IMPACTS OF HARNESSING TRAFFIC ENERGY ON VEHICLES AND USERS

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

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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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.

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APPROVAL FOR SUBMISSION

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

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Signature : ______________________________

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Date : ______________________________

Specially dedicated to

my beloved grandmother, mother and father

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IMPACTS OF HARNESSING TRAFFIC ENERGY ON VEHICLES AND USERS

ABSTRACT

The reasons of carrying out this research are to investigate the impacts of traffic energy harnessing generating system on the vehicles and users and to find out whether is it practical to implement the traffic energy harnessing generating system into our daily life. One of the traffic energy harnessing systems is the smart speed breaker. The smart speed breakers will cause more discomfort to the vehicles' occupant as compared to conventional speed breakers because they are more focusing on obtaining the mechanical energy, which is the vibration to generate the electrical energy. Apart from that, the smart speed breaker also will implant more forces on the suspension of the vehicle. The smart speed breaker tries to obtain as much force as possible from the vehicle to produce higher electric energy and by Newton's third law there will be more force on the car suspension system as well. Besides that, the smart speed breaker also will cause higher fuel consumption as compare to the convention speed breaker. The smart speed breaker tries to obtain more force from the vehicle and this in turn increase the torque required by the vehicle to pass through the speed breaker and this in turn increase the fuel consumption of the vehicle. Furthermore, the vehicles' tyre wear rate is also higher when going through the smart speed breaker as the smart speed breaker emphasizes more on friction to obtain more force from the vehicle. As a conclusion, smart speed breakers did indeed cause negative impacts. The negative impact on the comfortability level of vehicle occupants is huge while the impacts on the fuel consumption rate and tyre wear rate are almost negligible. By implementing some recommendations such as undergoing the experiment practically, results that are more accurate can be obtained.

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LIST OF SYMBOLS / ABBREVIATIONS

a_0,a_1,a_2	dimensionless model parameter
a_0,a_1,a_2,a_3	model coefficient
A	tyre rolling resistance coefficient
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)
g	gravitational constant (9.81 ms^{-2})
K	friction factor of engine (kJ/revL)
KCr_2	calibration factor
L	engine displacement (L)
LHV	the factor lowers heating value of the fuel
m	mass of vehicle
N	number of data points
N	speed of engine (rps)

P	power output of engine (kW)
P_{acc}	power for accessories (kW)
P_b	brake power (kW)
R	curvature radius (m)
RMS	root mean square
VDV	vibration dose value

v	velocity, ms^{-1}
a	acceleration, ms^{-2}
fs	frequency, Hz
η	efficiency of engine
η_t	transmission efficiency
μ	coefficient of friction of different materials
ϕ	fuel/air ratio
ρ	mass air density (kg/m^3)

CONFAC	congestion modification factor
CTCON	increase of tyre consumption due to congestion
dFUEL	increase of fuel consumption due to congestion
DEF	Benklemen Beam rebound deflection (mm)
NT	new tyre (%/km)
F	friction force (N)
FCR	fuel consumption rate
IRI	international roughness index (m/km)
MODFAC	tyre life modification factor
mph	miles per hour
N_W	number of wheels
TWR	Tyre Wear Rate (%/km)
Tdsp	texture depth using sand patch (mm)
TYREFA	tyre type modification factor
VEHFAC	vehicle specification modification factor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the energy consumption is increasing dramatically. Day by day, the energy required to be used by humanity increases due to the advanced in technology, which uses massive amount of energy such as air conditioner, refrigerator, water heater and others. The amount of people using those high energy-consuming technologies is always increasing thus the energy consumption also increase.

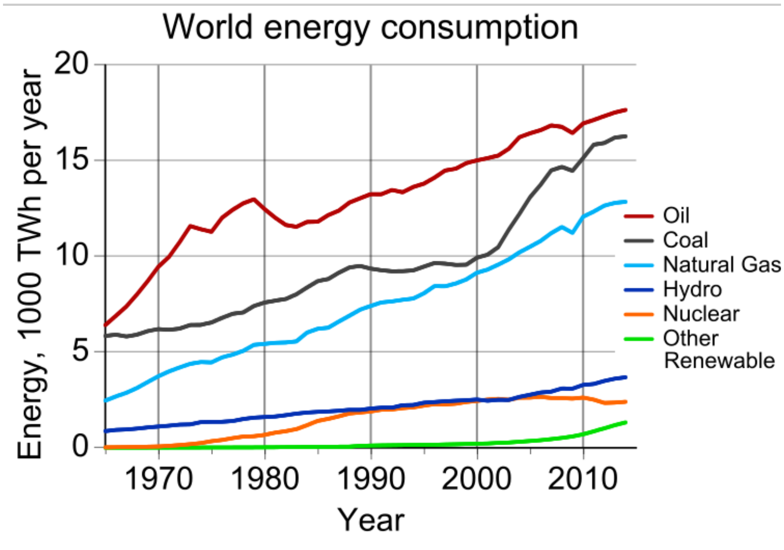


Figure 1.1: Figure of World Energy Consumption

There are many different types of energy sources such as oil, coal, natural gas, hydro, nuclear and others. However, most of the main energy sources of the world are all non-renewable such as oil, coal and natural gas. They are all obtained from fossil fuels, which only formed after millions of years through anaerobic decomposition. This means that they will be a time that all of the resources will be exhausted and this arise major issue of one day there will be no more resources to produce the energy required.

Thus, to prevent and overcome this issue, many researches on renewable energy such as hydro, solar, geothermal, biomass and others are carried out in the present. Although many researches have been carried out on the renewable energy, there are other concerns that the efficiency of renewable energy generation is not high thus it may not be able to supply sufficient energy if the fossil fuels resources run out.

