# Analytical Comparison of Automobiles Commonly Used in Palestine

*(An Insight for the Pre-design Stage)*

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## Abstract

This study aims to outline the specifications and features that should be taken into consideration when designing a car. This study focused on investigating these features in the context of the topo-geography of the roads in Hebron as a part of Palestine. The study methodology relied on investigating and analyzing the automobile data published online and reliable Palestinian statistics. Both handling and performance equations were applied on the selected designs. By applying these equations, it can be determined which are the features for the vehicle (car) design that is more suitable to the roads and that has the best performance, safe, fuel economy and less emission effect. It was revealed that the car which is designed to have less frontal area and less body weight, would in turn have low total resistance. This enables the car to have a higher force and better performance when moving on the roads. Its recommended that the comparison between the different designs must be done using the torque of the engine alongside the gear ratios, in order to decide the more efficient one for a specified use. Also the decision of the vehicle operating cost was made only on the fuel consumption assuming the other costs constant.

**Keywords:**

Vehicle dynamics, Static margin, Fuel economy, Vehicle emissions, Emissions rate, Emissions intensity, Car Operating Costs, Road Loads

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## Introduction

When an automobile is designed, the arrangement, choice, and type of components depend on various factors. The use of the automobile is one factor. Some cars are required only for local driving; these cars may be capable of achieving good fuel economy on short trips, but they may be less comfortable to drive at high speeds. A sports car, built for speed, will have enhanced steering and handling abilities, but requires a stronger engine, more fuel, and a more sophisticated suspension system.

Yet, an automobile must also be flexible enough to perform in every situation and use.

Other factors in the design of automobiles include the requirements for pollution-control components that have been placed on the modern automobile. Safety features are also a factor in the automobile's design, affecting everything from the braking and steering systems to the materials used to construct the body. The design of the body must incorporate standards of safety, size and weight, aerodynamics or ways to reduce the friction of airflow, and appearance.

### ✓ The Study Objectives

This study proposes a specified standard for measuring different models of vehicles; in order to find the most suitable model in terms of (Safety, fuel consumption and amount of emissions).

The methodology of measuring will be by comparing those different models from different manufacturer taking into that these models is available in Palestine. In order to find an accurate result in comparing there must be constant Features (body type, engine size, model class, etc.) for all the models to form a reference for measuring.

The way of comparing depends on physical principles to model propulsion systems in the vehicle. The results of comparison will identify the properties of the best model, and take these Features as the standards parameters for importing cars to Palestine.

The study also will use these results alongside of vehicles internal cost as a reference to guide and consult people when they choose their vehicles.

✓ **The Study framework**

The first chapter will clarify the concept of vehicle, and the way of power transfer from engine to the wheels (Power flow) and fuel economy in general. The second chapter will illustrate Vehicles emission and its factors. Third chapter will explain the financial part of vehicles (Internal costs). Fourth chapter will handle the road loads basics and how to measure its effect on vehicle by mathematical relations. The fifth chapter will show a group of statistics about vehicles and chosen models. The sixth chapter will talk about vehicle safety and handling equations. In the final chapter, the study references and data sources are listed.

## The Study Terminology

**According to Oxford Dictionaries.com, the definition for internal combustion engines is:** an engine that generates motive power by the burning of gasoline, oil, or other fuel with air inside the engine, the hot gases produced being used to drive a piston or do other work as they expand.

**Emission standards:** are legal requirements governing air pollutants released into the atmosphere. Emission standards set quantitative limits on the permissible amount of specific air pollutants that may be released from specific sources over specific timeframes. They are generally designed to achieve air quality standards and to protect human health.

**Emission intensity:** is the average **emission** rate of a given pollutant from a given source relative to the **intensity** of a specific activity; for example grams of carbon dioxide released per mega joule of energy produced, or the ratio of greenhouse gas **emissions** produced to **gross domestic product (GDP).**

**Vehicle emissions control:** is the study of reducing the motor vehicle emissions—emissions produced by motor vehicles, especially internal combustion engines.

**Fuel economy:** of an automobile is the fuel efficiency relationship between the distance traveled and the amount of fuel consumed by the vehicle

**Cost of capital:** of owning a car: is the income that the car owner could have obtained with the money spent on such car.

**Company car tax:** A tax which is payable on a certain percentage of the total P11d value (value is based on the car's list price) of your car. The percentage is determined based on the emissions of the car.

**Carbon monoxide poisoning:** A potentially fatal condition caused by inhalation of **carbon monoxide** gas which competes favorably with oxygen for binding with hemoglobin and thus interferes with the transportation of oxygen and **carbon** dioxide by the blood.

**Kaya identity**: is an equation relating factors that determine the level of human impact on climate, in the form of emissions of the greenhouse gas carbon dioxide

**Flue gases**: is the **gas** exiting to the atmosphere via a **flue**, which is a pipe or channel for conveying exhaust **gases** from a fireplace, oven, furnace, boiler or steam generator. Quite often, the **flue gas** refers to the combustion exhaust **gas** produced at power plants.

**Instrument meteorological conditions** (IMC): is an aviation flight category that describes weather **conditions** that require pilots to fly primarily by reference to instruments, and therefore under **instrument** flight rules (IFR), rather than by outside visual references under visual flight rules (VFR).**carbon intensity per kilowatt**, or **CIPK**

**Octane number** (RON): A value used to indicate the resistance of a motor fuel to knock .they are based on a scale on which isooctane is 100 (minimal knock) and heptane is 0 (bad knock) (www.kfu.edu.sa)

**Conformity of production(COP)**: is a **means** of evidencing the ability to **produce** a series of products that exactly match the specification, performance and marking requirements outlined in the type approval documentation (www.dft.gov.uk)

**European emission standards** define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.

**ISO 3833-1977**: Defines terms relating to some types of road vehicles designated according to certain design and technical characteristics (www.iso.org)

**EPA**: it is an **agency** of the United States federal government whose mission is to **protect** human and **environmental** health.

**CFEIS database**: Certification and Fuel Economy Information System , is a relational database management system for processing vehicle emission and fuel economy information.(www.investopedia.com)

**Torque converter:** A mechanical or hydraulic device for changing the ratio of **torque** to speed between the input and output shafts of a mechanism. (www.thefreedictionary.com)

The National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation of the United States government recently promulgated rollover resistance ratings for automobiles (http://www.carsdirect.com/encyclopedia/buying-a-safer-car)

A **greenhouse gas** (sometimes abbreviated **GHG**) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect.

**Brake specific fuel consumption** (**BSFC**) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power.

The **mean effective pressure** is a quantity relating to the operation of a reciprocating engine and is a valuable measure of an engine's capacity to do work that is independent of engine displacement.

**Urban** fuel consumption is established through tests that emulate driving in **urban** environments, with an average speed of 19mph.

# Chapter 1: The Concept of Vehicle, Power Flow & Fuel Economy

This chapter is an introductory chapter.

**A vehicle** (from Latin: *vehiculum*) is a mobile machine that transports people or cargo. Most often, vehicles are manufactured, such as wagons, bicycles, motor vehicles (motorcycles, cars, trucks, buses), railed vehicles (trains, trams), watercraft (ships, boats), aircraft and spacecraft.

**Fuel Consumption** can be expressed in terms of volume of fuel to travel a distance, or the distance travelled per unit volume of fuel consumed. Since fuel consumption of vehicles is a significant factor in air pollution, and since importation of motor fuel can be a large part of a nation's foreign trade, many countries impose requirements for fuel economy.

**Units of measurement:** MPG to L/100 km conversion chart: blue: US, red: imperial gallon. Fuel economy is the relationship between the distance traveled and fuel consumed.

**Fuel economy can be expressed in two ways:**

- ✓ **Units of fuel per fixed distance:** Generally expressed as liters per 100 kilometers (L/100 km), used in most European countries, China, South Africa, Australia and New Zealand. British and Canadian law allow for the use of either liters per 100 kilometers or miles per imperial gallon.

- ✓ **Units of distance per fixed fuel unit:** Miles per gallon (mpg) is commonly used in the United States, the United Kingdom, and Canada (alongside L/100 km). Kilometers per liter (km/L) is more commonly used elsewhere in the Americas, continental Europe, Asia, parts of Africa and Oceania. When the mpg unit is used, it is necessary to identify the type of gallon used, as the imperial gallon is 4.5 liters and the US gallon is 3.785 liters. (See Figure 1.)

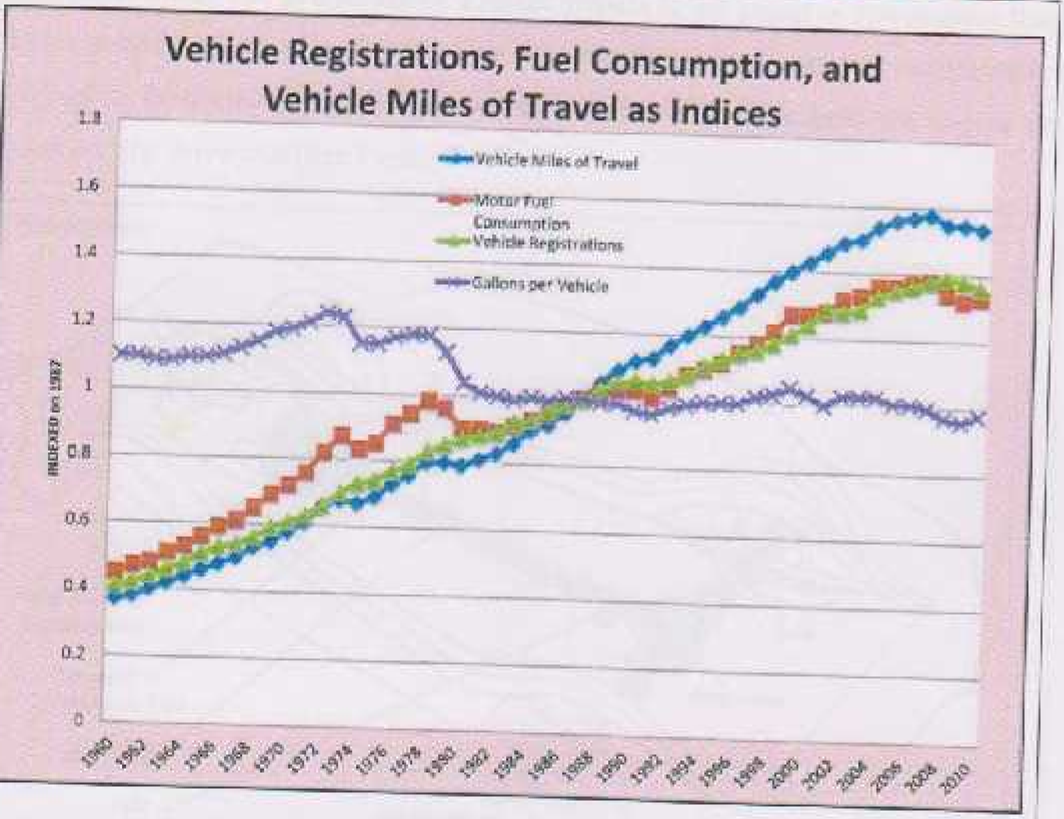


**Figure 1.1: Year Vehicle Miles of Travel Motor Fuel Consumption Vehicle Registrations Gallons per Vehicle**

**Table 1.1: Conversion of Units**

| | |
|---|---|
| **Miles per US gallon → L/100 km** | 235 / $mpg_{US}$ = L/100 km |
| **Miles per Imp. gallon → L/100 km** | 282 / $mpg_{Imp.}$ = L/100 km |
| **L/100 km → miles per US gallon** | 235 / (L/100 km) = $mpg_{US}$ |
| **L/100 km → miles per Imp. gallon** | 282 / (L/100 km) = $mpg_{Imp.}$ |

A **car** is a wheeled, self-powered motor vehicle used for transportation. Most definitions of the term specify that cars are designed to run primarily on roads, to have seating for one to eight people, to typically have four wheels, and to be constructed principally for the transport of people rather than goods.

**Drivetrain:** The **drivetrain** of a motor vehicle is the group of components that deliver power to the driving wheels. This excludes the engine or motor that generates the power. In contrast, the powertrain is considered to include both the engine or motor and the drivetrain (See Figure 2).

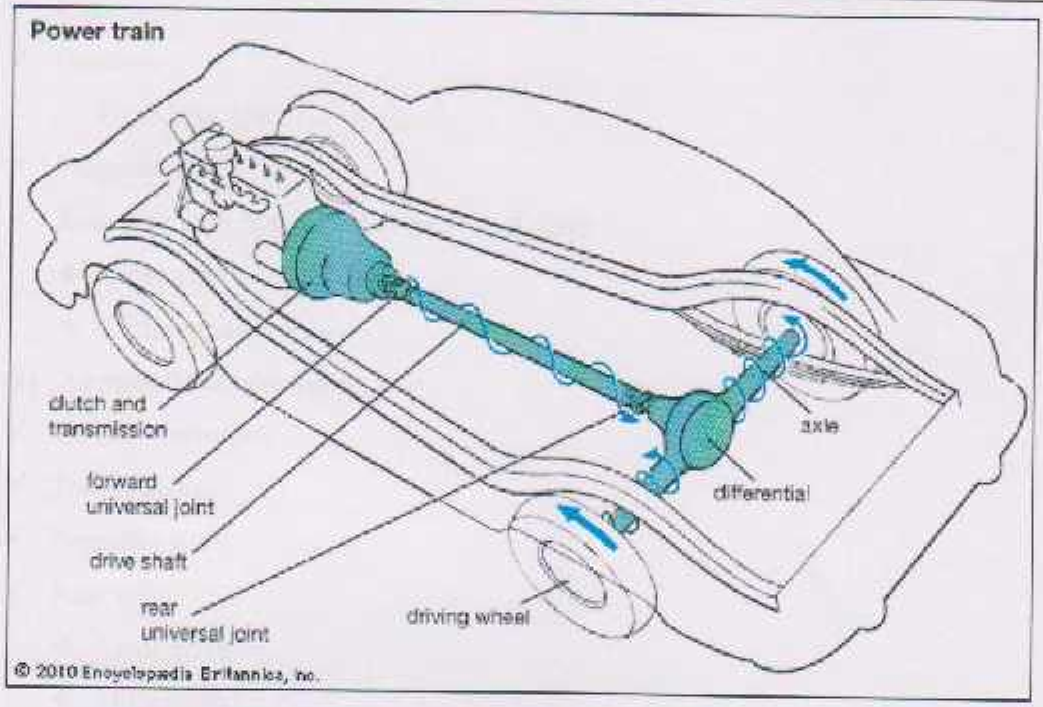


**Figure 1.2: Power flow in Vehicle**

- ✓ **The Drivetrain's Function:** The function of the drivetrain is to couple the engine that produces the power to the driving wheels that consume this mechanical power. This connection involves physically linking the two components, which may be at opposite ends of the vehicle and so requiring a long propeller shaft or drive shaft. The operating speed of the engine and wheels are also different and must be matched by the correct gear ratio. As the vehicle speed changes, the ideal engine speed must remain approximately constant for efficient operation and so this gearbox ratio must also be changed, either manually, automatically or by an automatic continuous variation.

