THE MAIN FACTORS AFFECTING KEY CHARACTERISTICS OF FUEL-EFFICIENT DRIVING AND SAFE DRIVING

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Statement 1

This thesis is the result of my own investigation, except where otherwise stated.
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Abstrak

Dalam kajian ini, kaedah pengajian kualitatif dan kuantitatif telah digunakan untuk memperolehi kolerasi antara ciri-ciri utama bagi cara memandu yang berunsurkan kecekapan bahan api dan berunsurkan keselamatan. Kajian ini berobjektif untuk membekalkan motivasi yang betul pada cara memandu berunsurkan kecekapan bahan api ke arah cara memandu berunsurkan keselamatan, disebabkan adakalanya sesetengah amalan memandu berteraskan kecekapan bahan api tidak semestinya selamat. Ciri-ciri utama bagi cara memandu berunsurkan kecekapan bahan api dan keselamatan telah dikenal pasti serta disusun atur. Selepas itu, hubungan antara kedua-dua amalan memandu yang disebutkan dianalisiskan. Untuk menyenagkan proses pengiraan, pendekatan berdasarkan penskalaan telah diaplikasikan untuk mengkuantitikan setiap ciri-ciri memandu yang utama. Kedudukan dan penskalaan dilakukan terhadap kecekapan bahan api mengenai tahap peningkatan bahan api yang dapat dilihat melalui tahap kenderaan terbiar, pemecutan serta pembrekan, dan kelajuan kenderaan. Manakala bagi amalan memandu secara selamat pula, penskalaan dilakukan berasaskan kecenderungan bagi kemalangan untuk berlaku dan tahap kritikal yang disebabkan oleh amalan memandu yang berkenaan. Penskalaan tersebut akan berbeza dari kaedah ke kaedah yang berlainan agar perbandingan dapat dilakukan untuk melihat tahap perbezaan dan ketepatan. Beberapa kaedah telah dijalankan untuk memperoleh pekali kolerasi dalam bentuk nilai-nilai berangka antara amalan memandu secara cekap dari segi bahan api, serta amalan memandu secara selamat. Purata pekali kolerasi antara kedua-dua amalan yang didapati adalah $r = 0.423$ dan berkesan sederhana secara keseluruhannya, manakala nilai p yang didapati adalah 0.097 yang dikatakan kurang penting.

Abstract

In this research, qualitative and quantitative research methods are used to determine the correlation between key characteristics of fuel-efficient driving and safe driving. It aims to give correct motivation on fuel-efficient driving towards safe driving. The key characteristics of fuel-efficient and safe driving are identified and ranked. The relationships for both variables are then been analysed. To ease the calculation process, scaling method is used to quantify each of key driving characteristics. The ranking and scaling are done for fuel-efficiency according to the degree of fuel improvement based on the level of idling, accelerating and braking, as well as speed of travel. While for safe driving, tendency for accident to occur and degree of fatality caused by respective driving characteristics. The scale will be different by approach used so that the comparison can be made on the level of variation and accuracy. Several approaches were used to obtain numerical values for correlation coefficient between fuel-efficient driving and safe driving. The average correlation coefficient between key characteristics of fuel-efficient driving and safe driving obtained is $r = 0.423$ which has medium positive impact in overall, with p-value of 0.097 which is less significant.

Chapter 1: Introduction

1.1 Overview

According to World Health Organization (WHO), road fatality has become the eighth of top ten causes of deaths worldwide in 2016. In merely 2016, 1.4 million of lives are taken by road accidents, among them around three quarters of casualties are male, which is 74% of total [1]

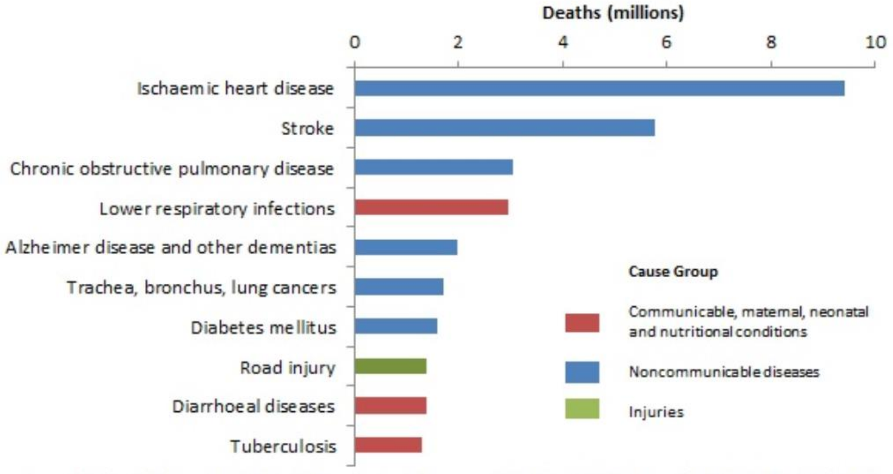

Figure 1. Top 10 Global Causes of Deaths in 2016. (World Health Organization, 2017)

Road accidents can actually be minimised through appropriate driving attitude and practice of proper driving behaviours. In this project, correlation between fuel-efficient driving and safe driving characteristics will be investigated. The key characteristics of both driving practices will be studied through quantitative and qualitative research method. Application of statistics will be used when analysing the data. For qualitative research method, study is carried out to gain better understanding on correlation, both fuel-efficient and safe driving characteristics. Both driving characteristics will then be categorized. While in quantitative research method, numerical data will be generated by conducting short surveys face-to-face and online. The correlation factor between key characteristics of fuel-efficient and safe driving will be obtained.

1.2 Problem Statement

Most of the time, many drivers focus only on driving safely, while easily ignore the importance of fuel-efficient driving. One may not realise the benefits of fuel-efficient driving immediately because the effect can only be seen in the long run. By practising fuel-efficient driving behaviour, unnecessary expenses can be avoided besides ensuring safety while driving. Case studies show that fuel consumption rate of vehicles that involved in crash are higher than vehicles that of vehicles not involved [2]. However, driving efficiently is not equivalent to driving safely for some cases. For example, coasting across red traffic lights is considered as fuel-efficient since the vehicle able to prevent cycle of brake deceleration, idling and pick up acceleration, but very dangerous and fatal.

Hence, the correlation factor between safe driving characteristics and fuel-efficient driving characteristics will be studied and justified.