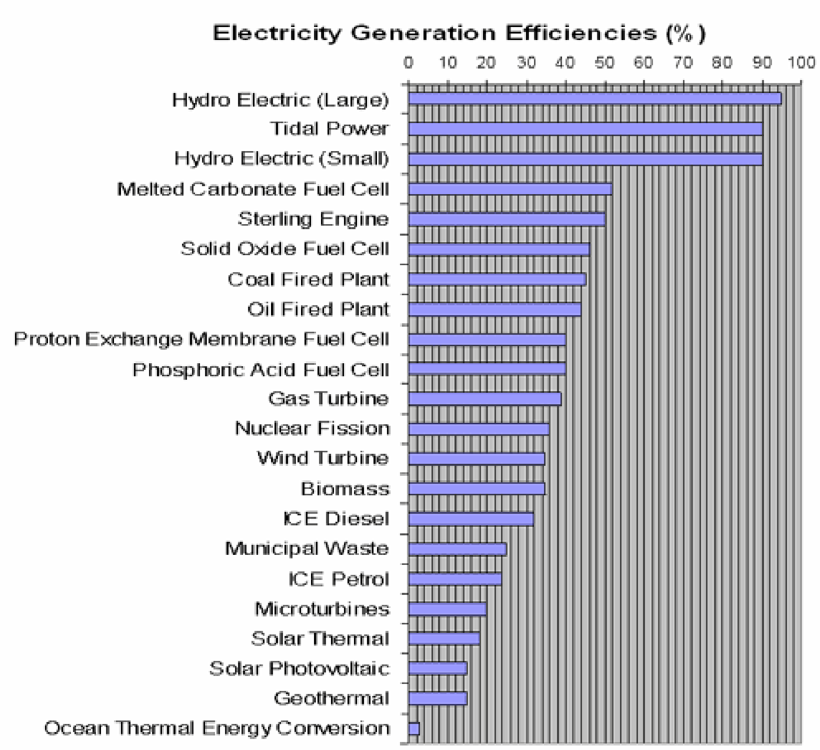


Figure 1.2: Figure of Electricity Generation Efficiencies

Therefore, more researches are carried out to find more ways to provide energy for humanity. This is where research about harnessing traffic energy comes in. The idea of harnessing traffic energy is by using the kinetic energy from the vehicles travelling through the traffic to generate electricity. Generation of road traffic aims to convert the force exerted by the moving vehicles on the road into useable electrical energy. There are some methods proposed to harness the traffic energy such as smart road and smart speed breaker. For smart road, the travelling vehicle will produce vibration, which is the mechanical energy to the piezoelectric surface of the road. The piezoelectric effect will then convert the mechanical strain into electrical energy. Both the smart road and smart speed breaker used the same concept of converting mechanical energy produced by kinetic energy of travelling vehicle into electrical energy.

1.2 Problem Statement

There are many researches on the ways to generate energy from the travelling vehicle on the road. However, there are not many researches on the impacts of generating the energy from travelling vehicle. This is extremely important since even if the generation of energy is very high or very efficiency, it is not practical to implement it in our daily life if it brings many disadvantages. Most of the researches on the generation of energy from harnessing the traffic energy tend to hide or do not expose much of the disadvantages of the system. Thus, it is hard to find out whether the generation of energy system they proposed is practically implementable or the other way round.

1.3 Aims and Objectives

The aim of carrying out this research is to investigate the impacts of those traffic energy harnessing generating systems on the vehicles and users.

The objectives of carrying out this research are:

1) Find out the possible impacts of traffic energy harnessing generating system on vehicles and users.
2) Find out whether is it practical to implement the traffic energy harnessing generating system into our daily life.
3) Investigate the impact of traffic energy harnessing generating system on suspension system of the vehicles.
4) Investigate the impact of traffic energy harnessing generating system on the comfortable rate of the passengers.
5) Investigate the impact of traffic energy harnessing generating system on the fuel consumption rate of vehicle.
6) Investigate the impact of traffic energy harnessing generating system on the tyre wear rate of vehicle.
7) Compare and find out which types of traffic energy harnessing produces less negative impacts.

1.4 Structure of the Research Report

This research report consists of five main chapters:

1) Chapter 1 (Introduction). In this chapter, the brief background of the research, the problem statement as of why we need to carry out this research and the aims and objectives of this research are stated.
2) Chapter 2 (Literature review). In this chapter, some information from journals on the types of traffic energy harnessing system and the information on the possible impacts or ways to find the possible impacts of the traffic energy harnessing system are discussed.
3) Chapter 3 (Methodology). In this chapter, the software used to investigate the impacts is stated and the methods to investigate the impacts are narrated. The equations used to investigate the impacts are also stated clearly in this chapter.

4) Chapter 4 (Results and Discussions). In this chapter, the results such as graphs are covered and discussed. The calculation process is also covered in this chapter.
5) Chapter 5 (Conclusion and Recommendations). In this chapter, the conclusion is drawn by using the results obtained from the research. Some recommendations are also given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the first part will be explaining the mechanism of generating of electricity using smart speed breakers while the second part will be explaining the possible impacts of the smart speed breakers on vehicle and users. This chapter will be talking about:

1) Generation of electricity with the use of speed breaker
    1.1) Roller mechanism speed breaker
    1.2) Crank shaft speed breaker
    1.3) Rack and pinion speed breaker
2) Vehicular discomfort
3) Suspension analysis
4) Effect of road geometry on fuel consumption
5) Impact of pavement roughness on tyre wear costs

2.2 Generation of Electricity with Use of Speed Breaker

By using the typical change of energy, the kinetic energy of a car pass through a speed breaker can be converted into electrical energy.

2.2.1 Roller Mechanism Speed Breaker

One type of design for generation of electricity by using speed breaker is the roller mechanism design. (Piyush Bhagdikar, May, 2014). The spinning motion of the rollers connected to the generator when a vehicle passes through generates the mechanical energy required to be converted into electrical energy. The chain drive mechanism is used to transfer the mechanical motion to the generator for generation of electricity.

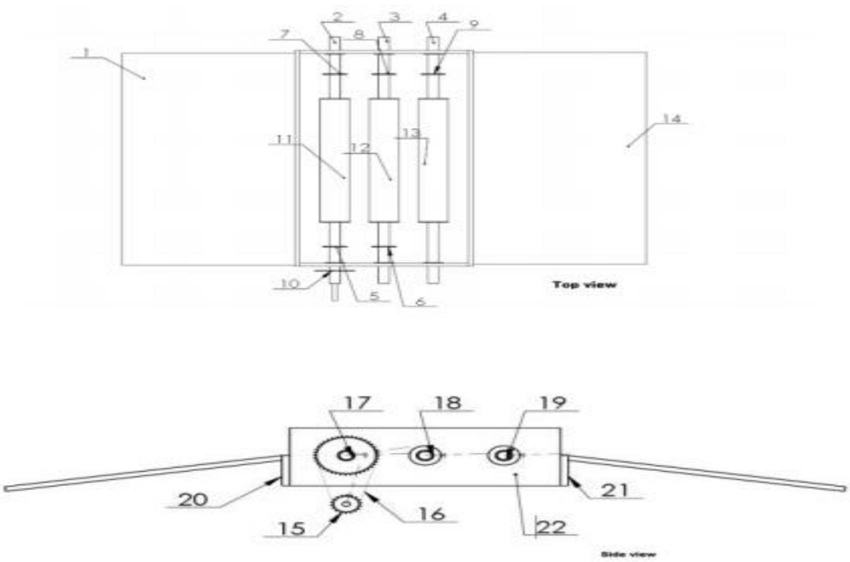


Figure 2.1: Figure of Speed Breaker with Roller Mechanism to Generate Electricity

2.2.2 Crank Shaft Speed Breaker

Apart from that, another type of design for generation of electricity by using speed breaker is the crank shaft design. (A.Padma Rao, February, 2014). When a vehicle passes through the speed breaker, the speed breaker will be forced down, a lever will be cranked to fit into the ratchet-wheel type mechanism, and that will rotate the geared shaft, which is loaded with designed recoil springs. After that, the output of the shaft of the speed breaker is then coupled to a dynamo. Through the dynamo, the kinetic energy will then be converted into electrical energy.

