability to predict energy demand, a bottom-up approach was undertaken due to its capability to account for the flow of energy based on simple engineering relationships, such as traveling demand, fuel consumption and vehicle numbers. Firstly, the number of registered vehicle (NV) was predicted from the survey carried out to determine number of trips a vehicle can make annually in this sector. The vehicle kilometer of travel (VKT) is a parameter to reflect how heavily the considered vehicle is used. Hence, this parameter varies depending on the vehicle type and its driven area. Moreover, it should be noted that the VKT was constant in this case and depend much on number of trips and trip distance. Vehicle Kilometer of Travel (VKT) was also determine from the field survey.

Lastly, fuel economy (FE) is defined as the quantity of energy consumed in a unit of driven distance, which depends on the vehicle size, vehicle type, vehicle’s power train technology (engine type) and fuel type used.

Therefore, Fuel Economy (FE) can be extrapolated as the function of engine size, engine technology and fuel used, which are dependent on vehicle type and fuel proportion of the vehicle owner. Finally, the validation of the energy demand model with the historic supply record will be calibrated before scenario analyses are conducted. The energy demand function in the transportation sector can be modeled as described in Equation (3):

$$ED = NV * VKT * FE * ECF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..5$$

Where ED is the energy demand of petroleum products distribution in year k

NV is the number of vehicles used for transportation

VKT is the vehicle kilometres travelled per vehicle

FE is the fuel economy

ECF is energy converting factor

In other words, the energy demand in the transportation sector can be determined by integrating the results over every fuel type and vehicle type. Despite the simple looking relationship shown in Equation (3), technicalities involved in model construction go beyond merely data collection since, unlike typical developed countries, developing countries like Kenya still lack many necessary time-series transportation data.

4.0 CHAPTER FOUR: RESULTS AND DISCUSSIONS

The data used on this study was divided into two parts (1) factors that influence fuel demand and (2) determination of annual fuel energy consumption.

4.1 RESULTS 1: FACTORS INFLUENCING FUEL ENERGY DEMAND

The personal characteristics of drivers, managers and truck owners are presented in tables 4,5,6,7 and 8. Table 4 shows the gender of drivers, transport managers and truck owners used for distribution of petroleum in Kenya. The table indicates that all the 90 drivers and 4 truck owners were males. It also shows that 2 of the managers were females and 8 were males. This implies that majority of respondents were males amounting to 98.1% and only 1.9% were female. This may be due to either the nature of the work which requires them to be out of the family most time or cultural values that had classified work on genders. The survey carried out by Transport research laboratory (TRL, 1999) showed that age and annual mileage are strongly related to speed choice with an indication that understated differences might exist between male and female. It concluded that women drivers drive about 1.6 km/hr slower than men.

Table 4 Respondent Gender

Respondent Gender	**Female**	**Male**	**Total**
Driver	0, (.0%)	90, (100.0%)	90, (100.0%)
Manager	2, (20.0%)	8, (80.0%)	10, (100.0%)
Owner	0, (.0%)	4, (100.0%)	4, (100.0%)
Total	**2, (1.9%)**	**102, (98.1%)**	**104, (100.0%)**

Table 5 Shows respondents' age group for drivers, managers and truck owners .The table shows that most of drivers were at age group of between 37-42 years accounting for 50% while 50% of managers were at age group of between 43-48 years. It also indicates that 40% of managers were at age group of 37-42 while 38.9% of the drivers were at age group of between 43-48 years. This was may be due to the experience which was required. Finally it indicates that 50% of trucks owners were over 61 years.

Table 5 Respondent Age

Age Group (Years)	**31-36**	**37-42**	**43-48**	**49-54**	**55-60**	**Over 61**	**Total**
Driver	2, (2.2%)	45, (50%)	35, (38.9%)	8, (8.9%)	0, (.0%)	0, (.0%)	90, (100%)
Manager	0, (.0%)	4, (40%)	5, (50%)	0, (.0%)	1, (10%)	0, (.0%)	10, (100%)
Owner	0, (.0%)	0, (.0%)	0, (.0%)	1, (25%)	1, (25%)	2, (50.0%)	4, (100%)
Total	**2** **(1.9%)**	**49** **(47.1%)**	**40** **(38.5%)**	**9** **(8.7%)**	**2** **(1.9%)**	**2** **(1.9%)**	**104** **(100%)**

Table 6 show the distribution of respondent's gender by age group while figure 3 provides a graphical depiction of the values. It indicates that all the females and 85.3% of males were at the age group of 37-48 years. Overall there was uneven spread of ages for both males and females with majority of the respondent being at the age group of 37-48 years. The uneven distribution of ages can be associated with the experience required for both drivers and managers.

The survey carried out by (TRL, 1999) showed that speed is affected by sites, vehicle ownership (company or private), engine size, journey purpose (mainly work versus non-work), whether a passenger is being carried or not and the consequences of motoring offences all significantly distinguish between groups of drivers in terms of the speed at which they drive. It indicated that there is a clear age effect whereby 17-29 year old male and female drivers drive 6.4-8 km/hr faster than those over 60 years. According to (TRL, 1999) the age group of between 37- 48 will tend to drive at an average speed of 67 km/hr.

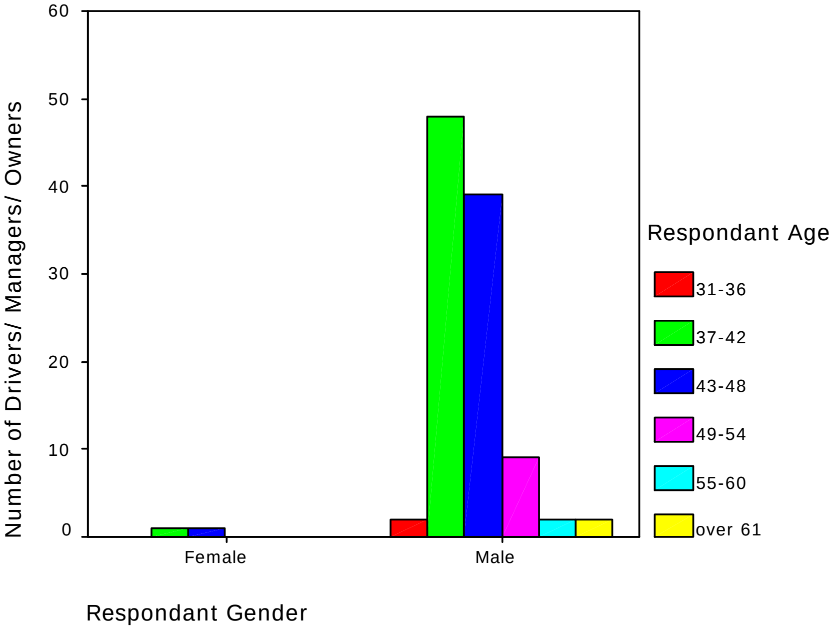

Figure 3 Numbers of Drivers/Managers/Owners versus Gender

Table 6 Respondent Gender versus Respondent Age

Age Group (Years)	**31-36**	**37-42**	**43-48**	**49-54**	**55-60**	**Over 61**	**Total**
Female	0, (.0%)	1, (50.0%)	1, (50.0%)	0, (.0%)	0, (.0%)	0, (.0%)	90, (100%)
Male	2, (2. %)	48, (47.1%)	39, (38.2%)	9, (8.8%)	2, (2 %)	2, (2%)	102, (100%)
Total	**2, (1.9%)**	**49, (47.1%)**	**40, (38.5%)**	**9, (8.7%)**	**2, (1.9%)**	**2, (1.9%)**	**104, (100%)**

Table 7 show the education level of drivers, transport managers and owners of trucks used for distribution of petroleum in Kenya. It shows that 87.1% of the drivers were Form 1-4 graduates, 7.7% were A-level graduates and 2.9% had attained tertiary and above level of education. It also indicates that 90% of managers were Form1- 4 graduates while 10% were A-level graduates. Finally it indicates that 75% of the truck owners were Form 1- 4 graduates and 25% have attained tertiary and above. This implies that most of the employee in this sector were Form 1-4 graduates, may be due to either gradual career progression from driver to manager and then truck owner or the Standard 8 graduate didn’t participate in answering the questionnaire. It also implies that energy conservation and efficiency together with implication of fuel consumption to environmental and emission should be introduced at secondary school level.

Table 7 Respondent Education Level

Education level	**Form 1-4**	**A-level**	**Tertially and Above**	**Total**
Driver	81 (90.0%)	7 (7.8%)	2 (2.2%)	90 (100%)
Manager	9 (90.0%)	1 (10.0%)	0 (.0%)	10 (100%)
Owner	3 (90.0%)	0 (.0%)	1 (25.0%)	4 (100%)
Total	**93** **(89.4%)**	**8** **(7.7%)**	**3** **(2.9%)**	**104** **(100%)**

Table 8 shows the number of drivers who are employed in a single truck that transports petroleum products in Kenya. It indicates that most of the companies have employed more than one driver to handle a truck accounting to 93.2% while only

6.7% were driven by one driver. This may be due to the Laws of Kenya, Traffic acts, chapter 403, part V ,66A which requires a person not to drive a public service vehicle for not more than 8 hours within a period of 24 hours(a day).

Table 8 Number of Drivers

Number of Drivers	Frequency	Percentage
One Driver	7	6.7
Several Drivers	96	92.3
N.A.	1	1.0
Total	**104**	**100.0**

4.2 TYPE OF FUEL

The study established that all trucks use diesel as a source of energy for distribution of petroleum products in Kenya. This may be due to either the cost of the diesel which was less compared to the petrol or the energy content value of diesel. The source of energy was an important factor to consider because it determines work done. The gross energy content of the automotive diesel oil has been listed as 38.5MJ per litre, (Abare, 1993); Affleck (2002), Laird and Adorini-Braccessi (1993). The study established that trucks used for distribution of petroleum products in Kenya between Mombasa and Nairobi road consumed 400 litres of diesel a distance of 970 kilometres. This implies that the trucks used 15.88MJ of energy to transport petroleum products for distance of 1 kilometre.

4.3TYPE OF THE VEHICLE

The study established that all trucks used were articulated. This may due to the amount of weight these trucks were allowed to carry on the road as provided in the Twelfth Schedule of Traffic act 1993, revised edition 2009, where rigid vehicles were allowed a maximum of 4 axles and carry a maximum of 28000kg compared to articulated which had 6 axles and allowed to carry a maximum of 48000 kg.

According to Apelbaum (1998) rigid trucks has specific energy consumption of 0.074 and 0.076 litres per NTK (net tonnage kilometres) in urban areas and rural areas respectively while articulated trucks has specific energy consumption of 0.037 and 0.028 litres per NTK in urban areas and rural areas respectively. This implies that per trip energy were conserved using articulated trucks hence their choice.