1.3 Scope of Projects

1. Study and identify the key characteristics for fuel-efficient driving and safe driving.

2. Study the definition and characteristics of correlation factor.

3. Predict the trend of correlation between fuel-efficient driving and safe driving.

4. Study the relationship between each key characteristic of fuel-efficient driving and safe driving using qualitative and quantitative method.

5. Study the effects of each key characteristic in terms of cost-saving.

6. Determine and comment on the correlation between key characteristics of fuel-efficient driving and safe driving.

1.4 Objectives

1. Determine the correlation between key characteristics of fuel-efficient driving and safe driving.

2. Justify the ranking of driving characteristics for fuel-efficient driving and safe driving.

Chapter 2: Literature Review

2.1 An overview of Fuel economy

Fuel economy is often measured by the distance a vehicle can travel on a given volume of fuel (or the inverse) [3]. In the U.S. fuel economy is measured in vehicle miles per gallon of fuel while litres per 100 kilometres is the preferred measure for the European Union. Fuel economy is an imprecise measure of energy efficiency as vehicle mass, passenger or cargo capacity, engine power or other possible attributes that may affect the value of a vehicle's performance are not taken into account. In addition, different fuels contain varying amounts of energy per volume. For example, diesel fuel contains approximately 11% more energy per volume than gasoline [4].

Besides, energy conversion from fuel to useful work by a vehicle's power train, factors like vehicle mass, aerodynamics and rolling resistance, as well as how the vehicle is driven have significant impact on fuel economy. Speed affects Fuel economy is affected by the speed of vehicle moving through the number of engine revolutions required per distance travelled and aerodynamic drag increases with the square of velocity. Idling reduces fuel economy because fuel is consumed even though the vehicle is not moving. Furthermore, braking vehicle frequently will reduce fuel economy through the conversion of kinetic energy of the vehicle into heat energy which is then dissipated. Cold weather also degrades fuel economy because internal combustion engines are much less efficient before they are fully warmed up and warm up takes longer in cold weather.

2.2 An overview of Drive Cycles

To permit consistent comparisons among different vehicles, governments and vehicle manufacturers measure passenger car and light truck fuel economy under laboratory conditions over strictly specified driving cycles. A driving cycle is defined by a program of vehicle velocity as a function of time [5]. The U.S., European Union and Japan all use different driving cycles to better approximate typical driving conditions in their regions. The fuel economy individual drivers realize will deviate from these standardized measures depending on the conditions under which they drive and their driving styles.

2.2.1 European Driving Cycles

1) The NEDC

The NEDC is used as reference cycle for homologating vehicles until Euro6 norm in Europe and some other countries. It is made of an urban part called ECE-15 (or sometimes just being called as UDC), which repeated four times and plotted from 0s to 780s, plus an extra-urban part, the Extra-Urban Driving Cycle (EUDC) which plotted from 780s to 1180s. ECE-15 represents common driving condition of busy cities in European countries, characterised by low engine load, low exhaust gas temperature and maximum speed of 50km/h. While EUDC represents driving style of more aggressive and high-speed driving. Maximum speed of EUDC cycle is 120km/h [6].

Table 2.1. Main characteristics of NEDC

Distance	11023 m
Duration	1180 s
Average speed	33.6 km/h

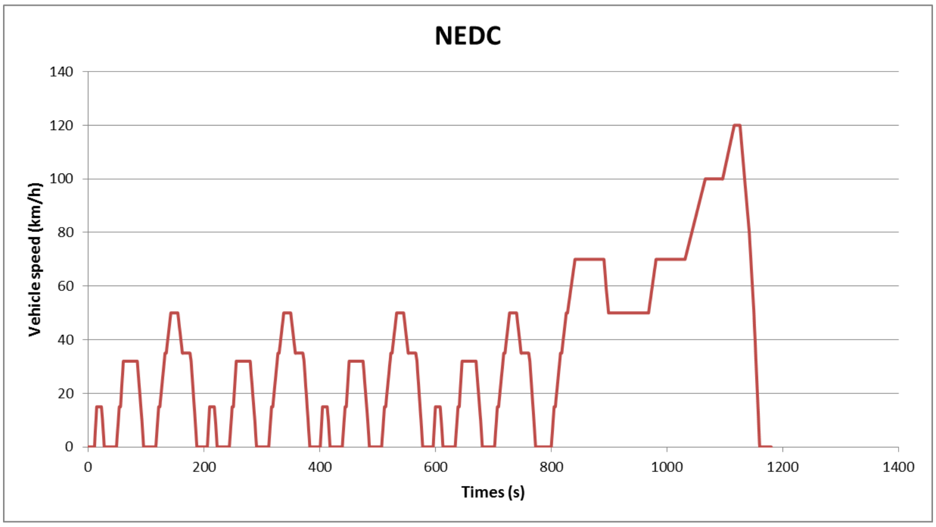

Figure 2.1. Illustration of drive cycle of NEDC. (UNECE World Forum for Harmonization of Vehicle Regulations, 1970)

However, this cycle is criticized by experts as it does not represent real life driving conditions. Indeed, accelerations are very soft; there are a lot of constant speed cruises and a lot of idle events [7]. This make impossible to obtain certified values when driving with the vehicle in real conditions. For those reasons, a solution to replace the NEDC is being explored by European authorities [8]. The new cycle called Worldwide Harmonized Light Vehicle Test Procedure (WLTP) will probably appear for the upcoming norm Euro7.

2) The Urban driving cycle

This cycle is based on a statistical study done in Europe within the so-called Artemis project [9]. It is made of 3 different configurations, plus an additional variant: the urban cycle, the rural one, the motorway 130 km/h and the motorway 150 km/h.

Table 2.2. Main characteristics of Artemis Cycle.