- ✓ **The Drivetrain's Components:** The precise components of the drivetrain vary according to the type of vehicle.

**Here are some typical examples:**

1) **Manual transmission car**

✓ Clutch

✓ Gearbox

- Overdrive *Only rarely fitted*

✓ Propeller shaft

✓ Rear axle with hypoid bevel gear final drive

❖ Final drive

❖ Differential

2) **Automatic transmission car**

✓ Torque converter

✓ Transmission

✓ Propeller shaft

✓ Rear axle

❖ Final drive

❖ Differential

3) **Front-wheel drive car:** Front wheel drive manual transaxle, showing the gearbox and final drive incorporated in the same housing:

✓ Clutch

✓ Transaxle

❖ Gearbox

❖ Final drive

❖ Differential

❖ Drive shafts and constant-velocity joints to each wheel

# Chapter 2: Vehicle's Emissions & the Emission Factors

This chapter illustrates the different types of vehicle emissions, their sources and their related concepts.

## 2.1 Vehicle Emissions

Air pollutant emission factors are representative values that attempt to relate the quantity of a pollutant released to the ambient air with an activity associated with the release of that pollutant.

These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per mega gram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages.

Emission rates vary based on the speed a vehicle is traveling. VOC emission rates typically drop as speed increases, whereas NOX and CO emission rates increase at high speeds (See Figure 4). Emission rates at all speeds have been falling over time as newer, more controlled vehicles enter the fleet (See Figure 3).

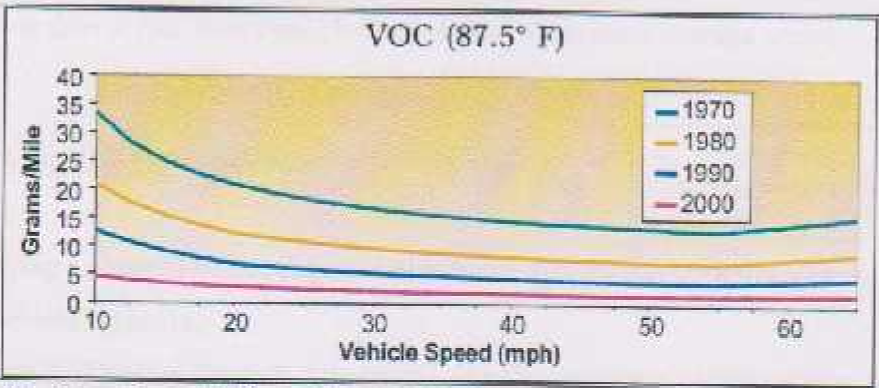


**Figure 2.1: How Speed Affects The Vehicle Emissions**

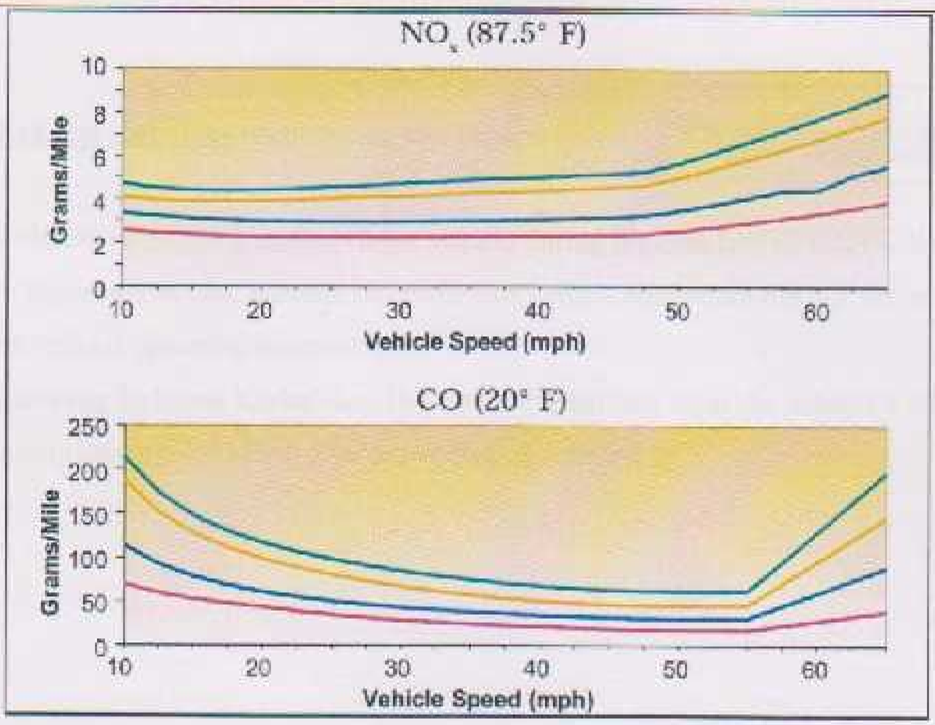


**Figure 2.2: Emissions Rates Change when the Vehicle Travel at Different Speeds as the Vehicle's Control is Advancing**

These curves do not represent the full range of effects associated with travel at different speeds. Emission rates are higher during stop-and-go, congested traffic conditions than at free flow conditions operating at the same average speed.

✓ Evaporative emissions occur in several ways:

1) **Running Losses:** The hot engine and exhaust system can vaporize gasoline while the vehicle is running.
2) **Hot soak (Cooling Down):** The engine remains hot for a period of time after the vehicle is turned off, and gasoline evaporation continues when the car is parked while cooling down.
3) **Diurnal Emissions (Emissions while Parked and Engine is Cooling):** Even when the vehicle is parked for long periods of time, gasoline evaporation occurs as the temperature rises during the day.
4) **Refueling:** Gasoline vapors escape from the vehicle's fuel tank while the tank is being filled.

✓ **<u>Exhaust emissions</u>** occur during two modes:

1) **Cold Start:** Starting and driving a vehicle during the first few minutes will result in higher emissions, because the emissions control equipment has not yet reached its optimal operating temperature.
2) **Running Exhaust Emissions:** Pollutants are emitted from the vehicle's tailpipe during driving and idling after the vehicle is warmed up.

## 2.2 Types of Emissions

Emissions of many air pollutants have been shown to have variety of negative effects on public health and the natural environment (See Table 2). Emissions that are principal pollutants of concern include (See Figures 5 and 6):

- ✓ **Hydrocarbons:** A class of burned or partially burned fuel. Hydrocarbons are toxins. Hydrocarbons are a major contributor to smog, which can be a major problem in urban areas. Prolonged exposure to hydrocarbons contributes to asthma, liver disease, lung disease, and cancer. Regulations governing hydrocarbons vary according to type of engine and jurisdiction.

- ✓ **Carbon monoxide (CO):** A product of incomplete combustion, carbon monoxide reduces the blood's ability to carry oxygen; overexposure (carbon monoxide poisoning) may be fatal. Carbon Monoxide poisoning is a killer in high concentrations.

$$CO + \frac{1}{2} O_2 \rightarrow CO_2 + \text{heat}$$

- ✓ **$NO_x$:** Generated when nitrogen in the air reacts with oxygen at the high temperature and pressure inside the engine. $NO_x$ is a precursor to smog and acid rain. $NO_x$ is the sum of NO and $NO_2$. $NO_2$ is extremely reactive. $NO_x$ production is increased when an engine runs at its most efficient (i.e. hottest) part of the cycle.
- ✓ **Particulate matter:** Soot or smoke made up of particles in the micrometer size range. Particulate matter causes negative health effects, including but not limited to respiratory disease and cancer.
- ✓ **Sulfur oxide ($SO_x$):** A general term for oxides of sulfur, which are emitted from motor vehicles burning fuel containing sulfur. Reducing the level of fuel sulfur reduces the level of Sulfur oxide emitted from the tailpipe.

$$H_2 + S \rightarrow H_2S$$
$$O_2 + S \rightarrow SO_2$$
$$2\,SO_2 + O_2 \rightarrow 2\,SO_3$$

- ✓ **Volatile organic compounds (VOCs):** Organic compounds which typically have a boiling point less than or equal to 250 °C such as chlorofluorocarbons (CFCs) and formaldehyde. Volatile organic compounds are a subsection of Hydrocarbons that are classified separately because of their dangers to public health.

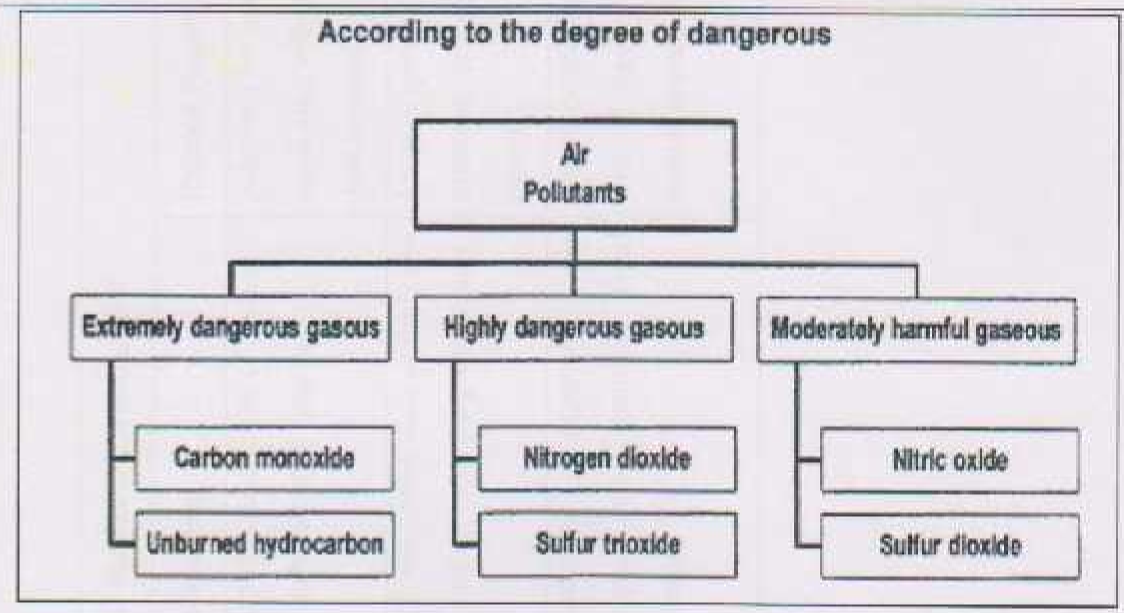


**Figure 2.3: Classification of Air Pollutants**

**Table 2.1: Types of Vehicle's Emissions and Their Effects on Public Health & Environment**

| No. | Type of Emission | Main Characteristics | Main Sources | Related Health Effects |
|---|---|---|---|---|
| 1 | Carbon Monoxide (CO) | Colorless, odorless gas with strong affinity to hemoglobin in blood | Incomplete combustion of fuels and other carbonaceous materials | Absorbed by lungs; impairs physical and mental capacities; affects fetal development |
| 2 | Hydrocarbons (HC) | Organic compounds in gaseous or particulate form (such as methane) | Incomplete combustion of fuels and other carbon containing substances | Acute exposure causes eye, nose, and throat irritation; chronic exposure suspected to cause cancer |
| 3 | Lead (Pb) | Heavy, soft, malleable, gray metallic chemical element | Occupational exposure in nonferrous metal smelting, metal fabrication. | Enters primarily through respiratory tract and wall of digestive system, serious physical and mental impairment |

| | | | | |
|---|---|---|---|---|
| 4 | Nitrogen oxides (NOx) | Mixture of gases ranging from colorless to reddish brown | Stationary combustion (power plants), mobile sources and atmospheric reactions | Major role as component in creating photochemical smog; evidence linking respiratory problems and cardiovascular illnesses |
| 5 | Particulate Matter | Any solid or liquid particles dispersed in the atmosphere | Stationary combustion of solid fuels; industrial process such as cement and steel manufacturing | Toxic effects or aggravation of the effects of gaseous pollutants; aggravation of respiratory or cardiorespiratory symptoms |
| 6 | Sulfur dioxide ($SO_2$) | Colorless gas with pungent odor | Combustion of sulfur containing fossil fuels, smelting of sulfur bearing metal ores, certain industrial processes | Classified as mild respiratory irritant; major cause of acidic rain |

## 2.3 Emissions Control

Engine efficiency has been steadily improved with improved engine design, more precise ignition timing and electronic ignition, more precise fuel metering, and computerized engine management.

Advances in engine and vehicle technology continually reduce the toxicity of exhaust leaving the engine, but these alone have generally been proved insufficient to meet emissions goals. Therefore, technologies to detoxify the exhaust are an essential part of emissions control.

### ✓ Exhaust Emission Control Methods:

#### 1) Air Injection

One of the first-developed exhaust emission control systems is secondary air injection. Originally, this system was used to inject air into the engine's exhaust ports to provide oxygen so unburned and partially burned hydrocarbons in the exhaust would finish burning.

Air injection is now used to support the catalytic converter's oxidation reaction, and to reduce emissions when an engine is started from cold. After a cold start, an engine needs an air-fuel mixture richer than what it needs at operating temperature, and the catalytic converter does not function efficiently until it has reached its own operating temperature.

The air injected upstream of the converter supports combustion in the exhaust head pipe, which speeds catalyst warm up and reduces the amount of unburned hydrocarbon emitted from the tailpipe.

#### 2) Exhaust Gas Recirculation

It is a system that routes a metered amount of exhaust into the intake tract under particular operating conditions. Exhaust neither burns nor supports combustion, so it dilutes the air/fuel charge to reduce peak combustion chamber temperatures. This, in turn, reduces the formation of $NO_x$.

