INVESTIGATION ON THE IMPACTS OF HARNESSING TRAFFIC ENERGY ON VEHICLES

LIEW SHIN YING

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2016

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ______________________________

Name : LIEW SHIN YING

ID No. : 1104115

Date : 16/04/2016

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATION ON THE IMPACTS OF HARNESSING TRAFFIC ENERGY ON VEHICLES"** prepared by **LIEW SHIN YING** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ______________________________

Supervisor : ______________________________

Date : ______________________________

Specially dedicated to

my beloved grandmothers, mother and father

ACKNOWLEDGEMENTS

I would like to extend my gratitude to everyone who had contributed to the successful completion of this project. Special thanks are dedicated to my research supervisor, Dr. Stella for her invaluable advice, guidance and her enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement.

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ABSTRACT

Energy plays an important role in the country's development. In the recent era, spike in fuel price has turned the attention of society towards renewable energy source. Unlike other renewable energy source like wind and solar energy, traffic energy is an unfamiliar form of energy sources for society. Over the years, experiments and projects utilizing traffic energy have been carried out to improve the functionality and efficiency of the equipment and device used for traffic energy harvester. However, there have always been doubts on the possible impacts of traffic energy harvester on the vehicles which passed over them. This was one of the main reasons for the low implementation of traffic energy harvester in the world. To further promote this future promising energy, verification of the possible impacts these traffic energy harvesters could bring to the vehicles needs to be done to clear doubts of society. In this project, the performance of vehicle when passing over the energy harvester was studied from few aspects namely the fuel consumption rate, the vehicle efficiency, effect on vehicle suspension and lastly the vehicle tyre wear rate. After precise calculations, simulations using MATLAB-Simulink are carried out to help further analyses on the results obtained. The project revealed much about the degree of influence of the harvester on vehicles' performance.

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LIST OF SYMBOLS / ABBREVIATIONS

a	speed of acceleration (m/s^2)
a_0,a_1,a_2	dimensionless model parameter
a_0,a_1,a_2,a_3	model coefficient
A	tyre rolling resistance coefficient
AF	frontal area of vehicle (m^2)
b_{11},b_{12},b_{13}	rolling resistance parameter
B	speed-correction to rolling resistance
C	air drag coefficient
CD	drag coefficient
C_f	front suspension damping rate
C_r	rear suspension damping rate
CD_{mult}	Drag Coefficient Multiplier
C_{otc}	tread wear rate constant (dm^3/1000km)
C_s	tyre stiffness (kN/rad)
C_{tcte}	tread wear coefficient (dm^3/MNm)
CR_1	rolling resistance tyre factor
CR_2	rolling resistance surface factor
E	superelevation (m/m)
f	coefficient of friction
F_a	aerodynamic force (N)
F_g	gradient force (N)
F_r	rolling resistance force (N)
F_{front}	upward force on vehicle body from front suspension
F_{rear}	upward force on body from rear suspension
g	gravitational constant (9.81 m/s^2)
grade	road grade or gradient
I_{yy}	body moment of inertia about gravity centre

K	friction factor of engine (kJ/revL)
KCr_2	calibration factor
K_f	front suspension spring constant
K_r	rear suspension spring constant
L_f	horizontal distance from gravity centre to front suspension
L_r	horizontal distance from gravity centre to rear suspension
LHV	the factor lowers heating value of the fuel
m	mass of vehicle (tonne & kg)
m_b	body mass
M_y	pitch moment induced by vehicle acceleration
N	speed of engine (rev/s)
P	power output of engine (kW)
P_{acc}	power for accessories (kW)
P_b	brake power (kW)
R	curvature radius (m)
V	engine displacement (L)
v	speed of vehicle (m/s)
z	bouncing distance or vertical distance
λ	wavelength of microtexture
η	efficiency of engine
η_t	transmission efficiency
μ	coefficient of friction of different materials
ϕ	fuel/air ratio
ε	vehicle drivetrain efficiency
ρ	mass air density (kg/m^3)
θ	rotational pitch angle
$\dot{\theta}$	rate of change of rotational pitch angle
$\dot{z}$	rate of change of bouncing distance
CONFAC	congestion modification factor
CFT	circumferential force on the tyre (N)
CTCON	incremental change of tyre consumption related to congestion

dFUEL	incremental change of fuel consumption related to congestion
DC	direct current (A)
DEF	Benklemen Beam rebound deflection (mm)
DW	diameter of wheel (m)
emf	electric motive force (V)
EPA	environment protection agency
EQNT	equivalent new tyre (%/km)
F	friction force (N)
FR	fuel rate
GA	generic algorithm
hp	horse power
IRI	international roughness index (m/km)
LFT	lateral force on the tyre (N)
MODFAC	tyre life modification factor
mph	miles per hour
NFT	normal force on the tyre (N)
NW	number of wheels
PIARC	permanent international association of road congress
TC	Tyre Consumption per Vehicle (%/km)
Tdsp	texture depth using sand patch (mm)
TE	tyre energy (MNm/1000km)
TRLHP	track road load horsepower
TWT	total change in tread wear
TYREFA	tyre type modification factor
VEHFAC	vehicle specification modification factor
VOL	tyre volume
W	weight of vehicle (N)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Energy surrounding our environment exists in many forms. Traffic energy is one of the many forms of renewable energy wasted if left untapped. By using a specially designed speed breaker, the kinetic energy in vehicle while slowing down which will otherwise be transformed into heat energy can be converted into electric power. With generators and proper mechanism as prime movers, the force exerted by the vehicle towards the ground is tapped into useful electrical energy. Another method to generate traffic energy from moving vehicles is through the application of piezoelectric material as the material for roads. Piezoelectric generator is used to harness the vibrational energy from a speed breaker and its surroundings whereas the mechanical system is used to harness the kinetic energy of a vehicle when it strikes the speed breaker.

Throughout the years, there are few projects and studies being carried out regarding harnessing of traffic energy. At Guwahati a businessman Gogoi.K has successfully developed a mechanism to produce electric power when a vehicle passes by the speed breaker through conversion of potential energy into kinetic energy. The idea has raised attention from Indian Institute of Technology-Guwahati, which then funded a pilot project related to electricity generation from speed-breakers

(Priyadarshini, 2007). Besides, in the paper Design of Power Generation Unit Using Roller Mechanism, the performance of a speed breaker utilizing roller mechanism to harness traffic energy has been experimented (Sarma, Jyothi and Sudhir 2014).

1.1.1 Advantages of Traffic Energy

Traffic energy is a relatively new renewable energy as compared to wind and solar etcetera. However, there are many advantages for harnessing traffic energy. Taking speed breaker as the method to harness traffic energy, almost all of the techniques used to implement the technology require low maintenance cost and installation cost. Furthermore, there is no manual work necessary during the power generation process. Generally speaking, the construction of these speed breakers is simple, leading to matured technology and the maintenance is easy. As traffic energy is another form of renewable energy, it does not require fossil fuel to produce electricity. The source of energy for it is the friction energy produced between the vehicle and the ground as the vehicles come to halt at the speed breakers. If it is a speed breaker using the piezoelectric generator, this mechanism potentially senses the ambient vibrations; therefore, it can still generate power when a vehicle does not roll over the bump (Sarma, Jyothi and Sudhir 2014).

1.2 Problem Statement

There has always been doubt among people regarding the effect of traffic energy harvester mechanisms on vehicles when passing through them. This is probably the core reason this renewable energy harnessing has not been implemented widely despite the favorable return it brings to the society. It is crucial for an investigation on the impacts of traffic energy harnessing to be carried out in order for the concept of traffic energy to be more accepted by society. Therefore, some investigation on the possible impacts of traffic energy harvester mechanism on vehicle has been proposed and discussed in this project. The work aims to clear doubts about the potential drawbacks of the harvester device.

1.3 Aims and Objectives

The aim of this report is to study the impacts of harnessing traffic energy on the vehicles. There is very few application of traffic energy harvester currently. By carrying out this study, it is expected that the study will aid the society in understanding this renewable energy and thus promoting its usage in the society.

The objectives of this study are as follow:

1. To identify the possible impacts of the traffic energy harvester to the vehicle while harnessing the energy.
2. To design the model of a vehicle for the simulation.
3. To investigate if the traffic energy harvester influences the fuel consumption of vehicle.
4. To study if the traffic energy harvester causes any changes to the vehicle tyre tread wear.
5. To study the effect of traffic energy harvester on the vehicle suspension system.
6. To study the vehicle’s efficiency while harnessing the energy.

1.4 Topic Outline

This project was carried out by steps. In this report, the steps carried out to achieve the aim and objectives of study would be illustrated clearly.

In the next chapter, researches and project reports of topic related to traffic energy harvester would be discussed in detail. Few common types of traffic energy harvester were studied including the rack and pinion method, the roller mechanism, the crankshaft mechanism, hydraulic mechanism and air compression mechanism. Some researches regarding the possible impacts were also included in the chapter.

In chapter three, the procedures of carrying out study in the project were narrated and demonstrated. Choices of equations for calculations for each impacts (fuel consumption rate, tread wear rate, effects of vehicle suspension and vehicle efficiency) and simulation software were explained.

Chapter four has covered the results from calculation and simulation of software for all the studied impacts. Calculation process, table of results, graphs and discussion of results were included in this chapter.

The final chapter of this report would be concluding the studies that had been carried out in this project. From the results obtained, conclusion was able to be deduced. To ensure further investigation could be carried out on the topic, some suggestions were given to improve the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Traffic energy is a rather new form of renewable energy which is not widely used in the society yet. However, experiments and projects have been carried out from time to time to study the performance and functionality of traffic energy harvester. These studies have enabled more appropriate techniques to be used for traffic energy harnessing. The studies have demonstrated various technique used for traffic energy harnessing.

The performance of vehicle on the traffic energy harvester is the most important concern among people who are using the road. Throughout the years, many studies have been conducted to study the fuel consumption rate with regard to the pavement structure and roughness. In the studies, the relationship of fuel consumption rate with the environment factors affecting it is deduced with equations.

2.2 History of Traffic Energy

In 1817, the piezoelectric effect was introduced to the society by a French mineralogist called Rene Just Hauy. Sixty-three years later, Pierre Curie and his brother Jacques demonstrated piezoelectricity (Samal et al., 2014). Electric charges are produced when hemihedral crystals-like quartz is being pressurized. A device was invented based on this phenomenon. The name of piezoelectric effect consists of two parts; the word piezo represents pressure, and electric stands for electricity. Direct piezoelectric effect takes place in a piezoelectric material when a charge is developed in the material due to a force (Grujicic, Zhao, Austin, 2005).

Today, piezoelectric material has been used for various applications including power generation. One of its applications includes harnessing power from regenerative vehicle suspensions. Besides, it is also used to harvest bike vibration energy. Research & Development department of JR East Group has even come up with floor which generates power. Energy harvesting has also been implemented in railway tracks. Furthermore, generation of electricity from road vibrations using piezoelectric materials has also been developed (Samal et al., 2014).

The electro-kinetic road ramp is a way to generate electricity by harnessing the kinetic energy of vehicles that pass through the ramp. Mr. Peter Hughe who is an electrical mechanical engineer has invented an electro-kinetic road ramp in year 2002. This ramp produces around 50kW of power each time a car passes through it. For the past 12 years, he has been slowly developing the concept. The prototype was being tested at Hughes Research unit base in Somerset (BBC News, 2005). When a piezoelectric generator is used in a speed breaker, the piezoelectric generator senses the vibrations when the vehicle rolls over the surface of the bump, thereby converting it into some useful work.

2.3 Energy Harvesting from Traffic Vibrations

Travelling on the road, the road roughness, accelerations, decelerations, and unevenness of road often causes unwanted vibrations. This energy is wasted unless being converted into electrical energy. Many studies have been carried out to study on energy harvesting from traffic vibration. In a study which monitors the bridge health by using vibration harvesting system Galchev (Galchev et. al., 2011) has proposed an electromagnetic inertial micro power generation system to harvest vibration energy present on a bridge. A feasibility study about energy harvesting from bridge vibrations has been done (Williams et al., cited in Pelgney and Siegert, 2013). The study is done by combining the vibrational responses of small span concrete bridges measured and an energy harvester's theoretical model.

A paper written by Ye described the best performing design of a piezoelectric energy harvester by a genetic algorithm (GA) based method using data of real vibration. He also shows an experiment that was carried out using acceleration data and presents the power spectrum generated when a vehicle drives over a manhole cover (Ye, 2009).

In a comparative analysis of piezoelectric energy harnessing from micro-vibration utilizing non-adaptive circuit (Mat Darus, Mustadza and Yatim, N.D.), micro-vibration harnessed using piezoelectric vibration-to-electricity converter is compared between simulation and experimental findings. The experiment is implemented by using magnetic shaker to produce the micro vibration. A vibration source at 120 Hz has been used and it is classified as the middle of the range of low level vibration sources. From the study, it is concluded that more power is harnessed as the acceleration magnitude is increased.

2.4 Energy Harvesting using Speed Breakers

Speed breakers normally functions to lower the traffic speed at certain area to take care of the safety of pedestrian. The paper "Design, Modeling and Test of a Novel Speed Bump Energy Harvester" suggested a novel speed breaker energy harvester that generates electric power up to few hundred watts as cars pass on the speed breaker. The motion mechanism enables the up-and-down motion to turn the generator in unidirectional direction, producing energy from speed breaker. This design offers the speed breaker a new purpose other than ensuring road safety (Todaria et al., 2015).

2.4.1 Rack and Pinion Method

A rack and pinion is used to convert between rotary and linear motion. It is a type of linear actuator that consists of a pair of gears. The circular gear is also called the pinion whereas the linear "gear" bar with teeth on it is known as the rack. As the pinion starts moving in a rotational motion, the rack starts to move in linear motion. The piston which is coaxial to the rack gives hydraulic assistance force, and the rotary valve that is open-centered manipulates the assistance force level (Kumar et al., 2015).

The work of Fawade describes the rack and pinion method along with principle of reciprocating air compressor used for the project. The whole mechanism is fixed underground exactly below speed breaker with the head of piston rod at the road surface level. When vehicles are driven over the speed breaker, the rack is moved downward. The rack is jointed to piston rod and the piston reciprocates in the cylinder. The piston and cylinder arrangement then converts these reciprocating motions into air compression. The pressure of air increases due to compression of air in the low volume area which is caused by the motion of the pistons inside the cylinder (Fawade, 2015).

In Aniket Mishra et al.'s paper, rack and pinion method is used to harness traffic energy. The weight of the vehicle drove over the speed breaker system is transmitted to rack and pinion arrangement. This arrangement with axis of pinion attached with the sprocket arrangement then changes the reciprocating motion of the traffic energy harvester into rotary motion. The rotary motion is then used to turn the generator to produce electricity. From the study, it is also known that when a 300kg vehicle passes through the speed breaker, the output power developed in one minute is 7.3575W, which is 441.45W/hour and 10.5948kW/day. The energy generated is said to be able to light up four street lights for the whole night (Mishra, Kale and Kamble, 2013).

Generation of electricity through rack and pinion method is also discussed in the paper "Every Speed Breaker is now a Source of Power". The experimental investigation performed has shown that the amount of power generated using rack and pinion method depends on the speed and weight of vehicle. The slower the speed of the vehicle, the more the power generated. The amount of power generated is also directly proportional to the weight of the vehicle (Aswathaman and Priyadharshini, 2011). As shown in Figure 2.1 is the rack and pinion gear arrangement which could be used for power harnessing speed breaker and Figure 2.2 shows the kinematic definitions for rack and pinion gear set.