Characteristic	Urban	Rural Road	Motorway 130	Motorway 150
Duration, s	993	1082	1068	1068
Distance, km	4.874	17.275	28.737	29.547
Average speed (trip), km/h	17.7	57.5	96.9	99.6
Maximum speed, km/h	57.3	111.1	131.4	150.4
Speed distribution, %				
- Idle (S = 0 km/h)	21	2	1	1
- Low speed (0 < S ≤ 50)	77	32	15	14
- Medium speed (50 < S ≤ 90)	2	59	14	14
- High speed (S > 90)	0	7	70	71

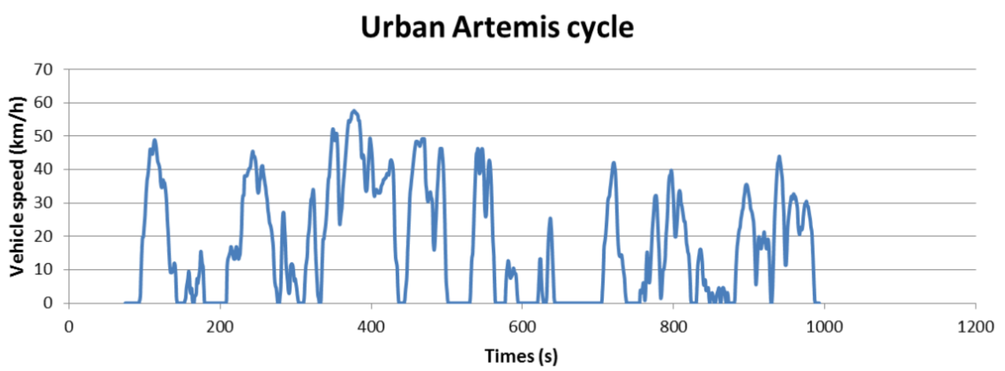

Figure 2.2. Graph of Urban Artemis Cycle (UNECE World Forum for Harmonization of Vehicle Regulations, 1990)

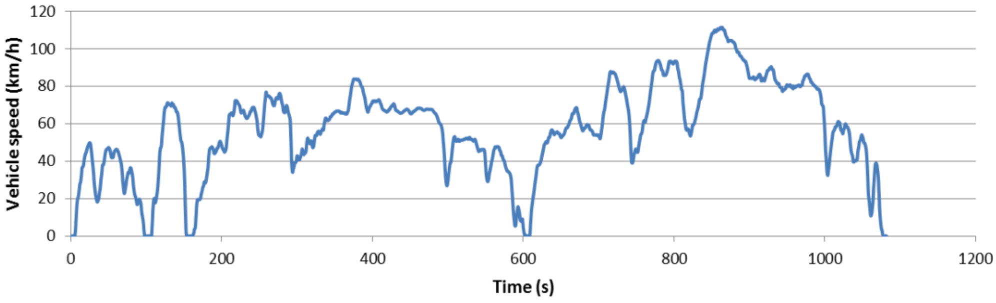

Figure 2.3 Graph of Rural Artemis Cycle (UNECE World Forum for Harmonization of Vehicle Regulations, 1990)

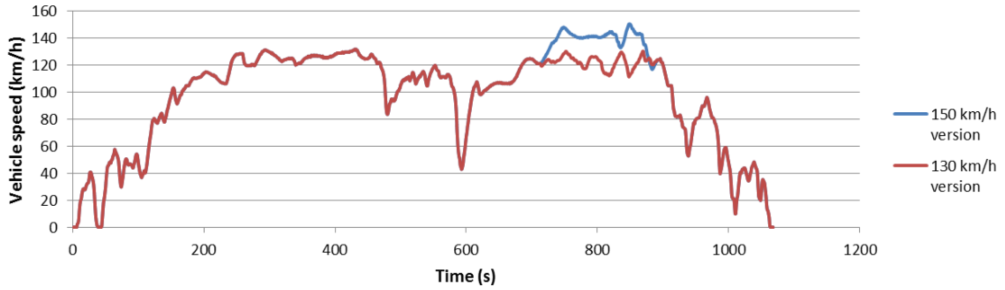

Figure 2.4 Graph of Artemis cycle on highway (UNECE World Forum for Harmonization of Vehicle Regulations, 1990)

Artemis cycles are not used for certification of pollutants or fuel consumption. However, car manufacturers use this kind of cycle to better understand real driving conditions and to assess real performances of their vehicles. In European countries, Real driving emissions (RDE) testing by means of portable emissions measurement systems (PEMS) can potentially minimise the variation between lab and road tests, which will complement the dynamometer type-approval procedure from September 2017 onwards [10].

2.2.2 Highway Fuel Economy Test cycle

The Highway fuel economy test (HWFET) is used to assess fuel economy over highway driving cycle.

Table 2.3. Main characteristics of HWFET cycle

Distance	12.26 miles (16.45 km)
Duration	765 s
Average speed	48.3 mph (77.7 km/h)

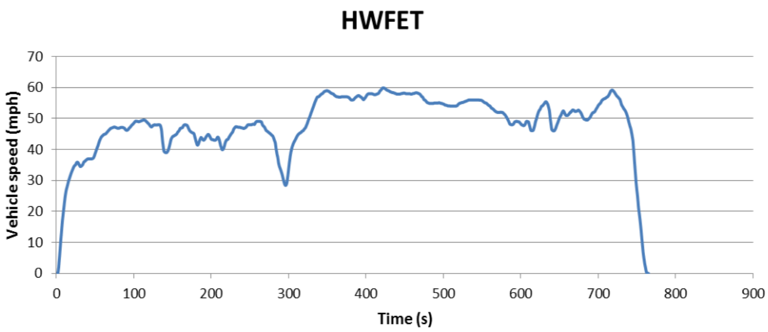

Figure 2.5. Graph of HWFET drive cycle (EPA Federal Test, 1978)

In 2007, EPA decided to add 3 more cycles to the existing ones, in order to better reflect real world driving conditions [11]. The first one is the US06, which is a complement to what is missing in FTP-75 cycle. Indeed, this cycle has a higher top speed of 80 mph (130 km/h) and some higher acceleration which represents a much more aggressive driving behaviour. The SC03 is another added cycle which particularity is to be performed at 35°C ambient temperature. This is needed for taking into account the air-conditioning in fuel consumption and emissions calculations. The last added cycle is the “cold cycle”. This is in fact a FTP-75 performed at -7°C ambient temperature.

For the Federal Test Procedure (FTP-75), FTP cycle (for Federal Test Procedure) has been created by US EPA (Environmental Protection Agency) to represent a commuting cycle with a part of urban driving including frequent stops and a part of highway driving [12].

Table 2.4. Main characteristics of FTP-75 cycle

Distance	11.04 miles (17.77 km)
Duration	1874 s
Average speed	21.2 mph (34.1 km/h)

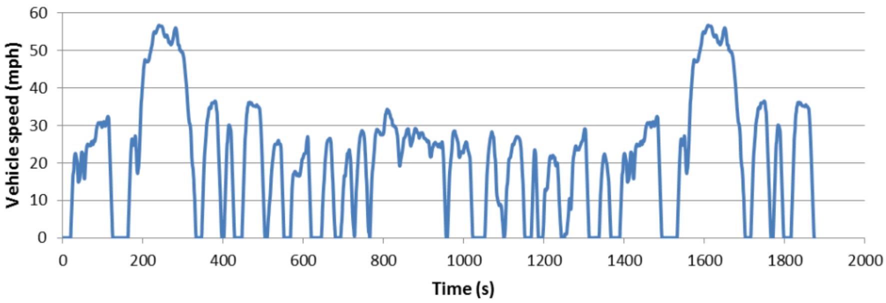

Figure 2.6. Graph of FTP-75 drive cycle. (EPA Federal Test, 1978)

2.2.3 Japanese Driving Cycles

a) The 10-15 mode cycle

The 10-15 mode Japanese cycle is being used for emissions and fuel consumption certification in Japan [13]. It simulates both urban and motorway cycle, including idling, accelerations, cruising and decelerations. The measurements are performed while engine is hot, after a standard warming procedure.