4.4 ENGINE SIZE

Table 9 shows the engine sizes of trucks used for distribution of petroleum products in Kenya. Figure 4 provides a graphical depiction of the values listed in table 9. It indicates that 13.7% had 380 horse power,4.9% had 410 horse power,16.7% had 415 horse power,41.2% had 420 horse power and 23.5% had 520 horse power. The mean and standard deviation of engine size see attached appendix 4. The majority of trucks used for transportation of petroleum products had 420 horse power engine sizes. The choice of engine size may be due to make, model or load factor. The choice of make and model of truck may be due to either reputation of certain brand or energy consumption. The load factor implies the ratio of the load a vehicle is carrying to the total weight that vehicle can carry. The concept of load factor is an appropriate method for the adjustment of fuel consumption rates, which is a function of vehicle mass. CSIRO, PPK and Unisa (2002) suggested a direct linear proportionality relationship between load factor and fuel correction factor. Therefore the load factor was determined by the amount of weight a truck carried. In Kenya the weight was determined by Twelfth Schedule of Traffic act 1993, revised edition 2009, which recommends maximum carriage of 48000 kg. This may had lead to majority of trucks having 420 horse powers (HP).

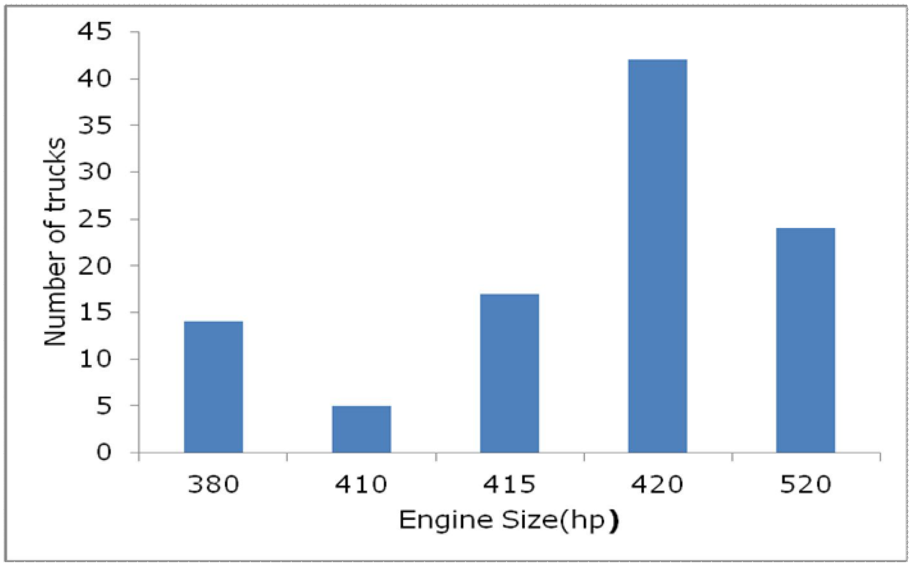

Figure 4 Number of Trucks versus Engine size (hp)

Table 9 Engine Size (HP)

Engine Size (HP)	**Frequency**	**Percent**
380	14	13.5
410	5	4.8
415	17	16.3
420	42	40.4
520	24	23.1
N.A.	2	1.9
Total	**104**	**100.0**

Table 10 shows the Pearson correlations between average speed per trip (km/hr) and engine size (hp). The table indicates that there was a positive correlations between the two variables (r = .458, p =.000) with engine size being associated with average speed per trip. It can therefore be concluded that engine size also determines the average speed of a truck.

Table 10 Correlations between Average Speed per Trip and Engine Size

		Average Speed Trip(km/hr)	Engine Size (HP)
Average Speed /Trip (km/hr)	Pearson Correlation	1	.458**
	Sig.(2-tailed)	-	.000
	N	104	102
Engine Size (HP)	Pearson Correlation	.458**	1
	Sig.(2-tailed)	.000	-
	N	102	102

**Correlation is significant at the 0.01 level (2-tailed)

4.5 NUMBER OF WHEELS

Table 11 shows the number of wheels trucks used for distribution of petroleum in Kenya while Figure 5 provides a graphical depiction of the values listed. The table indicates that 1.9% of the trucks had 18 wheels, 23.1% had 20 wheels and 75% had 22 wheels. The mean, mode and standard deviation of number of wheels was 21.5,22 and 0.97 respectively while the chi-square was 3.662 since the x^2 for d_f =103, and 5% significance level=127.689, and 3.662<127.689 therefore H_o is correct. It implies that as the number of wheels increases more energy was required to overcome rolling resistance according to Newton's second law of motion.

Table 11 Number of Wheels

Number of Wheels	Frequency	Percentage
18	2	1.9
20	24	23.1
22	78	75.0
Total	**104**	**100.0**

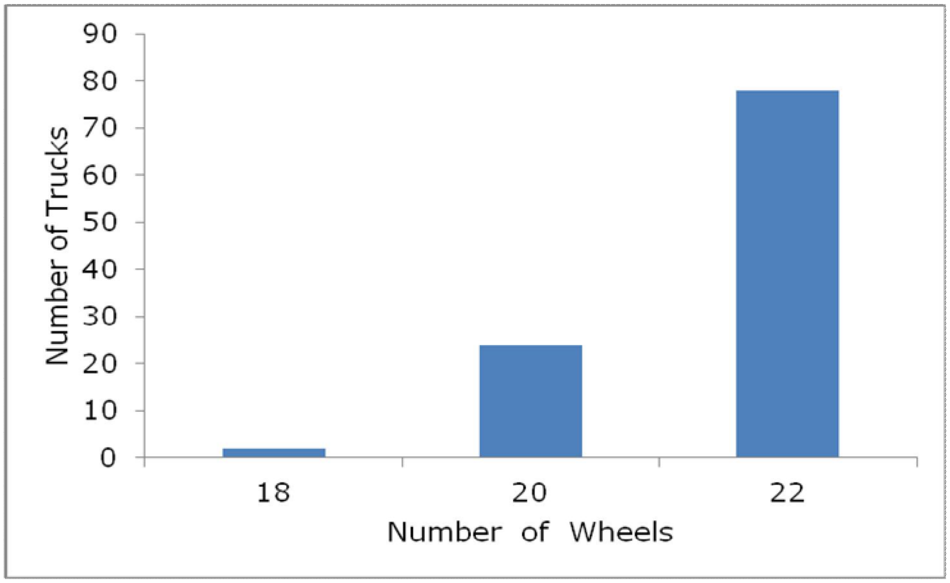

Figure 5 Numbers of Trucks versus Number of Wheels

Figure 6 shows the relationship between engine size (HP) and total gross weight (tonnes).It indicates that as the engine size increases the total gross weight also increases. Table 12 shows the Pearson correlations between total gross weight and engine size. From the Table 12 it can be concluded that there was a positive correlation between the two variables (r = .494, p =.000) with engine size being associated with total gross weight.

Table 12 Correlations between Engine Size (HP) and Total Gross Weight (Tonnes)

		Average Speed /Trip	Distance Travelled (km/Litre) when loaded
Engine Size	Pearson Correlation	1	.494**
	Sig.(1-tailed)	-	.000
	N	102	102
Total Gross Weight	Pearson Correlation	.494**	1
	Sig.(1-tailed)	.000	-
	N	102	104

**Correlation is significant at the 0.01 level (1-tailed)

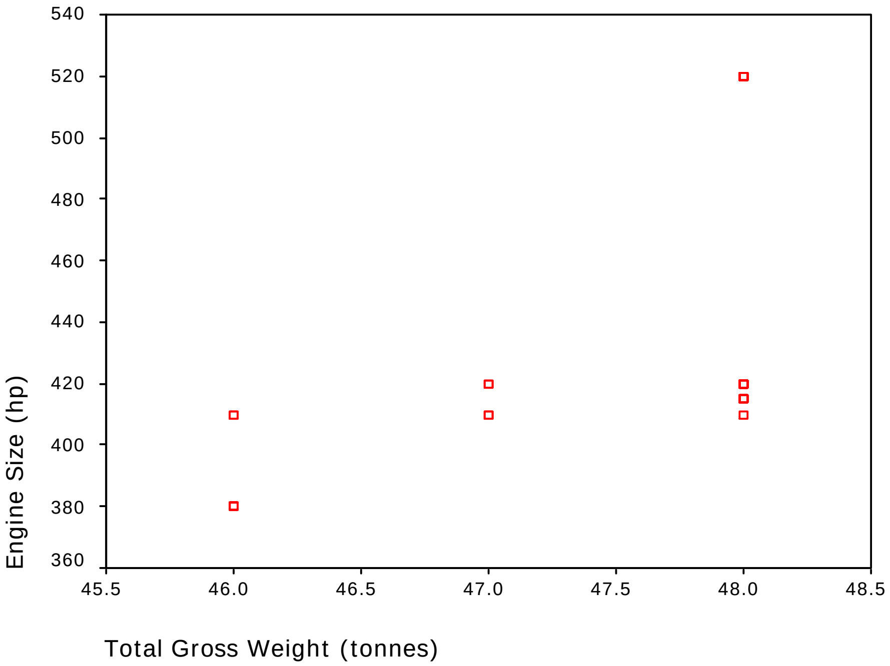

Figure 6 Engine Size versus Total Gross Weight

In conclusion having established the relationship between engine size and total gross weight from Figure1 and having established positive correlations between engine size (HP) and an average speed per trip (km/hr), it can be concluded that engine size and total gross weight also determines the average speed of a truck. Speed and acceleration are significant factors affecting fuel consumption rates. Generally, fuel consumption rates increase as speed and acceleration increases. Also, fuel consumption rates are reduced by engine friction, tires and accessories such as power steering and air conditioning at low speeds and are dominated by the effect of aerodynamic drag on fuel efficiency at high speeds (Ross 1993a).

4.6 TRUCKS OPERATING FACTORS

The trucks operating factors considered in this study are presented in Table 13,14,15,16,17,18,19 and 20 they include the average speed, number of times a vehicle undergoes service annually, distance traveled before being serviced, distance traveled using 1 litre of diesel when loaded and when unloaded.

4.7 AVERAGE SPEED

Table 13 shows the average speed trucks used for distribution of petroleum products in Kenya were driven at while Figure 7 provides a graphical depiction of the values listed. It indicates that 92.3% were driven at an average speed of between 41-60km/hr and 7.7% driven at an average speed of between 61-80km/hr. These were trucks with the same total gross weight. This implies that majority of the trucks were driven at an average speed of between 41 to 60 km per hour per trip. This data was verified through observation and discussion with owners and transport managers. This speed was less compared to the maximum limit as stated in Traffic (Speed Limits) rules under section 119 of Traffic acts chapter 403, (1993) Revised Edition (2009) ,(C), which state that, all articulated vehicles and other motor vehicles not drawing trailer on any type of road will not exceed a speed limit of 80km/hr.