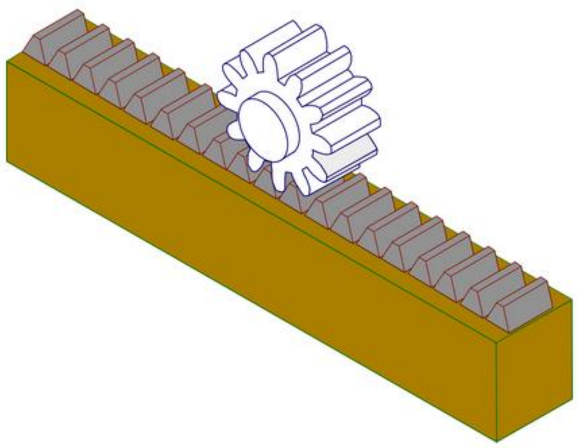

Figure 2.1: Rack and Pinion Gear Arrangement

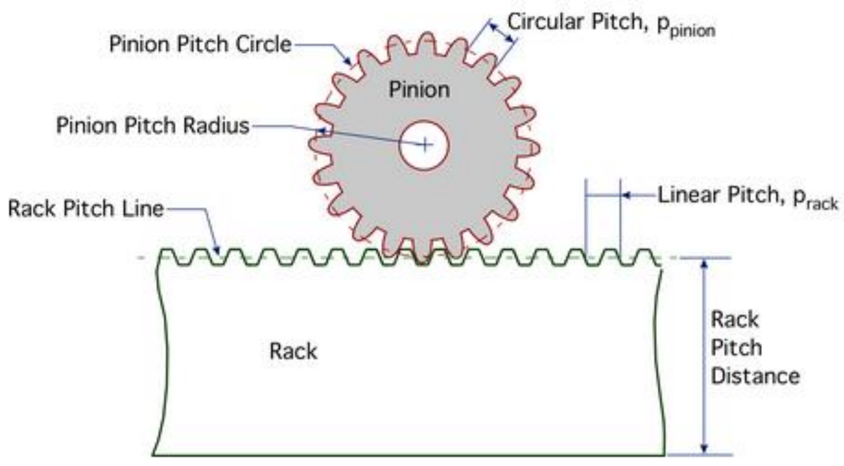

Figure 2.2: Kinematic Definitions for Rack and Pinion Gear Set

2.4.2 Hydraulic Mechanism

Hydraulic method employs piston mechanism which consists of a cylinder arrangement with the piston mounted on the connecting rod. This mechanism is able to convert linear motion of the piston into electrical energy. It needs more kinetic energy for the generation of desired electrical power. Besides, this method is also hard to be implemented. Nevertheless, it is able to generate higher range of electrical energy if compared to other methods of generation (Kumar et al., 2015).

When a vehicle passes over speed breaker constructed of cylinder and piston, the piston rod is then subjected to a compressive force. This force pressurizes the oil and causes it to exit from outlet nozzle. The oil which comes out from the outlet nozzle then strikes the turbine blades at a pressurized speed. This turbine which is coupled with an electrical generator converts the potential energy of pressurized oil to electrical energy via movement of turbine blades. The exhausted oil is recycled back to the cylinder through the inlet control valve with the help of spring tension. The speed breaker is then able to return to its original position (Ravivarma et al., 2013). For an example, Figure 2.3 illustrated how hydraulic compression mechanism could be applied to speed breaker for power harnessing.

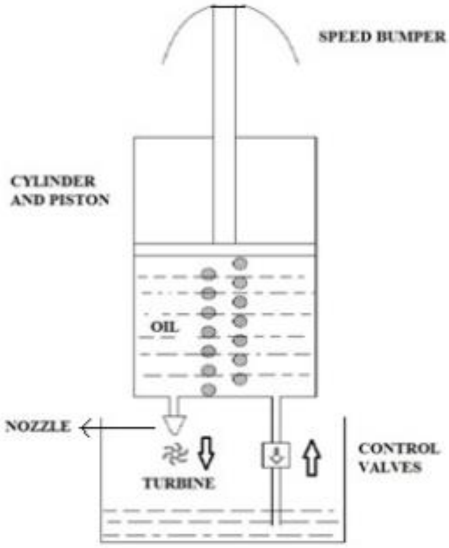

Figure 2.3: Speed Breaker using Hydraulic Compression Method

2.4.3 Air Compression

Air compression mechanism is discussed descriptively in "Power Generation from Speed Breakers by Air Compression Method". The mechanism utilizes the weight of vehicle when passes through the speed breaker to push the piston down. Just like hydraulic mechanism, the compressed air is sent to rotate the turbine. However, this mechanism consists of a tank which stores the compressed air. The turbine is connected to alternator or any type of electric generator to produce electricity. This method has the advantage of lower cost of construction and higher efficiency. Moreover, it is able to produce constant output without using battery. The tank enables storage of air that give constant output for longer period of time compared to other mechanism (Dave Jamin, 2015). Figure 2.4 as shown below demonstrated air compression mechanism used by power harnessing speed breaker.

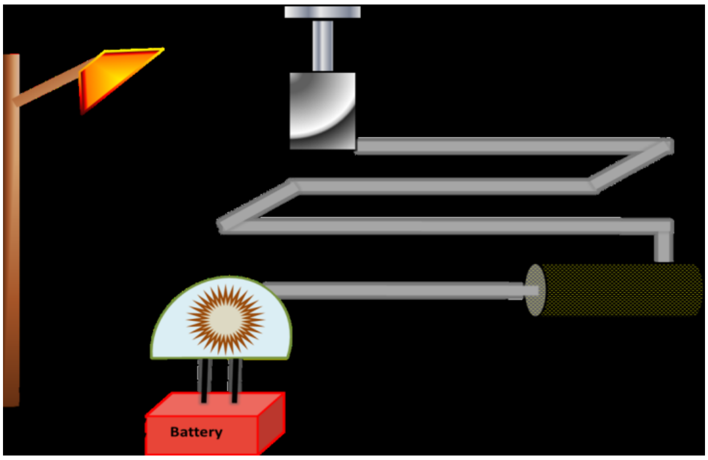

Figure 2.4: Air Compression Mechanism

2.4.4 Roller Mechanism

This mechanism consists of bar shaft, couplers, dynamo and linear motor. The bar functions as the speed breaker for this mechanism. The vehicle rotates the roller when passing the speed breaker and thus the hub of dynamo is rotated with aid from chain and pulley (Kumar et al., 2015).

An experiment to investigate roller mechanism was carried out. In this mechanism, a roller is fixed as part of the speed breaker. Grip must be provided on the speed breaker to rotate the roller whenever a vehicle passes by the speed breaker. This will in turn rotates the DC generator with the help of chain drive. The chain drive serves to provide different speed ratios. As the generator rotates, electricity is produced and stored in a battery. It is also found that the weight of vehicle is directly proportional to the voltage and current generated. On the other hand, the vehicle speed is inversely proportional to the voltage and current generated. This is because more grips exist between vehicle and speed breaker at low speed. In short, the generator can produce a power of 1.67 W in a minute by a constant mass of vehicle 205kg passing over the speed breaker (Sarma, Jyothi and Sudhir, 2014).

In an experiment carried out to investigate electrical energy generated from speed breakers due to motion of vehicle, it is found that a maximum of 15W power can be obtained by using rolling mechanism. The roller attached with gear arrangement will rotate when a vehicle moves over it. If the kinetic energy of the roller is 4541J then 5V electrical power is generated at 4sec. The efficiency is about 40%. (Amod et al., 2015)

A project aims to explain the roller mechanism of speed breakers used for power generation. The friction force produced from vehicle movement is transmitted to the chain sprocket arrangements. A larger sprocket and another one smaller make up the sprocket arrangement. The smaller sprocket's axis is joined to gear arrangement with gears of different dimensions. The larger gear wheel is joined to the smaller sprocket's axis. Hence, the speed is passed on to the larger gear wheel when it is accelerated at the smaller sprocket. As the larger gear rotates, the smaller gear also accelerates. This is followed by the larger gear with the high intensity multiplied speed. Although the speed at the larger sprocket wheel is slower, but the final speed obtained is high as the power is transmitted to gears. This speed which rotates the rotor of a generator in a static magnetic stator then cut the surrounding magnetic flux then generates the electric motive force (emf). This emf is then forwarded to an inverter to be regulated, and then to the storage battery to be stored (Bhagdikar et al., 2014). As shown in Figure 2.5 is the roller mechanism used in speed breaker for traffic energy harvesting purpose.

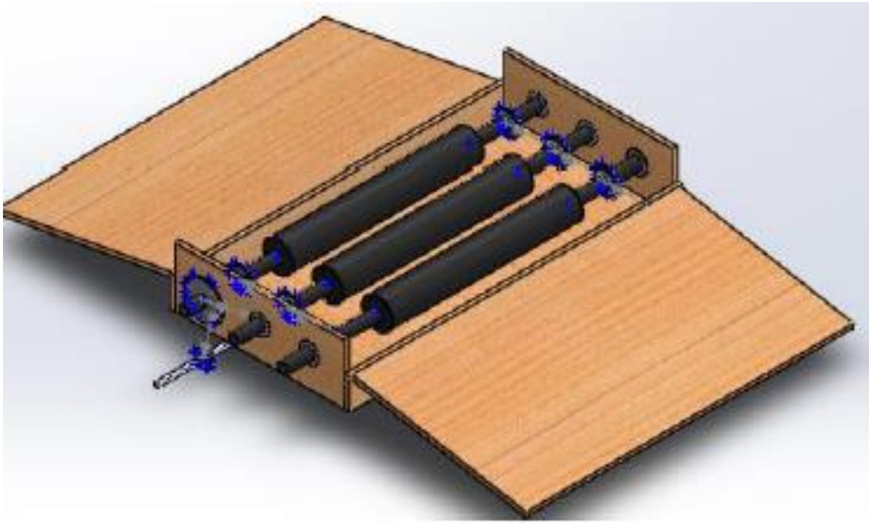

Figure 2.5: Speed Breaker using Roller Mechanism

2.4.5 Crankshaft Mechanism

A crank mechanism was used in a project of power generating speed breaker which works based on crank shaft mechanism. The crank is used for conversion of circular motion to reciprocating motion, or the other way round. The connecting rod is joined to the end of the crank using a pivot. One end of the rod that is fixed to the crank moves in a circular motion, while another end moves in a linear sliding motion. This crank mechanism is linked to the generator to produce electric power directly from the kinetic motion of the crank mechanism (Prasath, 2015).

Besides, there is also a project which utilizes crank mechanism to convert the stroke motion of vehicle on the moving plate installed on the road into electricity. The crank mechanism consists of a keyway flywheel system. One flywheel is driven to another flywheel once a predetermined velocity is determined. This system has managed to obtain large amount of moment of inertia in a small space. The electricity generated was fed into the power grid to light up the street lights. This project has demonstrated the relationship between the power generated with the speed of vehicles and weight of vehicles (Fatima and Mustafa, 2012).

2.5 Fuel Consumption of Vehicle

Fuel consumption rate of a vehicle depends on many elements. In the study carried out to construct a statistical model of vehicle fuel consumption, a formula is used to represent the fuel consumption rate. The formula is further discussed in the following chapter regarding its application in this project.

The fuel rate is kept a small constant value when no engine power is applied. In the case when engine power is required, fuel consumption rate is mostly dependent on the speed of engine and vehicle's demanded power. The stoichiometric ratio represents the mass of air desired to ideally oxidize the fuel completely. When more power is needed, engines functions with a fuel-rich mixture ($\phi > 1$) to avoid the overheating catalyst and thus damaging it. Enrichment also happens at cold-starts to warm the exhaust and engine faster to enable light-off of catalyst sooner. (Cappiello et al., 2002)

The K value, ε value and the N value are all depending on the vehicle speed and other quantities. This is discussed in the paper "Development of a Comprehensive Modal Emissions Model". K value is the fuel energy used to overcome the engine friction produced in each engine revolution and also in a unit of engine displacement. For early-to mid-1990s cars, K_o which represents the engine friction factor in kJ/ (lit.rev), ranges from 0.19 – 0.25 kJ/ (rev*liter). N which is the engine speed, is determined based on vehicle velocity, power demand and gear shift schedule. Drivetrain efficiency (ε) drops at low engine speed range because of the torque converter slippage. The vehicle drivetrain efficiency drops both during slow speed and at high Specific Power values. As for the engine speed N value, its relationship with the vehicle speed can be illustrated with an equation which will be discussed in the next chapter. (Bath et al. 2000).

Apart from that, the model of elemental fuel consumption deduced by GM Research Lab scientists also presented that a vehicle's fuel consumption rate differs depending on many variables. Although the speed alone affects the fuel consumption rate of vehicle by 75%, the rolling resistance of road was also mentioned to be an important factor to be considered. The rolling resistance of road is a function of road surface condition and road type. Fuel consumption rate differs by the factor of rolling resistance is estimated to be more important for heavy vehicles like trucks (Ardekani and Sumitsawan 2010).

Although many of the factors which affects the rolling resistance are vehicle dependent, pavement properties is one of the most integral part in determining the overall rolling resistance a vehicle needs to overcome. The vehicular rolling resistance is mostly affected by the pavement surface texture, pavement roughness and pavement stiffness. The pavement surface texture and pavement roughness cause tyres and suspension of vehicles to vibrate. These vibrations absorbed by the shock absorbers and tyres of the vehicle will result in loss of energy loss in the vehicular system. Furthermore, these vibrations will ultimately affect the fuel consumption rate of vehicle. From the study, it can be seen that smooth roads reduce fuel consumption rate. There are many studies conducted regarding rolling resistance with the pavement properties, each study assessed the effect of smoothness on pavement vehicle interaction and showed that smooth pavements reduce rolling resistance. The Missouri rehabilitation project has shown that reduction of the IRI of pavement from 130 to 60 in/mile save up to 2.46% of fuel (Willis, Robbins and Thompson, 2015).

2.6 Vehicle Efficiency

Vehicle efficiency is often linked to the carbon dioxide regulations or fuel efficiency of vehicle. In fact, increase in fuel efficiency will influence the energy efficiency of vehicles. It is said that by refining the design and technology employed by vehicles will help achieving vehicle efficiency. However, technology employed by vehicle is only one of the components affecting the fuel efficiency. One of the ways to improve fuel efficiency is through designation of tyres such as the tyre tread and shoulder designs and using different tyre materials to reduce the flexing and other sources of energy loss. The importance of rolling resistance is equivalent for both city driving and highway driving (Kobayashi, Plotkin and Ribeiro, 2009).

It is mentioned in a report that to improve vehicle fuel efficiency, the vehicle technology should be refined. Some of the techniques include gasoline direct injection, cylinder deactivation and variable valve lift and timing. Each of the method could contribute to efficiency improvement by 3 to 10 per cent. In the coming future, some other further efficiency improvements expected are dual clutch, continuous variable transmissions and reduction in aerodynamic drag, and rolling resistance. (Kasseris and Heywood, cited by Chech et al., 2007)

The energy required at the vehicle wheel to get a vehicle driven for a driving cycle has been determined to be related with vehicle weight, drag coefficient, and tyre rolling resistance coefficient (Sovran and Bohn, cited by Duleep, 2011). The energy requirement at the wheel and thus the energy needed at the engine output shaft through factor of transmission and driveline efficiency is computed based on it. Other energy requirements are assumed a constant amount of energy in terms of engine size. The total engine output energy is thus determined (Duleep, 2011).

2.7 Vehicle Tyre Wear Rate

The roughness and frictional characteristics of a pavement surface have crucial importance in ensuring road safety and determining tyre wear rate. The pavement texture plays different role in the functionality of vehicle parts. To classify the deviations of pavement surface from true planar surface, a scale based on wavelength of deviations was introduced by the Permanent International Association of Road Congress (PIARC). The scale is as shown in the Figure 2.6 (Flintsch et al., 2012).