Table 2.5. Main characteristics of 10-15 mode driving cycle

Distance	4.16 km
Duration	660 s
Average speed	22.7 km/h

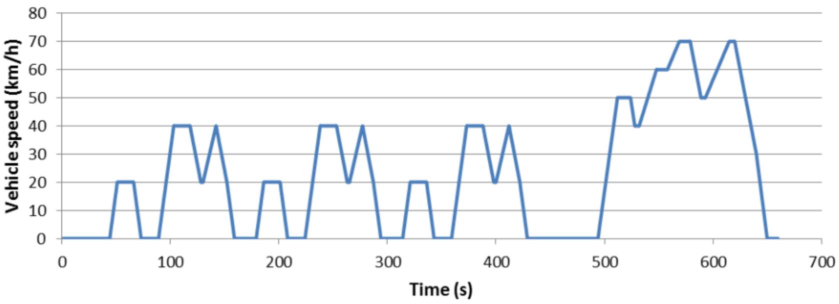

Figure 2.7. Graph of 10-15 mode driving cycle (Ministry of Economy, Trade and Industry (METI) Japan, 1991)

b) The JC08 cycle

The JC08 is a transient cycle which is much more demanding than 10-15 mode cycle. It is performed both with cold and warm start and it represents driving in congested condition, with strong accelerations and decelerations [14].

Table 2.6. Main characteristics of JC08 Drive Cycle

Distance	8.17 km
Duration	1204 s
Average speed	24.4 km/h

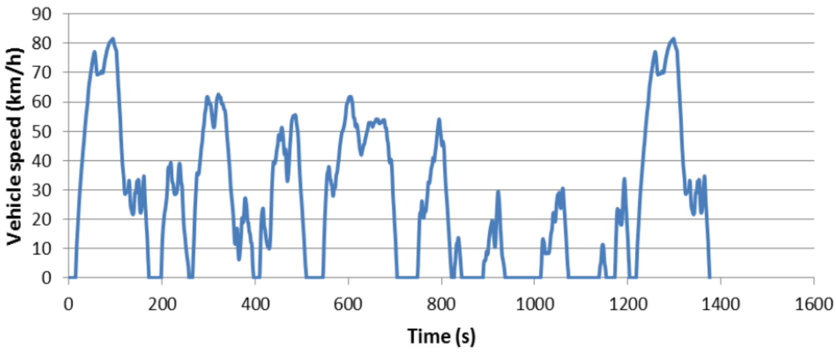

Figure 2.8. Graph of JC08 driving cycle (Ministry of Economy, Trade and Industry (METI) Japan, 2008)

2.2.4 Global harmonized driving cycle

Like previous cycles, the Worldwide Harmonized Light vehicle Test Procedures (WLTP) is a test performed on chassis dynamometer. It allows to evaluate the pollutants and emissions, the fuel economy but also the electric range of light duty vehicles (passenger cars and vans) [15]. It is developed by European, Japanese and Indian experts in order to replace the NEDC cycle by 2013-2014. The test procedure is divided into 3 cycles, depending on a power to mass ratio of the tested vehicle. This power to mass ratio (PMR) is defined as the rated power in W divided by the curb weight in kg. 3 classes are then defined as given in the following table:

Table 2.7. Main characteristics of Class 1, 2 and 3 cycles.

(Car-Engineer: The Different Driving Cycles, 2015)

	POWER TO MASS RATIO	COMMENTS
Class 3	PMR ≥ 34	If V_{max} < 135 km/h, the Extra High speed part is replaced with Low speed part
Class 2	22< PMR < 34	If V_{max} < 90 km/h, the High speed part is replaced with Low speed part
Class 1	PMR ≤ 22	If V_{max} < 70 km/h, the Medium speed part is replaced with Low speed part

(i) Class 3 cycle

Class 3 cycle is made of four speed zones: one representative of urban driving, one suburban driving, one extra-urban driving, and a highway zone [16].

Table 2.8 (a). Main characteristics of WLTP Class 3 cycle

Distance	23.262 km
Duration	1800 s
Average speed	46.5 km/h

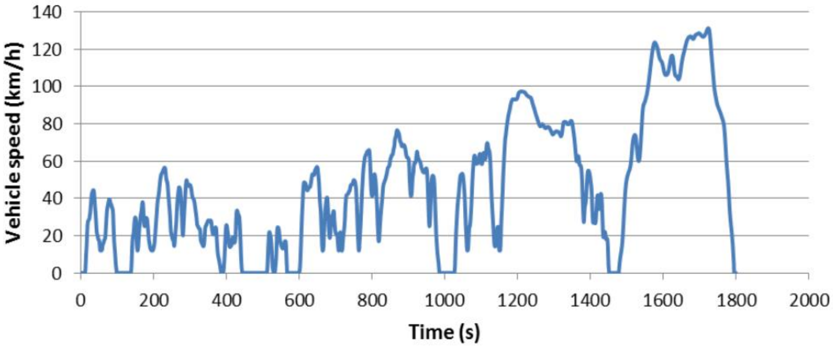

Figure 2.9 (a). Graph of WLTP Class 3 cycle (UNECE World Forum for Harmonization of Vehicle Regulations, 2015)

(ii) Class 2 cycle

Class 2 cycle is representing low, medium and relatively high vehicle speeds, covering Indian vehicles and European and Japanese low power vehicles [15].

Table 2.8 (b). Main characteristics of WLTP Class 2 cycle.