## 3) Catalytic Converter

The catalytic converter is a device placed in the exhaust pipe, which converts hydrocarbons, carbon monoxide, and $NO_x$ into less harmful gases by using a combination of platinum, palladium and rhodium as catalysts.

There are two types of catalytic converter, a two-way and a three-way converter. Two-way converters were common until the 1980s, when three-way converters replaced them on most automobile engines.

- ✓ **Estimating Emissions:**

Emission factors assume a linear relation between the intensity of the activity and the emission resulting from this activity:

$$Emission_{pollutant} = Activity * Emission\ Factor_{pollutant}$$

Intensities are also used in projecting possible future scenarios such as those used in the IPCC assessments, along with projected future changes in population, economic activity and energy technologies. The interrelations of these variables are treated under the so-called Kaya identity.

The level of uncertainty of the resulting estimates depends significantly on the source category and the pollutant. **Here are some examples:**

- ✓ **Carbon dioxide ($CO_2$) emissions**: They are produced from the combustion of fuel can be estimated with a high degree of certainty regardless of how the fuel is used as these emissions depend almost exclusively on the carbon content of the fuel, which is generally known with a high degree of precision.
- ✓ **non-$CO_2$ greenhouse gas emissions:** These emissions are basically caused by either incomplete combustion of a small fraction of the fuel (carbon monoxide, methane, non-methane volatile organic compounds) or by complicated chemical and physical processes during the combustion and in the smoke stack or tailpipe. Examples of these are particulates, $NO_x$, a mixture of nitric oxide, NO, and nitrogen dioxide, $NO_2$).
- ✓ **Nitrous oxide ($N_2O$) emissions**: They are produced from agricultural soils are highly uncertain because they depend very much on both the exact conditions of the soil, the application of fertilizers and meteorological conditions.

## 2.4 Emission Intensity:

Emission intensities are used to derive estimates of air pollutant or greenhouse gas emissions based on the amount of fuel combusted , on industrial production levels, distances traveled or similar activity data.

Emission intensities may also be used to compare the environmental impact of different fuels or activities. The related terms emission factor and carbon intensity are often used interchangeably, but "factors" exclude aggregate activities such as GDP (gross domestic product), and "carbon" excludes other pollutants.

One commonly used figure is carbon intensity per kilowatt, or CIPK, which is used to compare different sources of electrical power.

**The fuel efficiency of vehicles can be expressed in more ways (See Table 3):**

- ✓ **Fuel consumption** is the amount of fuel used per unit distance; for example, liters per 100 kilometers (L/100 km). In this case, the lower the value, the more economical vehicle is (the less fuel it needs to travel a certain distance); this is the measure generally used across Europe (except the UK, Denmark and The Netherlands) New Zealand, Australia and Canada. Also in Uruguay, Paraguay, Guatemala, Colombia, China, and Madagascar.

- ✓ **Fuel economy** is the distance travelled per unit volume of fuel used; for example, kilometers per liter (km/L) or miles per gallon (MPG), where 1 MPG (imperial) ≈ 0.354006 km/L. In this case, the higher the value, the more economical a vehicle is (the more distance it can travel with a certain volume of fuel). This measure is popular in the USA and the UK (mpg), but in Europe, India, Japan, South Korea and Latin America the metric unit *km/L* is used instead.

## 2.5 Emission Standards

The NOx and PM Law introduces emission standards for specified categories of in-use vehicles including commercial goods (cargo) vehicles such as trucks and vans, buses, and special purpose motor vehicles, irrespective of the fuel type. The regulation also applies to diesel powered passenger cars (but not to gasoline cars).

In-use vehicles in the specified categories must meet 1997/98 emission standards for the respective new vehicle type (in the case of heavy duty engines (NOx = 4.5 g/kWh, PM = 0.25 g/kWh). In other words, the 1997/98 new vehicle standards are retroactively applied to older vehicles already on the road.

Vehicle owners have two methods to comply:

1) Replace old vehicles with newer, cleaner models
2) Retrofit old vehicles with approved NOx and PM control devices

Vehicles have a grace period, between 8 and 12 years from the initial registration, to comply. **The grace period depends on the vehicle type, as follows:**

- ✓ Light commercial vehicles (GVW $\leq$ 2500 kg): 8 years
- ✓ Heavy commercial vehicles (GVW > 2500 kg): 9 years
- ✓ Micro buses (11-29 seats): 10 years
- ✓ Large buses ($\geq$ 30 seats): 12 years
- ✓ Special vehicles (based on a cargo truck or bus): 10 years
- ✓ Diesel passenger cars: 9 years

✓ **Stages and Legal Framework for Emissions**

The stages are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6 for Light Duty Vehicle standards (See Figure 7 in the next page).

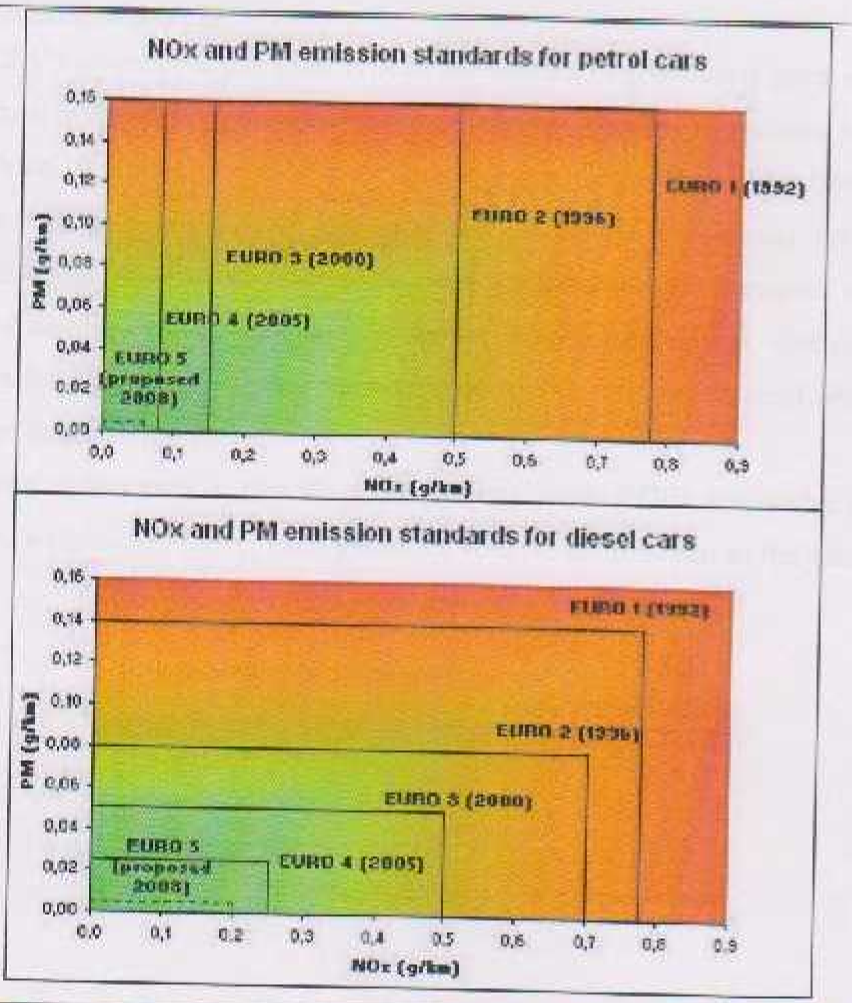


**Figure 2.4: Stages and Legal Framework for Emissions**

**2.6 Greenhouse gas score**

EPA's greenhouse gas score reflects the amount of greenhouse gases a vehicle will produce over its lifetime, based on typical consumer usage. The scoring is from 0 to 10, where 10 represents the lowest amount of greenhouse gases. The Greenhouse gas score is determined from the vehicle's estimated fuel economy and its fuel type. The lower the fuel economy, the more greenhouse gas is emitted as a by-product of combustion. The amount of carbon dioxide emitted per liter or gallon burned varies by fuel type, since each type of fuel contains a different amount of carbon per gallon or liter.

The ratings reflect carbon dioxide (CO2), nitrous oxide (N20) and methane (CH4) emissions, weighted to reflect each gas' relative contribution to the greenhouse effect.

# Chapter 3: The Vehicle's Internal Costs

This chapter describes the vehicle's internal and operating costs.

## 3.1 Vehicle Costs

The vehicle costs are divided into fixed costs, which are unaffected by mileage, and variable costs, which increase with mileage. These indicate the savings from transportation improvements that allow consumers to reduce their vehicle ownership and use.

## 3.2 Definitions and Perspectives

Vehicle Costs include direct user expenses to own and use private vehicles (plus incremental costs for mobility substitutes such as telework). These indicate the savings that result from reduced vehicle ownership and use.

Vehicle costs can be measured in various ways, including per vehicle-mile, passenger-mile, vehicle-year, household-year, producing different results. These can be divided into **fixed** (also called ownership or time-based, which are unaffected by the amount a vehicle is driven) and **variable** (also called operating, marginal or incremental, which increase with vehicle mileage)

- ✓ **Fixed costs** are those ones which do not depend on the distance travelled by the vehicle and which the owner must pay to keep the vehicle ready for use on the road, like: insurance or road taxes (See Table 5).
- ✓ **Variable** or running costs are those which depend on the use of the car, like fuel or tolls (See Table 5).

**Table 3.1: Examples of Variable Costs & Fixed Costs**

| Variable Costs | Fixed Costs |
|---|---|
| - Maintenance and repair | - Vehicle purchase or lease |
| - Fuel, fuel taxes and oil | - Insurance |
| - Paid parking and tolls | - Registration and vehicle taxes |

Compared to other popular modes of passenger transportation, especially buses or trains, the car has a relatively high cost per passenger-distance travelled.

For the average car owner, depreciation constitutes about half the cost of running a car. Nevertheless the typical motorist underestimates this fixed cost by big margin, or even ignores it altogether.

- ✓ **Depreciation**

The yearly depreciation of a car is the amount of a financial quantity, the car value decreases every year (See Figure 9 below). Normally this value is correlated with the price a certain car has on the market, a car has depreciation around 15% to 20% per year.


**Figure 3.1: Used Vehicle According to Year of Production**

✓ **Car taxes**

Car taxes, road taxes, vehicle taxes or Vehicle Excise Duty are the amount of money car owners pay to the state or to certain regional government within a country, normally yearly, to allow the car to circulate within that region or state.

These taxes serve either to maintain the roads and all the correspondent infrastructures or to compensate the negative caused by the motor vehicles.

**These taxes normally depend on**:

1) $CO_2$ emissions
2) The engine displacement of the vehicle motor
3) The vehicle weight or on some percentage of the car value.

✓ **Insurance**

The Insurance serves to provide financial protection against physical damage and/or bodily injury resulting from traffic collisions and against liability that could also arise there-from. The prices may largely vary depending on the coverage levels.

Every country has specified regulations for vehicle insurance, here are the regulations **in Palestine** that prevent vehicle's insurance (based on information obtained from Al-Mashreq Insurance Co.):

1) A change in vehicles body or chassis or its data without informing the Vehicles Licensing Department.
2) The existence of malfunction or damage in body or chassis of the vehicle.
3) Non-conformity (VIN) on vehicle license or any other features.

**Insurance types include** (See Table 6):

1) Total mandatory insurance.
2) Third party insurance.

→ Depends on engine size

3) Comprehensive insurance.
4) Third party + Comprehensive insurance

→ Depends on vehicle's price

**Table 3.2: Insurance Prices for Private& Dual-Use Vehicles According to Engine Size**

| Engine Size (CC) | Total Mandatory Insurance | Third Party Insurance (NIS) | Third Party + Total Mandatory |
|---|---|---|---|
| **Until 1000 or less** | 705 | 230 | 935 |
| **Between 1001-1500** | 805 | 230 | 1035 |
| **Between 1501-2000** | 1055 | 285 | 1340 |
| **More than 2000** | 1405 | 285 | 1690 |

✓ **Inspection**

Vehicle inspection is a procedure mandated by national or subnational governments in many countries, in which a vehicle is inspected to ensure that it conforms to regulations governing safety, emissions, or both. Normally, these inspections are made annually and the price varies depending on the region.

✓ **Car finance**

The subject of car finance comprises the different financial products which allow someone to acquire a car with any arrangement other than a single lump payment.

When used, and for the purpose of assessing the private financial costs, one must consider only the interests paid by the car owner, as some part of the amount the owner pays each month for the finance is already embedded in the depreciations costs.

✓ **Cost of Capital**

The cost of capital, applied to a purchase of a car, is the amount of money the car owner could have obtained, if they, instead of buying the car, applied that amount of money to other worthy investment.

The cost of capital is the rate of return that capital could be expected to earn in an alternative investment of equivalent risk. Considering by default the car has depreciation, and that such depreciation is already considered at a certain cost item. One example could be a common standard interest rate in a deposit account.

However, many motorists need their vehicles to get to their place of employment. Consequently the opportunity cost might not be worth considering, only in the case that no alternative transportation is possible.

## 3.3 Running costs

✓ **Fuel**

The fuel costs depend basically on four factors:

1) The distance travelled by the car
2) The price paid for the fuel
3) The energy efficiency of the car
4) The type of driving.

In Western countries, this cost normally is the second highest after depreciation.

✓ **Maintenance**

The maintenance of a car can have the purpose to be a long term or short term maintenance. This cost might be very irregular and somewhat unpredictable but tends to increase with the age of the car. On this item are included car parts that need to be replaced after a certain period of time (for example every two years) or with a specific number of travelled kilometers or miles, like tires or filters.

✓ **Repairs and Improvements**

Repairs costs are completely unpredictable because they depend on the number and severity of car collisions, like dents repairing for example. These costs also refer to spare parts substitution due to malfunctioning.

On this cost item, it might be included also the parts bought to improve the performance or the aesthetic of the vehicle.

✓ **Parking**

The costs of parking include all the money the user needs to pay to park their car. This applies normally to car parking lots, like in offices, public buildings, shopping centers or in the downtown but also on the public space (normally in the inner part of some city) using parking meters.

This cost might be relatively predictable, if the user for example has a monthly contract with some parking lot company, or if they rent a private parking space.