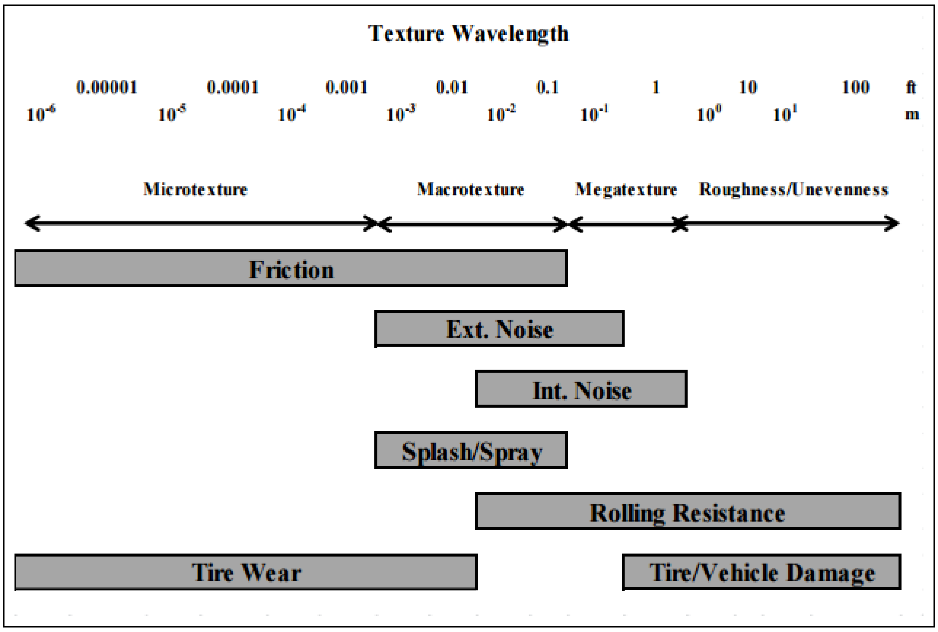

Figure 2.6: Influence of Texture Wavelength on Tyre Pavement Interaction

The micro-texture represented the surface roughness quality at the sub-visible or microscopic level with wavelength λ less than 0.5mm and peak-to-peak amplitude A between 1 to 500 μ m. It is a function of surface properties of the particles contained in the paving material like asphalt or concrete. Macro-texture on the other hand has λ in the range of 0, 5 to 50mm and A in the range of 0, 1 to 20mm and it stands for the roughness quality defined by mixture properties of asphalt paving material and method of finishing used on concrete paving material. The mega-texture has λ in the range of 50 to 500 mm and A in the range of 0, 1 to 50mm. It is illustrated as texture with wavelength in same order of size as pavement-tyre interface. Distress and defects of pavement surface is described under this category. It was proposed that any wavelength longer than 500mm is defined as roughness or unevenness. Each of these wavelengths brings impact to different parts of vehicles (Institute for Research in Technology, N.D.).

In a report from National Cooperative Highway Research Program, the effect of pavement roughness on the tyre wear has been carried out using estimation of HDM 4 model (Bennett and Greenwood, cited by Chatti, K. and Zaabar, I., 2012). An accurate estimate on tyre wear was obtained. The change in tyre wear as a function of IRI for different speeds generated at 17 ℃ when the average profile depth is 1 mm and grade is 0% is shown in Figure 2.7. The result indicates that roughness of pavement will disturb passenger car tyres more severe compared to articulated truck tyres (Chatti and Zaabar, 2012).

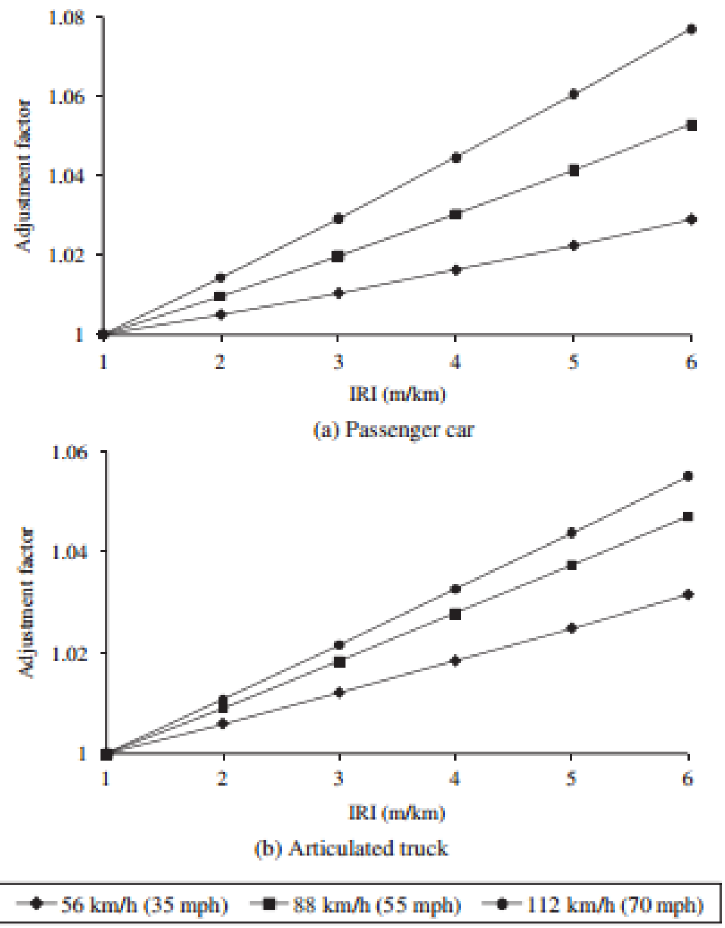

Figure 2.7: Effect of Roughness on Tyre Wear

The road condition can contribute to tyre wear in several ways such as the horizontal alignment, the surface texture, the surface roughness, and the structural section. Horizontal alignment indicates the curves exist on the road. The tyre wears increases along with the number of curves on the road because of the lateral forces acting on the tyres (Carpenter and Cenek cited by Weissman et al., 2003). It is required that the road surface possesses a certain minimum value of coefficient of friction (f) between the tyre and road to ensure a safe stopping distance. However, tyre wear will increase as the coefficient of friction increases. The roads designers are expected to set the surface friction according to each site as different sited require different frictional resistance for safety reasons.

Besides, the influence of pavement roughness has been shown through a recent study done by Papagiannakis (Papagiannak, cited by Weissman et al., 2003). In the study, he showed that the tread wear increases with the International Roughness Index (IRI) value. Traffic noise is greatly affected by the surface texture. Although the effect of texture on tyre wear is not well documented, the anecdotal evidence suggests that large aggregate in concrete causes tyres wear off at faster rate.

2.8 Vehicle Suspension System

Suspensions are used in vehicles to support load and protect passenger from shocks coming from tyre and road interaction. They provide directional stability and yaws control of vehicle. The suspension systems are designed to achieve a balance among these conflicting requirements because these conflicting parameters are hard to be achieved at the same time. The main objective of suspension is for enhancement of ride quality, directional stability and handing of the vehicle.

Front suspension is the independent suspension system where its main components include an upper control arm, lower control arm, spindle, brake caliper and brake rotor. Each of these main components is attached to several additional components and plays important role in the performance of suspension. As vehicles passed over terrain like road bumps, the front suspension permits the tyre to move vertically with regard to the frame of the vehicle. The spring and shock absorber are joined to the lower control arm which controls the specific direction of movement and also the frame of the vehicle. As the tyre moved upwards, an opposed direction force was generated by the spring to resist the motion. The shock absorber stamped the motion. (Pathmasharma, S. et al., 2013)

According to Wong's Theory of Ground Vehicles, the suspension system installed in vehicles absorbs shock experienced by vehicles due to weight of vehicle while trying to eliminate vibrations induced by various factors. Such factors include road surface irregularities, vibrations of the engine and driveline, and non-uniformity of the tyre/wheel assembly. Usually, road surface irregularities act as major source that stimulates the vibration of the vehicle body through the suspension system (Wong, 1998).

Generally, vehicles' suspension systems are classified into three well-known categories of passive, semi-active and active systems. Nevertheless, there are also various systems exist in between these three systems. Typical features are the required energy and the characteristic frequency of the actuator. All systems implemented in vehicles' today are based on hydraulic and pneumatic operation. However these solutions do not solve the oscillation problems satisfactorily or they are of high cost and consumes more energy. Nevertheless, the most traditional way which is the passive systems are still the most common. (Florin, A. et al., 2013)

The passive suspension system as shown in Figure 2.8 is an open loop control system. Its' design is to achieve a compromise between stability and ride comfort only. The characteristic of the passive suspension is such that it is fixed and could not be adjusted mechanically. The design of passive suspension owes a problem that if it is heavily damped or too hard, it will transfer a lot of road input. In other words, the vehicles will be highly affected by the unevenness of road. On the other hand, if the suspension is lightly damped or soft, it will give reduced stability to vehicle at turns or during change lane. In other words, the soft suspension will swing the car at certain road condition. Thus, the performance of the passive suspension is highly dependent on road profile. (Agharkakli, A., 2012)

Md. Zahid Hossain et al. had published a paper on comfort level of driving experience for a 4 degree of freedom (DoF) suspension. In the study, the mathematical model of 4 DoF heavy vehicle suspensions is derived using a half car model. The vibration characteristics due to parametric changes are investigated for heavy vehicle suspension system. By using MATLAB/ Simulink, the model is simulated to observe the vibration pattern. Ride comfort is observed and measured by obtaining the vibration amplitude. (Zahid Hossain and Nurul Absar Chowdhury, 2012)

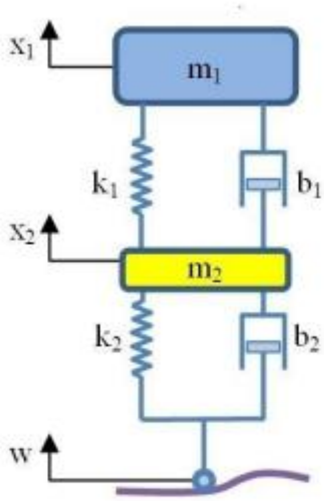

Figure 2.8: The Passive Suspension System

2.9 Conclusion

There has been some number of studies done on traffic energy harnessing in the world especially at India where electric power is very much needed for nation development. As the price for fossil fuel which was commonly used for electricity generation traditionally, researchers have turned their head to renewable energies such as wind and solar energies. Recently, traffic energy has slowly come into the picture and being implemented and tested for its performance all over the world. Studies have claimed that it is efficient in power generation. However, there are no studies found regarding the impacts of traffic energy harvester. This is most probably the reason people still have doubts on the practicability of traffic energy harnessing in real life instead of laboratory.

In this project, the impacts of traffic energy harvester on the vehicles are investigated. It is our aim to verify and clear doubts regarding the negative impacts, if there is any, when vehicles are drove over the traffic energy harvester. There are many methods used for traffic energy harnessing from the papers studied. Each of the method has its advantages and disadvantages. For this project, more emphasis are put in traffic energy harnessing through speed breakers as it is much easier and cheap to be implemented as compared to road harvester which mostly utilizes piezoelectric material that requires much maintenance work. Among the number of ways used in power generating speed breaker, rack and pinion method and roller mechanism are most commonly used for their efficiency and convenience. These methods are primarily used for this study so that the implementation on traffic energy harvester can be promoted in society by clearing doubts of society regarding these devices.

CHAPTER 3

METHODOLOGY

3.1 Introduction

To achieve the aim and objectives of this project, steps were taken for further planning. After identifying the topic to be studied, reading materials related to the topic were collected. Much reading and analysis on materials collected were done to obtain further understanding on how the traffic energy harvester would affect the vehicles.

From the materials available in the literature, the relationship between the fuel consumption rate and the speed breaker harvester was obtained. Apart from that, the correlation of the traffic energy harnessing device with the vehicles' power efficiency was inferred based on the studies which have been carried out. Meanwhile, information about the vehicle tread wear was used to investigate the connection between tyre wear off rate and the traffic energy harvester used. On the other hand, by studying how vehicle suspension could be affected by road condition, suggestion on how traffic energy harvester may affect the suspension was made. Based on the deduction and research done, several equations were used for the investigation. The parameters' value required for the investigation are obtained either from calculation or from the information in database made based on certain assumptions. To reduce complexity, only rack and pinion method for the traffic energy harvester has been applied in the study and the choice of vehicle was 2004 Toyota Camry.

Calculations were done to get rough understanding on the effects of traffic energy harvester on the vehicles. To start a simulation for verification of the calculations and deduction, software was chosen and studied prior the usage on it. By using the software, relationships between the traffic energy harvesters with the studied parameters were obtained. The results obtained through both the calculations and simulations are analyzed in order to achieve the objectives of this project.

3.2 Software

Matlab-Simulink was chosen for simulation study on the impact of vehicles passing over the traffic energy harvester. This software provided block diagram atmosphere for Model-Based Design and enabled multi domain simulation. Apart from simulation function, it also support functions such as automatic code generation. Simulink is suitable for use because it is commonly used as a graphical editor, has block libraries which can be tailored, and also has solvers for modeling and simulating dynamic systems. The SIMULINK was used together with MATLAB so that the algorithms can be integrated into models. Furthermore, the simulation results were compatible with MATLAB for further analysis.

In this project, the possible impacts on the vehicles which drove over the power generating speed breaker were to be studied. Several aspects of the vehicles' performance were looked into to compare if there was any difference when the ordinary speed breaker was replaced with a power generating speed breaker. All theoretical analysis was done via MATLAB and MATLAB-SIMULINK software.

MATLAB was used as an analysis tool for investigation on impacts of power harnessing speed breaker on fuel consumption rate and vehicle tread wear rate. Meanwhile, SIMULINK library block was used to study the difference of impact caused to vehicle suspension due to the speed breakers the vehicles passed through. Some modifications were made to fit the circumstances of the situation. For example, road height pattern was amended to study and compare the amount of force the vehicle suspension experienced during the usage of speed breakers. Figure 3.1 to Figure 3.3 shows modification made to the suspension model in SIMULINK.