The choice of the speed may be due to road conditions factors such as road gradient, road roughness, road curvature, traffic congestion and loading factor. The road between Mombasa and Nairobi is in between 58 metres above sea level and 1800 metres above sea level .Therefore the road gradient is steep and has many road curves for climbing the attitude hence reducing the speed. Traffic flow is a complex phenomenon and it can be observed that as traffic increases there is generally a corresponding decrease in speed. Naturally, there is one particular vehicle flow associated by traffic stream (Lay, 1986a, 1986b). Therefore slow speed on this particular road was also associated with traffic congestion in Nairobi being the capital city, Mombasa town and major part of the road is two lanes.

The loading factor is defined as the ratio of the average load to the total load capacity i.e. the percentage utilisation of the capacity and load correction factor which is included in fuel estimation equation (CSIRO, PPK and UNISA, 2002). However in Kenya the maximum volume bulk liquid tank was controlled by Traffic Acts Chapter 403, (1993) Revised Edition (2009), Thirteenth Schedule as 35m^3 for 6 axle's vehicle with 22 wheels. The vehicles were restricted to carry 33 m^3 for diesel, 35m^3 for gasoline, petrol and kerosene and 28m^3 for fuel oil depending on the densities of the liquid see Appendix 6. Thereby space was left in the tanker, which makes the movement of liquid while driving and makes its uncomfortable at high speed hence reducing of the average speed.The aerodynamic and rolling resistances on the power requirements depend on the vehicle speed. Globally, it is estimated that at a speed above 80 km/hr, the aerodynamic drag dominates the rolling resistance, while it is no longer the case at lower speeds where the rolling resistance accounts for a greater share of the power requirements. On highway, the aerodynamic drag can typically account for two thirds of the tractive load (VTT, 2006).Therefore on an average speed of 40-60km/hr rolling resistance dominates aerodynamic as in case of Kenyan roads.

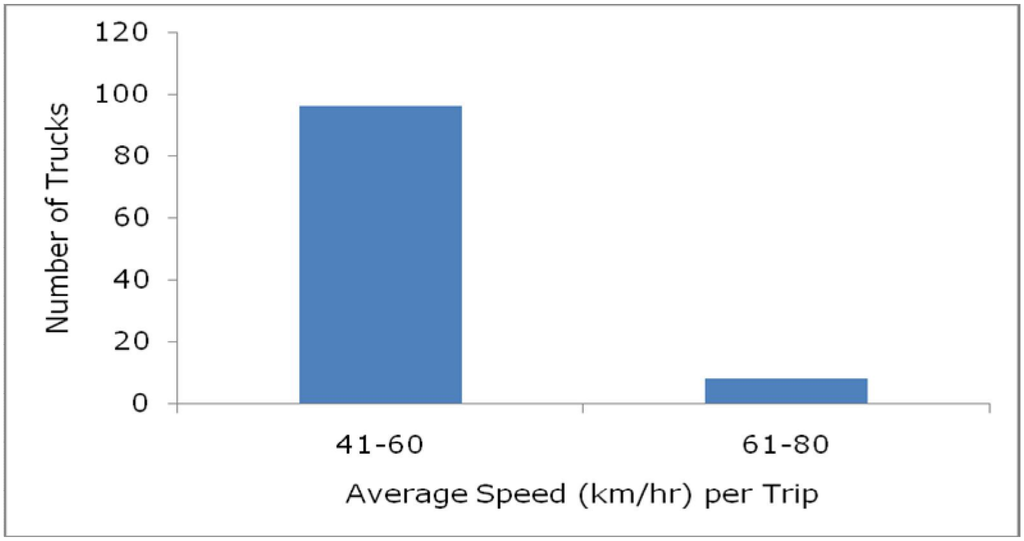

Figure 7 Numbers of Trucks versus Average Speed (km/hr) per Trip

Table 13 Average Speed (km/hr)

Average Speed (km/hr)	**Frequency**	**Percentage**
41-60	96	92.3
61-80	8	7.7
Total	**104**	**100.0**

4.8 VEHICLE MAINTENANCE

Table 14 show the number of times trucks used for distribution of petroleum in Kenya were serviced annually while figure 8 provides a graphical depiction of the values. It shows that; 24.0% undergoes services 6 times while 76.0% do 8 times a year. This data was verified from the vehicles log book. The mean and standard deviation of number of times a vehicle undergoes services in a year were 7.52 and 0.859 respectively. This may due to either the model or the age of the truck. Different manufacturers construct truck with different efficiencies hence different times for services. In addition to that an old truck tends to travel short distance and requires service. The implication of this was that those truck undergoes several services were either having lower efficiencies or travelled more distances hence translated to high energy demand and emissions.

Table 14 Vehicle Maintenance

Number of Times Vehicle Undergoes Service Annually	**Frequency**	**Percentage**
6	25	24.0
8	79	76.0
Total	**104**	**100.0**

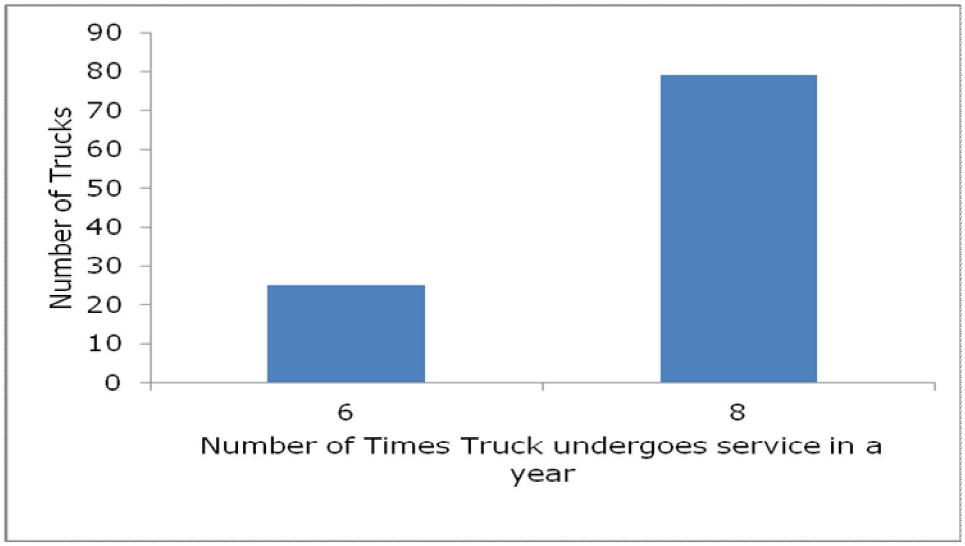

Figure 8 Number of Trucks versus Number of Times Truck undergoes service annually

4.9 DISTANCE TRAVELLED BEFORE SERVICE

Table 15 show the distances travelled by trucks used for distribution of petroleum in Kenya before serviced while figure 9 provides a graphical depiction of the values. It indicates that 76.0%, travelled10000 kilometres whereas 24.0%, travelled 15000 kilometres. This data was verified from the vehicles log book. The mean and standard deviation of distances travelled before service were 11,201.92 kilometres and 2,146.93 respectively. The distance travelled before service may due to either the model or the age of the truck. Therefore trucks that travelled lesser distance before service has lower efficiencies and translates to high energy demand and emissions.

Table 15 Distance Travelled (km) Before Service

Distance Travelled (km) Before Service	Frequency	Percentage
10,000	79	76.0
15,000	25	24.0
Total	**104**	**100.0**

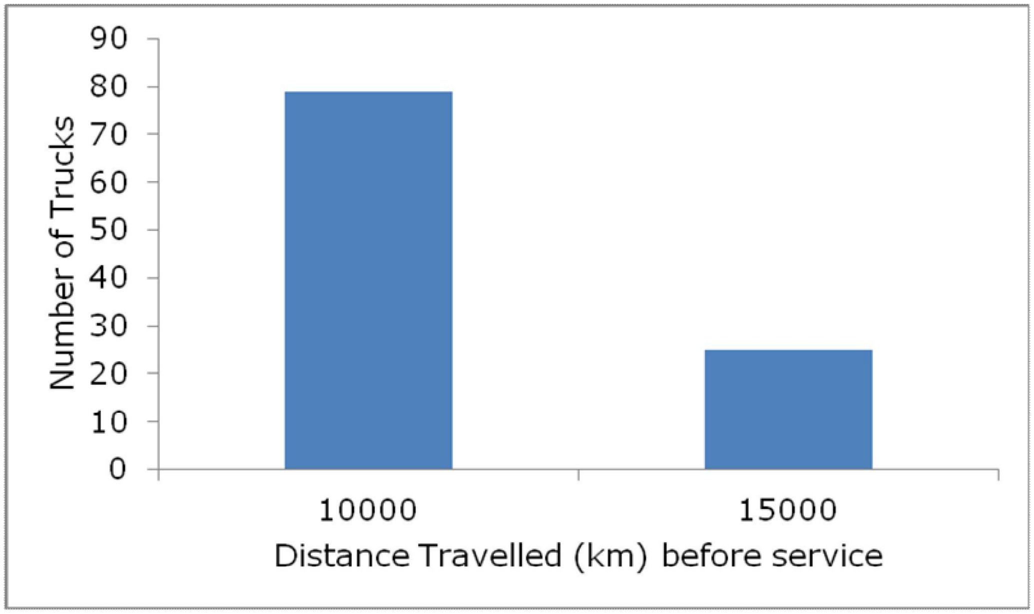

Figure 9 Number of Trucks versus Distance Travelled (km) before service

Table 16 show the number of times a trucks undergoes for service in a year compared to the distance travelled. It indicates that those serviced 6 times annually travelled 15,000 kilometres whilst those serviced 8 times a year travel 10,000 kilometres. This may be due to either the model or the age of the vehicle. The old vehicle will tend to travel short distance and require more attention compared to the new vehicles. Therefore the trucks undergo several services either they have lower efficiencies or travelled more distance hence translated to high energy demand and emissions. The data was independently validated by checking the service cards.

Table 16 Vehicle Maintenance Annually Versus Distance Travelled (km)

		Distance Travelled(km) Before Service		**Total**
		10,000	**15,000**	
Number of Times Vehicle Undergoes Service Annually	6	1 (4.0%)	24 (96.0%)	25 (100.0%)
	8	78 (98.7%)	1 (1.3%)	79 (100%)
Total		**79, (76.0%)**	**25, (24.0%)**	**104, (100%)**

4.10 DISTANCE TRAVELLED PER LITRE WHEN LOADED

Table 17 show the number of kilometres travelled by trucks used for distribution of petroleum in Kenya when fully loaded using one litre of diesel while Figure 10 provides a graphical depiction of the values. It indicates that 39.4% travelled between 1 to2 kilometres using 1 litre of diesel while, 43.3% travelled between 2.1 to 3 kilometres and 17.3% did not indicate. The data was independently validated by checking the service cards.This implies that trucks travelled a distance of between 2.1 to 3 kilometres using 1 litre of diesel when fully loaded.