✓ **Fines**

A traffic fine or traffic ticket is a notice issued by a law enforcement official to a motorist accusing violation of traffic laws. Traffic tickets generally come in two forms, citing moving violation, such as exceeding the speed limit, or a non-moving violation, such as a parking violation.

These tickets almost always imply the payment of a certain quantity of money. This cost might be completely unpredictable, but one way for the user to assess it, is to calculate per year the total money spent in fines, in the last few years.

# Chapter 4: Gasoline Spark Ignited Internal Combustion Engine

This chapter specify the internal combustion engine, and the equation used in this study that's depend on its specification .(**the values and calculations will be listed in the last chapter**)

## 4.1 Traditional internal combustion engine

The internal combustion engines (ICE) converts chemical into mechanical energy. This combustion process, as well as the losses inherent to it, is a critical element to the modeling of vehicles. The formalism is described well in Ross (1997), which will be briefly reviewed here .The basis for the engine model lies in the linear relationship between brake power and fuel consumption.

The mean effective pressure is a good parameter to compare engines for design or output because it is independent of engine size and/or speed. In order to use power in comparison, the value of piston speed become very important. (Willard W.Pulkrabek.2005).

The mep can be calculated by:

✓ **Equation 1:**

$$\mathbf{mep} = n\dot{W}/V_d N$$

Where:

n- number of revolutions per cycle

$\dot{W}$- engine power

$V_d$- displacement volume

N-engine rpm

✓ **Equation 2:**

For an engine with Ne cylinders:

$$V_d = N_c(\pi/4)B^2S$$

Where:

B = Cylinder bore

S = stroke

Nc = number of engine cylinder

The piston speed can be found by equation 3.

✓ **Equation 3:**

$$\overline{U}_p = 2SN$$
$$\dot{W} = (\text{mep})A_p\overline{U}_p/4$$

Where:

$A_p$: Pistons area

$\overline{U}_p$: Average pistons speed

S: engine stroke

It is clear that the overall efficiency increases with the load (omitting wide-open throttle and fuel enrichment) while the indicated thermal efficiency (inverse slope) remains constant at roughly 40%. Thus, it can be used in the comparison.

The product of the indicated and mechanical efficiency is the overall engine efficiency. Thus, the mechanical efficiency is dependent on load and engine speed, and the most efficient operating points are those with low engine speed and high load.

To calculate a final overall vehicle (or "pump-to-wheel" efficiency, it is also necessary to factor in transmissions and final drive losses. Accessories can also play a minor role. In general, the overall efficiency of the vehicle is defined as the amount of fuel energy converted to useful work (See Equation 10 below):

✓ **Equation 4:**

$$Efficiency = \frac{EnergyOut}{EnergyIn} = \frac{Pb(tractivework)}{fuelconsumed * LHV}$$

**4.2 Advanced Internal Combustion Engine (ICE)**

In this study, "advanced" technology is defined as a vehicle (or component) that is improved over those in most vehicles currently. Advanced ICE vehicles might employ one or more nonstandard engine or driveline technologies with superior thermal, and/or driveline efficiencies, which lead to better fuel economy and performance. Examples include: lean-burn gasoline engines, variable displacement, direct injection gasoline, and continuously variable transmission (CVT).

By this technology a new stage of engine design is reached , which is a smaller engine size with a higher performance (higher power ). this trend in the automobile manufacturing is observed from the data that has been collected about the new models of the chosen designs.

***Note: the comparison between the designs will also take into consideration the new models.***

Figure (15) below shows generic peak torque and power curves for a 2.0 liter gasoline engine based on the bmep curves in Weiss et al. (2000). The curves can be scaled to different engine sizes using standard torque/bmep relationships in Sandoval and Heywood (2000).

The equation of the bmep:

✓ **Equation 5:**

$$\text{bmep} = w_b / \Delta v$$

Where:

$w_b$ - the brake work

$\Delta v$ - displacement volume

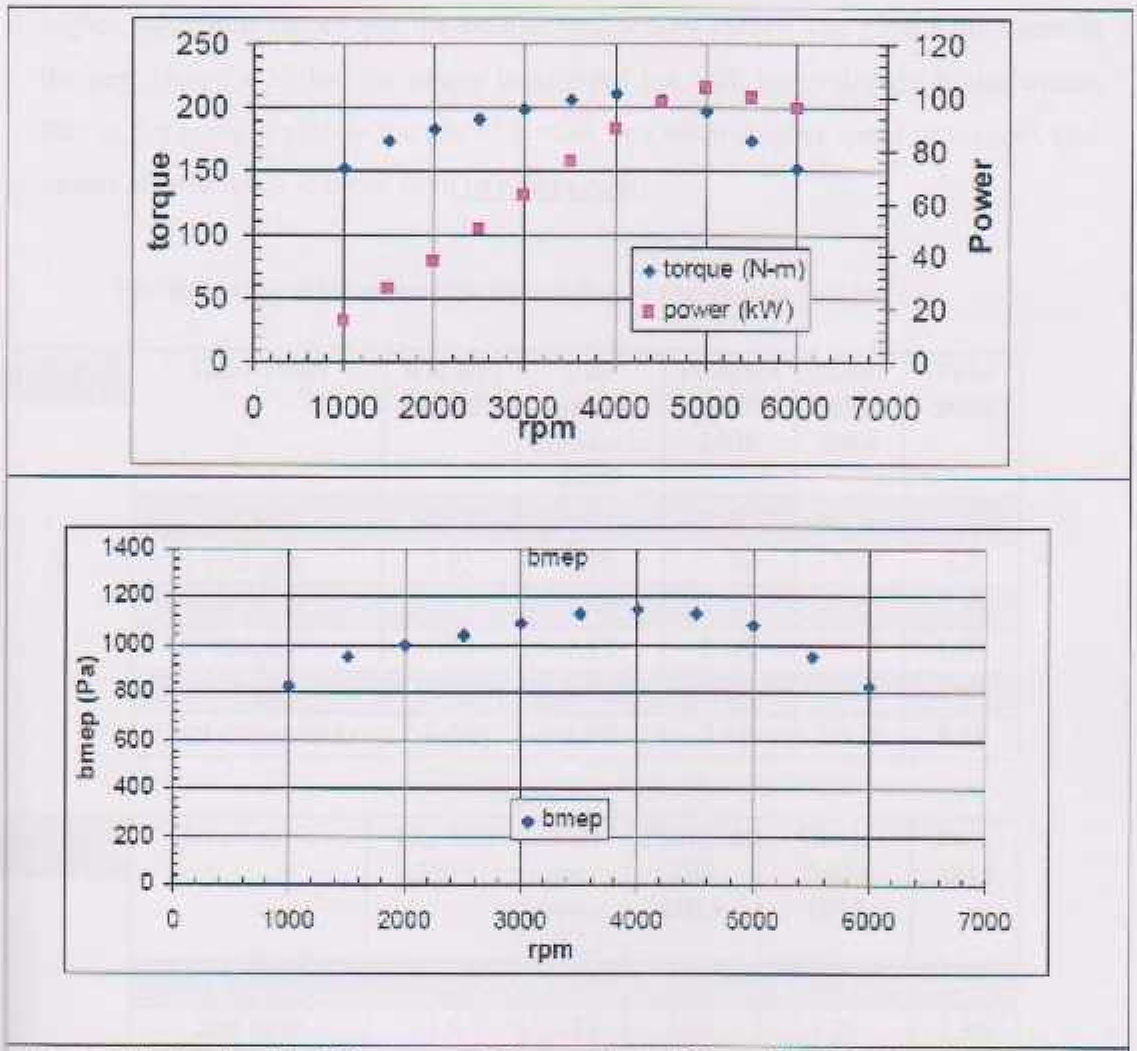


**Figure 4.1: Engine Peak Torque and Power for a "Generic" 2.0L Gasoline Engine**

## 4.4 Transmissions and Gear ratios

Another element required to calculate total vehicle efficiency is transmission and final drive efficiency. All vehicle power plants must connect to the wheels via a transmission. Sometimes this is as simple as a single gear reduction (as in some fuel cell and electric vehicles).

The transmission efficiency was taken as the average value of the experimental values of the efficiency at a different engine speed for front wheel drive vehicle , which is (0.86). ( A. IRIMESCU* ,2010)

When comparing between the values of gear ratios it is important to specify the higher value(blue color) and the smaller one(yellow color). The higher the value of the gear ratio the higher the torque transferred but with low velocity. Which means that in designing a vehicle the use of it must be known (higher speed or torque). (the values of gear ratios is taken from **car-data.com**)

The following table shows the gear ratios of the chosen designs :

Table 4.1

| Gear ratio | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| 1st gear | 3.62 | 3.91 | 3.46 | 3.455 | 3.46 |
| 2nd gear | 2.05 | 2.16 | 1.89 | 1.955 | 2.1 |
| 3rd gear | 1.37 | 1.48 | 1.15 | 1.281 | 1.39 |
| 4th gear | 1.03 | 1.12 | 0.82 | 0.927 | 1.03 |
| 5th gear | 0.84 | 0.92 | 0.66 | 0.74 | 0.81 |
| final driver ratio | 4.06 | 4.07 | 3.59 | 3.611 | 3.88 |

Table 4.2

| Gear ratio | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| 1st gear | 3.55 | 3.91 | 3.42 | 3.62 | 3.77 |
| 2nd gear | 1.9 | 2.16 | 1.81 | 1.95 | 1.96 |
| 3rd gear | 1.19 | 1.48 | 1.28 | 1.28 | 1.28 |
| 4th gear | 0.91 | 1.12 | 0.98 | 0.93 | 0.93 |
| 5th gear | 0.72 | 0.92 | 0.77 | 0.74 | 0.74 |
| final driver ratio | 4.6 | 4.07 | 4.54 | 3.93 | 3.63 |

## Chapter 5: Selected Vehicle Designs & Their Specifications

This chapter shows the chosen vehicle designs and the specifications for each design along with the reasons for selecting these designs.

✓ **The five designs are from the same class and share some features:**

1) Production date 2008.
2) Body type is hatchback.
3) Engine size 1.4, Petrol (gasoline).
4) Subcompact class (economical feature).
5) Front wheel drive, and manual transmission

✓ **Why these models were chosen for the study:**

1) Because of high rates of unemployment in Palestine, people can't afford to buy and operate any vehicle.
2) Vehicles of a production year between (2005-2013) forms the highest number of total vehicles number (See Figure 17).
3) In year 2013, the tax on importing cars from outside the country was raised form 25% to 75%.

It was found that the total Number of vehicles in west bank is 162,512 at the end of year 2014. Figures (16, 17 & 18) show some statistics of vehicles **in Palestine** [Source: Ministry of Transportation – Ramallah].

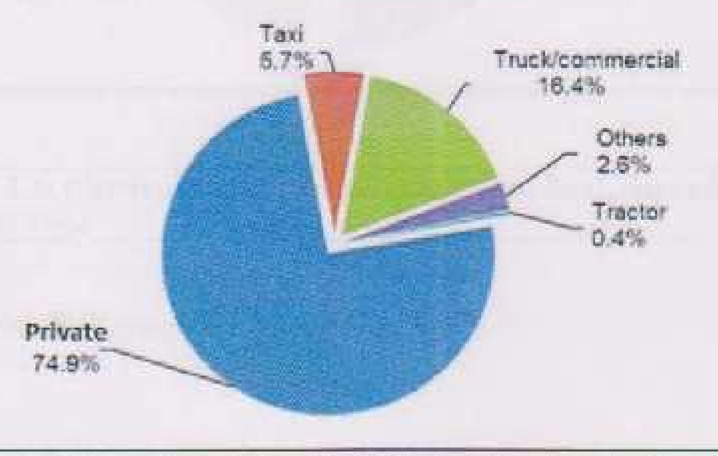


**Figure 5.1: Distribution of Vehicles in the West Bank According to the Vehicle Type**

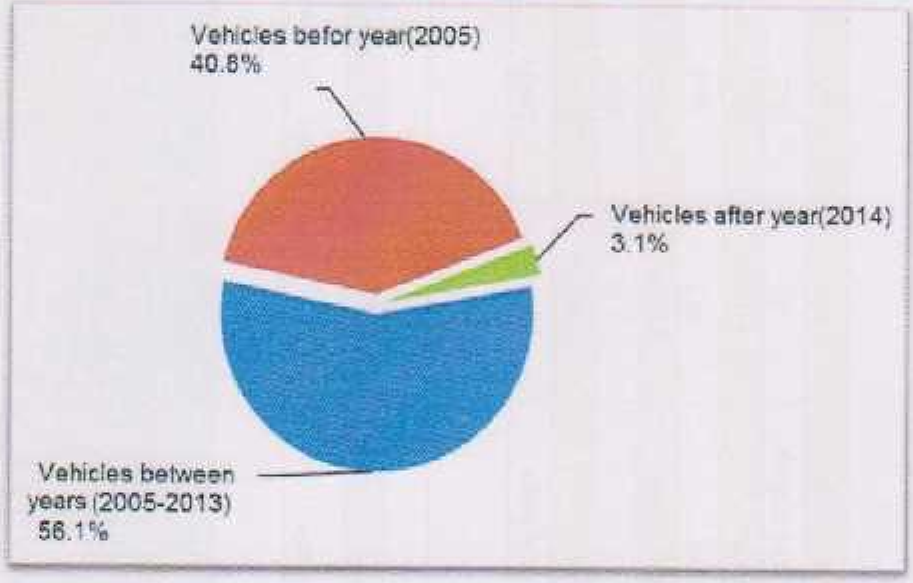


**Figure 5.2: Distribution of Vehicles in the West Bank depending on the Year of Production**

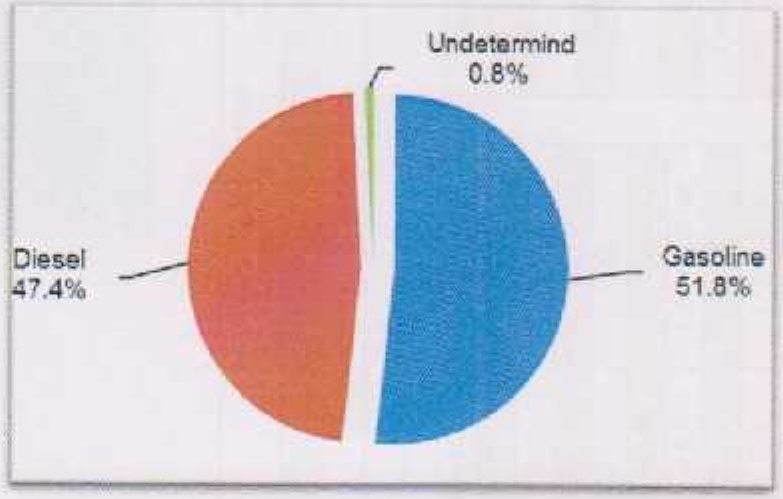


**Figure 5.3: Distribution of Vehicles in the West Bank depending on the Fuel Type**

*The features for every design are given hereafter.*

*Table(5.1) Analytical Comparison for **Polo** (2008&2015)*

Polo 2008

Polo 2015

| Dimensions (mm) | Wheelbase | Height | Track rear | track front | width (body) | total length | weight | bass weight | payload |
|---|---|---|---|---|---|---|---|---|---|
| polo 2008 | 2470 | 1462 | 1456 | 1463 | 1682 | 3970 | 1650 | 996 | 654 |
| polo 2015 | 2470 | 1453 | 1456 | 1463 | 1682 | 3972 | 1580 | 1145 | 435 |