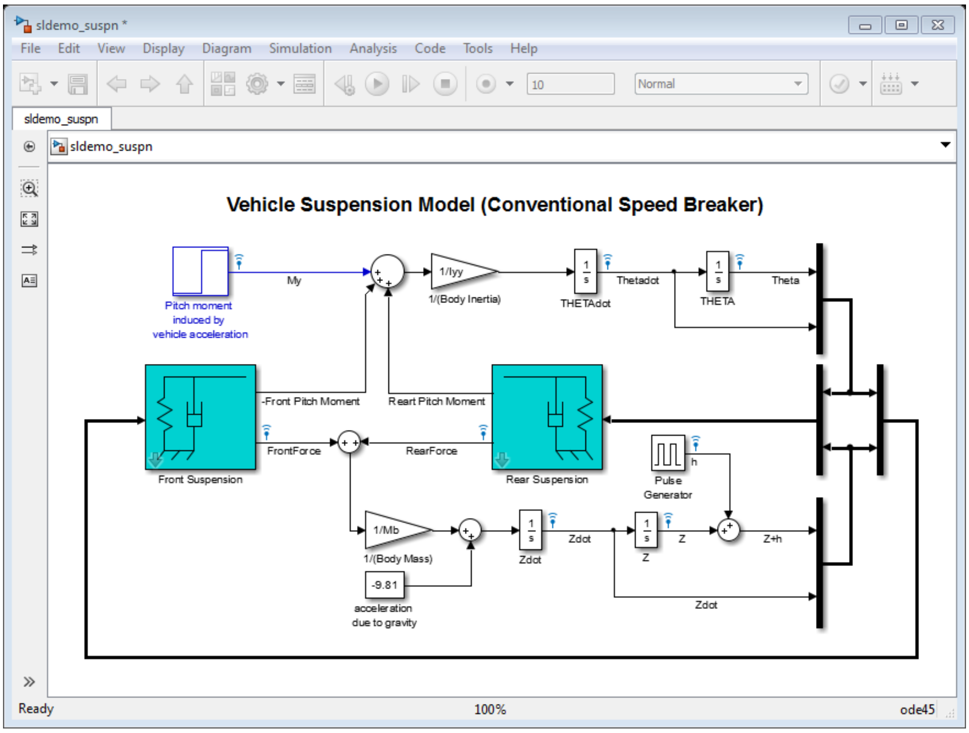

Figure 3.1: Vehicle Suspension Model for Conventional Speed Breaker

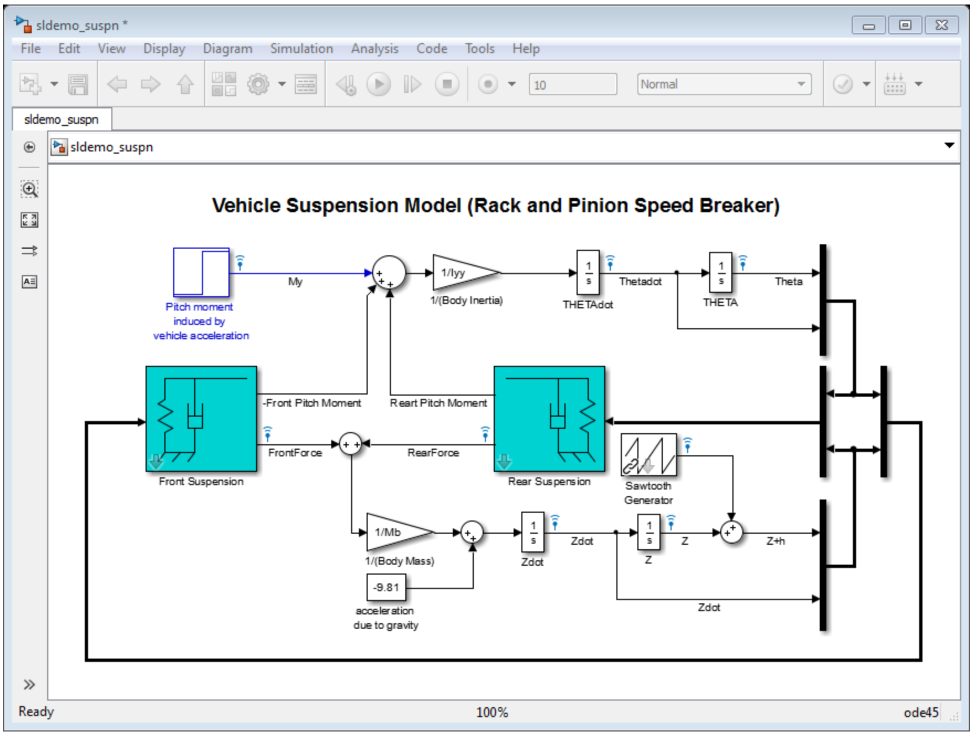

Figure 3.2: Vehicle Suspension Model for Rack and Pinion Speed Breaker

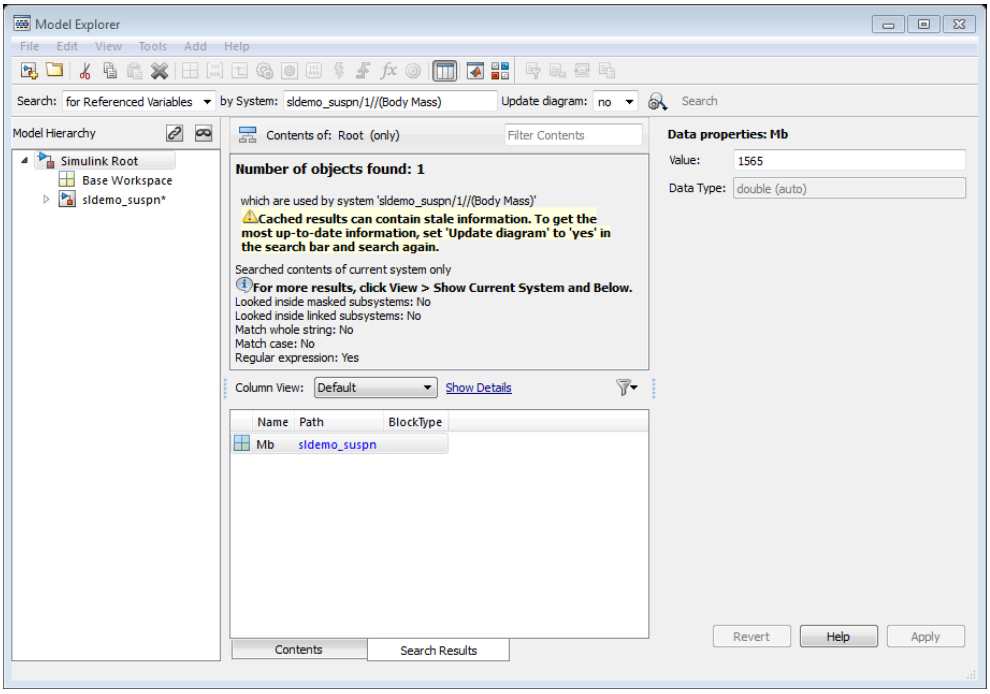

Figure 3.3: Modification to the Vehicle Parameter

3.3 Fuel Consumption of Vehicle

To study how the traffic energy harvester would affect the fuel consumption rate of vehicles, equation 3.1 was used. From the equation, calculation was done. These values for the parameters needed in the equation were either obtained from assumptions made and information provided in other sources or from taken from further calculations.

$$FR = \frac{\Phi[KNV + \frac{\left(\frac{P_b}{\eta_t} + P_{acc}\right)}{\eta}]}{LHV} \tag{3.1}$$

where

Φ = fuel/air ratio,

K = friction factor of engine (kJ/revL),

N = speed of engine (rev/s),

η = efficiency of engine,

V = engine displacement (L),

P_b = brake power (kW),

η_t = transmission efficiency,

P_{acc} = power for accessories (kW),

LHV = the factor lower heating value of the fuel

3.3.1 Brake Power

In Sovran and Bohn's paper, Formulae for the Tractive-Energy Requirements of Vehicles driving the Environment Protection Agency (EPA) Schedules, a road load methodology as shown in Figure 3.4 was introduced. The model showed the conventional internal combustion engine vehicle model flow. Their work produced a detailed analysis of tractive energy requirements on the EPA fuel economy test schedule. For each driving cycle, a specified speed in function of time was used. The force required to move the vehicle over the driving cycle was hence obtained. (Sovran and Bohn, cited in Nam and Giannelli, 2005)

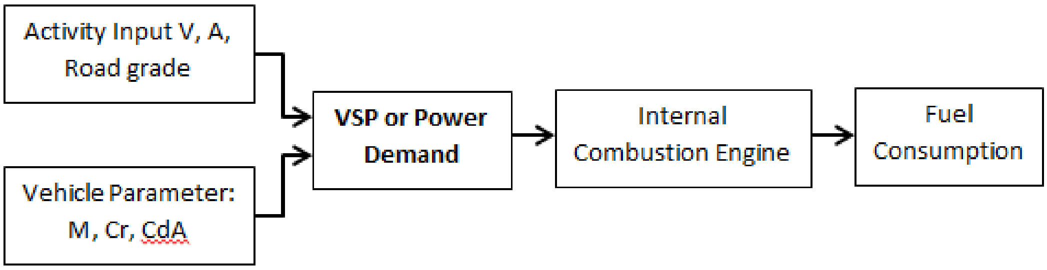

Figure 3.4: Conventional Internal Combustion Engine Vehicle Model Flow

First of all, the power demand which was also called the brake or tractive power of a vehicle was obtained by using the following equation.

$$P_b = Av + Bv2 + Cv^3 + mv\,(a + g \times grade) \qquad (3.2)$$

where

A = tyre rolling resistance coefficient

B = speed-correction to rolling resistance

C = air drag coefficient

v = vehicle speed (ms^1)

m = mass of vehicle (tonne)

a = vehicle acceleration (ms^{-2})

g = acceleration due to gravity (ms^{-2}) = 9.81 ms^{-2}

grade = road grade or gradient

3.3.2 Vehicle Acceleration

According to equation 3.2, the higher the acceleration rate of vehicle, the more the tractive power it needs. This relationship is consistent with Newton's Second Law of Motion as illustrated in Figure 3.5, whereby the acceleration of an object is directly proportional to the net force acting upon the object and inversely proportional to the mass of the object. Excluding the aerodynamic resistance and grade resistance, the deceleration of vehicle caused only by the rolling resistance or friction between the surfaces was obtained by using the Newton's Law equation.

$$F = ma - \mu W \tag{3.3}$$

where

m = mass of vehicle (kg),

a = acceleration of vehicle (ms^{-2}), μ =coefficient of friction of different materials,

W =weight of vehicle (N)

To find the force caused only by friction between the traffic energy harvester and the vehicle, the vehicle was assumed to move at a constant speed. With the coefficient of friction values for both the asphalt road, material used for traffic energy harvester and with the weight of vehicle acting as the normal force acting on the vehicle, the friction force acting opposite of the throttle force of vehicle was attained. By using the value of the frictional force and the equation for Newton's Second Law of Motion, the deceleration rate of vehicle due to the traffic energy harvester was calculated.

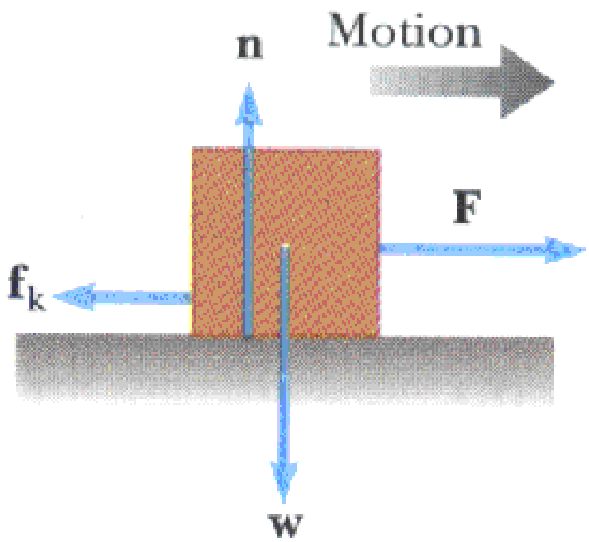

Figure 3.5: Forces Acting on an Object

3.4 Vehicle Tyre Wear Rate

It was required that the road surface possessed a minimum value of coefficient of friction between the tyre and road to enable a safe stopping distance. However, tyre wear would increase as the coefficient of friction increased. This coefficient of friction represented the roughness of the road surface and was indicated in terms of International Roughness Index. This value determined the rolling resistance of the traffic energy harvester. Thus, simulation for the effect of vehicle tyre wear off can only be carried out after the value of rolling resistance for the traffic energy harvester was obtained.

In Chatti and Zaabar's report of estimating the Effects of Pavement Condition on Vehicle Operating Costs, the research approach used for developing the appropriate models to estimate the effects of pavement condition on tyre wear was described. The general form of the tyre consumption model was as follows. (Chaati, K. and Zaabar, I., 2012)

$$TC = \frac{NW \times EQNT}{MODFAC} \qquad (3.4)$$

where

TC = Tyre Consumption per Vehicle (% / km)

NW = Number of Wheels

EQNT = Equivalent New Tyre (% / km)

MODFAC = Tyre Life Modification Factor

3.4.1 Tyre Life Modification Factor

The tyre life modification factors were proposed by Harrison and Aziz (1998) to depend upon the roughness, tyre type and congestion level. It was calculated with the following equation.

$$MODFAC = VEHFAC \times TYREFA \times CONFAC \tag{3.5}$$

where

VEHFAC = Vehicle Specification Modification Factor

TYREFA = Tyre type Modification Factor

CONFAC = Congestion Modification Factor

In this project, the default values for VEHFAC, TYREFA and CONFAC were set to be 2, 1.2 and 1 respectively for simplicity. Thus, the MODFAC value was calculated to be 2.4. In reality, the modification factors were not based on theoretical analysis. Hence, the inaccuracy of value for this parameter may result in discontinuities in the prediction of the tyre consumption rate.

3.4.2 Equivalent New Tyre

The equivalent new tyre was a parameter was calculated in terms of per 1000km, where the equation was represented as following.

$$EQNT = \frac{TWT}{10 \times VOL} \tag{3.6}$$

where

TWT = Total Change in Tread Wear

VOL = Tyre Volume (dm^3)

3.4.3 Total Change in Tread Wear

Total change in tread wear was dire in investigating the impact of traffic energy harvester on the tyre wear off rate. The relationship between the harvester and the change in tread wear was observed using calculation based on formula and also MATLAB.

$$TWT = C_{otc} + C_{tcte} \times TE \tag{3.7}$$

where

C_{otc} = Tread Wear Rate Constant (dm^3/1000km)

C_{tcte} = Tread Wear Coefficient (dm^3/MNm)

TE = Tyre Energy (MNm/1000km)

3.4.4 Tyre Energy

Tyre energy parameter from the model which represented the forces experienced by vehicle tyres was calculated using formula 4.8.

$$TE = \frac{CFT^2 + LFT^2}{NFT} \tag{3.8}$$

where

CFT = Circumferential Force on the Tyre (N)

LFT = Lateral Force on the Tyre (N)

NFT = Normal Force on the Tyre (N)

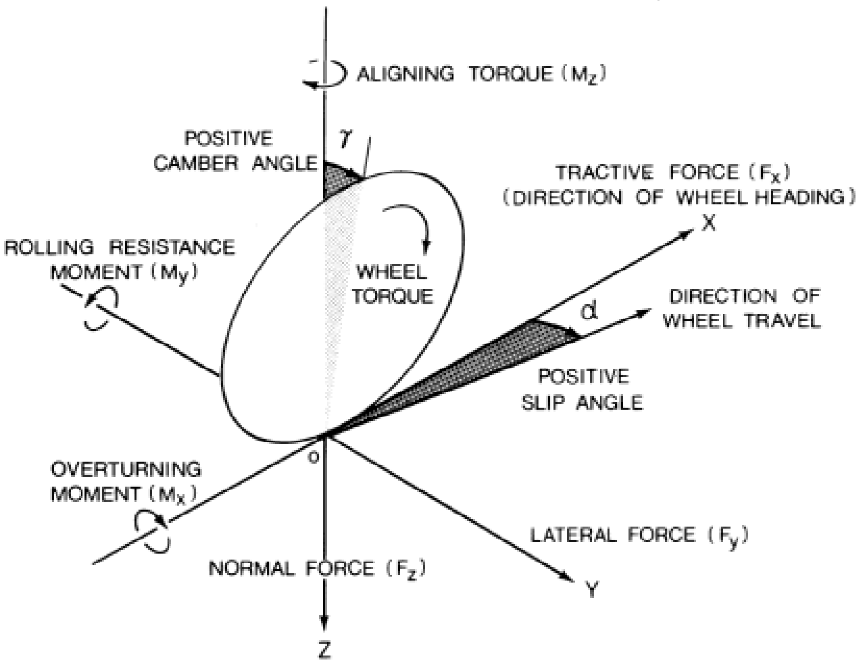

Figure 3.6: Axis System Indicating Forces and Moments acting on Tyre

3.4.5 Circumferential Force on the Tyre

Circumferential force by definition referred to force applied perpendicular to the radius of object. In this case, it was the perpendicular force acting on the vehicle's tyre. The equation used to obtain CFT was as below.

$$CFT = \frac{(1+CTCON \times dFUEL)\times(F_a + F_r + F_g)}{NW} \tag{3.9}$$

where

CTCON= Incremental Change of Tyre Consumption Related to Congestion

dFUEL= Incremental Change of Fuel Consumption Related to Congestion

F_a = Aerodynamic Forces (N)

F_r = Rolling Resistance Forces (N)

F_g = Gradient Forces (N)

3.4.5.1 Aerodynamic Force

$$F_a = 0.5 \times \rho \times CD_{mult} \times CD \times AF \times v^2 \tag{3.10}$$

where

ρ = Mass Air Density (kg/m^3)

CD_{mult} = Drag Coefficient Multiplier

CD = Drag Coefficient

AF = Frontal Area of Vehicle (m^2)

v = Vehicle Speed (m/s)

3.4.5.2 Gradient Force

$$F_g = m \times GR \times g \tag{3.11}$$

where

m = Mass of Vehicle (kg)

GR = Gradient

g = gravity (m/s^2)