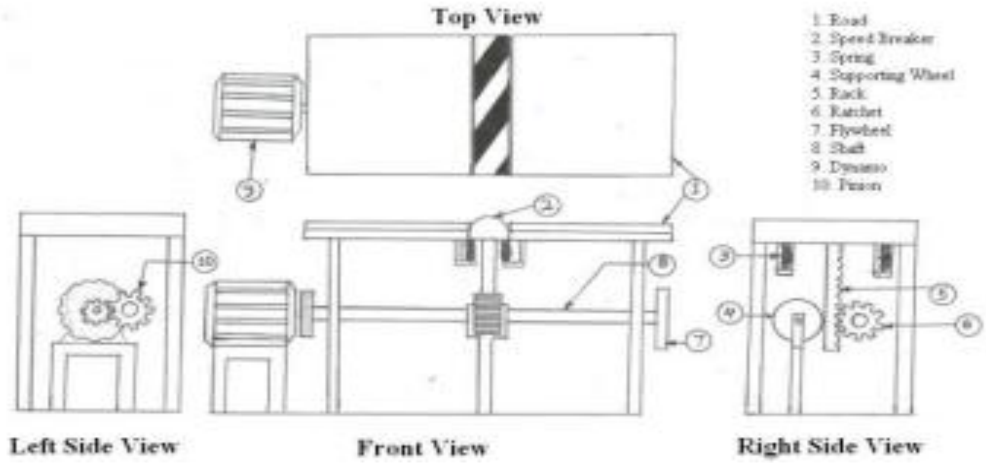


Figure 2.2: Figure of Speed Breaker with Crank Shaft Mechanism to Generate Electricity

2.2.3 Rack and Pinion Speed Breaker

Besides that, by using rack and pinion mechanism, when the vehicles travel through the speed breaker, the speed breaker will be compressed with the help of spring and the rack. When the teeth of the rack are connected to the gear, the up and down motion of rack will be converted into the rotary or spinning motion of gears which will then produce the mechanical energy required to generate electrical energy. (K.Ravivarma, June, 2013).

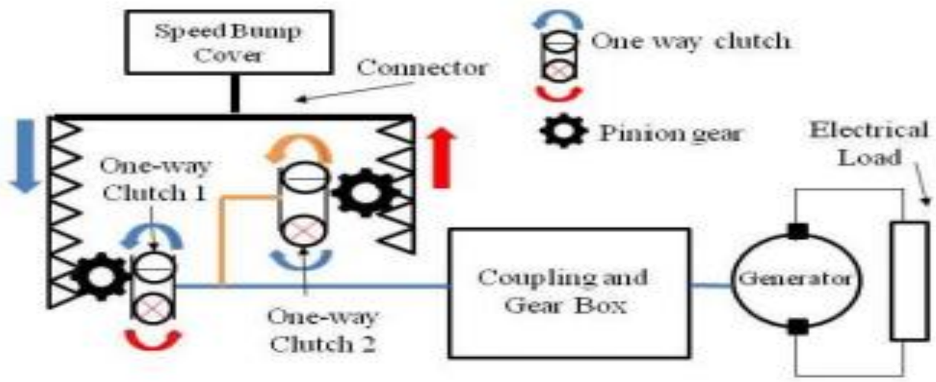


Figure 2.3: Figure of Speed Breaker with Rack and Pinion Mechanism to Generate Electricity

2.3 Vehicular Discomfort

By using different types of vehicle such as motorcycle, car and bus to go over a speed breaker, the comfortable rate of the driver and the passenger can be known. (Lima E.A, 2015). The models were simplified to facilitate the simulation. A constant initial speed and gravitational acceleration was used on the model so that the dynamic analysis can be performed. The whole simulations were carried out with the same conditions on the distance from the speed breaker, velocity of the vehicle and simulation time to ensure consistency and accuracy on the comparison of the results. Various methods can be used to find out about the comfort level of the driver and passenger. One of it is the RMS acceleration value. A table to is used to compare the calculated value of the RMS acceleration value to find out the comfort level of the driver and passenger.

Table 2.1: RMS Acceleration Correspond to Comfort Level

RMS Acceleration (ms^{-2})	Comfort Level
Lower than 0.315	Comfortable
Between 0.315 and 0.63	A bit uncomfortable
Between 0.5 and 1	Middling uncomfortable
Between 0.8 and 1.6	Uncomfortable
Between 1.25 and 2.5	Highly uncomfortable
Higher than 2	Extremely uncomfortable

Besides, the crest factor can also be used as a method to know the comfort level of the driver and passenger. Crest factor is the total damage of the vehicle occupants suffers due to the vibration of vehicle. Thus, the crest factor is preferred to be as low as possible to ensure the vehicle occupants are at a comfortable level. The VDV (vibration dose value) can also be used to know the discomfort rate of vehicle occupants. The magnitude of VDV value of 8.5$ms^{-1.75}$ will cause medium discomfort to occupants of the vehicle while the magnitude of VDV value of of 15$ms^{-1.75}$ will cause severe discomfort to the occupants of the vehicle. (Castro, 2014). The results showed that the heavier vehicles such as buses and trucks have VDV values around $8.5ms^{-1.75}$, which cause medium discomfort to the occupant of the vehicle.

2.4 Suspension Analysis

A transient analysis can be applied to find out the dynamic interaction between a vehicle and speed bump. Suspension designs have three major criteria, which are the road handling, load carrying and passenger comfort. (Abdolvahab, 2012). Same vehicle with the same suspension system pass through different types of road profiles such as normal road, road with bump and others. The suspension analysis is obtained and by comparing the suspension analysis which road or type of suspension will provide best comfort of the vehicle occupants can be concluded.

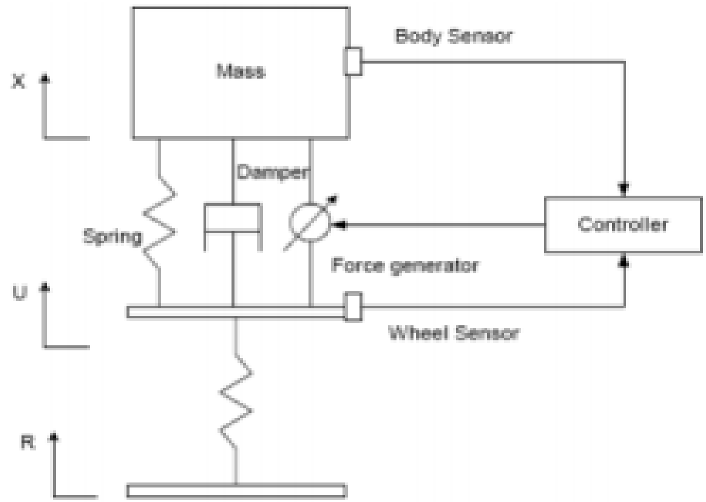


Figure 2.4: Figure of Active Suspension System.