Distance	14.664 km
Duration	1477 s
Average speed	35.7 km/h

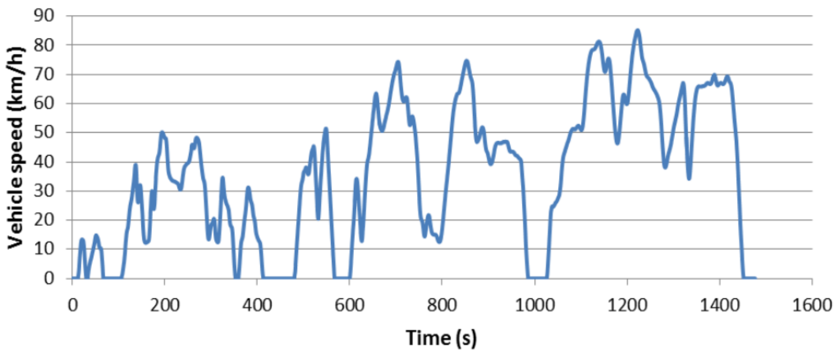

Figure 2.9 (b). Graph of WLTP Class 2 cycle (UNECE World Forum for Harmonization of Vehicle Regulations, 2015)

(iii) Class 1 cycle

This cycle is made of low and medium speed zones. It is typical of low power vehicles that can be found in India [15].

Table 2.8 (c). Main characteristics of WLTP Class 2 cycle.

Distance	8.091 km
Duration	1022 s
Average speed	28.5 km/h

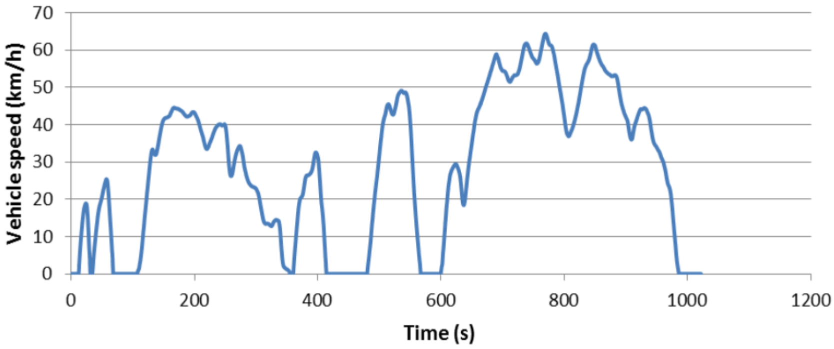

Figure 2.9 (c). Graph of WLTP Class 1 cycle (UNECE World Forum for Harmonization of Vehicle Regulations, 2015)

2.2.5 Heavy duty test cycles

Heavy duty vehicle's emissions and fuel consumption are assessed on engine test bench and not on vehicle test bench. It exists two world harmonized cycles used for homologation that are represented by a set of normalized engine load and engine speed (in % of maximum speed and load) versus time, the first one is stationary (WHSC for World Harmonized Stationary Cycle) and the second one is transitory (WHTC for World Harmonized Transient Cycle) [17]. The WHTC is depicted below:

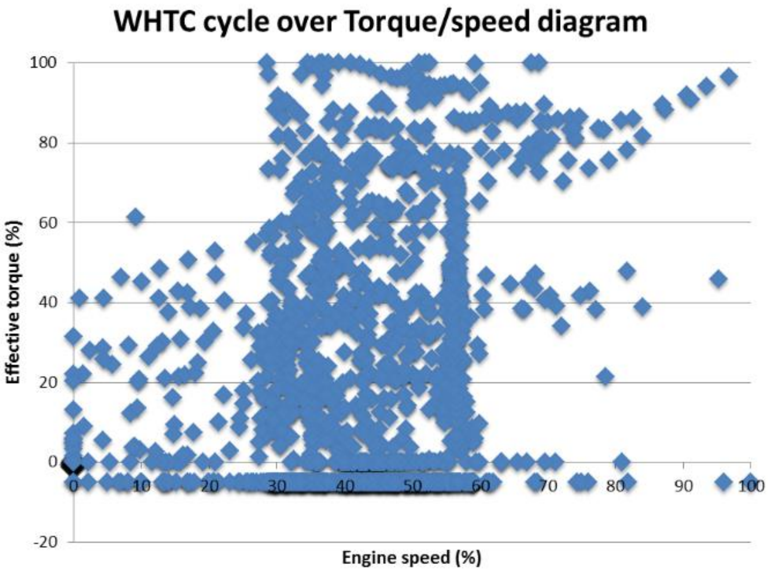

Figure 2.10. Scattered chart of heavy-duty test cycles (UNECE World Forum for Harmonization of Vehicle Regulations, 2001)

2.3 Key Characteristics of Fuel-efficient and Safe Driving

2.3.1 Planning your trip / Route planning

Before going on any trip or destinations, most suitable route should be planned in which several stops can be combined in one trip. Route that go through areas with heavy traffic, road constructions or even hilly terrain should be avoided. Besides, routes that involve toll is not preferable if time constraint is not the main factor [18]. Technologies like Global Positioning System should be utilised to have better view on road and traffic conditions since they are widely accessible. Heavy traffic conditions will increase time of idling which is not fuel-efficient; while slope route on hilly areas causes the drag force acting on the vehicle to increase. If necessary, errands at different places should be ran by few small groups at the same time. However, route planning is not strongly related to safety, but still able to decrease the possibility of encountering road accidents or fatality.

2.3.2 Putting vehicle in Idling condition

Vehicle idling can be categorised into forced idling and unforced idling. Unforced idling refers to the state of a vehicle with engine turned on but does not move, whereas forced idling is the common condition of vehicle with engine turned on while waiting for traffic lights or during heavy traffic.

Engine running at low load and low rated speed is considered as high idling conditions. At this condition, the engine cannot work at peak operating temperature. This leads to incomplete combustion and emissions level increase due to having fuel residues in the exhaust. Furthermore, idling contributes to increase in fuel consumption [19].

A study shows that the rate of fuel consumption while idling depends on types of car. Generally, an idling car uses somewhere between 1/5 to 1/7 gallon, which are approximately 0.8 litre to 0.5 litre respectively of fuel per hour. Small cars or compact cars that carry a 2-liter capacity engine burn around 0.16 – 0.3 gallons (approximately 0.6 litre to 1.1 litre respectively) of gas on per hour basis. While for a large-sized car with a 4.6-liter engine, burns approximately 0.5 – 0.7 gallons (approximately 1.9 litre to 2.7 litre respectively) of gas while idling. On the other hand, diesel engine’s fuel consumption at idle is not much because of the absence of any throttle restriction [20]. Car idling is highly related to fuel-efficiency but hardly have any relation with safe driving.