Table 17 Distance Travelled km/litre When Loaded

Distance Travelled using 1 litre	Frequency	Percentage
1.0-2.0	41	39.4
2.1-3.0	45	43.3
N.A.	18	17.3
Total	**104**	**100.0**

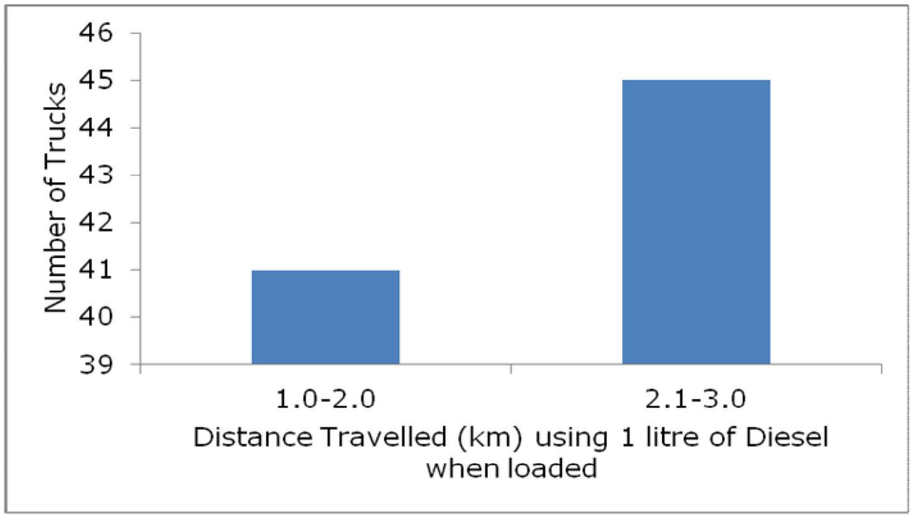

Figure 10 Number of Trucks versus Distance travelled (km) when loaded

Table 18 shows the Pearson correlations between average speed and distance travelled (km) using one litre of diesel fuel when fully loaded. From the table we concluded that there was a strong positive correlations between the two variables (r = .653, p =.000) with distance travelled (km) using one litre of diesel fuel when fully loaded being associated with average speed per trip.

Table 18 Correlations between Average Speeds versus Distance travelled (km)

		Average Speed /Trip	Distance Travelled (km/Litre) when loaded
Average Speed /Trip	Pearson Correlation	1	.653**
	Sig.(2-tailed	-	.000
	N	104	94
Distance Travelled (km/Litre) when loaded	Pearson Correlation	.653**	1
	Sig.(2-tailed	.000	-
	N	94	94

**Correlation is significant at the 0.01 level (2-tailed)

4.11 DISTANCE TRAVELLED PER LITRE WHEN UNLOADED

Table 19 show the number of kilometres travelled by trucks used for distribution of petroleum products in Kenya when unloaded using one litre of diesel while Figure 11 provides a graphical depiction of the values. It shows that 81.7% travelled between 2.1 to3 kilometres using 1 litre of diesel whereas, 1.0% travelled over 4 kilometres, while 17.3% did not indicate. This implies that trucks travelled a distance of between 2.1 to 3 kilometres using 1 litre of diesel when unloaded. Figure 9 and 10 indicates that most trucks travelled the same distance of between 2.1 to 3 kilometres using 1 litre of diesel when loaded and unloaded.

This may be due to weight and speed whereby when the trucks are unloaded they tend to be driven at high speed hence consuming more energy whilst when loaded they tend to be driven at lower speed and still consume more energy. This implies that drivers need to be educated on important of energy conservation

Table 19 Distance Travelled km/litre When unloaded

Distance Travelled using 1 litre	Frequency	Percentage
2.1-3.0	85	81.7
Over 4.0	1	1.0
N.A.	18	17.3
Total	**104**	**100.0**

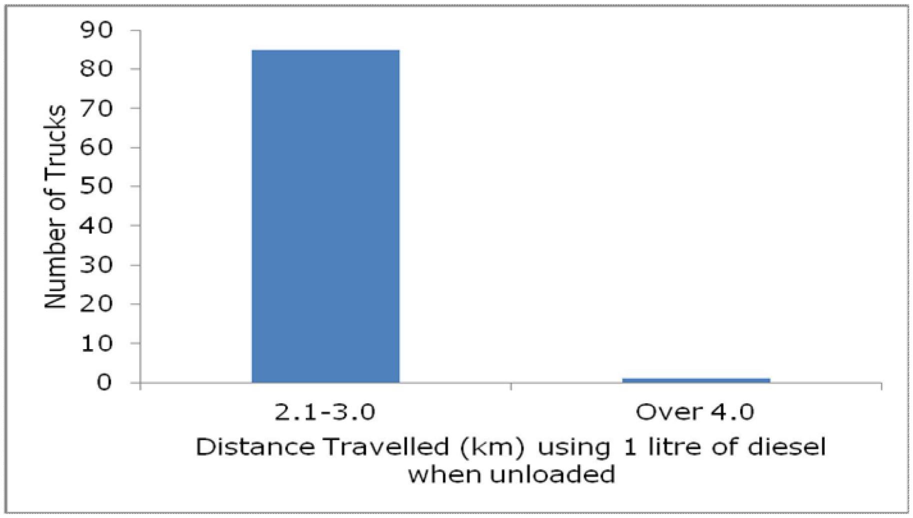

Figure 11 Number of Trucks versus Distance travelled (km) using 1 litre of diesel when unloaded

Table 20 shows the Pearson correlations between average speed and distance travelled (km) using one litre of diesel fuel when unloaded. From the table we concluded that there was a strong positive correlations between the two variables (r = .916, p =.000) with distance travelled (km) using one litre of diesel fuel when fully loaded being associated with average speed per trip.

Table 20 Correlations between Average Speeds versus Distance Travelled (km)

		Average Speed(km/hr /Trip	Distance Travelled (km/Litre) when unloaded
Average Speed (km/hr) /Trip	Pearson Correlation	1	.916**
	Sig.(2-tailed	-	.000
	N	104	94
Distance Travelled (km/Litre) When unloaded	Pearson Correlation	.916**	1
	Sig.(2-tailed	.000	-
	N	94	94

**Correlation is significant at the 0.01 level (2-tailed)

4.12 RESULTS 2: DETERMINATION OF FUEL ENERGY CONSUMPTION

The following data was required in order to determine fuel energy consumption annually. It include fuel consumed per trip, gross weight a truck can carry per trip, number of trips trucks made annually, petroleum products sales historical data and Kenya traffic acts.

4.13 FUEL CONSUMED (litres) PER TRIP

The study established that trucks consumed 400 litres of diesel for distribution of petroleum in Kenya per trip between Mombasa and Nairobi. This data was verified by checking the vehicle log books. This data was also confirmed by the deport managers who explained how they fuel the trucks.

4.14 NUMBER OF TRIPS PER YEAR

Table 21 shows the average trips trucks used for distribution of petroleum in Kenya makes in a year while figure 12 provides a graphical depiction of the values listed. It shows that 10.6% do 72 trips, 83.7% do 96 trips and 5.8% do 100 trips annually. The mean and standard deviation of average trip per year are 93.69 and 7.554 respectively while the chi-square is 62.75 since the x^2 for d_f =103, and 5% significance level=127.689, and $62.75<127.689$ therefore H_o is correct. This implies that trucks travelled an average of 94 trips annually between Mombasa and Nairobi totaling to distance of 91180 kilometres. This may be due to average speed, traffic congestion, road conditions, distance, number of stops, loading, unloading and queuing in the weighing bridges. Taking that a truck consumes 400 litres of diesel per trip this amounted to 37600 litres per year and multiplying by 38.5MJ per litre of diesel it translated to 1447600 MJ annually.

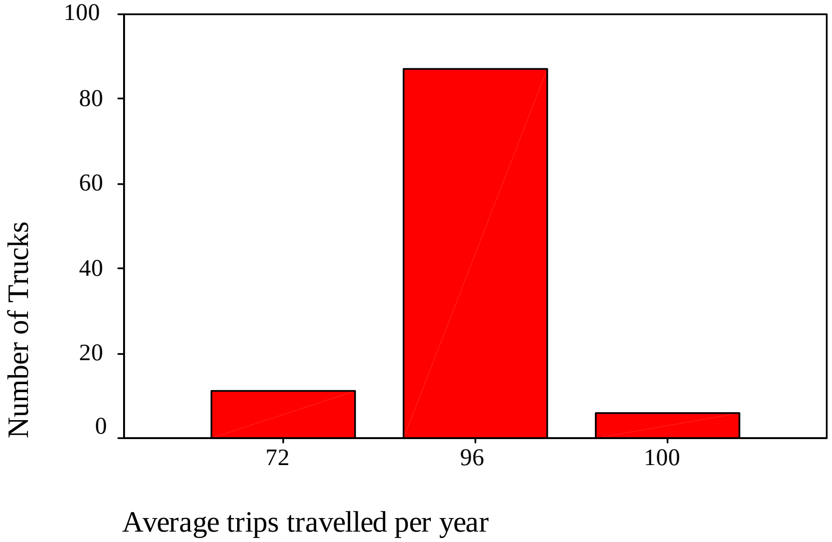

Figure 12 Numbers of Trucks versus Average Trips per year

Table 21 Average Trips Travelled per Year

Number of Trips per Year	**Frequency**	**Percentage**
72	11	10.6
96	87	83.7
100	6	5.8
Total	**104**	**100.0**

4.15 TRIP DISTANCE

Table 22 shows the trip distance trucks used for distribution of petroleum products in Kenya travel while figure 13 provides a graphical depiction of the values listed. It indicates that 89.4% travel 1060 kilometres per trip while 10.6% travel 1240 kilometres per trip. This data was verified from the vehicle log book. The mean and standard deviation of average trip per year are 1079 and 56 respectively. This may be due to distance between Mombasa and Nairobi which is 970 kilometres. The difference between trips means distance and that of Mombasa and Nairobi may be due to the location of the companies' depot. Taking that a truck do 94 trips per annum as indicated in Figure 10 it implies that they travel 101,426 kilometres per year. This implies that trucks used 14.3MJ per kilometres of energy.