| | Kia Rio 2015 | Kia Rio 2007 |
|---|---|---|
| Engine | 1.2 1.25 | 1.4 MPI |
| Piston bore and piston | 71*78.8 | 75.5*78.1 |
| V tot | 1248 | 1399 |
| compression ratio | 10.5 | 10 |
| maximum power(EEC) | 62Kw @6000 | 71Kw@6000 |
| maximum torque | 121Nm@4000 | 126Nm@4700 |
| Max speed | 171 | 173 |
| Tires | 185/65 R15 | 175/70 R14 |
| Drag coefficient | 0.33 | 0.32 |
| Weight to power ratio | 17.84 | 16.12 |
| acceleration (0-100km/h) in seconds | 13.1 | 12.3 |

| | | |
|---|---|---|
| acceleration (0-100km/h) in hours | 0.0036 | 0.0034 |
| acceleration in km/h2 | 27480.91 | 29268.29 |
| top gear ratio | 0.72 | 0.84 |
| brake mean effective pressure(KPa) | 1218.4 | 1122.8 |
| specific power output | 66.5 | 68.6 |
| specific torque output | 96.96 | 89.35 |
| Fuel consumption(combined)(l/100km) | 5 | 6.2 |
| Co2 rates | 114 | 147 |

*Table(5.2) Analytical Comparison for **Kia** (2008&2015)*

Kia 2008

Kia 2015

| Dimensions (mm) | Wheelbase | Height | Track rear | track front | width (body) | total length | weight | bass weight | payload |
|---|---|---|---|---|---|---|---|---|---|
| Kia Rio 2007 | 2500 | 1470 | 1460 | 1470 | 1696 | 4015 | 1600 | 1079 | 521 |
| Kia Rio 2015 | 2570 | 1455 | 1511 | 1507 | 1720 | 4050 | 1609 | 1154 | 455 |

| | Fiat punto street 2015 | Fiat punto Dynamic 2008 |
|---|---|---|
| Engine | 1.2 8v MPI | 1.4 8v |
| Piston bore and piston | 70.8*78.9 | 72*84 |
| V tot | 1242 | 1368 |
| compression ratio | 11 | 11:01 |
| maximum power(EEC) | 51kw@5500 | 57kw @6000 |
| maximum torque | 102Nm@3000 | 115Nm @ 3000 |
| Max speed | 156 | 165 |
| tires | 185/65 R15 | 175/65 R15 |
| Drag coefficient | 0.32 | 0.34 |
| Weight to power ratio | 20.02 | 18.35 |

| | | |
|---|---|---|
| acceleration (0-100km/h) in seconds | 14.4 | 13.2 |
| acceleration (0-100km/h) in hours | 0.004 | 0.0037 |
| acceleration in km/h2 | 25000 | 27272.73 |
| top gear ratio | 0.83 | 0.92 |
| brake mean Effective pressure(KPa) | 1032 | 1056.4 |
| specific power output | 54.8 | 55.6 |
| specific torque output | 82.13 | 84.06 |
| Fuel consumption(combined)(l/100km) | 5.1 | 6.1 |
| Co2 rates | 119 | 145 |

### Table(5.3) Analytical Comparison for Peugeot (2008&2015)

Peugeot 207 2008

Peugeot 208 2015

| Dimensions (mm) | Wheelbase | Height | Track rear | track front | width (body) | total length | weight | Bass weight | payload |
|---|---|---|---|---|---|---|---|---|---|
| Peugeot 207 2008 | 2540 | 1470 | 1475 | 1515 | 1744 | 4027 | 1640 | 1240 | 400 |
| Peugeot 208 2015 | 2538 | 1460 | 1502 | 1518 | 1739 | 3973 | 1670 | 975 | 695 |

| | Peugeot 208 2015 | Peugeot 207 2008 |
|---|---|---|
| Engine | 1.2 Vti 3cylinder | 1.4 Vti 16v 95bhp |
| Piston bore and piston | 75*90.5 | 75*77 |
| V tot | 1199cm3 | 1397 |
| compression ratio | 11 | 11 |
| maximum power(EEC) | 60kw@6000 | 70kw@6000 |
| maximum torque | 118Nm@2750 | 136Nm@4000 |
| Max speed | 175 | 185 |
| tires | 185/65 R15 | 185/65 R15 |
| Drag coefficient | 0.31 | 0.3 |
| Weight to power ratio | 16.14 | 17.88 |

| | | |
|---|---|---|
| acceleration (0-100km/h) in seconds | 12.2 | 11.5 |
| acceleration (0-100km/h) in hours | 0.0034 | 0.0031 |
| acceleration in km/h2 | 29508.196 | 31304.347 |
| top gear ratio | 0.77 | |
| brake mean effective pressure(KPa) | 1236.7 | 1223.4 |
| specific power output | 67.6 | 67.3 |
| specific torque output | 98.42 | 97.35 |
| Fuel consumption(combined)(l/100km) | 4.5 | 6.1 |
| Co2 rates | 109 | 141 |

Table(5.4) Analytical Comparison for **Fiat punto**(2008&2015)

Fiat punto 2008


Fiat punto 2015

| Dimensions (mm) | Wheelbase | Height | Track rear | Track front | Width (body) | Total length | Weight | Bass weight | Payload |
|---|---|---|---|---|---|---|---|---|---|
| Fiat punto 2008 | 2460 | 1480 | 1392 | 1398 | 1660 | 3865 | 1620 | 1060 | 560 |
| Fiat punto 2015 | 2510 | 1478 | 1470 | 1483 | 1721 | 4065 | 1665 | 1185 | 480 |

| | fiat punto street 2015 | fiat punto Dynamic 2008 |
|---|---|---|
| Engine | 1.2 8v MPI | 1.4 8v |
| Piston bore and piston | 70.8*78.9 | 72*84 |
| V tot | 1242 | 1368 |
| compression ratio | 11 | 11:01 |
| maximum power(EEC) | 51kw@5500 | 57kw @6000 |
| maximum torque | 102Nm@3000 | 115Nm /@ 3000 |
| Max speed | 156 | 165 |
| tires | 185/65 R15 | 175/65 R15 |
| Drag coefficient | 0.32 | 0.34 |
| Weight to power ratio | 20.02 | 18.35 |

| | | |
|---|---|---|
| acceleration (0-100km/h) in seconds | 14.4 | 13.2 |
| acceleration (0-100km/h) in hours | 0.004 | 0.0037 |
| acceleration in km/h2 | 25000 | 27272.72 |
| top gear ratio | 0.83 | 0.92 |
| brake mean effective pressure(KPa) | 1032 | 1056.4 |
| specific power output | 54.8 | 55.6 |
| specific torque output | 82.13 | 84.06 |
| Fuel consumption(combined)(l/100km) | 5.1 | 6.1 |
| Co2 rates | 119 | 145 |

*Table(5.5) Analytical Comparison for **Skoda** (2008&2015)*


Skoda fabia 2008

Skoda fabia 2015

| Dimensions (mm) | Wheelbase | Height | Track rear | Track front | Width (body) | Total length | Weight | Bass weight | Payload |
|---|---|---|---|---|---|---|---|---|---|
| Skoda fabia 2008 | 2462 | 1498 | 1436 | 1426 | 1642 | 3992 | 1622 | 1137 | 515 |
| Skoda fabia 2015 | 2470 | 1498 | 1457 | 1463 | 1732 | 3992 | 1609 | 1129 | 480 |

| | Skoda Fabia 2015 | Skoda Fabia 2008 |
|---|---|---|
| Engine | 1.2 TSI | 1.4 16v |
| Piston bore and piston | 71*75.6 | 76.5*75.6 |
| V tot | 1197 | 1390 |
| compression ratio | 10.5 | 10.5 |
| maximum power(EEC) | 81kw@4600-5600 | 63kw@4000 |
| maximum torque | 175Nm@1400-4000 | 132Nm@3800 |
| Max speed | 196 | 174 |
| tires | 185/60 R15 | 165/60 R14 |
| Drag coefficient | 0.325 | 0.33 |
| Weight to power ratio | 14.02 | 16.92 |

| | | |
|---|---|---|
| acceleration (0-100km/h) in seconds | 9.4 | 12.3 |
| acceleration (0-100km/h) in hours | 0.002611111 | 0.003416667 |
| acceleration in km/h2 | 38297.87234 | 29268.29268 |
| top gear ratio | 0.61 | 0.81 |
| Brake mean effective pressure(KPa) | 1837.2 | 1193.4 |
| specific power output | 90.2 | 60.4 |
| specific torque output | 146.2 | 94.96 |
| Fuel consumption(combined)(l/100km) | 4.8 | 6.5 |
| Co2 rates | 110 | 155 |

✓ **Vehicle Categories**

Vehicle categories are defined according to the following classification:

1) **Category M:** Motor vehicles with at least four wheels designed and constructed for the carriage of passengers (passenger cars):

   - **Category M1:** Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.
   - **Category M2:** Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tones.
   - **Category M3:** Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tones.

2) **Category N:** Motor vehicles with at least four wheels designed and constructed for the carriage of goods.

3) **Category O:** Trailers (including semi-trailers).

4) **Off-road vehicles** (symbol G).

5) **"Special purpose vehicle"** which means a vehicle of category M, N or O for conveying passengers or goods and for performing a special function for which special body arrangements and/or equipment are necessary.

# Chapter 6: The Vehicle Handling

This chapter will talk about vehicle dynamics, safety and handling equations.

When choosing the vehicles to follow historically, often many different versions appeared so the necessity to prove that different versions would not influence a great deal. The versions, mainly, differ in the fuel system, fuel control, number of valves by cylinder and the lubrication system. Of course, that the vehicles of different versions can have other distinct features, but the ones more common are the ones referred.

## 6.1 Longitudinal Vehicle Dynamics

The external longitudinal forces acting on the vehicle include aerodynamic drag forces, gravitational forces, longitudinal tire forces and rolling resistance forces (See Figure 19). These forces are described in details in hereafter.

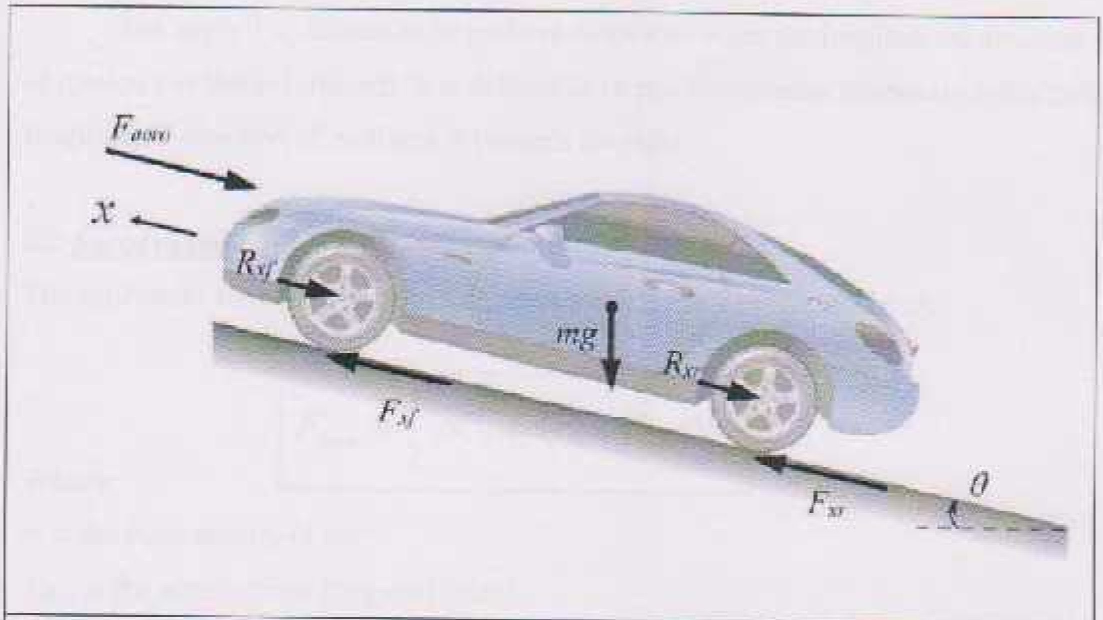


**Figure 6.1: Longitudinal Forces Acting on Vehicle Moving on An Inclined Road**

A force balance along the vehicle longitudinal axis yields:

$$m\ddot{x} = F_{xf} + F_{xr} - F_{aero} - R_{xf} - R_{xr} - mg\sin(\theta)$$

**Where:**

$F_{xf}$ is the longitudinal tire force at the front tires

$F_{xr}$ is the longitudinal tire force at the rear tires

$F_{aero}$ is the equivalent longitudinal aerodynamic drag force

$R_{xf}$ is the force due to rolling resistance at the front tires

$R_{xr}$ is the force due to rolling resistance at the rear tires

m is the mass of the vehicle

g is the acceleration due to gravity

θ is the angle of inclination of the road on which the vehicle is traveling

The angle θ is defined to be positive clockwise when the longitudinal direction of motion x is towards the left .It is defined to be positive counter clockwise when the longitudinal direction of motion x is towards the right.