Mathematical model of a quarter car was designed and the simulation is carried out by using MATLAB SIMULINK software. The performance of the vehicle suspension system in terms of ride quality of the vehicle and vehicle handling were observed. The parameters that observed are suspension displacement, wheel deflection and the acceleration of the car body. Different types of road conditions are also taken into account. The performance of both the passive and active vehicle suspension system is compared and it was proven that the active vehicle suspension system performs better. IF the improving of the occupant's ride comfort and better road handling is desired, active vehicle suspension system with LQR controller design can be used.

2.5 Effect of Road Geometry on Fuel Consumption

There are strong relationships between fuel consumption of vehicles and the other independent variables such as gradient of the road, curvature of the road and the roughness of the road surface. (Gunnar Svenson, 2014). The collection of data of fuel consumption, vehicle speed, road geometry and surface roughness enables the comparison of fuel consumption between smooth road and bump road. The influence of road characteristics on fuel consumption on a truck is observed. The average fuel consumption of a truck is around 91.8 litres/100km while the fuel consumption of a truck while travelling bump roads are 162.8 litres/100km. Thus, the increases in fuel consumption where vehicle travels on the bumpy road can be explained by greater curvature and rougher road surface.

Table 2.2: Table of Fuel Consumption Correspond to the Road Geometry

Road Class	Fuel consumption per litters/100km	Velocity, ms^{-1}	Gradient	Curvature	IR1, mm/m	No of Observation
1-4	71.3	17.7	0.2	1.5	2.1	201
5	81.1	13.2	-0.1	3.7	3.6	150
7	93.3	10.1	0	2.8	6.2	39
8	104.1	11.2	0.1	3.1	5.3	123
9	162.8	7.6	0.3	4.9	7.4	38

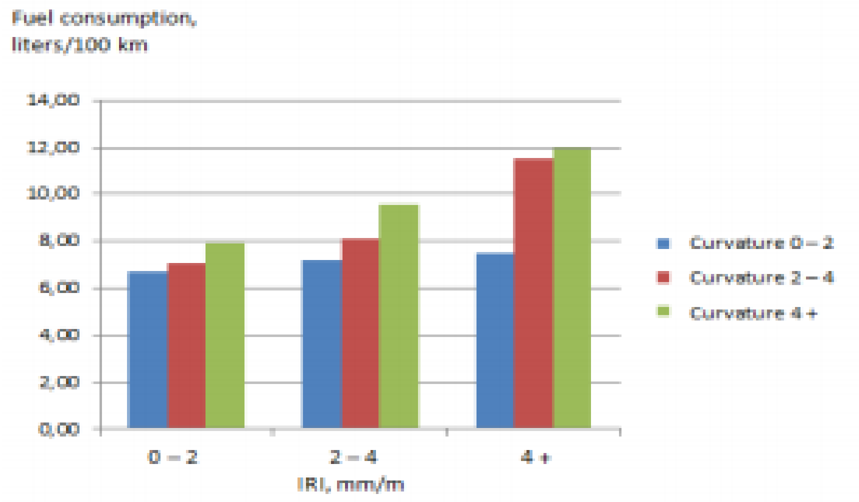


Figure 2.5: Bar Graph of Fuel Consumption Correspond to the Road Geometry

2.6 Impact of Pavement Roughness on Tire Wear Costs

Cost adjustment factors increased with the decreasing of SI (serviceability index) which indicates that rougher pavements will result in a higher tire expenses related to tire wear. (Mary M.Robbins, May, 2015). Costs associated with tire wear, maintenance and repair and depreciation were found to be influenced by pavement roughness. Although the researches in areas of tire weariness are still limited, some statistical data proves tire wears off faster while vehicle travels on bumpy roads. Various adjustment factors for various levels of pavement roughness are defined by PSI and IRI.

Table 2.3: Adjustment Factors for Pavement Roughness levels for Passenger vehicles

PSI	IRI (in/mile)	IRI (m/km or mm/m)	Adjustment multiplier
≤ 2.0	170	2.7	1.25
2.5	140	2.2	1.15
3.0	105	1.7	1.05
≥ 3.5	80	1.2	1.00

It has been concluded from statistical data that the rougher the surface of the road, the higher the tire wear costs.

2.7 Conclusion

In the present, there are many studies on the design of traffic energy harvester based speed breakers such as rack and pinion mechanism based speed breaker, roller mechanism based speed breaker and hydraulic mechanism based speed breaker but no research is done on the impacts of harnessing traffic energy by using these traffic energy harvester speed breakers. Possible impacts of the traffic energy harvester based speed breakers such as comfortability level of vehicle occupants, fuel consumption rate and tyre wear rate are listed down and the methods to investigate them are researched.