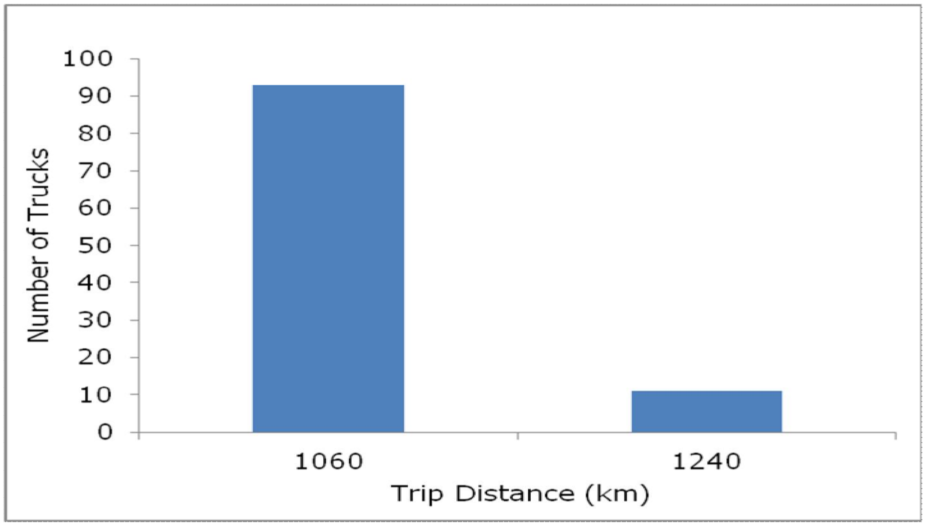

Figure 13 Numbers of Trucks versus Trip Distance (km)

Table 22 Trip Distance (km)

Trip Distance (km)	**Frequency**	**Percentage**
1060	93	89.4
1240	11	10.6
Total	**104**	**100.0**

Table 23 shows the trip distance versus average trips trucks used for distribution of petroleum in Kenya do annually. It indicates that those travelled 1,060 kilometres per trip do between 96 and 100 trips per year accounting to 83.7% and 5.8% respectively while those travelled 1,240 kilometres do 72 trips per year accounting to 10.6%. The table indicates an inverse proportional relationship between trip distance and an average number of trips. It shows that as trip distance increases the number of trips decreases.

Table 23 Trip Distance (km) Versus Average Trips

		Average Trips Annually			**Total**
		72	**96**	**100**	
Trip Distance (km)	1060	0 (.0%)	87 (93.7%)	6 (6.5%)	93 (100.0%)
	1240	11 (100.0%)	0 (.0%)	0 (.0%)	11 (100%)
Total		**11 (10.6%)**	**87 (83.7%)**	**6 (5.8%)**	**104(100%)**

4.16 NUMBER OF AXLES

Table 24 show the number of axles and total gross weight of the trucks used for distribution of petroleum products in Kenya. It indicates that all vehicles had 6 axles with 2.1% had 46 tonnes, 19.8% had 47 tonnes and 78.1% had 48 tonnes. The mean and standard deviation of total gross weights are 47.76 tonnes and 0.476 respectively while the chi-square is 0.45 since the x^2 for d_f =103, and 5% significance level=127.689, and 0.45<127.689 therefore H_o is correct. This implies that most of the trucks used had a total gross weight of 48 tonnes, may be due to the Traffic acts chapter 403, (1993) Revised Edition (2009), Twelfth Schedule, that have set the maximum allowable gross weight and number of axles as 48 tonnes and 6 respectively with corresponding weight per axle as 8 tonnes. According to Newton second law of motion energy needed to overcome inertia when accelerating and climbing grades are dependent on the weight of the vehicle (body) and the load it is carrying. Rolling resistance of vehicles is a function of vehicle weight plus the weight it is carrying, tire characteristics and drive train bearings. The parameter A of equation 1 was associated with fuel consumed to overcome rolling resistance which is approximately proportional to vehicle weight.

Table 24 Number of Axles versus Total Gross Weight (tonnes)

		Total Gross Weight			**Total**
		46	**47**	**48**	
Number Of Axles	6	2 (2.1%)	19 (19.8%)	75 (78.1%)	96 (100.0%)
Total		2 (2.1%)	19 (19.8%)	75 (78.1%)	96 (100.0%)

4.17 PROJECTED PETROLEUM DEMAND UNDER BUSINESS AS USUAL SCENARIO

Using the 2004 levels of economic, social and environmental indicators as the baseline, projections were made for up to 2030 as indicated in the Table 25. The indicators used include level of energy demand, prices, employment, incomes, greenhouse gas and lead emissions, energy-related respiratory disease incidence, and consumption of fuel, charcoal and firewood. The projection of petroleum demands on the business as usual scenario was based on the assumption of 3% average annual growth rate (Kamfor 2006).

Table 25 Growth Rate of Petroleum Demand

Growth rate of Petroleum Demand (%)	2005	2009	2015	2020	2025	2030
3	3329*	4106*	4903	5684	6589	7638

Source: Kamfor 2010, *Actual figures, M^3

4.18 PETROLEUM DEMAND IN KENYA (2005-2009)

Table 26 show the petroleum demand in Kenya and the mode of transport between 2005 to 2009.The table shows that majority of petroleum products were transported using pipeline accounting for an average of 72.74%, whereas 27.26% was done by road. It also indicates the increase for petroleum demand apart from 2008 which experienced a decrease, may be due to the post elections violence. However the transportation of fuel by pipeline has continued to increase at lower rate apart from 2009.This may be due to either KPC capacity to handle 6.5 billion litres on its Nairobi - Mombasa line which was not fully utilised (Ministry of Roads, Kenya) or due to the construction of four additional pumping stations at Samburu, Manama, Makindu and Konza (KNBS 2009).

Table 26: Sales and Mode of Transport of Petroleum Products 2005-2009

Year	Petroleum products sales	Petroleum products transported by pipeline	Petroleum products transported by road
2005	3,329,078	2,432,500	896,578
2006	3,730,620	2,589,500	1,141,120
2007	3,871,841	2,830,900	1,040,941
2008	3,664,965	2,633,600	1,031,365
2009	4,105,715	3,155,700	950,015

Source*:* KNBS 2010, units in m^3

4.19 NUMBER OF TRIPS AND FUEL DEMAND (LITRES) BETWEEN 2005-2009

Table 27 show the number of trips, fuel demand (litres) and energy demand (MJ).This table was established by the use of the traffic acts chapter 403 revised edition, 2009, (1993), twelfths and thirteen schedule using the maximum allowable volume a vehicle of the 6 axles can carry in Kenyan roads see appendix 6.Then those products that can be transported using the same weight or volume were grouped together and used to establish the number of trips in each year. It indicates that the energy demand increased from 492 mega joules in year 2005 to 525 mega joules in year 2006.This was may be due to good economic recovery in Kenya and integration of east Africa common market. It also indicates a decline on energy demand from 2007 to 2009.This may be due to post election violence which led to stagnation of all economic activities and hence there was no distribution of petroleum products for that period of time. Overall the table indicates increase of energy demand from year 2005 to year 2009 from 492 MJ to 556 MJ respectively. The implication of this high energy demand by road was increase of number of trips and imported fuel, road destruction and environmental pollution from consumption of fossil fuel.

Table 27: Number of Trips, Fuel Demand (litres) and energy demand (MJ)

Year	Number of Trips	Fuel demand (FD) Litres in 000	Energy demand (Mega Joules)
2005	31,950	11,190	492
2006	34,089	11,970	525
2007	34,839	12,250	537
2008	33,738	11,850	520
2009	36,084	12,700	556

4.20 FUEL CONSUMPTION MODEL

The following data was required in order to develop the fuel consumption model which includes average weight of the truck, number of wheels, fuel type, engine power, number of axles and type of carriage see attached Appendix 4 on the summary of questionnaire descriptive statistics. Using Thoresen (2003) lookup tables see appendix 5 equation 1 becomes 4 and the effect of various values of speed are shown in figure 16;

$$FC = \left(131.1 + \frac{11658.6}{V} + 0.0148V^2\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where FC is fuel consumption per trip

V is the average speed (km/hr) per trip

4.21 MODEL SIMULATION, VALIDATION AND RESULTS

The general shape of the fuel consumption function equation 4 is shown in figure 14.Fuel use as a function of speed decreases rapidly for low speeds,reaches a minimum at a speed of 50km/hr and increases gradually thereafter.On the first part of the curve the decreasing effect of a higher speed and increase of fuel use per kilometre was due to the rolling resistance force.On the second part of the curve the additional energy needed to overcome aerodynamic drag was the most important derterminant.At higher speed the U-shaped curve becomes narrower,which implies that deviations from the optimum speed results in larger increases in fuel use.The possibilities for improving fuel efficiency suggested by the fuel consumption curve were quite large,at speed of between70km/hr and 75km/hr compared to a speed of below 50km/hr and a speed of over 100km/hr with a saving of approximateraly 30 litres diesel per trip. However this speed cannot be maintained during a trip because of road conditions and other traffic issues which include police stops and weighbridge.

The data between speed and fuel consumption was collected using questionnaire and was used to validate the fuel consumption model.Only two data points were indicated by the drivers as follows.Some of the drivers indicated that trucks of the same total gross weight driven at an average speed of 41-60 kilometres per hour consumed 400 litres of diesel per trip while those driven at an average speed of 61-80 kilometres per hour consumed 360 litres of diesel. The data on fuel consumption was independently validated by checking the log books from the offices.The model shows that trucks travelling at an average speed of 50km/hr will consume 401 litres while whose travelling at an average speed of 70km/hr will consume 370 litres these trucks have the same total gross weight. Therefore results obtained using the model developed in equation 4 indicates less disparity between observed and modeled. Thus, the performance of calibrated model was practically satisfactory.

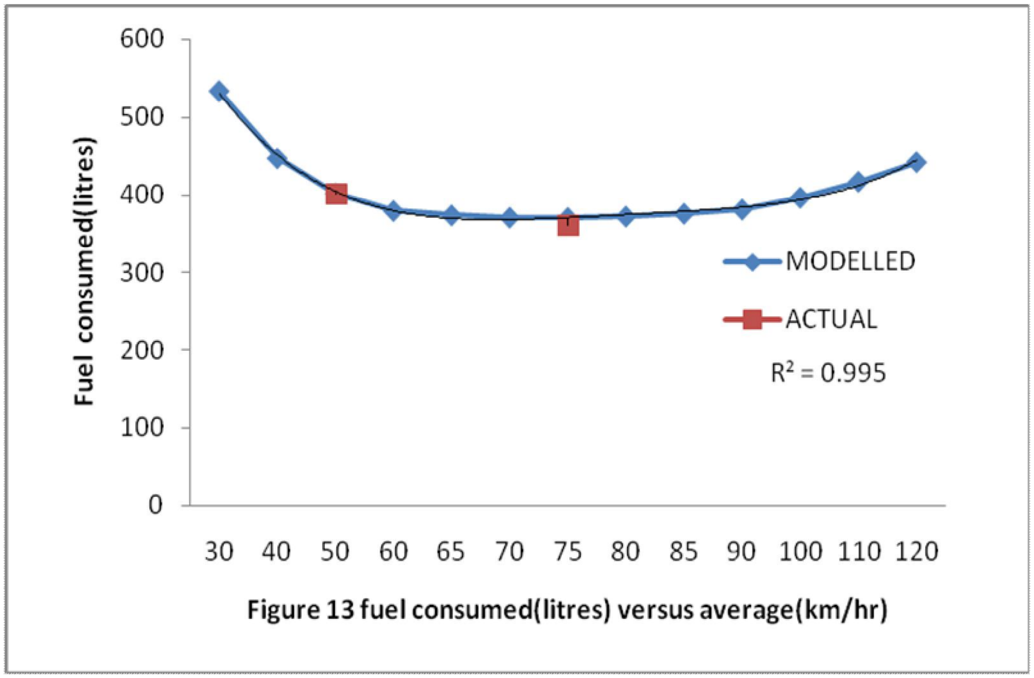

Figure 14 Fuel Consumed (litres) per Trip versus Average Speed (km/hr) per Trip

4.22 TRIP PRODUCTION MODEL AND ITS VALIDATION

The trip production model was modified from one developed by HDNP study 1991. The data of 2005 to 2009 was used for both modification and validation of trips production model while 2009 to 2013 data was used for further validation. The data on Table 26 was feed on SPSS and used to generate equation 5. It related the average number of trips a truck makes annually with the petroleum products sales (TED) in litres and the amount of fuel transported by pipeline. The coefficients of correlation number of trips (NT) can be explained by the level of energy demand (TED) in litres and amount of fuel transported using pipeline with high accuracy of (R^2=0.943) and significance level of 0.005. Hence equation 2 becomes equation 5 as follows;

$$NT = 5.364TED - 0.084PP + 12995 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where NT is number of trips
TED is level of energy demand
PP is the amount of fuel transported using pipeline

Table 28 shows the number of observed and modeled trips from 2005 to 2009 while figure 15(a) provides a graphical depiction of the values. Results obtained using the model developed indicate less disparity between the calculated values and the modeled values of trips with a correlation coefficient of 0.943. Therefore it indicates that the performance of the calibrated model was practically satisfactory.