2.3.3 High air conditioning usage

Many drivers in Malaysia prefer opening air-conditioning (a.c.) at high power, due to the hot weather throughout the year. This does not only increase the emissions of toxic gases that damage the ozone layer, at the same time increasing the fuel consumption of a vehicle as well. A vehicle's fuel consumption increases with the increasing number of usage and increasing power of air-conditioning system. The fuel consumption may be increased by up to 20% because of the extra load on the engine [21]. Vital issues like vehicle's interior size, the outdoor temperature and other conditions do contribute to the actual load. For a.c. usage, it has strong relation with fuel-efficient but not with safe driving.

Table 2.9 The estimated fuel costs and CO_2 emissions associated with a.c. usage. (Government of Canada, 2018)

Annual distance driven using a/c	Annual increase in fuel consumption with a/c use		Fuel cost of a/c use over 10 years*		CO_2 emissions from fuel used for a/c over 10 years**	
	If your a/c uses 1 L/100 km	If your a/c uses 2 L/100 km	If your a/c uses 1 L/100 km	If your a/c uses 2 L/100 km	If your a/c uses 1 L/100 km	If your a/c uses 2 L/100 km
14,000 km	140 L	280 L	$1,400	$2,800	3,220 kg	6,440 kg
12,000 km	120 L	240 L	$1,200	$2,400	2,760 kg	5,520 kg
10,000 km	100 L	200 L	$1,000	$2,000	2,300 kg	4,600 kg
8,000 km	80 L	160 L	$800	$1,600	1,840 kg	3,680 kg
6,000 km	60 L	120 L	$600	$1,200	1,380 kg	2,760 kg

2.3.4 Gear Selection

Engine efficiency of a vehicle is highly influenceable with speed and torque. Basically, lower RPMs consume less fuel due to lower revolutions, as only small friction is formed. In this case, frictions from the pistons rubbing against the cylinder walls, the bearings of the crankshaft, and the drag of things like the valvetrain, water pump, and other accessories are considered. For instance, an engine running at 6000 RPM has to overcome much higher friction than an engine loafing along at 2000 RPM [22].

Moreover, higher loads have an indirect effect on fuel consumption. For the most part, load is analogous to throttle opening. If you're cruising along in a light-load situation, you might only be using five percent throttle. This indicates the engine has to work harder to suck intake air through a throttle that's mostly closed. At wide open throttle, there's less restriction on the intake air, meaning the engine is not working so hard just to breathe.

Low gears provide lots of acceleration but will be running out of steam before the vehicle is able to move at high speed, thus the need of the change to higher gear. In contrast, high gears provide the speed but not the acceleration. To obtain smooth ride and gear transition, avoid changing gear with too much force. Gearshift is suggested to pause for a second as it crosses the neutral zone to make the gear change smoother. This will help to ensure the durability of the gearbox. Selecting the correct gear at different times is crucial for better fuel-efficient driving and safe driving.

2.3.5 Running across red traffic lights

Running across red traffic lights is common behaviour among drivers around the globe. It helps in fuel saving and conserving, which reduce cost in return. This can be explained in which coasting across red traffic lights or stop signs skips the process of drive cycle which involving braking, stopping, idling and accelerating to pick up. Furthermore, this practice contributes to minimize the wear and tear of tires and brakes. By doing that, expenses on vehicle maintenance and repairing can be greatly reduced. Rushing across red traffic lights is considered fuel-efficient when drivers do not perform sharp acceleration, especially when they are aiming to cross the junction when traffic light about to change from yellow to red [23]. However, running across red traffic lights is very dangerous as it is the main reasons road fatalities occur. A good example of more fuel-efficient and safer driving tips is cruising across the traffic lights with neutral-gear, when the traffic light is about to change from red to green.

2.3.6 Overtaking

Drivers usually overtake other vehicles to speed up their journey in order to save more time. Overtaking is not considered as fuel-efficient driving characteristic due to sharp acceleration is required to pass the vehicle in front. At the same time, possibility for motor vehicle accidents to occur are greatly increased. If necessary, shifting lane properly and overtaking by giving indicator ensure safety.

2.3.7 Tailgating/ Drafting

Tailgating is an action when a driver follows the vehicle in front closely as a signal for the driver in front to make way. Most tailgaters are aggressive drivers who actively want to intimidate the motorist in front of them. But there are also 'passive tailgaters' who just are not concentrating properly. Both create risk but the aggressive variety or 'violator' as we call them can be far more intimidating. Tailgating is considered dangerous as collision may occur due to not keeping safe distance from other vehicles [24]. Although tailgating is not considered as fuel-efficient as sometimes the tailgating driver has to slow down and then perform sharp acceleration to keep up the speed again when the driver in front fail to notice the tailgating vehicle at first.

While for drafting, travelling at very close distance to the vehicle in front can help reducing the wind resistance experienced, but the effect will only be significant if it is a large vehicle, a truck for example. However, the ultimate savings in fuel are negligible. Through observation in a test, 90km/h, there is only 20% reduction in fuel used while travelling in a car 15m behind a truck in front, whereas the minimum required distance by law is at least 36m. When reaching 15m, a driver will hit the back of the vehicle in front before having a chance to apply the brakes [25]. Hence, it is extremely dangerous. The fuel savings are only relevant while driving in this situation, whereas the majority of driving tends to be in situations that would make this impossible.

2.3.8 Momentum drive at junction

This driving characteristic is a practice in which vehicle is not slowing down when turning at junctions, or sometimes, accelerating when turning. This move avoids vehicle from slowing down and braking, ensuring better fuel efficiency. In contrast, it is very dangerous as the vehicle may be turned over due to centrifugal force. While momentum driving at junction is not advisable, for certain condition, performing left turn for Right-Handed Drivers, or performing right turn for Left-Handed Drivers, is applicable when there is a Give-Way signboard since it helps to avoid slowing down and braking.

2.3.9 Distractions while driving

Distraction is one of the major factors that brings about road accidents. It basically involves physical tasks, auditory or visual diversions or cognitive activities. Common examples of physical tasks are like eating or drinking; auditory or visual diversions such as loud music or checking news feed on smartphone while driving. While for cognitive activities refer to having conversation on a phone or with passenger. Some activities can incorporate all three modes of distraction. Sending a text message, for example, typically results in physical, visual, and cognitive distraction simultaneously [26]. Distraction caused by texting and mobile phone usage while driving is a major risk factor for motor vehicle collision and many involve injury and fatality [27]. In 2012, distracted driving was associated with 3300 deaths and 421,000 injuries in collisions in the US and reports stated that those are caused by using smartphones while driving [28].