CHAPTER 3

METHODOLOGY

3.1 Introduction

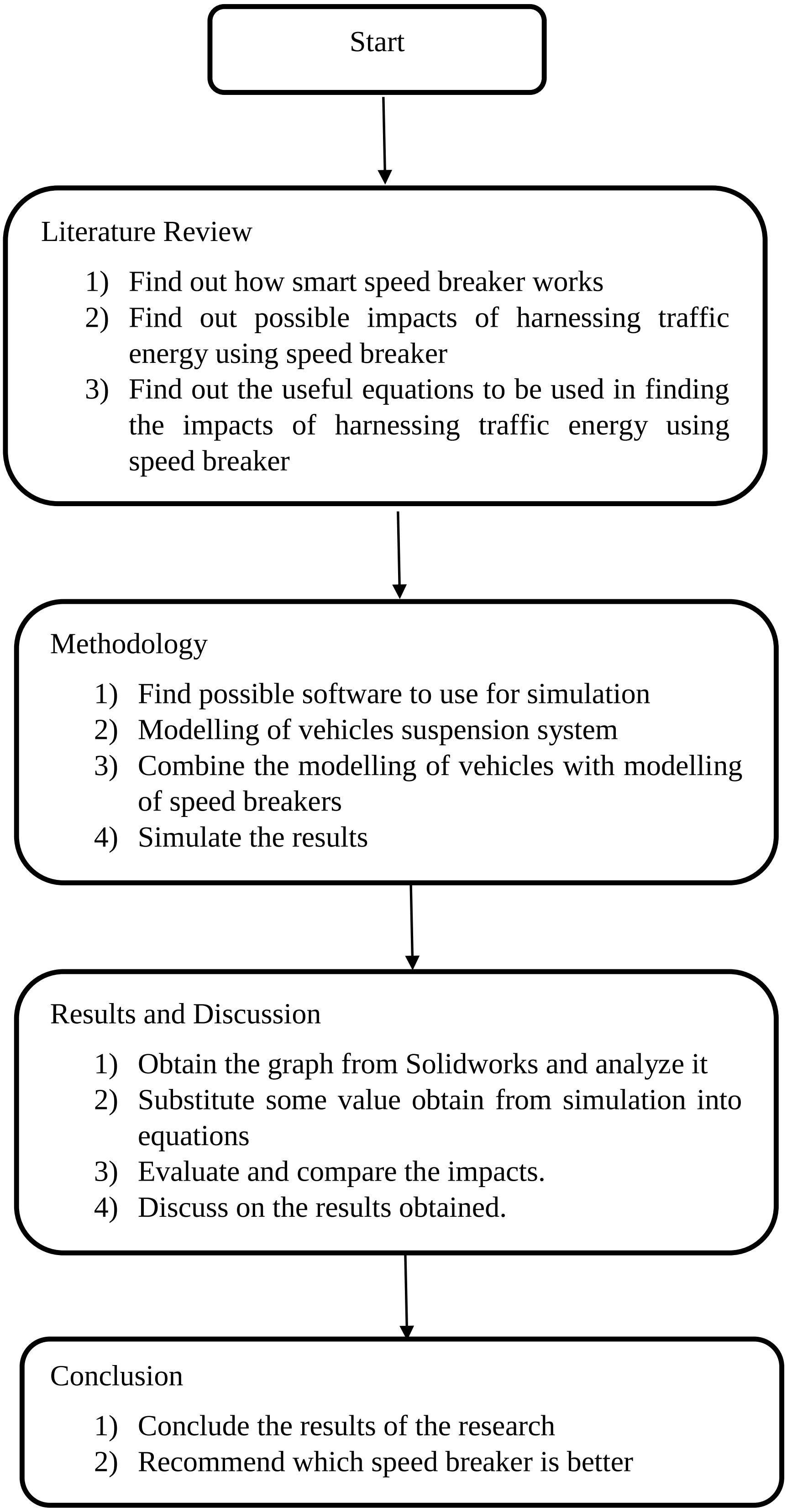
This Chapter 3, which is the methodology section, is to clarify the methods that going to be used to study the possible impacts of harnessing traffic energy on vehicles and users.

This methodology will focus on the possible impacts of vehicular discomfort, suspension analysis, fuel consumption of the vehicles and the tyre wear rate of the vehicles. Three different types of vehicles, which are motorcycle, car and truck, will be used to find out the impacts on them. The analysis of the vehicles pass through normal conventional speed breaker will be compared to the analysis of the vehicles pass through different types of smart speed breakers such as rack and pinion, air compressor mechanism.

This chapter covers:

1) Project pathway
2) Modelling of vehicles' suspension system
3) Suspension analysis
4) Vehicular discomfort
5) Fuel consumption
6) Tyre wear rate

3.2 Project Pathway



3.3 Modelling of Vehicles' Suspension System

The modelling of all two types of vehicles' suspension system is done in a software called SOLIDWORKS.