Figure 15(b) provides a graphical depiction of the values from 2009 to 2013. The graph obtained from these values indicates similar characteristics as ones in Figure 15 between the calculated and modeled values of trips. Thus indicates that the performance of the calibrated model was practically satisfactory. The Figure indicates the growth of the number of trips from over 30,000 in year 2005 to over 35,000 in year 2007.This may be due to good economic and population growth which was accompanied by high demand of petroleum products. It also indicates the decrease of number of trips between 2007 and 2008, from35, 000 to less than 32,000 which may be due to the post elections violence. It further indicates the growth of number of trips from 32,000 to over 38,000 in year 2009 to 2013. This may be due to growth of petroleum products transportation demand due to opening up of borders between Kenya and her neighbours, the creation of East African common market with enlarged membership and high economic growth. This may also be due to the growth of demand of some of the petroleum products which were not transported by pipeline like industrial fuel, avgas, liquefied petroleum gas (LPG) and bitumen.

Table 28 (a) Number of Trips

YEARS	**2005**	**2006**	**2007**	**2008**	**2009**	Annual Growth (%)
Calculated	31,950	34,089	34,839	33,738	36,084	2.59%
Modelled	30,647	32,791	33,527	32,433	34,754	2.68%

Table 28 (b) Number of Trips

YEARS	**2010**	**2011**	**2012**	**2013**	Annual Growth (%)
Calculated	35,775	38,547	38,728	38,925	2.20%
Modelled	34,471	37,265	37,448	37,646	2.30%

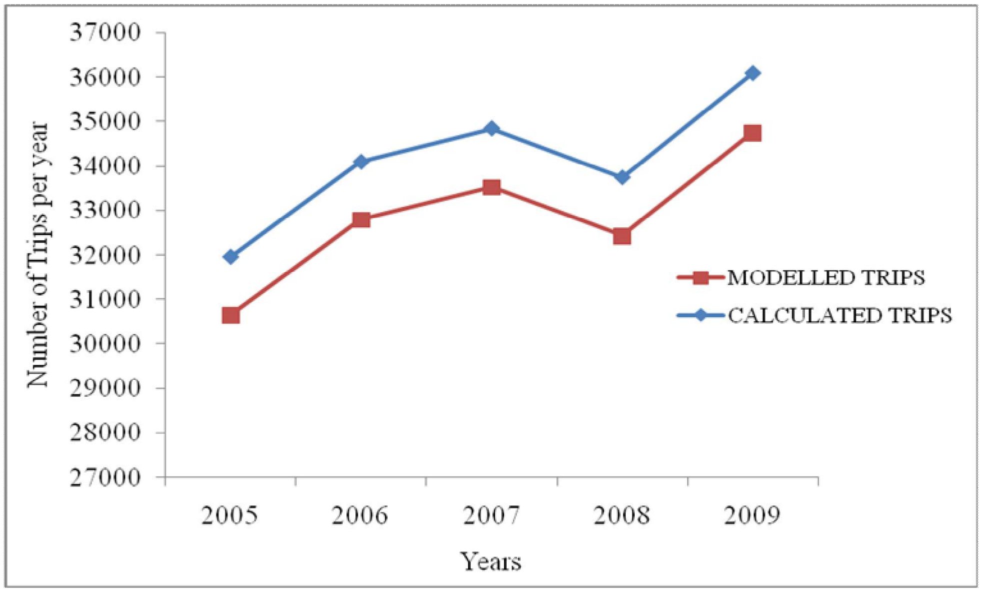

Figure 15 (a) Calculated and Predicted Number of Trips

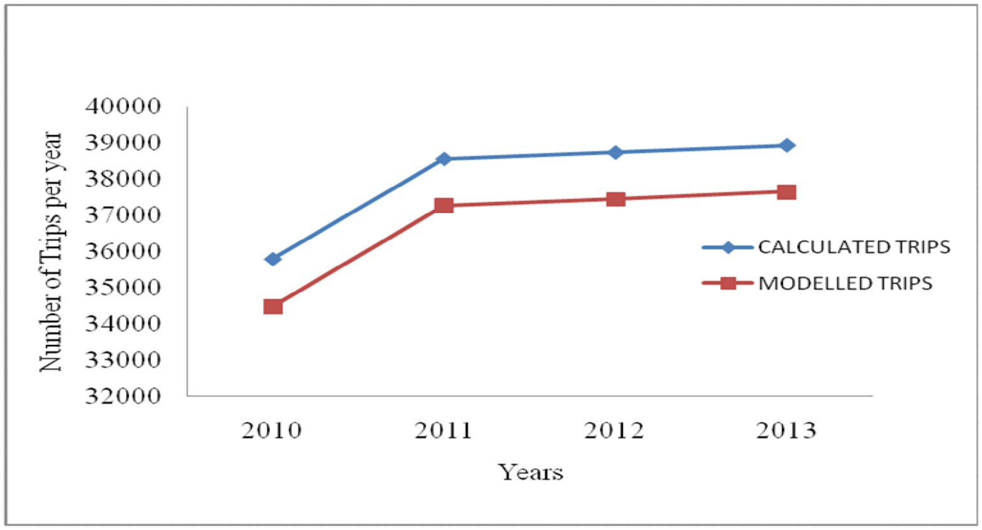

Figure 15 (b) Calculated and Predicted Number of Trips

4.23 NUMBER OF TRUCKS AND VEHICLE KILOMETRES TRAVELLED

In order to calculate the number of trucks the following data was required as input the total number of trips and the maximum number of trips a truck can make in a year as indicated in table 21.

$$NV = \frac{NT}{96} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Where NV is number of trucks

NT is number of trips

Table 29 shows the number of trucks, travel demand (km) and fuel demand (liters) from 2005-2009 used for distribution of petroleum products between Nairobi and Mombasa in Kenya. During this period, the number of trucks increased from 322 vehicles in 2005 to 362 vehicles in 2009, accounting for 2.48% growth rate annually.

Table 29 Number of Vehicles

YEARS	2005	2006	2007	2008	2009
Number of Vehicles	333	359	362	351	376

In order to calculate the vehicle kilometres travelled per vehicle the following data was required as input an average number of trips a truck can make in a year as indicated in Table 21 and trip distance.

$$\mathrm{VKT} = \sum 96 * 970 = 93120\ \mathrm{km/year} \ldots\ldots\ldots\ldots\ldots\ldots\ldots .9$$

Where VKT is vehicle kilometres travelled per vehicle
96 is the average number of trips trucks per annum
970 is the trip distance

4.24 ENERGY DEMAND MODEL FOR DISTRIBUTION OF PETROLEUM PRODUCTS

The energy demand model for road distribution of petroleum products in Kenya is function (ED) of fuel consumption model and trip production model multiplied with a constant of 38.5 which convert litres of diesel into Mega joules.

4.25 ENERGY DEMAND MODEL

Equation 6 shows energy demand model for distribution of petroleum products in Kenya (ED) which is a modification of Thoresen equation 1.In order to use the model, total petroleum sales were used as input to the trip production model equation 5 which produces the total number of trips.

$$\mathrm{ED} = \left(\frac{\mathrm{FC}}{970}\right) * \mathrm{NV} * 93120 * 38.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

Where ED is the energy demand of petroleum products distribution in Kenya
NV is the total number of vehicles
38.5 is a constant to convert litres of diesel into mega joules

4.26 MODEL VALIDATION

Table 30 shows the energy demand for distribution of petroleum in Kenya. The observed and modeled data covers the period of years 2005 to 2009 while figure 16 (a) provides a graphical depiction of the values listed in the table. The data of 2005 to 2009 was used for both modification and validation of energy demand model while 2009 to 2013 data was used for further validation. Results obtained using the modeled developed indicate less disparity between the calculated and the modeled energy demand with a correlation of coefficient of 0.996.

Figure 16(b) provides a graphical depiction of the values from 2009 to 2013. The graph obtained from these values indicates similar characteristics as ones in figure 16 (a) between the calculated and modeled values of energy demand. Thus indicates that the performance of the calibrated model was practically satisfactory. The Figure indicates the growth of the energy demand from over 480MJ in year 2005 to over 540MJ in year 2007.This may be due to good economic and population growth which was accompanied by high demand of petroleum products.

It also indicates the decrease of number of trips between 2007 and 2008, from540MJ to less than 500MJ which may be due to the post elections violence. It further indicates the growth of number of trips from 500MJ to over 600MJ in year 2009 to 2013. This may be due to growth of petroleum products transportation demand due to opening up of borders between Kenya and her neighbours, the creation of East African common market with enlarged membership and high economic growth. This may also be due to the growth of demand of some of the petroleum products which were not transported by pipeline like industrial fuel, avgas, liquefied petroleum gas (LPG) and bitumen.