2.3.10 Vehicle Service and maintenance

Motor vehicles need to be regularly maintained and repaired when necessary in order to ensure vehicle long lasting and at the same time ensuring human and vehicle safety [29]. Poor tires alignment may increase the friction between road and tiress, and high viscosity of engine oil may increase the friction of the piston inside the engine which cause damage to the engine. Situations like these will greatly degrade vehicle fuel efficiency. Therefore, frequent car maintenance should be carried out especially those scheduled by car manufacturer, may improve fuel consumption which ensure fuel efficiency [30]. To improvise safety and reduce cost of vehicle repair even more, it is highly recommended to have regular car inspection by drivers themselves. Have regular car service and maintenance is crucial to avoid car breakdown on road which may cause road accident.

2.3.11 Tires pressure maintaining

Improperly inflated tires not only affect handling and drive, but they also affect the health of your tire. According to FuelEconomy.gov, a joint Web site of the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA), underinflated tires reduce gas mileage by 0.3% for every 1 psi drop in all four tires. Estimation from DOE states that 3.56 million gallons of gas are wasted each day due to incorrectly inflated tires. Besides that, DOE advise drivers that by keeping tires inflated to the proper pressure can improve gas mileage by approximately 3.3% [31].

Under inflated tires increase rolling resistance. If driver continues to drive on underinflated tires, the edges of the tires will wear down more quickly. Excessive heat will be produced under and could cause internal damage to the tire. Furthermore, lower air pressure will decrease the load capacity. Lower air pressure will increase the amount of give or flex in the sidewall and can lead to tire failure [32].

In contrast, an over inflated tire will have lower rolling resistance, but the increased air pressure will cause the tire to be overly rounded and lead to the center of the tread wearing down more quickly than the edges of the tread. Maneuverability, which means the quality of being able to sail close to the wind with little drift to the leeward (even in a stiff wind) will be compromised. The extra pressure in the tire increases the possibility in which the tire will fail upon impact and result in accident [33]. Thus, keeping tires at proper pressure is important for both fuel-efficient driving and safe driving.

2.3.12 Speeding over limit

Traveling faster does not help improving fuel efficiency, instead it makes worsen the condition as more energy is required to be converted into work. When more air builds up in front of the vehicle, and the low pressure "hole" trailing behind gets bigger, too. Together, these create an increasing suction that tends to pull back harder and harder the faster you drive [34]. The increase is actually exponential, meaning wind resistance rises much more steeply between 70mph and 80mph than it does between 50mph and 60mph. While each vehicle reaches its optimal fuel economy at a different speed (or range of speeds), gas mileage usually decreases rapidly speeds above 55 miles per hour. Just slowing down from 65 mph to 55 mph can increase your miles per gallon by as much as 15 percent [35].

Vehicle will be at its highest gear with the engine at relatively low rpm when cruising on highway. The combined friction of vehicle's moving parts the tires on the road surface and the air flowing all around the vehicle, can be greatly overcome by maintaining its speed [36]. Increasing highway cruising speed of vehicle from 55mph (90km/h) to 75mph (120km/h) can raise fuel consumption as much as 20%. Gas mileage can be improved by 10 – 15% by driving at 55mph rather than 65mph (104km/h) [37].

2.3.13 Carrying excessive loads

The greater the load, the greater the fuel consumption to move that load around, especially in stop-and-go traffic where the load must be frequently accelerated & decelerated. Even on long straight hauls, though, any increase in load also increases the vehicle's rolling resistance at the cost of additional fuel. On common vehicle, fuel economy decreases by one to two percent for every 100 pounds of weight [38]. In addition, avoid putting bulky items on a roof rack, instead, putting them inside the vehicle or trunk will help to minimize drag acting on vehicle.

In term of road safety, carrying excessive loads worsen road safety, especially for those truck with large cargo. The larger the total mass of vehicle, the larger the inertia will be formed, which cause the vehicle more difficult to be stopped in short time, plus the impact force will be greater if collision happen.

2.3.14 Performing hard braking

Hard braking is an action when drivers jam their foot hard on the brake suddenly every time braking vehicle, even without an emergency on the road. It greatly increases vehicle's fuel consumption and reduce fuel mileage significantly. Whenever brake is applied hardly, vehicle transmission will have to downshift to lowest gears automatically or manually to regain lost momentum. Lower gears require faster engine revolutions which in turn demand more fuel [39].

Fuel consumption increases when acceleration is applied to recover lost momentum. Momentum helps to move your car in a linear direction with higher gears, lower engine revolutions and reduced consumption of the fuel energy. When the vehicle is slowed down gently or allowed to coast in gear while brake applied gently, driver tend to arrive at the junction or traffic lights as they turn green. This will allow driver to minimize the numbers of stopping, accelerate and picking up again, which requires acceleration in lowest gears to recover your momentum or speed.

Hard braking will also damage your tires as well as wear out your brakes and suspension prematurely. Frequent hard braking increases the likelihood of collision with the car in front or behind.

2.4 Factors affecting Driving Behaviour

Age and gender have been always one of the factors that been studied on their impact on accident rate. According to some researches on the area of driving safety, the differences in age and gender significantly impact driving performance [40] [41], which is expected to lead to different fuel efficiency. Age of drivers often relate to their driving behaviour, which affect the fuel economy of vehicles. According to study, drivers of late middle age recorded higher fuel efficiency than young drivers, and female drivers higher than male drivers [42].

Comparing gender, studies state that male driver is more frequent to be involved in accident [43] [44]. This phenomenon is most possibly due to the fact that male drivers has more number of kilometres driven as compared to female drivers. Besides, number of female drivers is significantly lower than the number of male drivers. However, driving behaviour differs for male and female. Instant reactions of male drivers to handle any sudden change and their nervousness and ability to handle emergency affect the rate of accidents which affecting driving safety [45].

Personality characteristics impact your performance on the road. Studies have shown that this correlation begins as a young adult and carries through to present day. Understanding the role of personality in driving not only helps enhance traffic safety policies and programs across the nation, it provides an individual with the opportunity to embrace these behaviours, or make a change where needed. Ownership of vehicle somehow affect fuel economy and safety of driving as well. Since the vehicle is purchased by large amount of money, the owners of vehicle tend to drive more carefully and fuel-efficient-wise comparing to those who are not. Relationship of fuel economy and traffic safety with driving experience had been studied by previous researcher. A very good example is red light running violation through simulation experiment examined by Wu et al. [46] for taxi drivers and non-professional drivers.