3.4.5.3 Rolling Resistance Forces

$$F_r = CR_2 \times \left(b_{11} \times NW + CR_1(b_{12} \times M + b_{13} \times v^2)\right) \tag{3.12}$$

where

CR_1 = Rolling Resistance Tyre Factor

b_{11}, b_{12}, b_{13} =Rolling Resistance Parameter

CR_2 = Rolling Resistance Surface Factor

3.4.5.3.1 Rolling Resistance Parameter

$$b_{11} = 37 \times DW \tag{3.13}$$

$$b_{12} = \frac{0.064}{DW} \tag{3.14}$$

$$b_{13} = \frac{0.012 \times NW}{DW^2} \tag{3.15}$$

where

DW =Diameter of Wheel (m)

NW =Number of Wheel

3.4.5.3.2 Rolling Resistance Surface Factor

$$CR_2 = KCr_2(a_0 + a_1 \times Tdsp + a_2 \times IRI + a_3 \times DEF) \tag{3.16}$$

where

KCr_2 = Calibration factor

Tdsp = Texture depth using sand patch (mm)

a_0, a_1, a_2, a_3 = Model Coefficient

IRI = International Roughness Index (m/km)

DEF = Benklemen Beam Rebound Deflection (mm)

3.4.6 Lateral Force on the Tyre

Lateral forces produced at tyres were responsible for adjusting the steering, cornering and side slope operation of vehicles (Crolla, D.A. and El-Razaz, A.S.A., 1987). In this project, the LFT was obtained by calculation via the following equation

$$LFT = \frac{F_c}{NW} \tag{3.17}$$

where

F_c = Curvature Forces (N)

NW = Number of Wheels

3.4.6.1 Curvature Forces

$$F_c = \max\left(0\,,\ \frac{\left(\frac{M \times v^2}{R} - M \times g \times e\right)^2}{NW \times Cs} \times 10^{-3}\right) \tag{3.18}$$

where

R = Curvature Radius (m)

e = Superelevation (m/m)

Cs = Tyre Stiffness (kN/rad)

3.4.6.1.1 Tyre Stiffness

$$C_s = a_0 + a_1 \times \left(\frac{M}{NW}\right) + a_2 \left(\frac{M}{NW}\right)^2 \quad (3.19)$$

where

a_0, a_1, a_2 = dimensionless model parameter

According to the car specs for choice of car (small ~ medium car),

a_0 = 43

a_1 = 0

a_3 = 0

$\therefore\ C_s = 43\ kN/rad$

3.4.7 Normal Force on Tyre

The normal force was described as the force of the underneath plane (etc. a road) pushing against another object (etc. a car) as the first object (car tyres) pushed down on the underneath plane. To calculate the NFT, the following equation was used.

$$NFT = \frac{m \times g}{NW} \quad (3.20)$$

where

m = vehicle mass (kg)

g = gravity (m/s^2) = 9.81 m/s^2

3.5 Effect on Car Suspension

From literature review, it was realized that the condition of vehicle suspension was dependent on the road condition. Here, the road condition referred to the surface of the traffic energy harvester compared to the asphalt surface of normal road. To explore how vehicle suspension might be affected, a simplified half-car model was modified in SIMULINK. The model included body pitches and bounce degrees of freedom as shown in Figure 3.7.

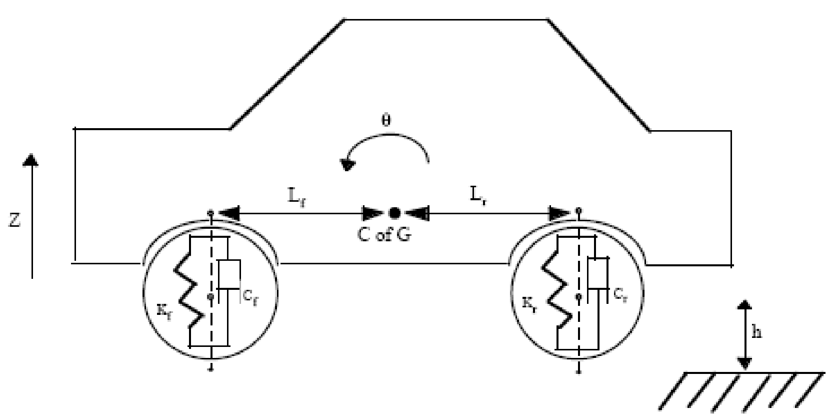

Figure 3.7: Free-body Diagram of the Half-Car Model

As shown in figure 3.5 was the modeled characteristics of the half-car. Spring and damper systems were used for the front and rear suspension system of the model. The pitch and bounce degrees of freedom for vehicles were represented in the model by four states. Equation 21 illustrated the bounces influenced by front suspension and equation 22 which was the equation of pitch moment due to front suspension showed how pitch contributed to front suspension whereas equation 24 which was the equation of pitch moment due to rear suspension consisted of expressions for rear suspension. The forces and moments caused body motions to follow Newton's Second Law as shown in equation 25 and equation 26. (Mathworks, N.D.)

$$F_{front} = 2K_f\left(L_f\theta - z\right) + 2C_f(L_f\dot{\theta} - \dot{z}) \tag{3.21}$$

where

F_{front} = upward force on vehicle body from front suspension

F_{rear} = upward force on body from rear suspension

K_f = front suspension spring constant

K_r = rear suspension spring constant

C_f = front suspension damping rate

C_r = rear suspension damping rate

L_f = horizontal distance from gravity center to front suspension

L_r = horizontal distance from gravity center to rear suspension

θ = rotational pitch angle

$\dot{\theta}$ = rate of change of rotational pitch angle

z = bouncing distance / vertical distance

$\dot{z}$ = rate of change of bouncing distance

$$M_{front} = -L_f F_f \tag{3.22}$$

$$F_r = -2K_r(L_r\theta + z) - 2C_r(L_r\dot{\theta} + \dot{z}) \quad (3.23)$$

$$M_r = L_r F_r \quad (3.24)$$

$$m_b\ddot{z} = F_f + F_r - m_b g \quad (3.25)$$

$$I_{yy}\ddot{\theta} = M_{front} + M_{rear} + M_y \quad (3.26)$$

where

m_b = body mass

M_y = pitch moment induced by vehicle acceleration

I_{yy} = body moment of inertia about gravity center

3.6 Vehicle Efficiency

Vehicle efficiency was often linked to the fuel efficiency of vehicle. From the studies conducted, it was found that the vehicle efficiency has close relationship to the power output to vehicle tyres as shown in Figure 3.8. Therefore, the efficiency of vehicle was likely to be influenced by rolling resistance of the traffic energy harvester. To study the effect of traffic energy harvester on the vehicle efficiency, the rolling resistance of the device was obtained in the first place.

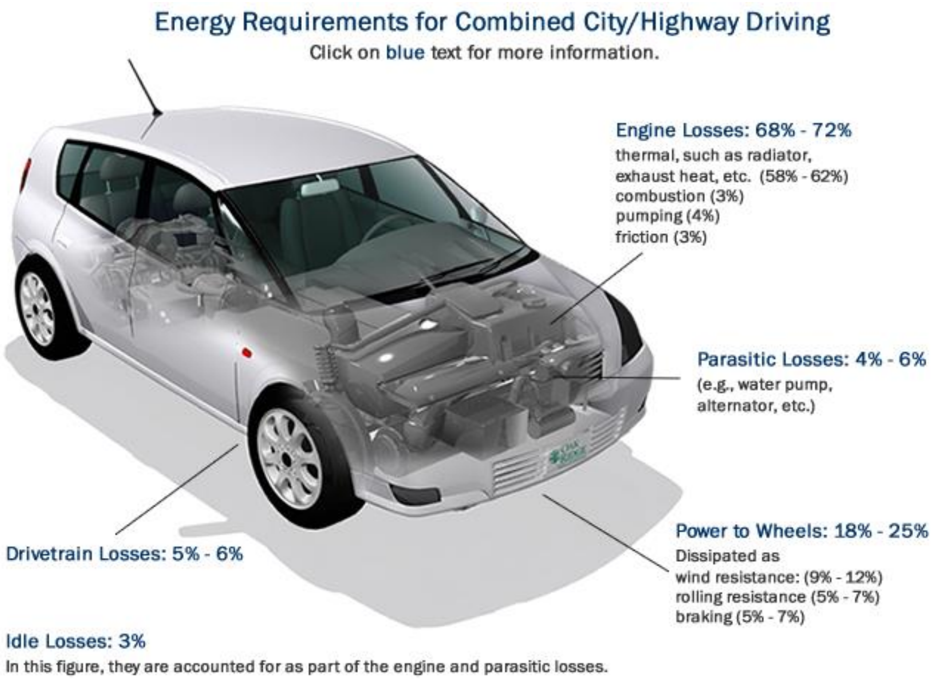

Figure 3.8: Energy Requirements for Combined Driving Style

3.7 Progress of Project

To better keep track with the project's progress, proper planning need to be done. Several project phases have been set to ensure the completion of project by deadline. Upon completion of first half part of the project, literature review, possible impacts' identification, equations and software determination should be done. Figure 3.9 to 3.11 below show the project phases proposed and the work which have been done in order to achieve the objectives of this project.

(1) Literature Review (4 weeks)	(2) Identify and Study Possible Impacts (5 weeks)	(3) Determining Equations and Softwares (5 weeks)	(4) Parameters Data Collection (2 weeks)	(5) Calculation and Computation (3 weeks)	(6) Simulation (2 weeks)	(2) Study on Impact on Vehicle's Suspension (2 weeks)	(6) Simulation on Vehicle's Suspension (1 week)	(7) Documentation and Report (3 weeks)

Figure 3.9: Project Phases

Project Phase 1	**Time (One Semester)**												
	Week												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Project Title Selection	/												
(1) <u>Literature Review</u>													
(1.1) Working Principles		/	/	/									
(1.2) Rack and Pinion Method		/	/	/									
(1.3) Hydraulic Mechanism			/	/									
(1.4) Air Compression Mechanism			/										
(1.5) Roller Mechanism				/	/								
(1.6) Crankshaft Mechanism				/									
(2) <u>Impacts to be Studied</u>													
(2.1) Fuel Consumption					/	/	/	/					
(2.2) Tyre Consumption							/	/	/				
(2.3) Vehicle Efficiency										/			
(3) <u>Determining Equations and Software</u>													
(3.1) Equations							/	/	/	/	/		
(3.2) Software										/	/	/	
(7) <u>Documentation</u>													
(7.1) Documentation of Papers Studied				/	/	/	/	/	/	/	/	/	/

Figure 3.10: Gantt Chart of Project Progress (Semester 1)

Project Phase 2	Time (One Semester)												
	Week												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
(4) <u>Parameters Data Collection</u>													
(4.1) Fuel Rate for Conventional Speed Breaker	/	/											
(4.2) Fuel Rate for Rack and Pinion Speed Breaker	/	/											
(4.3) Tyre Consumption for Conventional Speed Breaker		/	/										
(4.4) Tyre Consumption for Rack and Pinion Speed Breaker		/	/										
(4.5) Vehicle Efficiency Changes		/											
(5) <u>Calculation and Computation</u>													
(5.1) Fuel Consumption			/	/	/								
(5.2) Tyre Wear Off				/	/	/							
(5.3) Vehicle Efficiency					/								
(6) <u>Simulation</u>													
(6.1) Fuel Consumption for Conventional Speed Breaker				/	/	/							
(6.2) Fuel Consumption for Rack and Pinion Speed Breaker					/	/	/						
(6.3) Tyre Consumption for Conventional Speed Breaker							/	/					
(6.4) Tyre Consumption for Rack and Pinion Speed Breaker							/	/					
(6.5) Vehicle Suspension for Conventional Speed Breaker									/	/			
(6.6) Vehicle Suspension for										/	/		

Rack and Pinion Speed Breaker													
(2) <u>Impacts to be Studied</u>													
(2.4)Vehicle Suspension								/	/				
(8) <u>Documentation</u>													
(7.1)Documentation of Results and Simulation							/	/	/	/	/	/	/

Figure 3.11: Gantt Chart of Project Progress (Semester 2)

3.8 Conclusion

With correct choice of equations and software, the impacts were studied. Through calculation, preliminary insights on the effect of rack and pinion mechanism speed breaker were acquired. By using software, the result of calculation were verified and further studied on the relationship between the parameters.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

After proper planning of the methods to be carried out for the investigation of the possible impacts, parameters needed in the equations were sought and collected. In this project, the chosen vehicle was 2004 Toyota Camry. The specifications of the chosen vehicle were referred for some parameters' values.

With the values of parameters needed, calculation results were obtained. Verification of the calculation result was made based on the reference value for vehicles running over conventional speed breaker. By comparison, the impacts of speed breaker installed with rack and pinion method traffic energy harvester on vehicle's fuel consumption rate, tyre consumption rate, suspension and efficiency were deduced. The pattern of the relationship was further studied on a larger sample using software MATLAB and SIMULINK.

4.2 Fuel Consumption of Vehicle

As aforementioned, comparison of fuel consumption for vehicles running over conventional speed breaker and speed breaker installed with rack and pinion traffic energy harvester was done through calculation and simulation using MATLAB and SIMULINK.

4.2.1 Calculation for Fuel Consumption of Vehicle

For a conventional speed breaker, construction material commonly used is asphalt. Asphalt material has coefficient of friction of 0.7 when in contact with hard rubber material which was commonly used for vehicle tyres. Since the car was assumed to move at constant speed, the car acceleration was 0. With the value of 2004 Toyota Camry mass equals to 1565, the friction force experienced by the car was calculated.

$$F_T = 1565 \times 0 - (0.7)(1565 \times 10)$$
$$= -10955\ N$$

Knowing that F = ma, the deceleration conventional speed breaker caused to vehicle was obtained.

$$a = \left| -\frac{10955}{1565} \right|$$

$$= 7\ m/s^2$$

On the other hand, according to the design standard for metal bridges set by the authority, the coefficient of friction should be 0.8. By applying the same situation and vehicles, the friction force experienced by the car was calculated.

$$F_T = 1565 \times 0 - (0.8)(1565 \times 10)$$

$$= -12520\, N$$

Thus, the deceleration rack and pinion speed breaker caused to vehicle was obtained.

$$a = \left|\frac{-12520}{1565}\right|$$

$$= 8\ m/s^2$$

For both conventional speed breaker and rack and pinion speed breaker, the road grade was set as:

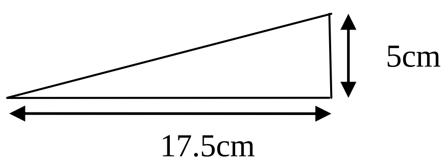

Figure 4.1: Model of Speed Breaker

$$Road\ grade\ or\ gradient = \frac{5}{17.5}$$

$$= 0.2857$$

Assembling all collected parameters, the tractive power and thus the fuel consumption rate for a conventional speed breaker was found to be as following.

$$P_b = (127.36 \times 5.56) + (0.9578 \times 5.56^2) + (0.4374 \times 5.56^3) + (1.565 \times 5.56)\,(7 + 9.81 \times 0.2857)$$

$$= 898.64\,W$$

$$FR = \frac{1(0.164 \times \frac{6000}{60} \times 2.4 + \frac{\left(\frac{0.8986}{0.88} + 0.75\right)}{0.4})}{43.7}$$

$$= 1.0021\ g/s$$

Contrariwise, for a speed breaker installed with rack and pinion traffic energy harvester, the tractive power of vehicle was calculated with different deceleration value.

$$P_b = (127.36 \times 5.56) + (0.9578 \times 5.56^2) + (0.4374 \times 5.56^3) + (4.565 \times 5.56)(8 + 9.81 \times 0.2857)$$

$$= 907.34\,W$$

$$FR = \frac{1(0.164 \times \frac{6000}{60} \times 2.4 + \frac{\left(\frac{0.9073}{0.88} + 0.75\right)}{0.4})}{43.7}$$

$$= 1.0026\ g/s$$

The difference of fuel consumption of vehicle crossing conventional speed breaker and speed breaker with tack and pinion traffic energy harvester was obtained to be 0.0005 g/s.