Table 30 (a) Energy Demand

YEARS	**2005**	**2006**	**2007**	**2008**	**2009**	Annual Growth (%)
Calculated(MJ)	492	525	537	520	556	2.60%
Modelled(MJ)	473	507	517	501	537	2.71%

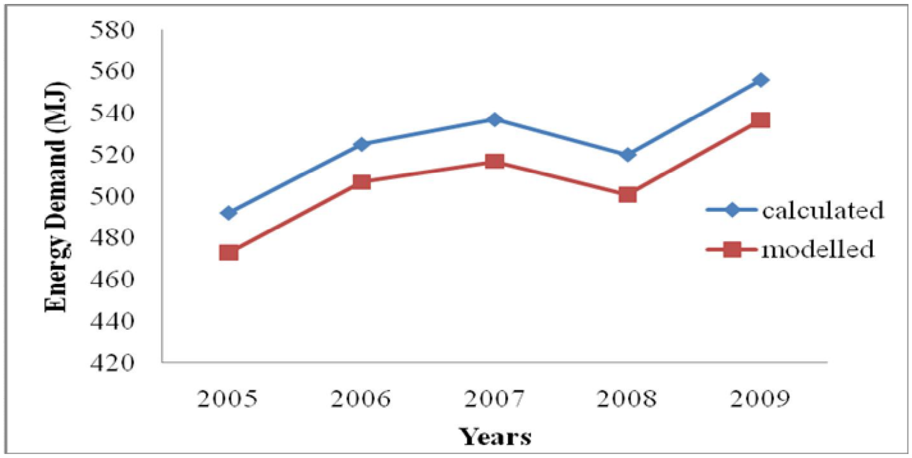

Figure 16(a) Calculated and Modelled Energy Demand

Table 30 (b) Energy Demand

YEARS	**2010**	**2011**	**2012**	**2013**	Annual Growth (%)
Calculated(MJ)	556	593	594	596	1.80%
Modelled(MJ)	532	575	578	581	2.03%

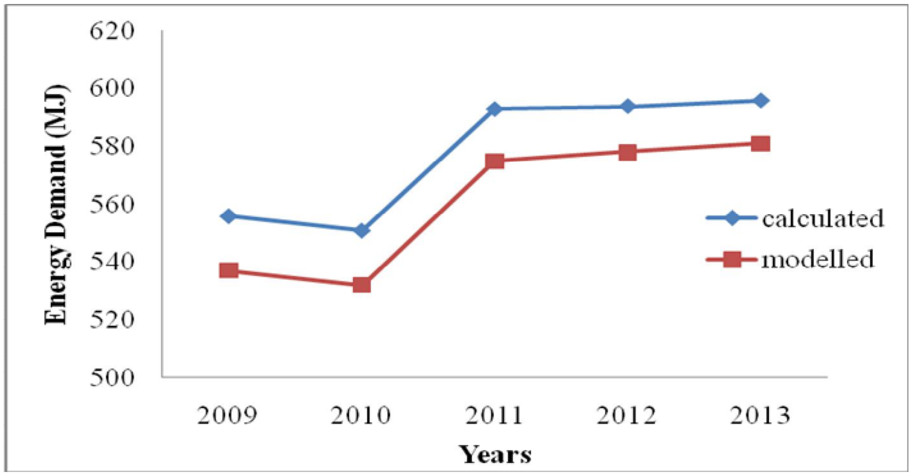

Figure 16(b) Calculated and Modelled Energy Demand

Table 31 shows the number of observed, modeled energy demand and modeled energy demand with correction factors from 2005 to 2009.It indicates that with correction factor of 0.039 at an average speed of 50km/hr the model can produce the actual results.

Table 31 Energy Demand with Correction Factors (Cf)

Average Speed(km/hr)	50km/hr	Correction Factor	0.039
Year	Actual	Modelled	Modelled-CF
2005	492	473	491
2006	525	507	527
2007	537	517	537
2008	520	501	520
2009	556	537	558

4.27 EFFECTS OF VARIOUS SPEEDS ON ENERGY DEMAND

Future demand for fuels on transport of petroleum products between Nairobi and Mombasa was determined on the basis of scenarios. The general approach was to setup a base case, reference, or “business as usual” scenario where past and current trends are simply extrapolated over the period of study. In the base case, driving speed habits don’t change resulting into high energy demand.

There are a large number of possible scenarios but for this study a generalized alternative “high efficiency” scenario and “low efficiency” scenario compared to the base scenarios were developed to reflect the possible outcome of the following basket of interventions:. The results of these scenarios were summarized in Figure 17 from 2005 to 2010. The figure indicates that if the trucks were driven at an average speed of 70 km/hr energy demand would be less as compared to 50km/hr.

It indicates that if vehicles were driven at an average speed of 30 km/hr the energy demand would be at the range of over 600MJ in2005 to over 700MJ in year 2010.While if they were driven at an average speed of 70 km/hr the energy demand would be at the range of over 400MJ in2005 to less than 500MJ in year 2010. This is less compared to the actual average speed of 50 km/hr that show that energy demand was in the range of over 500MJ to 600MJ.

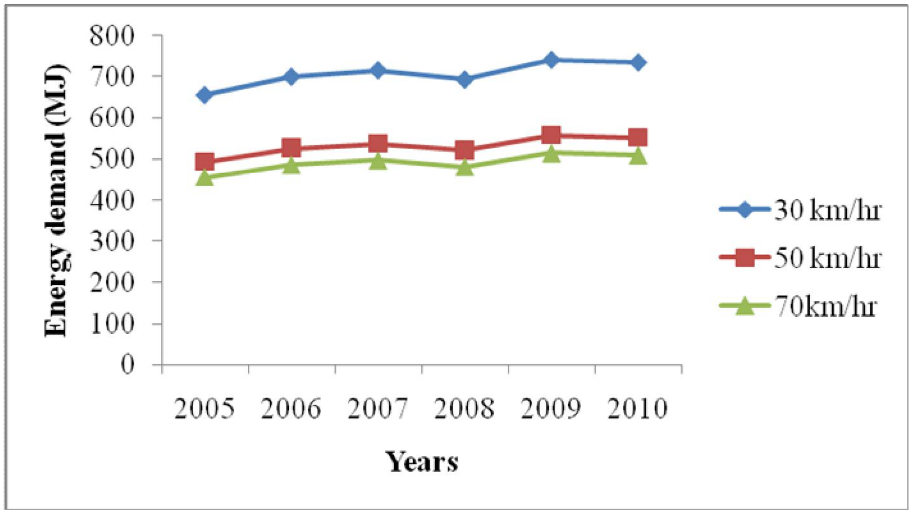

Figure 17 Effects of Various Speeds on Energy Demand

4.28 ENERGY DEMAND MODEL SIMULATION RESULTS

Figure 18 show the energy demand in mega joules (MJ) from 2005 to 2009 used for distribution of petroleum products in Kenya. During this period, the energy demand increased from 492 mega joules 2005 to 556 mega joules in year 2009, accounting for 2 % growth rate annually while the model indicates 2.01% at the same period.

It predicts growth of the energy demand for distribution of petroleum demand in Kenya from 2009 to 2030. The forecasting models predicts that the energy demand will increase from 492 mega joules in year 2009 to over 753 mega joules by year 2030, accounting for 2.57% growth rate annually. This will lead to more energy consumption, road destruction, emissions, road accidents and traffic congestions.

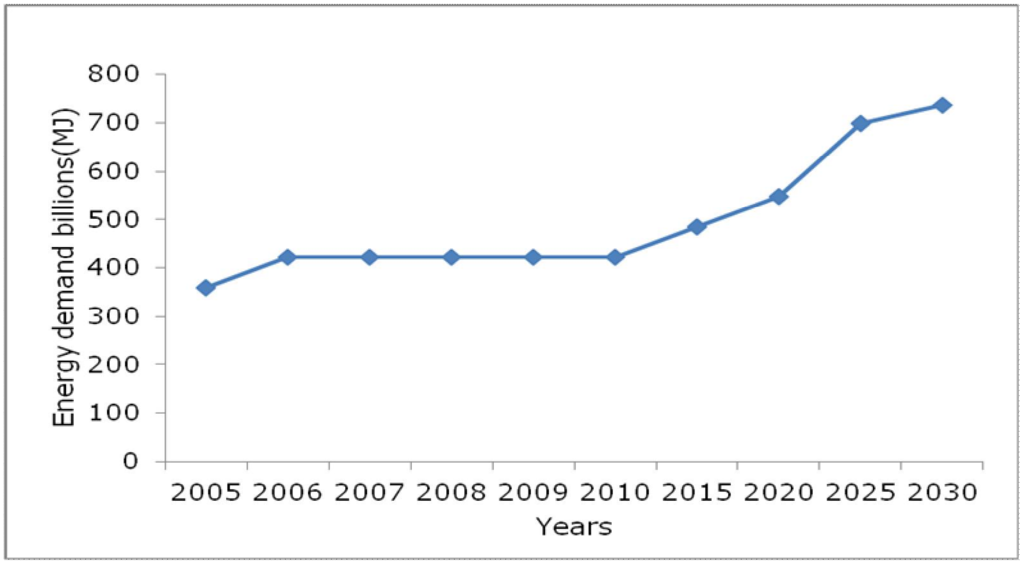

Figure 18 Projected Energy Demand (MJ)

5.0 CHAPTER FIVE

5.1 CONCLUSIONS

The following was concluded from the energy use in the distribution of petroleum products between Nairobi and Mombasa.The study found that all the vehicles used diesel as the source of energy. It also established that annual fuel consumption ranged from over 11 millioms litres of diesel in year 2005 to over 12 millions litres of diesel in year 2009.Three models were developed namely fuel consumption,trip production and energy demand. Fuel consumption model establishes relationship between fuel consumption and average speeds. The model establishes that an average speed had a polynomial relationship with fuel consumption.The model shows possibilities for improving fuel efficiency suggested by the fuel consumption curve were quite large, at speed of between70km/hr and 75km/hr compared to a speed of below 50km/hr and a speed of over 100km/hr with a saving of approximateraly 30 litres diesel per trip.

The trip production model established the relationship between petroleum products sales,amount of petroleum products transported by pipeline and number of trips.It established that the number of trips increased from 31,950 in 2005 to 36,084 in year 2009.The increase in use for those petroleum products that were not transported by pipeline like LPG contributed much to this increase.The number of trips and number of trips a vehicle can do annully was used to established the number of vehicles used per year.Finally the energy demand model was a product of number of vehicles, vehicle kilometres travelled per vehicle, fuel economy and energy converting factor.The model established that energy demand stood at 492MJ in year 2005 to 556MJ and is expected to increase to over 700MJ in year 2030. This will be accompanied by increases of road travel demand,number of trucks,fuel consumption, road destruction,accidents and air pollution.

5.2 RECOMENDATIONS

The study recommends that other models should be developed for petroleum products for other roads that are Nairobi to Nakuru, Nakuru to Kisumu, Nakuru to Eldoret and Nairobi to Nanyuki. It also recommends that other models to be developed using other types of loads like(cement, tea)etc, road sections, traffic characteristics and vehicles as per load they are carrying, number of tires, axles, power engine and capacity. It also recommends that the road between Nairobi and Mombasa should be upgraded in order to enable the vehicles increase the average speed to between70km/hr and 75km/hr. Finally the study establisbed that railway line remained unutilised in the transportation of petroleum products between Nairobi and Mombasa therefore it is recommended for a study to be carried out and establish it impact on energy demand.

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APPENDIX I: QUESTIONAIRE

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

INSTITUTE OF ENERGY AND ENVIRONMENTAL TECHNOLOGY (IEET)

DATE……………………………………………..