2.5 Fuel-efficient Driving and Safe Driving

Driving efficiently in terms of fuel usage, can be defined as driving wisely to improve fuel economy, which is to minimise the fuel consumption while maximising distance travelled. Efficiency may be described as ratio of the output to the input. The input refers to amount of petrol and time used, and the output as the distance travelled, in term of driving efficiency [47].

Driving safely is driving cautiously by obeying the law and regulations on the road and at the same time lower the possibility of occurrence of motor vehicle accidents. Safe driving can be described as defensive driving. Standard Safe Practices for Motor Vehicle Operations, ANSI/ASSE Z15.1, defines defensive driving skills as driving to save lives, time and money, in spite of the conditions around you and the actions of the others. This definition is taken from the National Safety Council's Defensive Driving Course [48].

2.6 Impact of Road Accidents on Economy

The loss of human lives is always been the highest price paid for car crashes, however most of the expenses associated with motor vehicle accidents are borne by society. According to the National Highway Traffic Safety Administration (NHTSA), U.S. motor vehicle crashes in 2010 cost almost $1 trillion in loss of productivity and loss of life.

According to NHTSA, approximate 50% of all motor vehicle crash costs are paid by private insurers. Individual crash victims pay about 26%, while third parties like uninvolved drivers delayed in traffic, charities and health care providers pay around 14%. Federal revenues account for 6%, while state and local municipalities receive about 3%. Overall, those not directly involved in crashes pay for nearly three-quarters of all crash costs, primarily through insurance premiums, taxes and travel delay [49].

Based on the latest report from the Malaysian Institute of Road Safety Research (Miros), road accidents cost Malaysia an estimated RM9.21bil in 2016, which shows an increase of RM581.3mil by comparing with 2015. Estimation from Miros states that a death cause the country an average of RM1.2mil, which is RM120,000 for severe injury and RM12,000 for light injury in medical cost, productivity loss and so forth. [50].

2.7 Correlation and Mathematical Method

2.7.1 Correlation definition

The Correlation is a statistical tool used to measure the relationship between two or more variables, which is the degree to which the variables are associated with each other, such that the change in one is accompanied by the change in another. Correlation between gender and amount of food intake and correlation between demand of product and its price are two of many common examples. For this project, correlation between fuel-efficient driving and safe driving will be determined.

When variables increase together, the correlation will be positive. On the other hand, if any variables decrease while another increases, the correlation will be negative. Correlation patterns can be represented by a value:

- 1 is the perfect positive correlation
- Any positive value between 0 and 1 is positive correlation
- 0 indicates no correlation (no relationship between two variables)
- Any negative value between 0 and -1 is negative correlation
- -1 is the perfect negative correlation

The value of correlation coefficient indicates how good the correlation is, which means how strong the relationship between two variables.

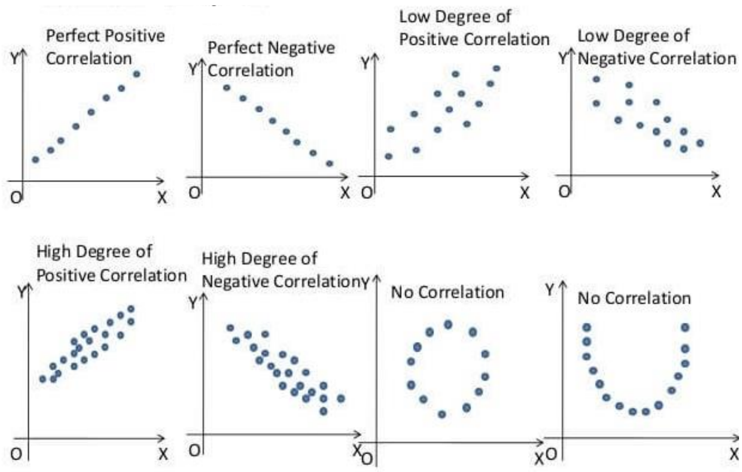

Figure 2.11. Type of correlation patterns. (Correlation Help: My Assignment Help, 2010)

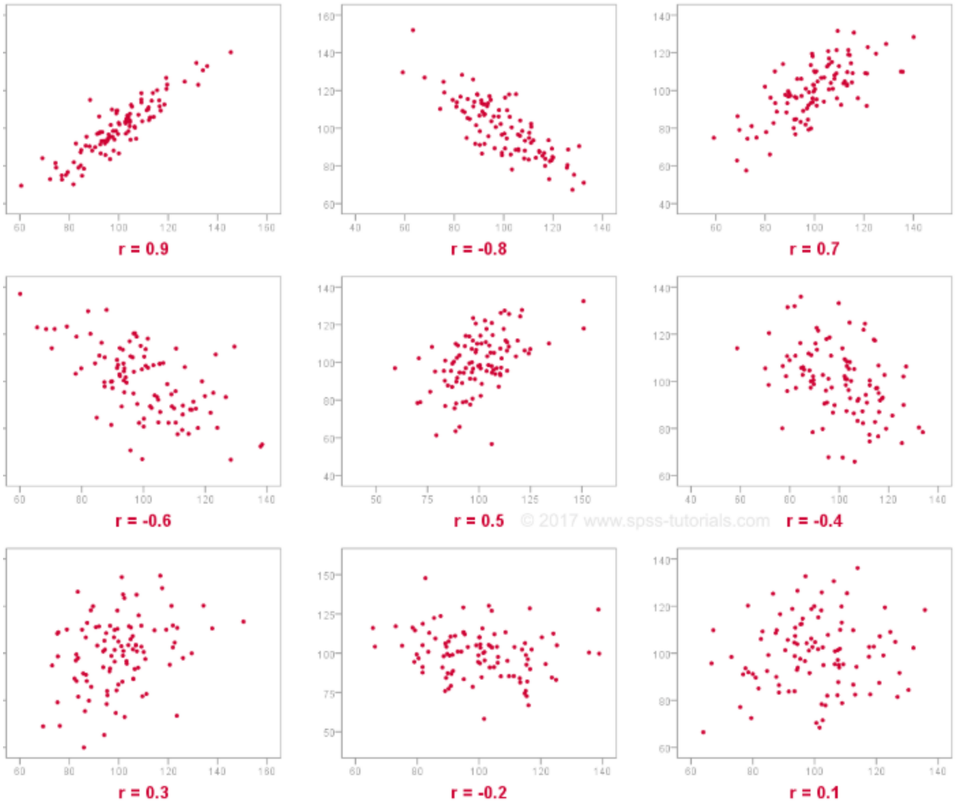

Figure 2.12. The patterns of correlation for positive and negative values.
(SPSS Tutorials: SPSS Correlation Analysis Tutorial, 2015)