4.2.2 Simulation for Fuel Consumption of Vehicle

Table 4.1: Table of Result for Fuel Consumption of Vehicle

Coefficient of Friction, u	Tractive Power, P_b (W)	Fuel Rate, FR (g/s)
0.7000	898.2082	1.001985
0.7111	899.1750	1.002047
0.7222	900.1418	1.002110
0.7333	901.1086	1.002173
0.7444	902.0754	1.002236
0.7556	903.0423	1.002299
0.7667	904.0091	1.002362
0.7778	904.9759	1.002425
0.7889	905.9427	1.002487
0.8000	906.9096	1.002550

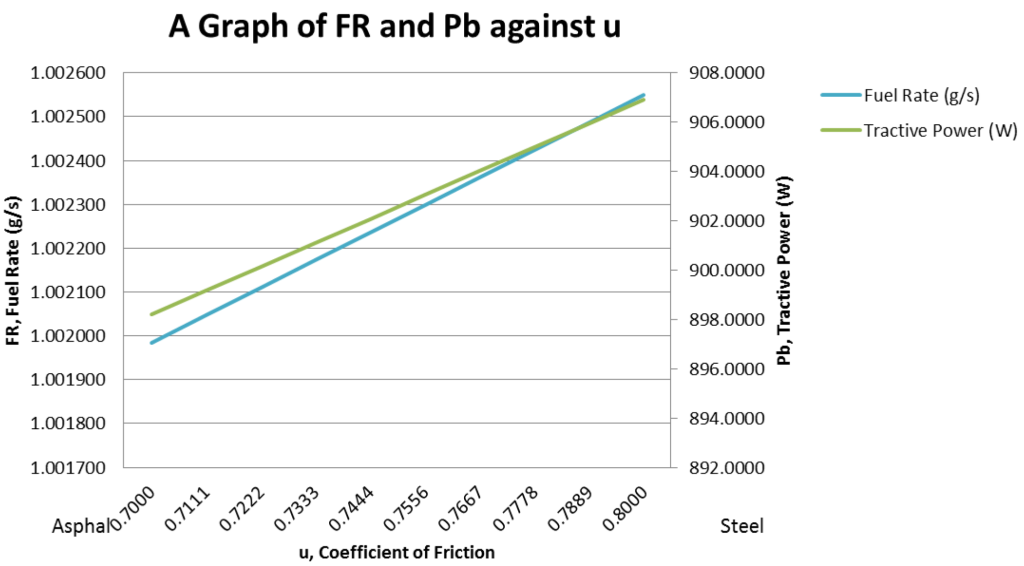

Figure 4.2: Graph of Fuel Consumption and Tractive Power against Coefficient of Friction

4.2.3 Discussion on Fuel Consumption of Vehicle

From calculation with the equations for fuel rate, it was found that the fuel consumption for vehicle crossing rack and pinion speed breaker was 1.0026 g/s, which was just slightly higher than a vehicle which passed by conventional speed breaker. The difference in the fuel consumption between the two situations was 0.0005 g/s. In other words, the fuel consumption rate has increased by 0.05% when it passed a rack and pinion power harnessing speed breaker.

It was known that fuel rate of vehicle and the tractive force acting by the vehicle has directly proportional relationship. The tractive force on the other hand, was directly proportional to the acceleration or deceleration movement of vehicle. To put it in simpler words, the movement of vehicle has direct influence to the fuel rate of vehicle. The deceleration of vehicle due to speed breaker only was obtained through calculation using the coefficient of friction between the speed breaker and vehicle tyres. The magnitude of the vehicle deceleration was used instead of the vector with the assumption of vehicle accelerated and decelerated using the same force.

In simulation, samples were taken between standard coefficient of friction between asphalt road and standard value for steel according to authority regulation. By referring to the result in both Table 4.1 and Figure 4.2, it was observed how the tractive power of vehicle and the fuel rate varied with the coefficient of friction. By looking at the values, it was seen that both the tractive power and the fuel rate increased with the rise in coefficient of friction value. At the coefficient value of 0.7, the tractive power was 898.2082W whereas at the coefficient value of 0.8, the tractive power was 906.9096W. A total amount of 8.7014W of extra power was used by the vehicle to cross over the speed breaker installed with rack and pinion traffic energy harvester.

4.3 Changes in Tread Wear of Vehicle

From studies and researches, it was confirmed that tread wear of vehicle varies with the road condition which can be measured in terms of International Road Index (IRI). As the IRI value of the road increases, it was expected that the tread wear would be more severe. The severity in the change of tread wear for vehicles passing through conventional speed breaker and speed breaker with traffic energy harvester was studied by using both calculation and simulation via MATLAB.

To avoid complexity, some parameters were set to the default values. Some values on the other hand were calculated to suit Malaysia's circumstances, such as the mass air density and IRI value of road.

4.3.1 Calculation for Tread Wear of Vehicle

Mass of Toyota Camry 2004 was given 1565 kg, hence the Normal Force on the Tyres was calculated to be as followed.

$$NFT = \frac{1565 \times 9.81}{4}$$

$$= 3838\ N$$

Mass density of air in Malaysia could be calculated using the following equation, giving the accurate value of Malaysia's mass density of air.

$$\rho = 0.0566 + 1.225 \times (1 - 2.26 \times 10^{-5} \times \text{Alt})^{4.225} - 0.00377 \times \text{TAIR}$$

where

Alt = Altitude above Sea Level (m)

TAIR = Temperature of the Air (℃)

$$\rho = 0.0566 + 1.225\ (1 - 2.26 \times 10^{-5} \times 46)^{4.225} - 0.00377 \times 34$$

$$= 0.924\ kg/m^3$$

The aerodynamic force and gradient forces for the given choice of vehicle were calculated as following.

$$F_a = 0.5 \times 0.924 \times 1 \times 0.28 \times 2.4 \times 5.56^2$$

$$= 9.6\ N$$

$$F_g = 1565 \times 0.2857 \times 9.81$$

$$= 4386\ N$$

To find the curvature force, the superelevation was obtained first via calculation.

$$e = max\ (0, \quad 0.045 - 0.68 \times \ln(R))$$

$$= \max\ (0, -5.4)$$

$$= 0$$

To find the curvature force value, the tyre stiffness C_s was obtained first. The model parameters were collected in order to calculate the tyre stiffness value. According to the car specs for choice of car (small ~ medium car), the model parameters were as following.

$$A_0 = 43$$

$$a_1 = 0$$

$$a_3 = 0$$

$$\therefore\ C_s = 43\ kN/rad$$

$$\therefore\ F_c = \max(0, \frac{\frac{1565\ \times\ 5.56^2}{3000} - 1565\ \times 9.81\ \times 0}{4\ \times 43}\ \times\ 10^{-3}$$

$$= \max(0, 0.00009376)$$

$$= 0.00009376\ N$$

The Rolling Resistance parameters of the car were calculated. In this case 205/65R15 Tyre was used for calculation. From research it was found that the diameter of wheel for the chosen model was 0.6477 m.

$$\therefore b_{11} = 37\ \times 0.6477 = 23.9649$$

$$\therefore\ b_{12} = \frac{0.064}{0.6477} = 0.09881$$

$$\therefore\ b_{13} = \frac{0.012\ \times 4}{0.6477^2} = 0.1144$$

Some values for variables are set to be default; some were set in such a way to obey the choice of car and tyre.

VEHFAC	= 2.0	CTCON	= 0
TYREFA	= 1.2	dFUEL	= 0
CONFAC	= 1.0	CD_{mult}	= 1
VOL	= 1.4	CD	= 1
g	= 9.81	R	= 3000

$CR_1 = 1$ $C_{otc} = 0.1747$

$KCr = 0.5$ $C_{ote} = 0.0001$

In general, IRI for normal Malaysia Asphalt Road was 2.5 m/km. Hence, the Rolling Resistance Surface Factor CR_2 for conventional speed breaker was calculated as below.

$$CR_2 = 0.5\,(\,0.5 + 0.02\ \times 1.3 + 0.1\ \times 2.5 + 0\ \times DEF)$$

$$= 0.388$$

Hence the Rolling Resistance Forces F_r was as following.

$$F_r = 0.388\,(23.9649\ \times 4 + 0.09881\ \times 1565 + 0.1144\ \times\ 5.56^2)$$

$$=\ 98.56\,N$$

The Circumferential Force and Lateral Force on Tyre were calculated.

$$CFT = \frac{(1 + 0\ \times 0)(9.6 + 98.56 + 4386)}{4}$$

$$= 1123.54$$

$$LFT = \frac{0.00009376}{4}$$

$$= 0.00002344$$

The Tyre Energy was thus obtained.

$$TE = \frac{1123.54^2 + 0.00002344^2}{3838}$$

$$= 328.91$$

Meanwhile, the Total Change in Tread Wear was calculated.

$$TWT = 0.1747 + 0.001(328.91)$$

$$= 0.5036$$

The Equivalent New Tyre was also calculated with equation.

$$\therefore EQNT = \frac{0.5036}{10 \times 14}$$

$$= 0.003597$$

With all the values required, the Tyre Consumption rate was thus obtained.

$$TC = \frac{4 \times 0.003597}{2.4}$$

$$= 0.005995 \ \% \ / \ km$$

For speed bump installed with rack and pinion method traffic energy harvester, IRI of metal road was unobtainable, hence using coefficient of friction as ratio; an estimation of IRI value for rack and pinion speed breaker was obtained. Using the same calculation flow, the Tyre Consumption rate for vehicle passing power harnessing speed breaker was obtained.

$$\frac{IRI_{asphalt}}{IRI_{metal}} = \frac{0.7}{0.8}$$

$$\frac{2.5}{IRI_{metal}} = \frac{0.7}{0.8}$$

$$IRI_{metal} = 2.86$$

$$CR_2 = 0.5\ (\ 0.5 + 0.02\ \times 1.3 + 0.1\ \times 2.86 + 0\ \times DEF$$

$$= 0.406$$

$$\therefore F_r = 0.406\ (23.9649\ \times 4 + 0.09881\ \times 1565 + 0.1144\ \times\ 5.56^2)$$

$$= 103.13\ N$$

$$\therefore CFT = \frac{(1 + 0\ \times 0)(9.6 + 103.13 + 4386)}{4}$$

$$= 1124.68$$

$$\therefore TE = \frac{1124.68^2 +\ 0.00002344^2}{3838}$$

$$= 329.57$$

$$\therefore TWT = 0.1747 + 0.001\ \times 329.57$$

$$= 0.5043$$

$$\therefore EQNT = \frac{0.5043}{10 \times 14}$$

$$= 0.003602$$

$$\therefore TC = \frac{0.003602 \times 4}{2.4}$$

$$= 0.006003\ \% / km$$

In different words, the difference in tyre consumption rate was $8 \times 10^{-6}\ \%/km$.

4.3.2 Simulation for Change of Tread Wear of Vehicle

Table 4.2: Result of Simulation for Change of Tread Wear of Vehicle

IRI	Fr	TE	TC
2.2500	95.3906	332.0849	0.060332
2.2562	95.4688	332.0964	0.060333
2.2623	95.5471	332.1079	0.060334
2.2685	95.6254	332.1194	0.060336
2.2746	95.7036	332.1309	0.060337
2.2808	95.7819	332.1424	0.060338
2.2870	95.8602	332.1539	0.060340
2.2931	95.9384	332.1654	0.060341
2.2993	96.0167	332.1770	0.060342

2.3055	96.0950	332.1885	0.060344
2.3116	96.1732	332.2000	0.060345
2.3178	96.2515	332.2115	0.060347
2.3239	96.3297	332.2230	0.060348
2.3301	96.4080	332.2345	0.060349
2.3363	96.4863	332.2460	0.060351
2.3424	96.5645	332.2575	0.060352
2.3486	96.6428	332.2691	0.060353
2.3547	96.7211	332.2806	0.060355
2.3609	96.7993	332.2921	0.060356
2.3671	96.8776	332.3036	0.060358
2.3732	96.9559	332.3151	0.060359
2.3794	97.0341	332.3266	0.060360
2.3856	97.1124	332.3381	0.060362
2.3917	97.1906	332.3497	0.060363
2.3979	97.2689	332.3612	0.060364
2.4040	97.3472	332.3727	0.060366
2.4102	97.4254	332.3842	0.060367
2.4164	97.5037	332.3957	0.060369
2.4225	97.5820	332.4072	0.060370
2.4287	97.6602	332.4187	0.060371
2.4348	97.7385	332.4303	0.060373
2.4410	97.8168	332.4418	0.060374
2.4472	97.8950	332.4533	0.060375
2.4533	97.9733	332.4648	0.060377
2.4595	98.0515	332.4763	0.060378
2.4657	98.1298	332.4878	0.060380
2.4718	98.2081	332.4994	0.060381
2.4780	98.2863	332.5109	0.060382
2.4841	98.3646	332.5224	0.060384
2.4903	98.4429	332.5339	0.060385
2.4965	98.5211	332.5454	0.060386

2.5026	98.5994	332.5570	0.060388
2.5088	98.6777	332.5685	0.060389
2.5149	98.7559	332.5800	0.060390
2.5211	98.8342	332.5915	0.060392
2.5273	98.9124	332.6030	0.060393
2.5334	98.9907	332.6146	0.060395
2.5396	99.0690	332.6261	0.060396
2.5458	99.1472	332.6376	0.060397
2.5519	99.2255	332.6491	0.060399
2.5581	99.3038	332.6606	0.060400
2.5642	99.3820	332.6722	0.060401
2.5704	99.4603	332.6837	0.060403
2.5766	99.5386	332.6952	0.060404
2.5827	99.6168	332.7067	0.060406
2.5889	99.6951	332.7182	0.060407
2.5951	99.7733	332.7298	0.060408
2.6012	99.8516	332.7413	0.060410
2.6074	99.9299	332.7528	0.060411
2.6135	100.0081	332.7643	0.060412
2.6197	100.0864	332.7758	0.060414
2.6259	100.1647	332.7874	0.060415
2.6320	100.2429	332.7989	0.060417
2.6382	100.3212	332.8104	0.060418
2.6443	100.3995	332.8219	0.060419
2.6505	100.4777	332.8335	0.060421
2.6567	100.5560	332.8450	0.060422
2.6628	100.6342	332.8565	0.060423
2.6690	100.7125	332.8680	0.060425
2.6752	100.7908	332.8796	0.060426
2.6813	100.8690	332.8911	0.060428
2.6875	100.9473	332.9026	0.060429
2.6936	101.0256	332.9141	0.060430

2.6998	101.1038	332.9257	0.060432
2.7060	101.1821	332.9372	0.060433
2.7121	101.2604	332.9487	0.060434
2.7183	101.3386	332.9602	0.060436
2.7244	101.4169	332.9718	0.060437
2.7306	101.4951	332.9833	0.060438
2.7368	101.5734	332.9948	0.060440
2.7429	101.6517	333.0063	0.060441
2.7491	101.7299	333.0179	0.060443
2.7553	101.8082	333.0294	0.060444
2.7614	101.8865	333.0409	0.060445
2.7676	101.9647	333.0524	0.060447
2.7737	102.0430	333.0640	0.060448
2.7799	102.1213	333.0755	0.060449
2.7861	102.1995	333.0870	0.060451
2.7922	102.2778	333.0986	0.060452
2.7984	102.3560	333.1101	0.060454
2.8045	102.4343	333.1216	0.060455
2.8107	102.5126	333.1331	0.060456
2.8169	102.5908	333.1447	0.060458
2.8230	102.6691	333.1562	0.060459
2.8292	102.7474	333.1677	0.060460
2.8354	102.8256	333.1793	0.060462
2.8415	102.9039	333.1908	0.060463
2.8477	102.9822	333.2023	0.060465
2.8538	103.0604	333.2138	0.060466
2.8600	103.1387	333.2254	0.060467