## 6.2 Aerodynamic drag force

The equivalent aerodynamic drag force on a vehicle can be represented as:

$$F_{aero} = \frac{1}{2}\rho C_d A_F (V_x + V_{wind})^2$$

**Where:**

ρ: is the mass density of air

$C_d$ : is the aerodynamic drag coefficient

$A_F$ : is the frontal area of the vehicle which is the projected area of the vehicle in the direction of travel

$V_x = \dot{x}$ : is the longitudinal vehicle velocity

$V_{wind}$ : is the wind velocity (positive for a headwind and negative for a tailwind)

Atmospheric conditions affect air density ρ and hence can significantly affect aerodynamic drag. The commonly used standard set of conditions to which all aerodynamic test data are referred to are a temperature of 15 C° and a barometric pressure of 101.32 KPa (Wong, 2001). The corresponding mass density of air ρ may be taken as **1.225 kg** $/m^3$.

- The frontal area is found from:

$$A_F = (H\text{-}GC)*W*0.93$$

**Where:**

- H is the vehicle height
- GC is the ground clearance
- W is the width.

- The longitudinal vehicle velocity can be calculated from engine speed:

$$V = \frac{(engine\ rpm * \pi * tyre\ diameter)}{(gear\ ratio * wheel\ axle\ ratio)}$$

The value of vehicle speed depend on the values of the gear ratios, and so the comparison between the vehicles will be by the values of gear ratios. In order to get an accurate values an assumption must be made which is the engine speed is assumed to be at (3000 rpm). this assumption was made based on the place where the vehicle will be used which is the urban area and the average values of engine speed is at this rate.

### 6.3 Longitudinal tire force

The longitudinal tire forces $F_{xf}$ and $F_{xr}$ are friction forces from the ground that act on the tires. This force can also be considered as the tractive effort of the vehicle at the tires, but in order to calculate it the transmission efficiency and reduction values must be taken into consideration(this equation taken from **Engineering Toolbox.com**), hence:

$$TE = (Et \times \eta \times Ng \times Na)/R$$

Where:

TE-tractive effort

Et-Engine torque in Nm

∏-Overall efficiency of power train

Ng-Transmission ratio

Na-Driving axle ratio

R-Tire rolling radius

In order to calculate tractive force , the value of **tire circumference** becomes very important:

$$RC = 2 \times \prod \times SLR$$

$$SLR = 0.96 \times R$$

Where:

SLR-static loaded radius for the wheel

R - tire outer radius

(RC)- Tire rolling circumference

When the tire is fitted with the vehicle (and loaded) it makes a flat contact with ground and thus its outer radius got reduced and that's why (R) is multiplied by 0.96.

The vertical force on a tire is called the tire normal load. The normal load on a tire comes from a portion of the weight of the vehicle and is influenced by fore-aft location of the c.g., vehicle longitudinal acceleration, aerodynamic drag forces and grade of the road.

The following tables shows the CG location

**Table 6.1**

| CG location | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| Wheelbase(mm) | 2500 | 2460 | 2540 | 2462 | 2470 |
| from front wheels (Lf) | 1359.375 | 1490.76 | 1568.91 | 1396.45 | 1309.99 |
| from rear wheels (Lr) | 1140.625 | 969.24 | 971.085 | 1065.55 | 1097.01 |
| Total weight(kg) | 1600 | 1620 | 1640 | 1622 | 1650 |
| Front weight($F_{zf}$) | 870 | 981.72 | 1013 | 920 | 898 |
| Rear weight($F_{zr}$) | 890 | 638.28 | 627 | 840 | 752 |

**Table 6.2**

| CG location | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| Wheelbase(mm) | 2570 | 2510 | 2538 | 2470 | 2470 |
| from front wheels (Lf) | 1389.62 | 1432.13 | 1568.484 | 1335.55 | 1344.43 |
| from rear wheels (Lr) | 1180.38 | 1077.87 | 969.516 | 1134.45 | 1125.57 |
| Total weight(kg) | 1609 | 1665 | 1670 | 1609 | 1580 |
| Front weight($F_{zf}$) | 870 | 950 | 1032.06 | 870 | 860 |
| Rear weight($F_{zr}$) | 780 | 850 | 637.94 | 780 | 770 |

## 6.4 Rolling Resistance

Due to the internal damping of the tire material, the energy spent in deforming the tire material is not completely recovered when the material returns to its original shape. This loss of energy can be represented by a force on the tires called the rolling resistance that acts to oppose the motion of the vehicle.

The rolling resistance equation:

$$R_{xf} + R_{xr} = f(F_{zf} + F_{zr})$$

Where $f$ is the rolling resistance coefficient. which have value that varies in the range 0.01 to 0.04. A value of 0.015 is typical for passenger cars with radial tires (Wong, 2001).

## 6.5 Grade resistance

The gravitational force acting on the vehicle :

$$R_g = W \sin \theta_g$$

Where:

$R_g$- the grade resistance

$W$– the weight of vehicle

$\theta$ – the inclination angle of the track

## 6.6 Longitudinal acceleration

$$a = \frac{Change\ in\ Velocity}{Time\ taken} = \frac{dv}{dt}$$

✓ **Calculation of normal tire forces**

In addition to the total weight of the vehicle, the normal load on the tires is influenced by:

a) Fore-aft location of the center of gravity (c.g)
b) longitudinal acceleration of the vehicle
c) aerodynamic drag forces on the vehicle
d) grade (inclination) of the road

The normal force distribution on the tires can be determined by assuming that the net pitch torque on the vehicle is zero. In other words, the pitch angle of the vehicle is assumed to have reached a steady state value.

Define the following variables:

h the height of the c.g. of the vehicle

$h_{area}$ the height of the location at which the equivalent aerodynamic force acts.

$\ell_f$ the longitudinal distance of the front axle from the c.g. of the vehicle.

$\ell_r$ the longitudinal distance of the rear axle from the c.g. of the vehicle.

$r_{eff}$ the effective radius of the tires.

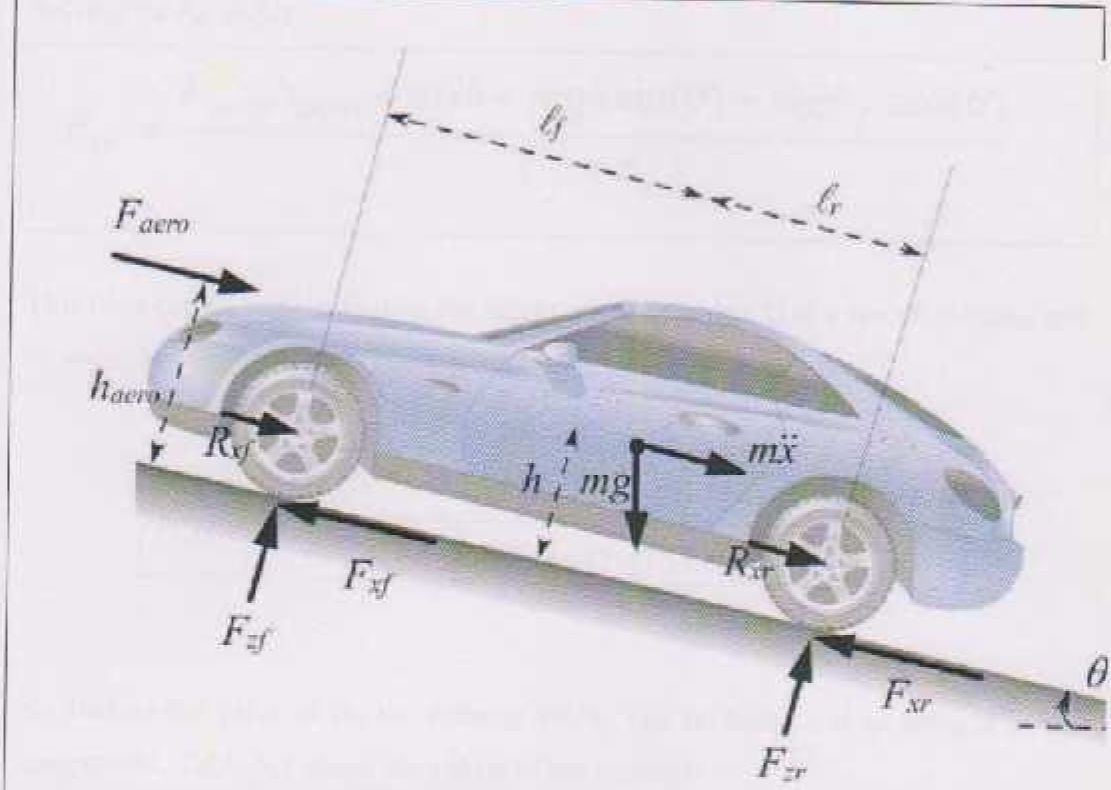


**Figure 6.2: Calculations of normal tire loads**

Taking moments about the contact point of the rear tire in Figure .

$$F_{zf}(\ell_f + \ell_r) + F_{aero}h_{aero} + m\ddot{x}h + mgh\sin(\theta) - mg\ell_r\cos(\theta) = 0$$

Solving for $F_{zf}$ yields

$$F_{zf} = \frac{-F_{aero}h_{aero} - m\ddot{x}h - mgh\sin(\theta) + mg\ell_r\cos(\theta)}{\ell_f + \ell_r}$$

Taking moments about the contact point of the front tire

$$F_{zr}(\ell_f + \ell_r) - F_{aero}h_{aero} - m\ddot{x}h - mgh\sin(\theta) - mg\ell_f\cos(\theta) =$$

Solving for $F_{zr}$ yields

$$F_{zr} = \frac{F_{aero}h_{aero} + m\ddot{x}h + mgh\sin(\theta) + mg\ell_f\cos(\theta)}{\ell_f + \ell_r}$$

This form can be used in finding the height of the vehicle CG at a specified speed and location, hence:

$$h_{CG} = \frac{mglrcos(\theta) - F_{ero}\,h_{ero} - F_{zf}\,L}{ma + mgsin(\theta)}$$

By finding the value of (h) the rollover ability can be found and so using it in the comparison. Table 6.3 shows the values of the cg height:

**Table 6.3a**

| | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| CG height(m) | 0.29 | 0.26 | 0.23 | 0.267 | **0.27** |

**Table 6.3b**

| | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| CG height(m) | **0.32** | **0.32** | 0.24 | 0.22 | **0.25** |

## 6.6 Rollover Dynamics

The primary dynamics that are of concern are those associated with the yaw and roll motions. Pitch dynamics (which cause longitudinal weight transfer) are neglected since longitudinal accelerations were kept small (See Figure 23).

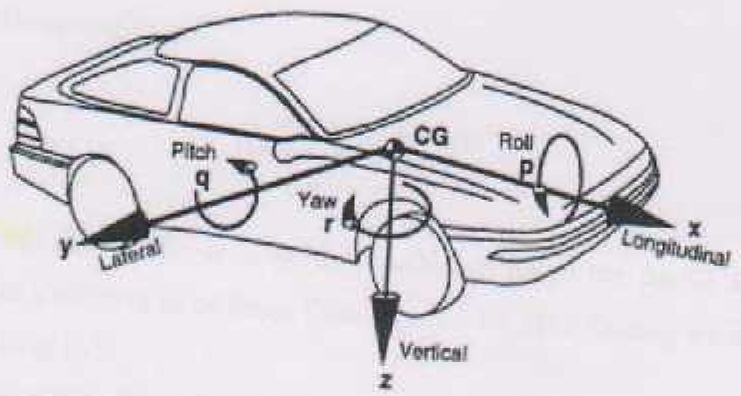


**Figure 6.3: Vehicle axis system**

A parameter called the Static Stability Factor (*SSF*) is assigned to each vehicle. It is defined as one-half the track width divided by the height of the center of gravity (See Figure 24).

A way to look at *SSF* is "equal to the lateral acceleration in *g*'s at which rollover begins in the most simplified rollover analysis of a vehicle represented by a rigid body without suspension movement or tire deflections".

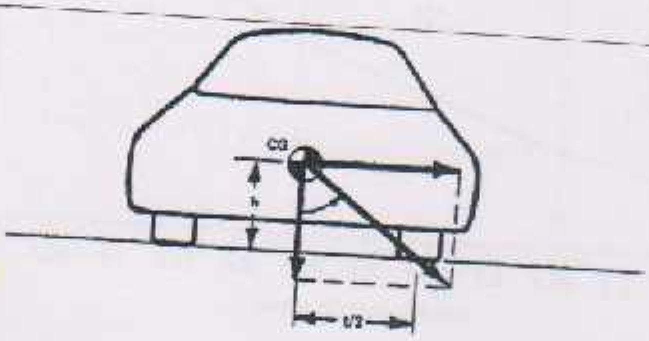


**Figure 6.4: Components of SSF shown at critical lateral acceleration**

This diagram shows the lateral acceleration vector $a$ to the right and the gravity acceleration vector $g$ downward. The vehicle will just start rotating about the pivot point at the right tire when:

$$SSF = \tan\theta = \frac{\frac{t}{2}}{h} = \frac{F_l}{F_g} = \frac{a}{g}$$

**Where:**

$F_l$ = lateral force

$F_g$ = downward force

**Therefore:** $$\boxed{a = g \cdot SSF}$$

One needs $SSF$ to be as large as possible to make the lateral acceleration required to cause a rollover to be large. (See Figure 25.). after finding we can find the velocity of roll over by:

$$v = \sqrt{a * r}$$

**Where** r is the radius of the circular path.

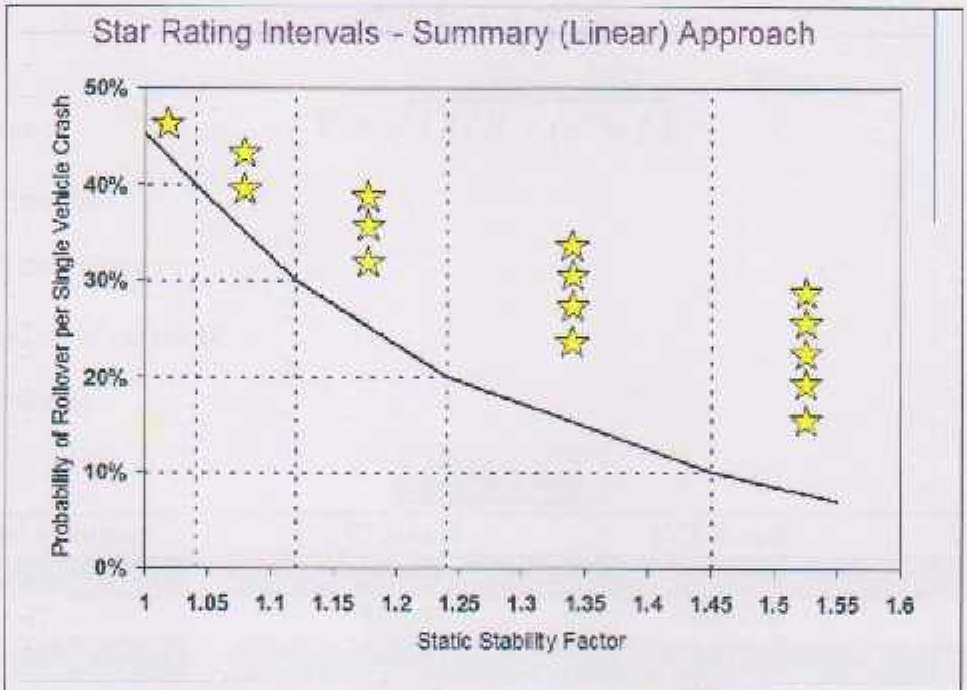


**Figure 6.5: Rating of vehicles safety according to SSF by stars**

Table(6.4) shows the rollover velocity of the chosen designs:

**Table 6.4**

**Rollover**

| | SSF | CG height | Acceleration | Velocity (m/s) | V(Km/h) |
|---|---|---|---|---|---|
| Polo 2008 | 2.67 | 2.73 | 26.167 | 38.28 | **137.81** |
| Polo 2015 | 2.91 | 2.502 | 28.545 | 39.98 | **143.94** |
| Skoda fabia 2008 | 2.69 | 2.673 | 26.353 | 38.42 | **138.3** |
| Skoda fabia 2015 | 3.35 | 2.17 | 32.865 | 42.90 | **154.44** |
| Peugeot 207 2008 | 3.24 | 2.27 | 31.768 | 42.18 | **151.84** |
| Peugeot 208 2015 | 3.11 | 2.41 | 30.542 | 41.36 | **148.88** |
| at punto dynamic 2008 | 2.67 | 2.61 | 26.168 | 38.28 | **137.81** |
| iat punto street 2015 | 2.32 | **3.165** | 22.779 | 35.72 | **128.58** |
| Kia Rio 2007 | 2.55 | 2.86 | 25.030 | 37.44 | **134.78** |
| Kia Rio 2015 | 2.39 | 3.15 | 23.504 | 36.28 | **130.61** |

The calculation of the velocity was done on an actual value of R (radius of curve) , (Table ) shows a various curve and the allowed speed on each one.( The radius values were taken using AutoCAD software and the GIS photo and civil 3D.

The allowed velocity on the curve is calculated for the elevation :

$$e + f = \frac{V^2}{127R}$$

Where :

$$V = \sqrt{127R * (e + f)}$$

e – Elevation

f – Side friction

R- radius of curvature

V- velocity

**Table 6.5**

| **Radius of curve** | **V^2(m/s)** | **V^2(Km/h)** | **V(Km/h)** |
|---|---|---|---|
| 56 | 995.68 | 3584.448 | **59.87** |
| 47 | 835.66 | 3008.376 | **54.85** |
| 52.9 | 940.562 | 3386.0232 | **58.19** |
| 15.5 | 275.59 | 992.124 | **31.50** |
| 31.7 | 563.626 | 2029.0536 | **45.05** |
| 21 | 373.38 | 1344.168 | **36.66** |
| 18 | 320.04 | 1152.144 | **33.94** |

This table shows the relationship between the velocity and the radius of the corner , the bigger the radius the higher the velocity that can be achieved without any risk to Rollover. The biggest value of the calculated radius of curve will be taken into the calculations of the SSF and so the tendency to Rollover.

The value of side friction was taken from the experimental values found by AASHTO for various values of speeds, and the value used in this equation (f = 0.14 @ 80 km/h). For the elevation value it was assumed 4%.

There are a broad range of metrics that denote the relative capabilities of various vehicles. Most of them apply to all vehicles while others are type-specific (See Table 10).

**Table 6.6: Metrics that denote the relative capabilities of various vehicles**

| Measurement | American unit | Metric unit | Affects | General preference |
|---|---|---|---|---|
| 0 to 100 to 0 mph | seconds | seconds | acceleration & braking | lower is better |
| Drag coefficient | (ratio) | (ratio) | economics, top speed, range | lower is better |
| Fuel economy | mpg | l/100 km and km/L | economics, range | greater is better (mpg and km/L), lower is better (L/100 km) |
| Maximum g-force(s) | g or ft/s$^2$ | g or m/s$^2$ | acceleration | higher is usually better |
| Power | hp | kW | acceleration | higher is better |
| Power-to-weight ratio | hp/lb. | W/kg | acceleration | higher is better |
| Roll center | inches | mm | handling | Too many variables to |

| Table 6.6: Metrics that denote the relative capabilities of various vehicles | | | | |
|---|---|---|---|---|
| **Measurement** | **American unit** | **Metric unit** | **Affects** | **General preference** |
| | | | | state a general preference. |
| Top speed | mph | km/h | Maximum rate of straight line travel | higher is better |
| Weight | lb | Kg | acceleration, braking distance, traction, fuel consumption, tire wear | lower is better for vehicle performance and taxation; larger is usually better for vehicles carrying loads |
| Weight distribution | % | % | handling, acceleration, traction | close to 50:50 (%Front:%Rear) |

## Chapter 7: Calculations

This chapter shows the calculations of this study and the results obtain from this study. The previous equations were used taken into consideration the (old and new models) .[blue color means the highest value, red color is the lowest]

❖ **First** the Mean effective pressure:

The values of the mean effective pressure describes the engine output pressure reaching the vehicle transmission, which means the higher the pressure the more power reaching the wheel the better performance.

**Table 7.1: Stroke engine for the old models (2008)**

| Stroke engine (1.4) | Kia Rio 2008 | Fiat punto dynamic 2008 | Peugeot 207 2008 | Skoda Fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| brake mean effective pressure | 1122.8 | 1056.4 | 1223.4 | 1193.4 | 1139.1 |
| Torque(T) | 126Nm@4700 | 115Nm @ 3000 | 136Nm@4000 | 175Nm@140 0-4000 | 132Nm@3 800 |
| | 126 | 115 | 136 | 175 | 132 |
| displacement volume | 1.399 | 1.368 | 1.361 | 1.39 | 1.39 |
| Brake work | 1570.36 | 1445.185 | 1664.687 | 1658.75 | 1583.28 |
| Output per displacement | 1122.8 | 1056.4 | 1223.4 | 1193.4 | 1139.1 |
| Specific volume | 0.00089 | 0.00095 | 0.00082 | 0.00084 | 0.00088 |
| # of revolutions per cycle | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Stroke (m) | 0.781 | 0.84 | 0.77 | 0.756 | 0.756 |
| Average piston speed | 93.72 | 100.8 | 92.4 | 90.72 | 90.72 |
| Bore (m) | 0.755 | 0.72 | 0.75 | 0.765 | 0.765 |
| Pistons area (m) | 0.448 | 0.407 | 0.442 | 0.46 | 0.46 |
| Power (kw) | 71 | 57 | 70 | 63 | 64 |
| mean effective pressure(MPa) | 0.6772 | 0.5558 | 0.6863 | 0.605 | 0.614 |

**Table 7.2: Stroke engine for new models (2015)**

| Stroke engine (1.2) | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda Fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| brake mean effective pressure | 1218.4 | 1032 | 1236.7 | 1837.2 | 1679.7 |
| Torque(T) | 121Nm@4000 | 102Nm@3000 | 118Nm@2750 | 132Nm@3800 | 160Nm@3500 |
| | 121 | 102 | 118 | 132 | 160 |
| displacement volume | 1.24 | 1.242 | 1.599 | 1.197 | 1.197 |
| Brake work | 1520.49 | 1282.25 | 1977.82 | 2199.61 | 2011.04 |
| Output per displacement | 1218.4 | 1032 | 1236.7 | 1837.2 | 1679.7 |
| Specific volume | 0.00082 | 0.00097 | 0.0008 | 0.000544 | 0.000595 |
| # of revolutions per cycle | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Stroke (m) | 0.788 | 0.789 | **0.905** | 0.76 | 0.76 |
| Average piston speed | 94.56 | 94.68 | 108.6 | 90.72 | 90.72 |
| Bore (m) | 0.71 | 0.708 | 0.75 | 0.71 | 0.71 |
| Pistons area (m) | 0.396 | 0.393 | 0.442 | 0.39 | 0.39 |
| Power (kw) | 62 | 51 | 60 | 81 | 66 |
| mean effective pressure(MPa) | 0.6628 | 0.5476 | **0.5009** | **0.9025** | 0.735 |

As seen in the tables the values of the (mep) for the same models (body type, name) in the 2008 differs from the new models 2015. Comparing the values of the (mep), its observed that the mean effective pressure value depend only on the value of the brake mean effective pressure, hence the values of engine (torque, cylinder dimension) isn't the right values for engine comparison. Although the engine cc is different between the old models(1.4) and the new models (1.2) but the (mep) values almost the same or higher, so the engine cc will not have a role in the comparison.

❖ **Second** Tire dimension:

**Table 7.3: Tire Dimension for (new and old models)**

| Tire Dimension (mm) | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| Tire type | 175/70 R14 | 175/65 R15 | 185/65 R15 | 165/60 R14 | 185/60R15 |
| Width of tire | 175 | 175 | 185 | 165 | 185 |
| aspect ratio | 70 | 65 | 60 | 60 | 60 |
| Depth of the tire | 122.5 | 113.75 | 111 | 99 | 111 |
| Rim outer radius | 177.8 | 190.5 | 190.5 | 177.8 | 190.5 |
| **Outer wheel radius** | 300.3 | 304.25 | 301.5 | 276.8 | 301.5 |

| Tire Dimension (mm) | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| Tire type | 185/65 R15 | 185/65 R15 | 185/65 R15 | 185/60 R15 | 185/60 R15 |
| Width of tire | 185 | 185 | 185 | 185 | 185 |
| aspect ratio | 65 | 65 | 65 | 60 | 60 |
| Depth of the tire | 120.25 | 120.25 | 120.25 | 111 | 111 |
| Rim outer radius | 190.5 | 190.5 | 190.5 | 190.5 | 190.5 |
| **Outer wheel radius** | 310.75 | 310.75 | 310.75 | 301.5 | 301.5 |

The value of the wheel outer radius play a big role in affecting the tractive effort reaching the wheels, the bigger the tire radius the higher the resistance of vehicle acceleration and motion. But there isn't a big difference between the values and so the tire dimension isn't a strong quantity in the comparison.

❖ **Third** vehicle speed :

(Note: the engine speed was assumed constant 3000 rpm for all engines)

**Table 7.4: Vehicle speed from engine speed(2008 models)**

| Vehicle speed from engine speed(kmph) | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| Vehicle speed @ 1st gear | 27.35 | 27.06 | **34.67** | 32.22 | 32.08 |
| Vehicle speed @ 2nd gear | 48.29 | 48.99 | **63.47** | 56.94 | 52.86 |
| Vehicle speed @ 3rd gear | 72.268 | 71.49 | **104.32** | 86.89 | 79.86 |
| Vehicle speed @ 4th gear | 96.12 | 94.48 | **146.30** | 120.08 | 107.77 |
| Vehicle speed @ 5th gear | 117.86 | 115.02 | **181.76** | 150.43 | 137.04 |

**Table 7.5: Vehicle speed from engine speed(2015 models)**

| Vehicle speed from engine speed(kmph) | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| Vehicle speed @ 1st gear | 26.37 | 27.06 | 27.74 | 30.27 | **31.47** |
| Vehicle speed @ 2nd gear | 49.27 | 48.99 | 52.41 | 56.19 | **60.53** |
| Vehicle speed @ 3rd gear | 78.67 | 71.49 | 74.11 | 85.61 | **92.69** |
| Vehicle speed @ 4th gear | 102.88 | 94.48 | 96.80 | 117.83 | **127.57** |
| Vehicle speed @ 5th gear | 130.03 | 115.02 | 123.20 | 148.09 | **160.33** |

The values of vehicle speed depend on the transmission efficiency (gear and final drive ratios ), the higher the gear ratios the lower the speed but a higher torque is transferred. By observing the values of the vehicle speed this effect of gear ratio is apparent. Note that the value of vehicle speed doesn't necessarily increase if the values of gear ratios increased.

❖ **Fourth** the tractive effort:

**Table 7.6: Tractive Effort (2008 models)**

| Tractive Effort (N) | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| Engine torque | 126 | 115 | 136 | 132 | 132 |
| Weight on the front axle | 870 | 950 | 1032.06 | 870 | 860 |
| Tractive Effort @ 1st gear | 4938.26 | 4880.2 | 4504.83 | 4705.24 | 4725.5 |
| Tractive Effort @ 2nd gear | 2796.53 | 2695.97 | 2460.73 | 2662.44 | 2868.1 |
| Tractive Effort @ 3rd gear | 1868.9 | 1847.24 | 1497.27 | 1744.55 | 1898.41 |
| Tractive Effort @ 4th gear | 1405.1 | 1397.91 | 1067.62 | 1262.45 | 1406.73 |
| Tractive Effort @ 5th gear | 1145.9 | 1148.3 | 859.3 | 1007.78 | 1106.26 |

**Table 7.7: Tractive Effort (2015 models)**

| Tractive Effort (N) | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| Engine torque | 121 | 102 | 118 | 175 | 160 |
| Weight on the front axle | 875 | 870 | 981.72 | 1013 | 920 |
| Tractive Effort @ 1st gear | 5086.87 | 4188.89 | 4728.16 | 6639.1 | 5838.98 |
| Tractive Effort @ 2nd gear | 2722.55 | 2314.1 | 2502.33 | 3576.3 | 3035.65 |
| Tractive Effort @ 3rd gear | 1705.18 | 1585.57 | 1769.6 | 2347.52 | 1982.46 |
| Tractive Effort @ 4th gear | 1303.96 | 1199.89 | 1354.85 | 1705.62 | 1440.39 |
| Tractive Effort @ 5th gear | 1031.7 | 985.62 | 1064.53 | 1357.16 | 1146.11 |

When calculating the tractive effort it's important to take in count the values of the gear and final drive ratios along with the torque, and that because a one value doesn't make a big difference in the tractive effort. By observing the gear ratio tables (4.1-4.2) the blue values in the gear ratio didn't result in increasing the tractive effort, that because of the value of the torque is small, which mean in order to get a higher tractive effort the value of the torque must be increased, with the gear ratios taken in count.