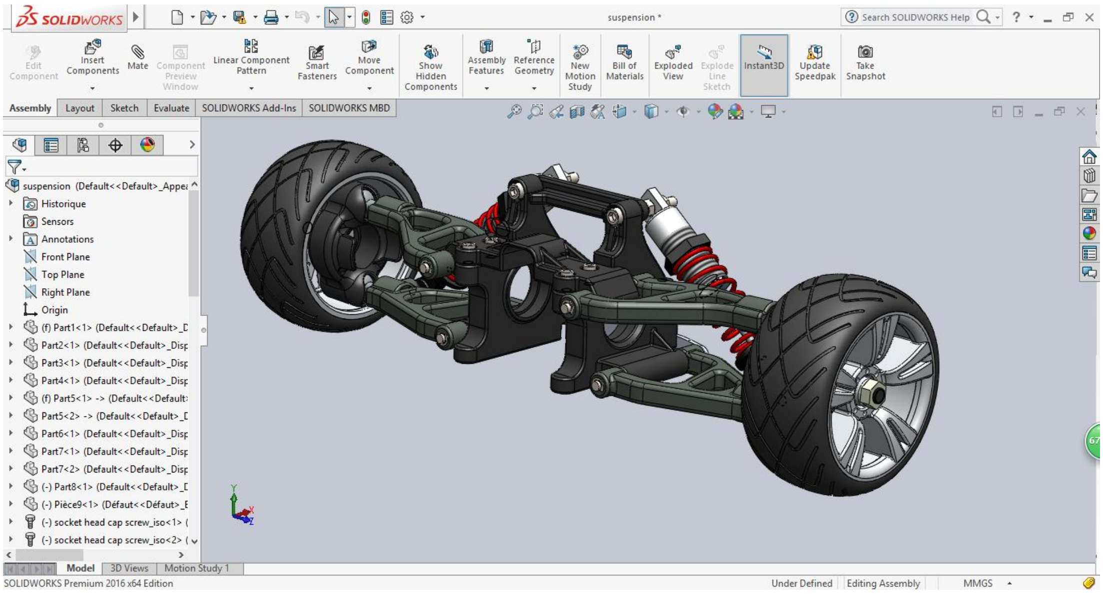


Figure 3.1: Figure of car suspension system

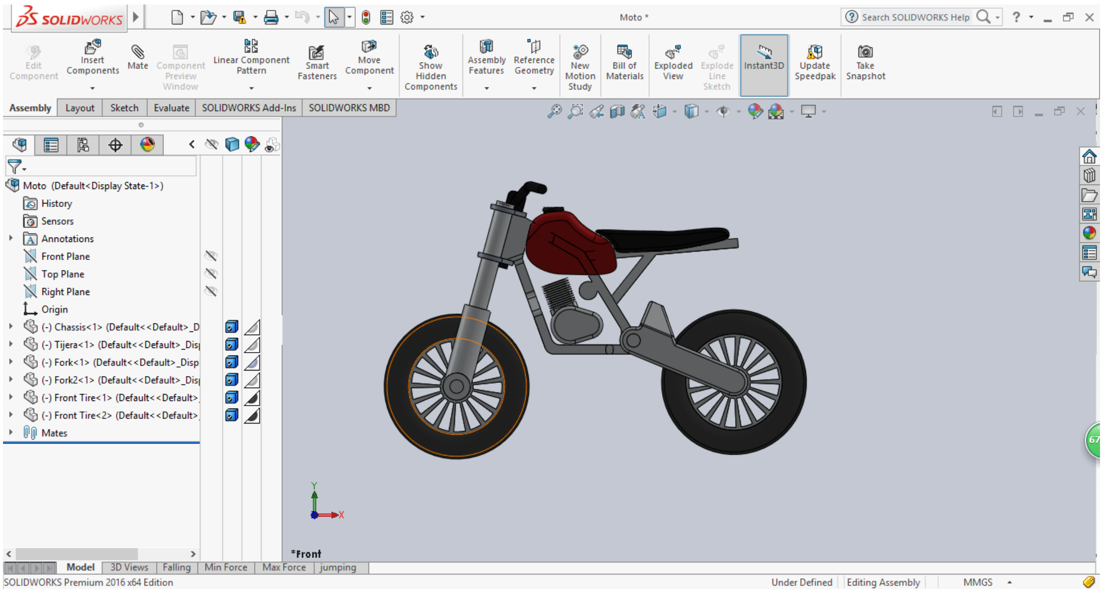


Figure 3.2: Figure of motorcycle and its suspension system

3.4 Suspension Analysis

The suspension analysis is going to be done using SOLIDWORKS. By entering the parameter of the vehicle suspension system and the parameter of the conventional and smart speed breaker, the graph for the movement of the suspension system should be able to be generated. After that, the graphs of different types of vehicles passing through different types of smart speed breaker will be compared and the impact can be studied.

3.5 Vehicular Discomfort

In order to find out the vehicular discomfort, we will need to find the vertical acceleration of the vehicles while passing through the speed breaker. From the graph simulated from the suspension analysis, the vertical acceleration of the vehicles can be found out using the formula

$$a = \frac{dv}{dt} ms^{-2} \tag{3.1}$$

a is the vertical acceleration of the vehicle (ms^{-2})

There are three types of vehicles used, which are motorcycle, car and truck. However, all of the initial conditions of the vehicles are assume to be constant. The differences between all the three vehicles are the mass of the vehicle and the force exerted on the speed breaker. The RMS (root mean square) vertical acceleration is calculated using the formula

$$a_{RMS} = \left(\frac{1}{N}\sum_{i=1}^{N} a^2\right)^{\frac{1}{2}} \tag{3.2}$$

N is the number of data points

The RMS acceleration is then used to determine the comfort level. The RMS acceleration is desired to be as lower as possible to obtain the best comfortable rate. Thus, if the calculated RMS acceleration is high then it is not comfortable.

The Vibration Dose Value (VDV) is also calculated using the formula

$$VDV = (\frac{1}{fs}\sum_{i=1}^{N} a^4)^{\frac{1}{4}} \qquad (3.3)$$

fs is the frequency of acquisition (Hz)

The VDV is then used to determine the comfort level. The VDV is also desired to be as lower as possible. The VDV value of 8.5 will start to trigger discomfort while the VDV value of 15 will trigger severe discomfort.

3.6 Fuel Consumption

In order to find out the impact of harnessing traffic energy on fuel consumption, the fuel consumption rate (FCR) is calculated using the formula

$$FCR = \frac{\Phi[KNL + \frac{\left(\frac{P_b}{\eta_t} + P_{acc}\right)}{\eta}]}{LHV} \qquad (3.4)$$

Φ is the fuel to air ratio

K is the friction factor of engine (kJ/revL)

N is the speed of engine (rps)

Ƞ is the efficiency of engine

L is engine displacement

P_b is the braking power (kW)

$Ƞ_t$ is the transmission efficiency of the engine

P_{acc} is the power for accessories (kW)

LHV is the factor lower heating value of the fuel

The braking power P_b is calculated using the formula

$$P_b = Av + Bv2 + Cv^3 + mv\,(a + g \times gradient) \qquad (3.5)$$

A is the tyre rolling resistance coefficient

B is the speed-correction to rolling resistance

C is the air drag coefficient

v is the vehicle speed (ms^{-1})

m is the mass of vehicle (tonne)

a is the vehicle acceleration (ms^{-2})

g is the acceleration due to gravity (ms^{-2})

The acceleration of the vehicle is calculated using equation derived from Newton's third law.

$$F = ma - \mu(mg) \tag{3.6}$$

m is the mass of vehicle (tonne)

a is the vehicle acceleration (ms^{-2})

g is the acceleration due to gravity (ms^{-2})

μ is the coefficient of friction

3.7 Tyre Wear Rate

The tyre wear rate can be calculated by using the formula

$$TWR = \frac{N_W \times NT}{MODFAC} \tag{3.7}$$

TWR is the tyre wear rate (% / km)

N_W is the number of wheels

NT is new tyre (% / km)

MODFAC is the tyre life modification factor

$$NT = \frac{Total\ change\ in\ Tread\ Wear}{10 \times Volume\ of\ Tyre} \tag{3.8}$$

$$Total\ change\ in\ Tread\ Wear = C_{otc} + C_{tcte} \times Tyre\ Energy \tag{3.9}$$

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

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

$$Tyre\ Energy = \frac{(Circumferentiol\ Force\ on\ Tyre)^2 + (Lateral\ Force\ on\ Tyre)^2}{Normal\ Force\ on\ Tyre} \tag{3.10}$$

$$Circumferentiol\ Force\ on\ Tyre = \frac{(1+CTCON \times dFUEL)\times(F_a + F_r + F_g)}{N_W} \tag{3.11}$$

CTCON is the increase of tyre consumption due to congestion

dFUEL is the increase of fuel consumption due to congestion

F_a is aerodynamic forces (N)

F_r is the rolling resistance forces (N)

F_g is the gradient forces (N)

$$F_a = 0.5 \times \rho \times CD_{mult} \times CD \times Front\ area\ of\ vehicle \times v^2 \tag{3.12}$$

ρ is the air mass density (kgm^{-3})

CD_{mult} is the drag coefficient multiplier

CD is drag coefficient

v is the vehicle speed (ms^{-1})

$$F_g = m \times Gradient \times g \tag{3.13}$$

$$F_r = CR_2 \times \left(b_{11} \times N_W + CR_1(b_{12} \times m + b_{13} \times v^2)\right) \tag{3.14}$$

CR_1 is the rolling resistance tyre factor

b_{11}, b_{12}, b_{13} are the rolling resistance parameter

CR_2 is the rolling resistance surface factor

$$b_{11} = 37 \times Wheel\ Diameter \tag{3.15}$$

$$b_{12} = \frac{0.064}{Wheel\ Diameter} \tag{3.16}$$

$$b_{13} = \frac{0.012 \times N_W}{(Wheel\ Diameter)^2} \tag{3.17}$$

$$CR_2 = KCr_2(a_0 + \ a_1 \ \times Tdsp + \ a_2 \ \times IRI + \ a_3 \ \times DEF) \tag{3.18}$$

KCr_2 is the calibration factor

Tdsp is the texture depth using sand patch (mm)

a_0, a_1, a_2, a_3 are the model coefficient

IRI is the International Roughness Index (mkm^{-1})

DEF is the Benklemen Beam Rebound Deflection (mm)

$$Lateral\ Force\ on\ Tyre = \frac{F_c}{N_w} \tag{3.19}$$

F_c is Curvature Forces (N)

$$F_c = \max\left(0\ ,\ \frac{(\frac{m\times\ v^2}{R} - m\ \times g\ \times e)^2}{N_W\ \times Cs}\ \times 10^{-3}\right) \tag{3.20}$$

R is the curvature radius (m)

e is superelevation

Cs is tyre stiffness ($kNrad^{-1}$)

$$Normal\ Forces\ on\ Tyre = \ \frac{m\ \times g}{N_W} \tag{3.21}$$

Since there are different types of smart speed breaker, there are also different materials used to build the speed breaker thus there will be different coefficient of friction. Thus, by obtaining the coefficient of friction of the materials, the wear rate experienced by the vehicles’ tyre can be calculated and compared. From the comparison, the impact of tyre wear rate can be studied.