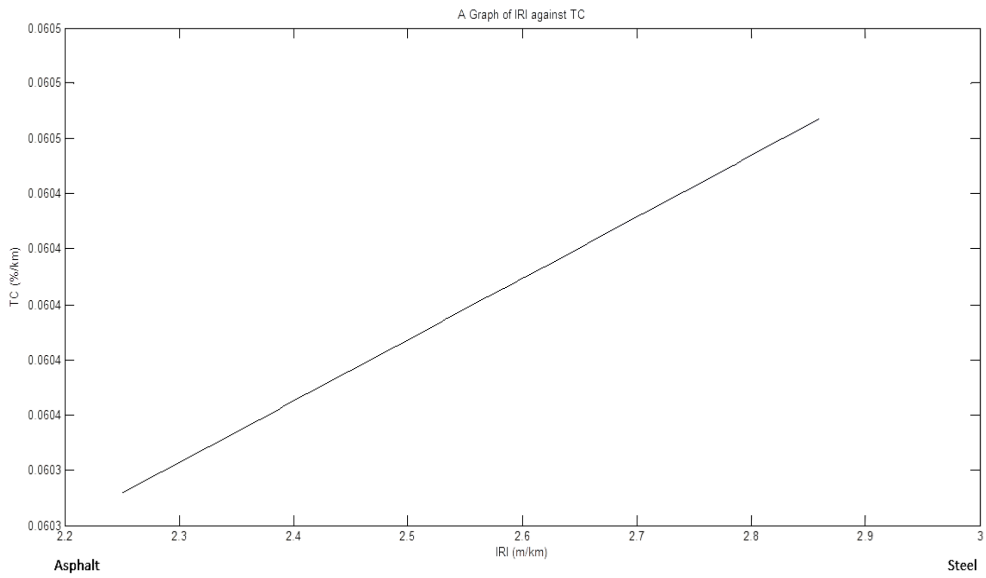

Figure 4.3: A Graph of IRI against TC

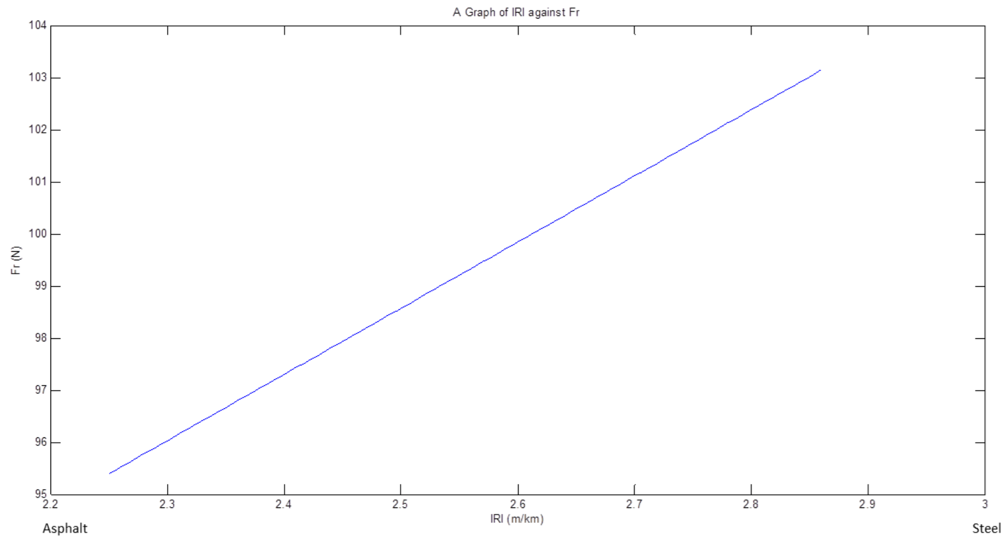

Figure 4.4: A Graph of IRI against F_r

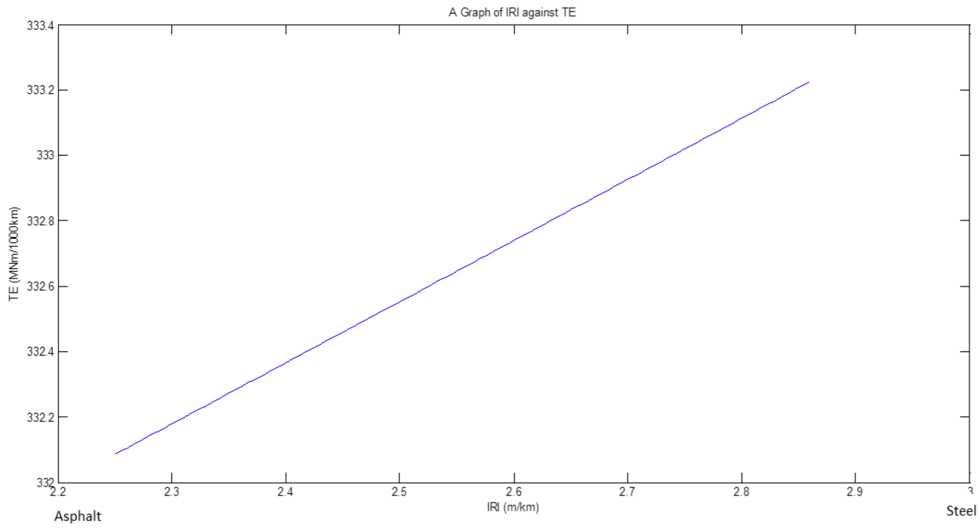

Figure 4.5: A Graph of IRI against TE

4.3.3 Discussion on Change of Tread Wear of Vehicle

It was known that the tread wear of vehicle would be affected by the condition of the road. Here, the type of speed breaker that was discussed about was the ordinary asphalt speed breaker used on the road and rack and pinion speed breaker using steel as its material. It was expected that there would be change in tread wear due to the different material of speed breaker. In this part of project, the change in the rate of vehicle tread wear was studied with equations for tyre wear off rate and further analysis using MATLAB.

From calculation via equations, it was known that the tyre consumption rate when running over conventional speed breaker constructed with asphalt (IRI = 2.5) was 0.005995 % / km. The rate increased to 0.006003 % /km when the vehicle crossing over speed breaker with traffic energy harvester constructed with steel (IRI = 2.86). The increase was slight, around $8 \times 10^{-6}\ \%/km$, which was around 0.1334%.

To observe how the tyre consumption rate was influenced, few other parameters like the rolling resistance force and tyre energy were studied against the IRI of the road. By looking at the equations and results in Table 4.2, it was observed that these parameters bore direct relationship with the IRI value, indicating a rise in IRI value would lead to the increase in these parameters' value. Figure 4.3 to Figure 4.5 has demonstrated that the IRI value directly affected the rolling resistance force of the vehicle and thus influenced both the tyre energy and tyre consumption rate of vehicle in the same way.

In short, the IRI value of the speed breaker material would affect the tyre consumption rate of the vehicle. Although the effect was mild, there was a rise in tyre consumption rate with the increase in IRI value.

4.4 Effect on Car Suspension

It was known that vehicle suspension would sustain a great force when the vehicle experienced acceleration, deceleration and brakes. There was no doubt that a speed breaker would result in negative effects on the vehicle suspension. It had been debated that the vehicle would need to brake anyway; hence the traffic energy harvester installed in speed breaker would not result in any difference to the vehicle. To verify this, simulation was done using SIMULINK library model.

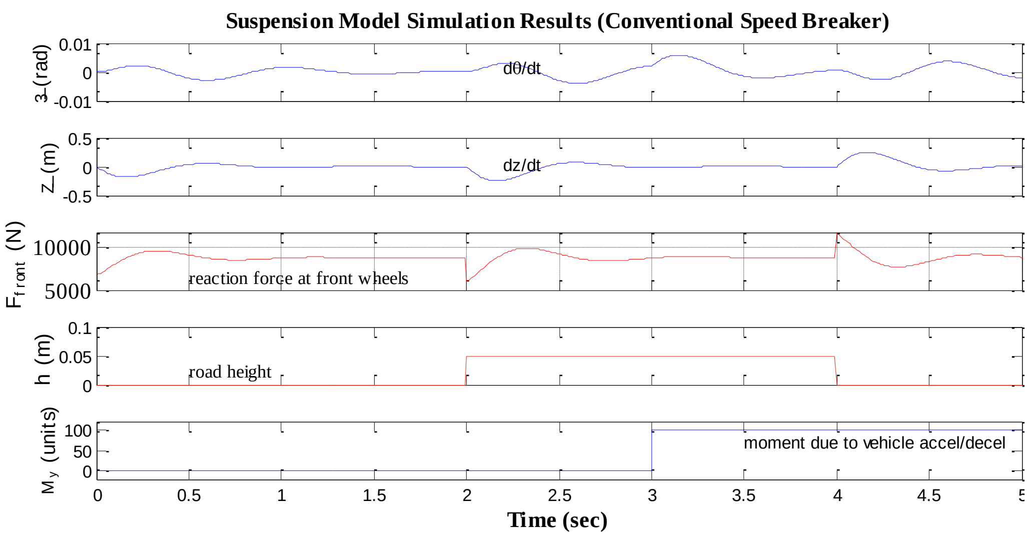

Figure 4.6: Simulation Result for Car Suspension passing a Conventional Speed Breaker

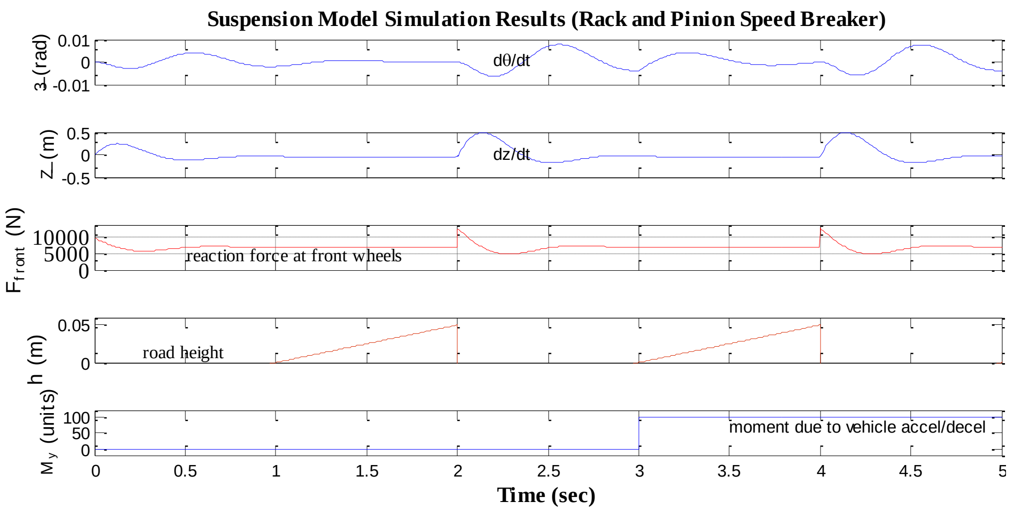

Figure 4.7: Simulation Result for Car Suspension passing a Rack and Pinion Speed Breaker

4.4.1 Discussion on Effect of Harvester on Vehicle Suspension

To verify if traffic energy harvesters affect the vehicle suspension more than conventional speed breaker, a half-car suspension model was modified to suit the given situation. For instance, the mass of vehicle and the change of road height were modified to observe the desired parameter, in this case the force at the front suspension, F_r.

From Figure 4.6 and Figure 4.7, it could be observed that the road height for conventional speed breaker was like a pulse wave while road height for speed breaker installed with rack and pinion traffic energy harvester was illustrated as alike to a saw tooth wave. When the vehicle crossed the conventional speed breaker, it was recorded that the front suspension experienced near 11770N of forces. Meanwhile, the front suspension of vehicle was applied with 13500N of force when it passed a rack and pinion speed breaker.

Springs in the vehicle suspension system allowed vehicle to absorb the energy from a bump or pothole without shuddering the passengers. The damper or shock which worked with it was responsible to damp the springs' natural tendency to oscillate especially when the vehicles passed a speed breaker. Shocks have a coil shape that responds to changes in the road, but when the force exceeded the amount it could handle, the shocks could be damaged, compromising suspension system's performance. In this case, the vehicle was subject to extra 1730N of forces when it passed through a rack and pinion speed breaker. The force was 1.47% higher than the amount of force it experienced when it was crossing a normal speed breaker.

4.5 Vehicle Efficiency

Vehicle efficiency was often referred to fuel efficiency. In Figure 4.8, energy flow in a vehicle typically a middle size car was shown. It could be seen that there were energy losses to various type of friction loss and transmission loss. To calculate the vehicle's efficiency, the difference in the power output was obtained and compared.

Since the coefficient of friction has increases by 14.29%, the rolling resistance was expected to be increased by 0.77%. The rolling resistance of speed breaker with rack and pinion speed breaker 6.15% took up 7.06% of the power before transmission loss. The total power output required to cross the rack and pinion speed breaker would be 20.88%, which was 11% higher than that passing over conventional speed breaker. Hence, it was concluded the speed breaker installed with traffic energy harvester do affect the vehicle's overall efficiency.

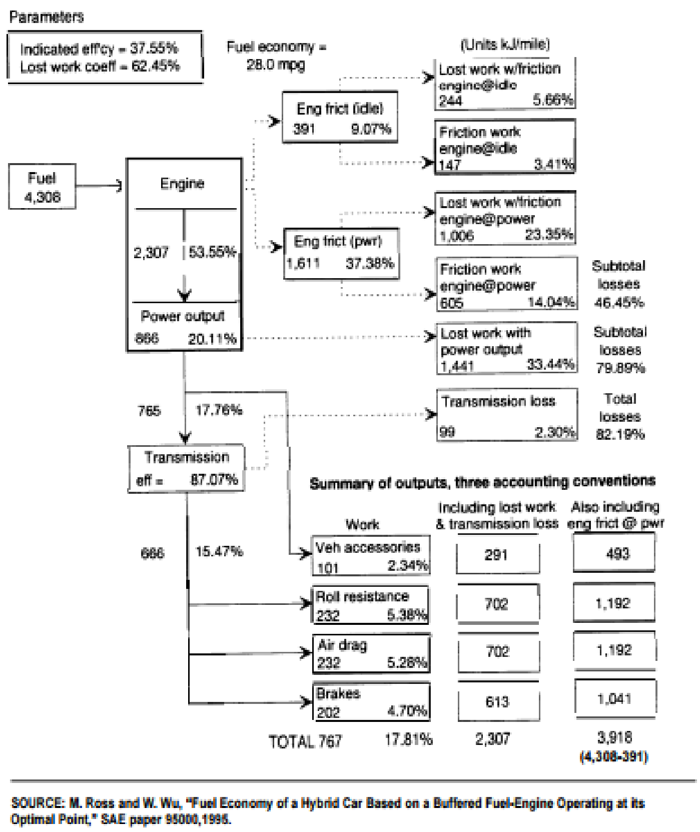

Figure 4.8: Energy Flow in Vehicle

4.6 Conclusion

The result output of the calculation and simulation has shown to be consistent. Trivial changes have been discovered to draw the conclusion that the impacts of traffic energy harvester on vehicles performance were not severe enough to raise concern.

CHAPTER 5

CONCLUSION AND FURTHER IMPROVEMENT

5.1 Summary

In this section, all the results from simulation and calculation for this study would be discussed and summarized.

Fuel rate was higher by 0.05% (0.0005 g/s) when a Toyota Camry crossed a traffic energy harvester installed speed breaker instead of a conventional speed breaker. This was mainly due to the difference in coefficient of friction between car tyres and speed breaker surface. As rack and pinion traffic energy harvester used steel as its material of construction, the coefficient of friction between tyre with it was higher.

In similar case, the road condition which was represented by IRI affected the car tyre consumption rate. Normal Malaysia road with 2.5 IRI value caused 0.005995 % / km of tyre consumption rate on the Camry. On the other hand, the IRI of speed breaker with traffic energy harvester was estimated as 2.86, resulting in 0.006003 % /km of tyre consumption rate for the Camry. The increase in the rate was $8 \times 10^{-6}\ \%/km$, around 0.1334% higher than that of the conventional speed breaker.