Dear Sir/ madam,

Re: Energy Demand Questionnaire

I am a postgraduate student undertaking a master’s of science in energy technology degree at Jomo Kenyatta University of Agriculture and Technology. I am currently carrying out a research on the energy demand model of road cargo transport for the distribution of petroleum products in Kenya. My approach to this survey is both consultative and collaborative and ensures that it causes minimum disruption to your schedule of activities. I kindly request you provide the requested information by responding to the questions. The information required is purely for academic purposes and will be treated in the confidentially. Please let us know if you would like a copy of the report based on this study. **Should you have any queries about the survey please do not hesitate to call Samuel Maina Ngure, 0721236909.**

THANK YOU FOR YOUR HELP

PERSONNAL INFORMATION

Q1 Gender : ☐ Male ☐ Female

Q2 Highest level of education

☐ Primary ☐ O level ☐ A level ☐ Above A level ☐ Any other

Q3 Age………………………………………..

Q4 Indicate when you were employed in this company as a driver ……………

Q5 Indicate when you acquired your driving license ………………………… …

A ABOUT THE VEHICLE YOU DRIVE

Please tell us about the vehicle you use the most.

Qa.1Model/Make of the vehicle you drive most …………………………..

Qa.2 Indicate the type of the fuel this vehicle use

☐ Petrol ☐ Diesel ☐ Any other specifies…………

Qa.3 Is this vehicle also driven by other driver in this company? ☐ Yes ☐ No

Qa.4 In what year was the vehicle first registered? ....

Qa.5 Indicate the size of the vehicle's engine (horse power)………………………..

Qa.6 Indicate the number of wheels this vehicle has

☐ 6 ☐ 10 ☐ 12 ☐ 14 ☐ 18 ☐ 20 ☐ 22 ☐ Any other specify………………..

Qa.7 Indicate the number of axle this vehicle has

☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ Any other specify………………..

Qa.8 Indicate the maximum gross weight(tonnes) of the vehicle

☐ 18 ☐ 24 ☐ 28 ☐ 34 ☐ 36 ☐ 40 ☐ 42 ☐ 48 ☐ Any other specify…………

Qa.9 Indicate the tire weight(tonnes) of the vehicle

☐ 6 ☐ 7 ☐ 8 ☐ 10 ☐ 15 ☐ 17 ☐ 18 ☐ Any other specify………………..

Qa.10 Indicate the loading capacity (tonnes) of the vehicle

☐ 14 ☐ 18 ☐ 19 ☐ 20 ☐ 23 ☐ 25 ☐ 27 ☐ 30 ☐ Any other specify…………

Qa.11 Indicate the type of the vehicle ☐ Rigid ☐ Articulated

Qa.12 Indicate the number of times this vehicle undergo an interim or full service in a year

☐ 2 ☐ 4 ☐ 6 ☐ 8 ☐ 12 ☐ Any other specify………………..

Qa.13 Indicate the kilometres this vehicle travel before it undergoes an interim or full service.

☐ 5000 ☐ 10000 ☐ 15000 ☐ 20000 ☐ Any other specify………………..

PART B Trip is the complete journey you make from loading deport to the place you are delivering the cargo.

Qb.1Indicate the total kilometres the vehicle was driven last year………………….

Qb.2Indicate the number of trips this vehicle does in a year

☐ 12 ☐ 24 ☐ 48 ☐ 72 ☐ 96 ☐ 108 ☐ Any other specify……………….

Qb.3Indicate the average distance of the trip……………………….

Qb.4 Indicate the amount of fuel (litres) consumed per trip …………………..

Qb.5 How many kilometres on average can this vehicle do without stopping? ....

Qb.6 How many times do you stop in one journey?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ Any other specify……………

Qb.7 How long do you take on those stopping (hours)?

☐ 1 ☐ 2 ☐ 3 ☐ Any other specifies…………..

Qb.8 Do those stopping affect fuel consumption on the vehicles? ☐ Yes ☐ No

Qb.9 If yes, how many litres per kilometre do you estimate this vehicle can do if driven without stopping when fully loaded? …………………..

Qb.10 How many litres per kilometre do you estimate this vehicle can do if driven without stopping when unloaded? …………………..

Qb.11 Indicate how many litres per kilometre does this vehicle can do when fully loaded? …………………

Qb.12 Indicate how many litres per kilometre does this vehicle can do when un loaded? …………………..

Qb.13 Indicate the average speed per trip (kilometres per hour)

☐ 0-20 ☐ 21-40 ☐ 41-60 ☐ 61-80 ☐ Over 80 ☐ Any other specify……………..

APPENDIX II: VEHICLE LOG BOOK

APPENDIX III: C++ MODEL

```
smn.cpp : main project file.
#include <iostream>
using namespace std;
#define energycontents 38.5

class energy
{
private:
      double fuelconsumption,speed;
public:
      void input_speed();
      void compute();
      void output();
};
void energy::input_speed()
{
      cout<<"\nInput the speed";
      cin>>speed;
}
void energy::compute()
{
      fuelconsumption =131.1+11658.6/speed+0.0148*speed*speed;
}
void energy::output()
{
cout<<"\nfuelconsumption:"<<fuelconsumption;
};

class edemand
{
private:
      int trips,petroleumsales,pipeline,fuelconsumption,energydemand;

public:
    void input_petroleumsales,pipeline();
      void compute();
      void output();

};
void edemand::input_petroleumsales,pipeline()
{
      cout<<"\nInput the petroleum sales";
      cout<<"\nInput the pipeline amount";
    cin>>petroleumsales;
      cin>>pipeline;
}

void edemand::compute()
{
      trips=(12995+5.364*petroleumsales-0.084*pipeline);

      energydemand=(fuelconsumption*trips*energycontents);
}
void edemand::output()
{

      cout<<"\nNumber of trips:"<<trips;
      cout<<"\nEnergy demand:"<<energydemand;
};
```

```
void main()
{
      energy a;

      a.input_speed();
    a.compute();
    a.output();

      edemand b,c;

    b.input_petroleumsales();
     b.compute();
      b.output();

 c.input_pipeline();
 c.compute();
 c.output();

}
```

APPENDIX IV: DESCRIPTIVE STATISTICS

	Statistic	Range	Mean	Std. Error	Std. Deviation	Variance
Trip distance	104	180	1079.04	5.45	55.62	3094.21
Engine size	102	140	436.72	4.77	48.21	2324.99
Fuel consumed per trip	104	100	415.38	3.56	36.25	1314.41
Average trips travelled per year	104	28	93.69	.74	7.55	57.06
Average speed/trip	104	15	51.15	.39	4.01	16.13
Total gross weight	96	2	47.76	.05	.476	.23
Number of wheels	104	4	21.46	.10	.975	.95
Number of axles	104	0	6.00	.00	.000	.00

APPENDIX V: TABLE OF REPRESENTATIVE OF VEHICLES AND THEIR CHARACTERISTICS

Vehicle Category		Maxi. Mass GCM (tonnes)	Effective Mass GVM (tonnes)	Number of Wheels	Fuel P Petrol D Diesel	Engine Power (kW)	Aerodynamic Drag (CD)	Frontal Area (Sq m)	Basic fuel consumption equation coefficient		
									A	B	C
1	Utility (2 axle 4 tyre)		2.5	4	P	100	0.6	2.2	59.9	1,915.30	0.0087
2	Light commercial van Petrol [P]				P				59.9	1,915.30	0.0087
3	Light truck (2 axle 6 tyre) Petrol [P]		2.7	6	P	124	0.7	5.0	42.1	2,596.70	0.0234
4	Light truck (2 axle 6 tyre) Diesel [D]		4.2	6	D	90	0.7	5.0	42.0	1,948.00	0.0143
5	Medium truck (2 axle 6 tyre)		8	6	D	120	0.65	6.0	43.3	354330	0.0159
6	Heavy Rigid Truck (3 axle)								65.1	5,408.30	0.0168
7	Rigid or Articulated 3 Axle Truck		14	10	O	170	0.6	8.0	65.1	5,408.30	0.0168
8	Articulated truck – 4 Axle		20	16		190	0.7	8.0	106.5	6,779.70	0.0169
9	Articulated Truck - 5 Axle			18		260		8.0	118.1	10,126.10	0.0158
10	Articulated Truck - 6 Axle		35	22	O O	280	0.7	8.0	131.10	11,957.50	0.0148
11	Rigid (3 axle) +5 Axle Dog Trailer	59.0	43	30	O O O	300	0.7	8.0	129.11	15,209.82	0.0180
12	Twin steer + 4 Axle Dog Trailer	60.5	49	28	O O	320	0.7	8.0	132.20	17,012.87	0.0180
13	Twin steer + 5 Axle Dog Trailer	64.0	52	32	O O O	330	0.7	8.0	140.97	18,085.63	0.0190
14	B double Combination		45	30		320	0.8	8.0	172.70	14,720.40	0.0160
15	Road Train (double)		54	44		320	0.8	8.0	223.60	1720180	0.0148
16	A B Combination	99.5	74	54		350	0.8	8.2	254.94	23,765.82	0.0170
17	Road Train (triple)		85	64		360	0.8	8.2	312.10	26,646.90	0.0150
18	B Triple Combination	83.0	62	46		350	0.8	8.2	235.82	20,512.58	0.0180
19	Double B Double Combination	119.0	87	66		370	0.8	8.2	282.40	28,144.99	0.0170

Source: Thoresen (2003)

APPENDIX VI: THIRTEENTH SCHEDULE OF MAXIMUM ALLOWABLE VOLUME

	MAXIMUM ALLOWABLE VOLUME BY PRODUCT (M^3)								
Product	*(i)*	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Regular Petrol...................	11	18	14	12	17	35	28	24	19
Super Petrol.......................	11	18	14	12	17	35	28	24	19
Kerosene	11	17	14	12	16	34	27	23	18
Aviation..........................	11	17	14	12	16	34	27	23	18
Poper Alcohol	11	17	14	12	16	34	27	23	18
Diesel.............................	10	16	13	11	15	31	25	22	17
Industrial Diesel	9	15	12	10	14	30	24	21	16
150mm...........................	50mm.	50mm.	50mm.	50inm.	50mm.	50mm.	50mm.	50rnm.	50mm.

Traffic acts 2009(1993)

APPENDIX VII: TITLES OF PAPERS PRESENTED IN CONFERENCES

Ngure S., M., Ochieng, F., X., Mailutha, J., T., Fuel consumption model for road distribution of petroleum products in Kenya, Science, Technology and Entrepreneurship for Sustainable Development, 8th JKUAT scientific, technological conference and exhibitions, November 2013.

APPENDIX VIII: PUBLICATION

Ngure, S., M., Ochieng, F., X., Mailutha, J., T.,”Fuel consumption model for road distribution of petroleum products in Kenya”, *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT),* Volume 8, Issue 1 Ver. IV (Feb. 2014), PP 56-60