3.8 Conclusion

The SOLIDWORKS software is used for the modelling of the vehicles and to simulate the suspension analysis to obtain the velocity-time graphs. From the velocity-time graphs, a_{rms} and VDV are calculated to investigate the impact on comfortability level of vehicle's occupant. Impacts of fuel consumption rate and tyre wear rate are investigated by calculation based on the formulas.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

After finding out the methods to investigate the possible impact of the smart speed breaker, the parameters needed are collected from trusted online sources. The vehicle models chosen for this research are Honda Civic Dx for car and Kawasaki Ninja 650R for motorcycle. The smart speed breaker models chosen for this research are conventional speed breaker, hydraulic mechanism speed breaker and rack and pinion with helical speed breaker.

By entering the models' parameters into SOLIDWORKS, the suspension graphs are then obtained and the calculation results are obtained by substituting the parameters into the equation. This chapter covers:

1) Suspension analysis
2) Vehicular discomfort
3) Fuel consumption
4) Tyre wear rate

4.2 Suspension Analysis

4.2.1 Simulation Results

In order to obtain the suspension graphs when the vehicles travel through the speed breaker, the parameters were entered into SOLIDWORKS for the simulation results after the modelling has been completed.

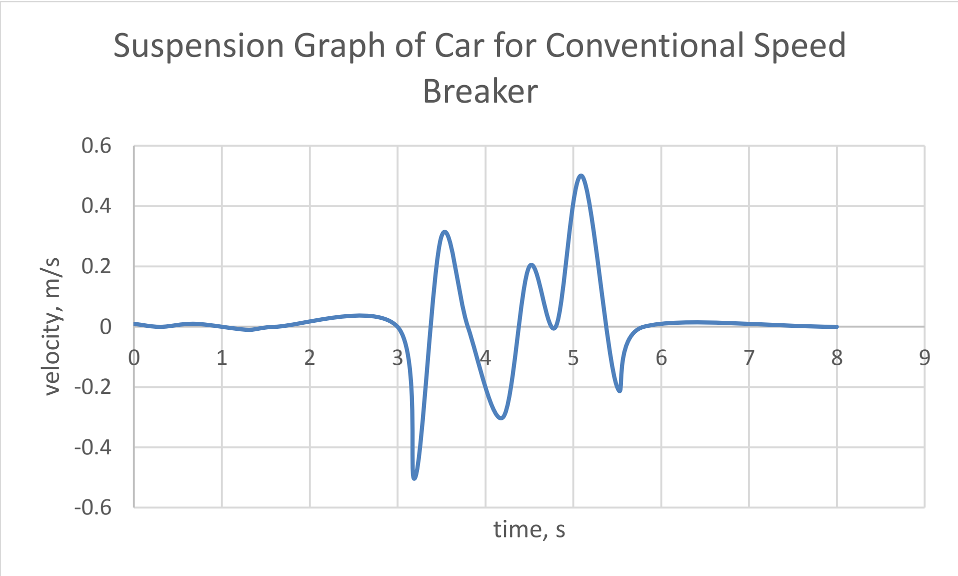


Figure 4.1: Suspension Graph of Car for Conventional Speed Breaker

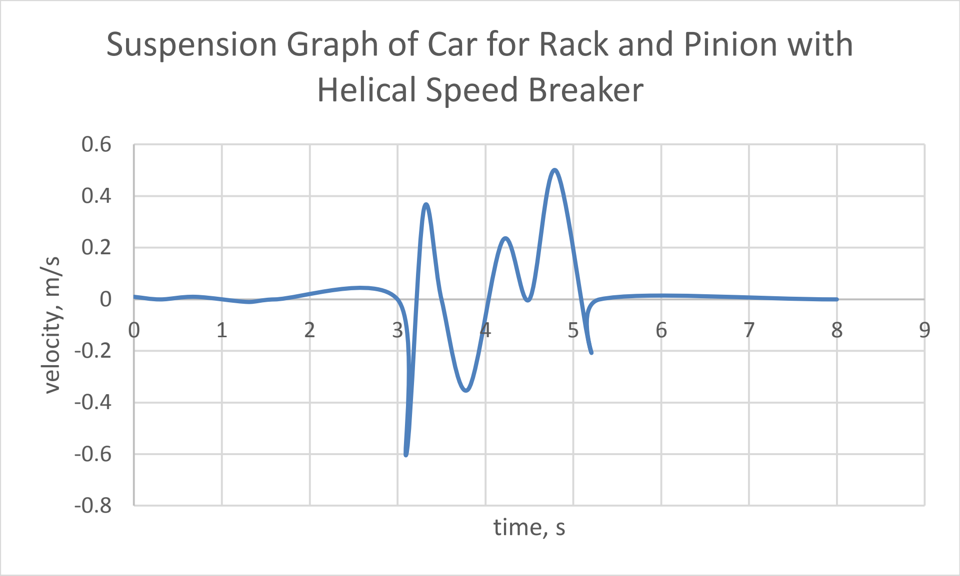


Figure 4.2: Suspension Graph of Car for Rack and Pinion with helical Speed Breaker