Through simulation, it was discovered that the Toyota Camry's front suspension system sustained 11770N force when it passed through a conventional speed breaker of height 5cm while the car which passed a speed breaker installed with traffic energy harvester experienced 13500N of forces. The difference in the force applied at the front suspension was 1730N, which was 1.47% higher.

Vehicle efficiency which was always linked to fuel consumption rate was calculated in terms of output power requirement for this project. Due to the rise of coefficient of friction by 14.29%, the rolling resistance has increased by 0.77. The total power output required to overcome the rack and pinion speed breaker would be 11% higher than that passing a conventional speed breaker.

In a nutshell, it was confirmed that the speed breaker installed with traffic energy harvester using rack and pinion method affected vehicles' performance. The influence was so small that it should not rise worrisome to people. The influence by long run would however be another question of debate.

5.2 Challenges Encountered

Being an Electrical and Electronic Engineering student, I've found ordeals in understanding mechanics of car. Lack of knowledge on the basics of mechanics in a car made it a challenge to understand on how a car might be affected by road conditions. Nevertheless, enquiry process to mechanical course seniors had brought fruitful results.

Traffic energy has been around for years yet it wasn't promoted widely because doubts about the effect the harvester could bring to the vehicles persist. Without previous studies on the possible impacts of traffic energy harvester on the vehicles, information collection process has proved challenging. The challenge was solved with brainstorming sessions with friends and seniors.

In the process of data collection, there had been contradiction and absurdity in the values of the parameters. Due to uncertainty in the standard values of result for reference, the parameters were tested with trial and error method to eliminate the most improbable values. Modification had been made during second phase of the project due to the inappropriateness for the application of the chosen equations.

The most serious hurdle was choice of software to be used for project simulation. With limited knowledge on the mechanical software, survey did not help much on the process of choosing software. At first, the Advance Vehicle Simulator (ADVISOR) was chosen as it has MATLAB interface and would aid in analyzing process. However, it was deemed unsuitable upon learning how it worked. The usage of SOLIDWORKS was proven unwise afterwards because it took professional's knowledge to assembly a moving vehicle in the software for simulation. Upon much discussion with supervisor, it was opted that MATLAB and SIMULINK were employed. For this, the plan of working together with partner on the software simulation as mentioned during phase one of study was rendered unworkable.

Due to the inability to demonstrate the project done, suggestion on additional objectives was proposed. A certain period of time was taken to study on the suspension of vehicles. Nevertheless, some simulation methods were found to be useful on study of the behavior of car suspension under different road condition. In the end, a half-car model was found on the MATLAB SIMULINK and modified to suit the use.

Regardless of the challenges laid upon the project, the process has proved to be productive as it had enhanced my problem solving skills. While the repetitive process of failure was discouraging, it had provided a valuable experience on exploring an interesting topic from different major.

5.3 Further Improvement

This project has been focusing on simulation and calculation instead of real experiments due to time and space issue. To provide an accurate result in the real world, the experiment should be carried out with hardware. A model of traffic energy harvester should be built and passed through by vehicles to obtain sets of values from vehicles. The experiment might even propose different insights on the possible impacts and a more accurate reading in a real life situation. This would provide a more convincing proof for people.

With more understanding on the possible impacts the vehicle might bear, more suitable software should be used to study the impacts. It is important for the project manager to have more knowledge on the software used because it would take up long time for one to understand it fully, not to say operating it for desired purpose. The software should be able to simulate mechanics for both vehicle and speed breaker in detail.

Last but not least, a more complete set of data for vehicles and circumstances could be obtained with more knowledge on the study. Default values and assumptions would not be as accurate as the parameters in real life situation as different places have different standards of regulation and environment readings. It would be ideal to get more sets of readings considering a variety of choices of vehicles. More variables could be studied on traffic energy harvester using other method such as the roller mechanism.

With more knowledge on the possible impacts, solutions for each of these impacts could be derived and thus solved the worries of people regarding the use of traffic energy harvester. This could very well lead to a new trend of renewable energy application.

5.4 Achievement

Under the encouragement and help of the Project Supervisor, Dr. Stella Morris, the project was submitted for Lee Kong Chian Faculty of Engineering and Science Final Year Project Competition. The project titled Impacts of traffic Energy Harvester on Vehicles has successfully obtained champion position on April 13, 2016.

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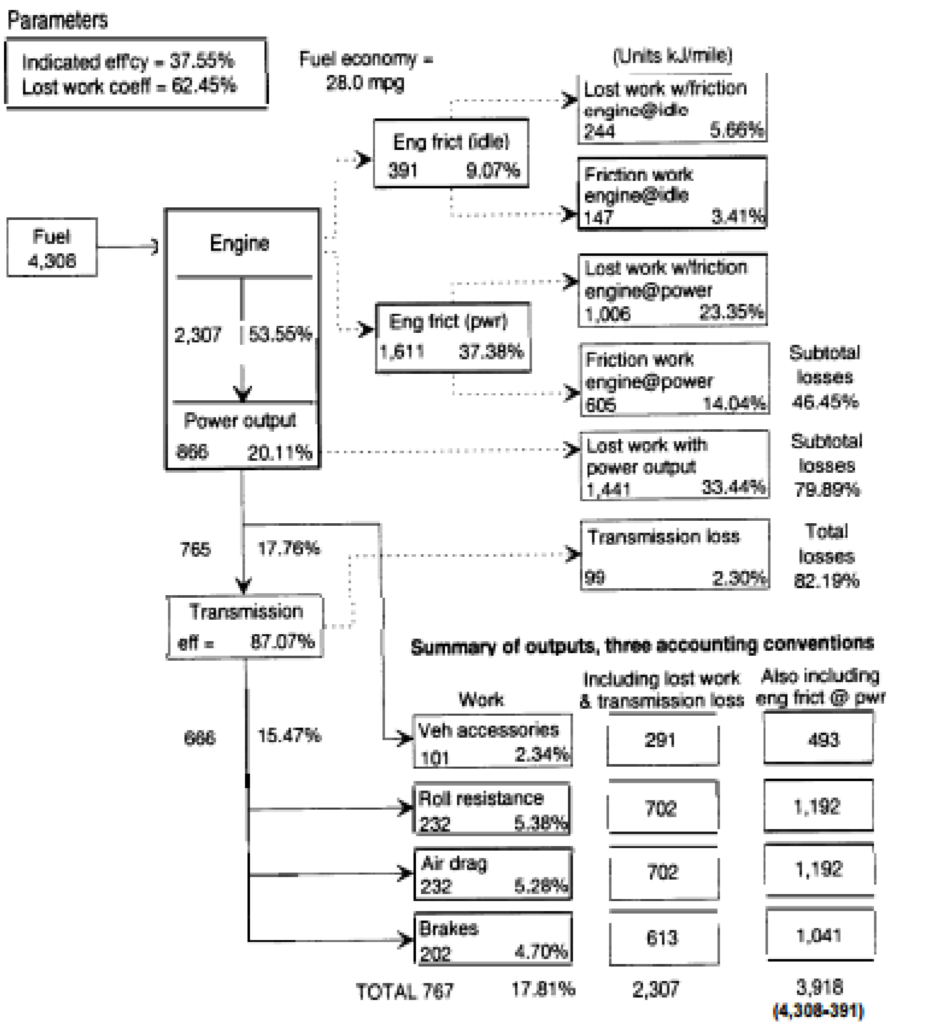
APPENDICES

APPENDIX A: Energy Flows, AVCAR'93, EPA Composite Cycle

Figure A-2: Energy Flows, AVCAR '93, EPA Composite Cycle



SOURCE: M. Ross and W. Wu, "Fuel Economy of a Hybrid Car Based on a Buffered Fuel-Engine Operating at its Optimal Point," SAE paper 95000,1995.

APPENDIX B: Tables of parameters for validation vehicles

Appendix B: Tables of parameters for validation vehicles.

Vehicle	MIT	Camry	Jetta	Jetta TDI	Civic DX	Civic HX	Civic Hybrid	Insight	Prius '01	Prius '04
Model Year	2020	2004	2004	2004	2004	2004	2004	2004	2001	2004
Vehicle wgt (kg)	1154	1565	1467	1483	1239	1224.2664	1354	989	1390	1447
Cr0 (rolling resistance)	0.006	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.007
Cd (drag coeff)	0.22	0.3	0.3	0.3	0.3	0.3	0.28	0.26	0.26	0.26
A (frontal area m^2)	1.8	2.4	2.11	2.11	2.14	2.14	2.14	1.92	2.11	2.33
Pacc (accessory - kW)	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
A (N)		127.36	111.25	111.25	105.47	105.47	125.58	53.76	86.33	88.63
B (N/mps)		0.9578	3.6834	3.6834	5.4276	5.4276	-0.9000	2.2837	2.2355	1.3849
C (N/mps^2)		0.4374	0.3764	0.3786	0.2670	0.2670	0.4474	0.3013	0.4144	0.3645
Engine										
Engine Displ (L)	1.11	2.4	2	1.9	1.7	1.7	1.35	1	1.5	1.5
k0 (N indep friction kJ/Lrev)	0.153	0.164	0.164	0.123	0.164	0.15088	0.15088	0.15088	0.164	0.164
k1 (N dependent fric)	0.00155	0.00155	0.00155	0.00215	0.00155	0.00155	0.00155	0.00155	0.00155	0.00155
P/T indicated eff (eta)	0.405	0.405	0.405	0.45	0.405	0.48	0.48	0.48	0.46575	0.46575
Transmission										
N/v (rpm/mph)	35.6	35.6	35.6	26.7	35.6	35.6	35.6	35.6	35.6	35.6
Nidle (rpm)	700	700	700	700	700	700	700	700	700	700
trans eff	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Shift point 1-2 (mph)	18	18	18	18	18	15	18	18	18	18
Shift point 2-3	25	25	25	25	25	25	25	25	25	25
Shift point 3-4	40	40	40	40	40	40	40	40	40	40
Shift point 4-5	50	50	50	50	50	50	50	50	50	50
g/gtop 1	4.04	4.04	4.04	4.04	4.04	4.04	4.04	3.461	4.04	4.04
g/gtop 2	2.22	2.22	2.22	2.22	2.22	2.22	2.22	1.75	2.22	2.22
g/gtop 3	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.096	1.44	1.44
g/gtop 4	1.00	1.00	1.00	1.00	1.00	1	1.00	0.86	1.00	1.00
g/gtop 5	0.90	0.90	0.90	0.90	0.90	0.9	0.90	0.71	0.90	0.90
Fuel										
LHV (kJ/g)	43.7	43.7	43.7	41.7	43.7	43.7	43.7	43.7	43.7	43.7
density gas (kg/L)	0.737	0.737	0.737	0.856	0.737	0.737	0.737	0.737	0.737	0.737
Motor										
overall efficiency	0.76						0.76	0.76	0.76	0.76
Regen Brake Eff	0.85						0.85	0.85	0.85	0.85
FWD power frac	0.7						0.75	0.75	0.7	0.95
Motor peak power (kW)	30						10	10	33	50
min regen (kW)	2.8						2.8	2.8	2.8	2.8
Motor Energy (kWhr)	1.8						1.8	1.8	1.8	1.8
Battery										
Initial SOC	0.56						0.56	0.56	0.56	0.56
Batt Energy (kWh)	1.8						0.936	0.936	1.8	1.3104
min SOC	0.2						0.2	0.2	0.4	0.4
max SOC	0.8						0.8	0.8	0.8	0.8
discharge eff	0.95						0.95	0.95	0.95	0.95
Hybrid										
hybrid threshold (kW)	1.75						2.2	1.5	2.18	2.9

APPENDIX C: Tread Wear Parameters

Table 4-10. Final parameters for tire stiffness (*Cs*) model.

Coefficient	≤ 2500 kg		> 2500 kg	
	Bias	Radial	Bias	Radial
*a*0	30	43	8.8	0
*a*1	0	0	0.088	0.0913
*a*2	0	0	−0.0000225	−0.0000114

Source: Bennett and Greenwood (2003b)

Table 4-11. Final parameters for rolling resistance coefficient (*CR*2) model.

Surface Type	≤ 2500 kg				> 2500 kg			
	*a*0	*a*1	*a*2	*a*3	*a*0	*a*1	*a*2	*a*3
Asphalt	0.5	0.02	0.1	0	0.57	0.04	0.04	1.34
Concrete	0.5	0.02	0.1	0	0.57	0.04	0.04	0

Source: Bennett and Greenwood (2003b)

Table 4-12. HDM 4 new default values—vehicle and tire characteristics.

Vehicle Class	Number of Axles	*Nw*	M (tons)	*Kcr*2	CD	AF (m^2)	WD	Tire Type	*CR*1	*b*11	*b*12	*b*13	C_{0tc} (dm^3/1000 km)	C_{tcte} (dm^3/MNm)	VOL (dm^3)	VEHF AC
Small car	2	4	1.9	0.5	0.42	1.9	0.62	Radial	1	22.2	0.11	0.13	0.01747	0.001	1.4	2
Medium car	2	4	1.9	0.5	0.42	1.9	0.62	Radial	1	22.2	0.11	0.13	0.01747	0.001	1.4	2
Large car	2	4	1.9	0.5	0.42	1.9	0.62	Radial	1	22.2	0.11	0.13	0.01747	0.001	1.4	2
Van	2	4	2.54	0.67	0.5	2.9	0.7	Radial	1	25.9	0.09	0.10	0.01602	0.00092	1.6	2
Four-wheel drive	2	4	2.5	0.58	0.5	2.8	0.7	Radial	1	25.9	0.09	0.10	0.01602	0.00092	1.6	2
Light truck	2	4	4.5	0.99	0.6	5	0.8	Radial	1	29.6	0.08	0.08	0.01602	0.00092	1.6	2
Medium truck	2	6	6.5	0.99	0.6	5	0.8	Bias	1.3	29.6	0.08	0.11	0.02999	0.00099	6	1
Heavy truck	3	10	13	1.1	0.7	8.5	1.05	Bias	1.3	38.85	0.06	0.11	0.03829	0.00135	8	1
Articulated truck	5	18	13.6	1.1	0.8	9	1.05	Bias	1.3	38.85	0.06	0.20	0.04328	0.00153	8	1
Mini bus	2	4	2.16	0.67	0.5	2.9	0.7	Radial	1	25.9	0.09	0.10	0.01747	0.00092	1.6	2
Light bus	2	4	2.5	0.99	0.5	4	0.8	Radial	1	29.6	0.08	0.08	0.01747	0.00092	1.6	2
Medium bus	2	6	4.5	0.99	0.6	5	1.05	Bias	1.3	38.85	0.06	0.07	0.02999	0.00099	6	1
Heavy bus	3	10	13	1.1	0.7	6.5	1.05	Bias	1.3	38.85	0.06	0.11	0.03829	0.00135	8	1
Coach	3	10	13.6	1.1	0.7	6.5	1.05	Bias	1.3	38.85	0.06	0.11	0.03829	0.00135	8	1

Table 4-3. Tread wear rate constants.

Vehicle type	C_{0tc} (dm^3/1000 km)	C_{tcte} (dm^3/MNm)
Motorcycle	0.00639	0.0005
Small car	0.02616	0.00204
Medium car	0.02616	0.00204
Large car	0.02616	0.00204
Light delivery car	0.024	0.00187
Light goods vehicle	0.024	0.00187
Four-wheel drive	0.024	0.00187
Light truck	0.024	0.00187
Medium truck	0.02585	0.00201
Heavy truck	0.03529	0.00275
Articulated truck	0.03988	0.00311
Mini bus	0.024	0.00187
Light bus	0.02173	0.00169
Medium bus	0.02663	0.00207
Heavy bus	0.03088	0.00241
Coach	0.03088	0.00241

Source: Bennett and Greenwood (2003b)