- **Fifth** the road resistance :

**Table 7.8: Resistance force (2008 models)**

| Resistance force (N) | Kia Rio 2008 | Fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| **Rolling resistance** | | | | | |
| Rr(for concrete) | 240 | 243 | 246 | 243.3 | 247.5 |
| Rr(for hard soil) | 1280 | 1296 | 1312 | 1297.6 | 1320 |
| | | | | | |
| **Aerodynamic Resistance** | | | | | |
| Drag coefficient(Cd) | 0.32 | 0.34 | 0.3 | 0.33 | 0.32 |
| Density/2(ρ) kg/m3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Width (body) | 1696 | 1660 | 1744 | 1642 | 1682 |
| Height | 1470 | 1480 | 1470 | 1498 | 1462 |
| Frontal area (A) squared | 2.15 | 2.12 | 2.22 | 2.12 | 2.12 |
| | | | | | |
| Raero(1st gear) | 22.63 | 23.40 | 27.71 | 27.05 | 26.16 |
| Raero(3rd gear) | 59.79 | 61.83 | 83.37 | 72.97 | 65.13 |
| | | | | | |
| TotalWeight(Kg) | 1600 | 1620 | 1640 | 1622 | 1650 |
| **Grade resistance** | -14166.49 | -14343.57 | -14520.65 | -14361.28 | -14609.20 |
| **Summing of all forces(N)** | | | | | |
| On an inclined road (1st gear) | 18842.13 | 18957.4 | 18751.78 | 18796.17 | 19061.1 |
| At straight road (3rd gear) | 1569.11 | 1542.4 | 1167.9 | 1428.28 | 1585.78 |
| Acceleration(1st gear) (Km/h) | 11.78 | 11.7 | 11.43 | 11.59 | 11.55 |

The a mount of the resistance force depend on the vehicle geometry (Body shape, weight and weight distribution). This table shows the effect of the resistance forces on the force reaching the vehicle wheels, the bigger the resistance the higher the force needed to move the vehicle. The value of the resistance that has the bigger effect on the total resistance is the grade resistance, which depend on the weight of the vehicle, hence the lighter the vehicle the lower the grade resistance.

## Table 7.9: Resistance force (2015 models)

| Resistance force (N) | Kia Rio 2015 | Fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| **Rolling resistance** | | | | | |
| Rr(for concrete) | 241.35 | 249.75 | **250.5** | 241.35 | 237 |
| Rr(for hard soil) | 1287.2 | 1332 | 1336 | 1287.2 | 1264 |
| | | | | | |
| **Aerodynamic Resistance** | | | | | |
| Drag coefficient(Cd) | 0.33 | 0.32 | 0.31 | 0.325 | 0.317 |
| Density/2($_e$) kg/m3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Width (body) | 1720 | 1721 | 1739 | 1732 | 1682 |
| Height | 1455 | 1478 | 1460 | 1498 | 1453 |
| Frontal area (A) squared | 2.32 | 2.20 | 2.19 | 2.246 | 2.11 |
| Raero(1$^{st}$ gear) | 24.30 | 22.86 | 22.68 | **26.51** | 25.27 |
| Raero(3$^{rd}$ gear) | 72.51 | 60.42 | 60.6 | **74.98** | 74.42 |
| | | | | | |
| Total Weight(Kg) | 1609 | 1665 | 1670 | 1609 | 1580 |
| **Grade resistance** | -14246.18 | -14742.01 | **-14786.28** | -14246.18 | -13989.42 |
| **Summing of all forces(N)** | | | | | |
| On an inclined road(1$^{st}$ gear) | 19067.39 | 18658.29 | 19241.26 | 20617.4 | 19566.12 |
| At straight road(3$^{rd}$ gear) | 1391.32 | 1275.4 | 1458.5 | 2031.18 | 1671.04 |
| Acceleration(1$^{st}$ gear) (Km/h) | 11.85 | 11.21 | 11.52 | 12.81 | 12.38 |

From table (7.9) its observed that(fifth column) the aerodynamic resistance doesn't have the a big influence as the grade resistance. Also the higher the tractive effort the higher the acceleration of the vehicle. As seen in the table the value of the tractive effort on the straight road was chosen at the 3$^{rd}$ gear, that's because the force needed to overcome the resistance and move the vehicle is smaller than on the inclined on.

❖ **Sixth** the fuel consumption:

**Table 7.10: Fuel consumption (2008,2015 models)**

| | Kia Rio 2008 | fiat punto Dynamic 2008 | Peugeot 207 2008 | Skoda fabia 2008 | Polo 2008 |
|---|---|---|---|---|---|
| Fuel consumption(Mpg) | 1458.33 | 1434.81 | 1434.81 | **1528.9** | 1387.77 |
| efficiency % | 7.75 | 7.78 | 7.19 | 7.04 | 7.79 |

| | Kia Rio 2015 | fiat punto street 2015 | Peugeot 208 2015 | Skoda fabia 2015 | Polo 2015 |
|---|---|---|---|---|---|
| Fuel consumption(Mpg) | 1176.07 | 1199.6 | 1058.47 | 1129.03 | **1199.6** |
| efficiency % | 9.9 | 7.99 | 10.2 | **13.46** | 11.14 |

In this table the efficiency describes the amount of power that was obtained from burning a measurable amount of the fuel. The relation between the efficiency and the fuel consumption is inversely proportional, this relation is noticeable in the old models(2008) but not in the new one (2015). The reason is that the value of the efficiency depend on the tractive effort, which is also affected by the other factors as mentioned earlier. The more the fuel consumed to produce the power the more the amount of emissions produced, which mean the higher the efficiency the lower the emissions produced .

## 7.1 Conclusion

Investigating the data collected of the chosen vehicle designs , it was concluded that when making a comparison between vehicles the following specifications must be taken into consideration to get the best choice , which is;

- ✓ The (mep) for the engine comparison.
- ✓ The torque along with the transmission ratios for the force reaching the wheels.
- ✓ Fuel consumption for vehicle operating costs.

## Appendix :

According to the recipient of the survey which was posted on Facebook randomly. It was revealed that:

- **The best car is the economical** (less fuel consumption) as the most of the survey recipient answered that the economical car is their first option.


**Figure A.1: The Types of Cars Which The Customers Would Like to Buy**

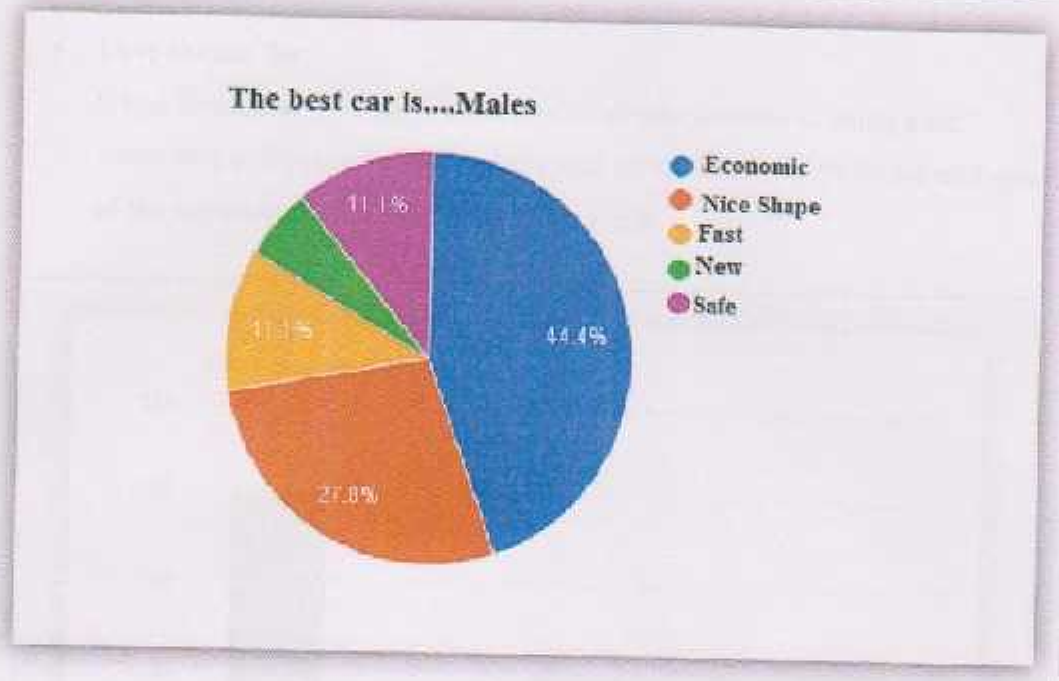


**Figure A.2 : The Types of Cars Which The Male Customers Would Like to Buy**

- **The price effect on the car purchasing decision**

  The survey results showed that the price is a significant factor the buyer take into consideration when he\she wants to purchase a car

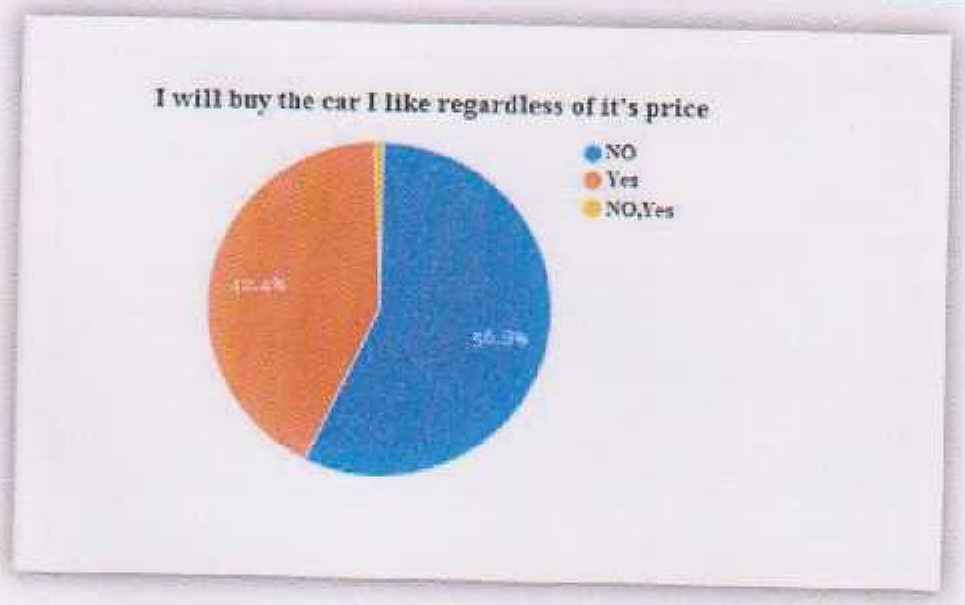


**Figure A.3 : The Car Price is a Significant Factor for its Purchasing**

- **I use the car for**

It was found that moving in town is number one purpose of using a car. According to this result, the chosen speed for calculation will be the mid speed of the car which lies between (50 to 80) Km/h.

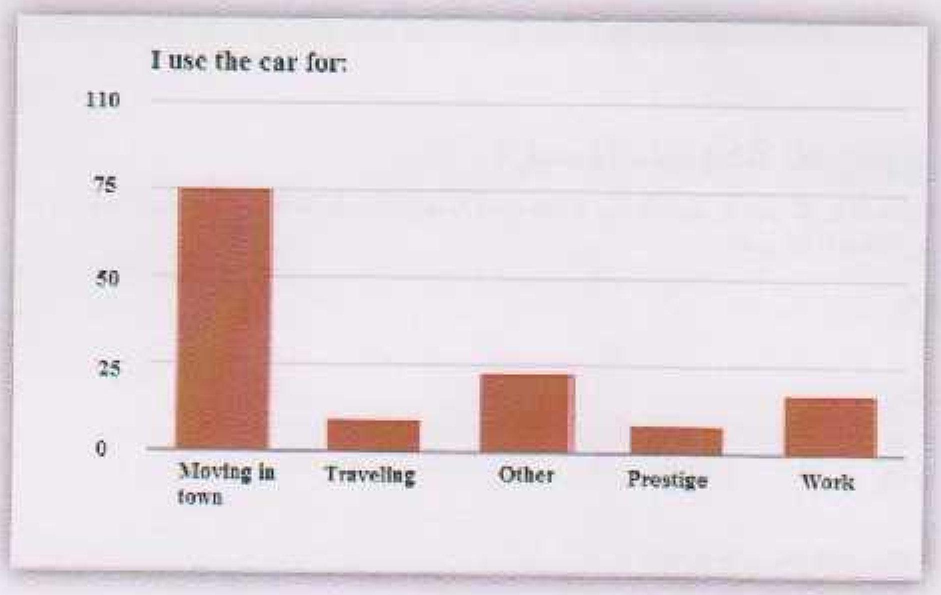


**Figure A.4: The Different Purposes for Using a Car**

**Hereafter is a copy of the questionnaire used in this study:**

## ميول الزبائن عند قيامهم بشراء سيارة

تهدف هذه الاستبانة إلى التعرف على ميول الزبائن عند قيامهم بشراء سيارة . المعلومات التي سيتم الحصول عليها من هذه الاستبانة هي للاستخدام العلمي فقط .

* Required

الجنس *

- ذكر
- أنثى

اذا كانت اجابتك نعم , ماهو نوعها ؟

ما هو نوع السيارة المفضل لديك؟ *

هل تملك سيارة (في الوقت الحاضر)؟ *

- نعم
- لا

هل لديك وظيفة/ عمل *

- نعم
- لا

استخدم السيارة لـ: *

- العمل
- السفر (خارج المدينة)
- التنقل داخل المدينة
- زيادة مكانتي الاجتماعية (برستيج)
- أخرى

أفضل السيارة التي تكون: *

اختر الأرقام حسب الأولوية، بحيث يكون رقم واحد الفئة الأهم.

| | موفرة للوقود | مريحة | ضخمة الحجم | واسعة من الداخل | ذات شكل مميز | آمنة | الأحدث |
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اشتري السيارة التي تعجبني بغض النظر عن سعرها *

- نعم
- لا

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