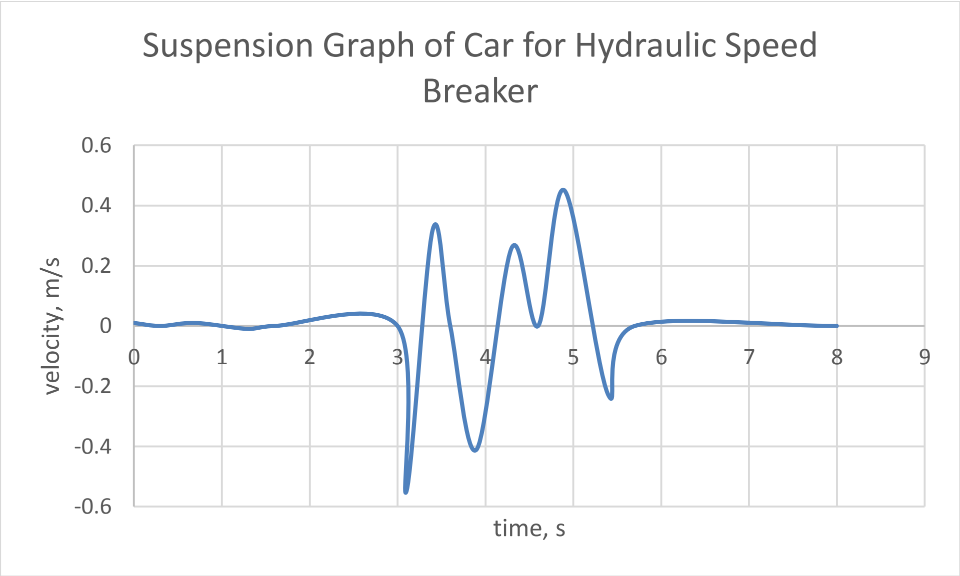


Figure 4.3: Suspension Graph of Car for Hydraulic Speed Breaker

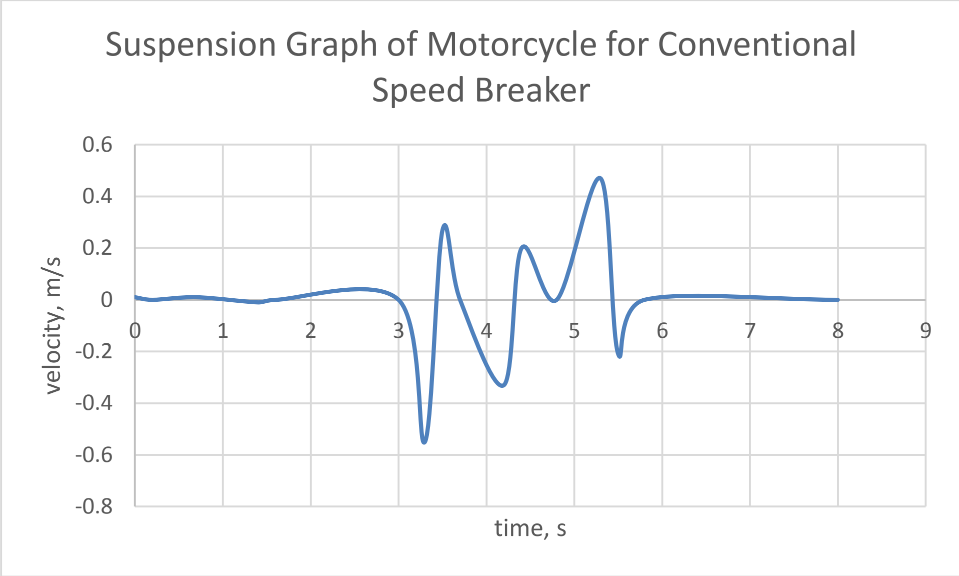


Figure 4.4: Suspension Graph of Motorcycle for Conventional Speed Breaker

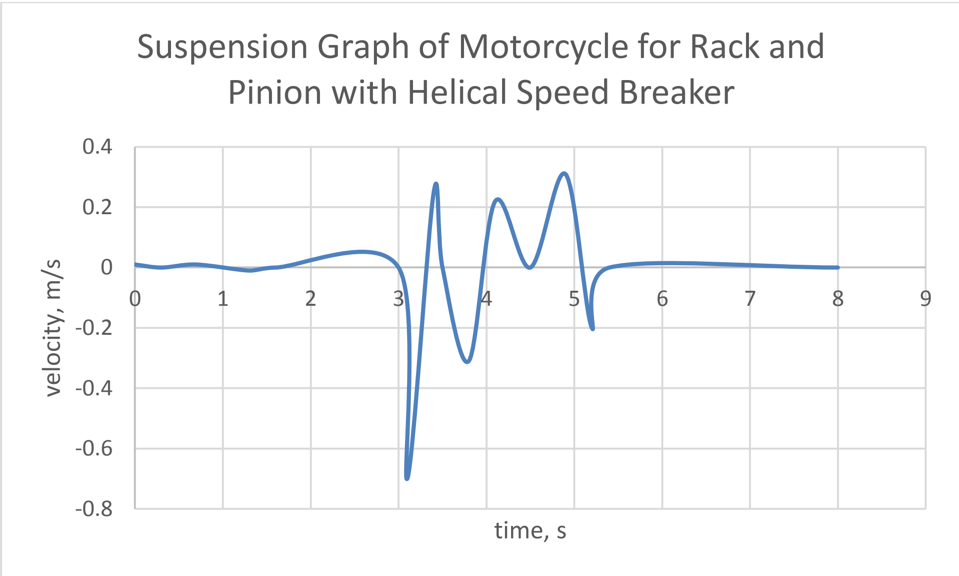


Figure 4.5: Suspension Graph of Motorcycle for Rack and Pinion with Helical Speed Breaker

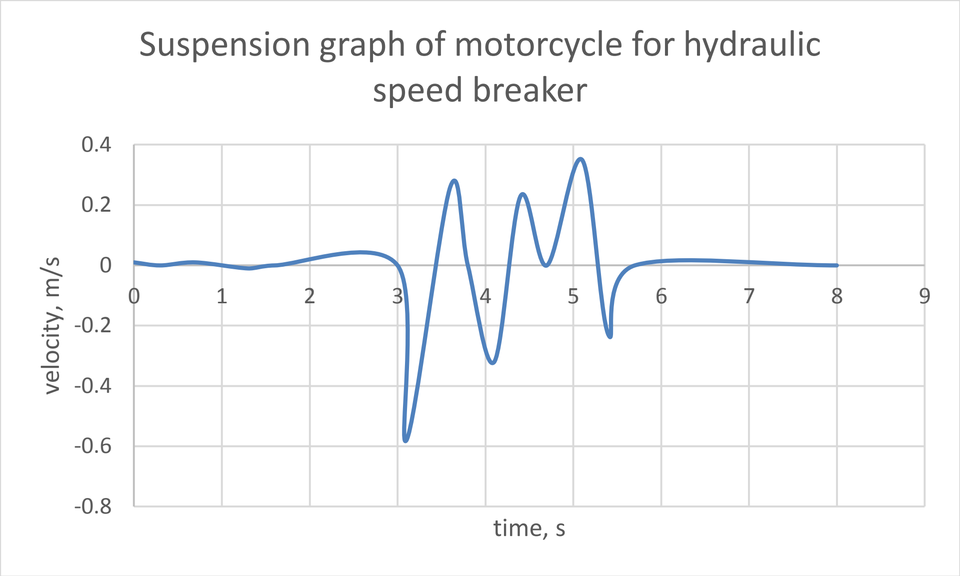


Figure 4.6: Suspension Graph of Motorcycle for Hydraulic Speed Breaker

4.2.2 Discussion on The Suspension Graphs

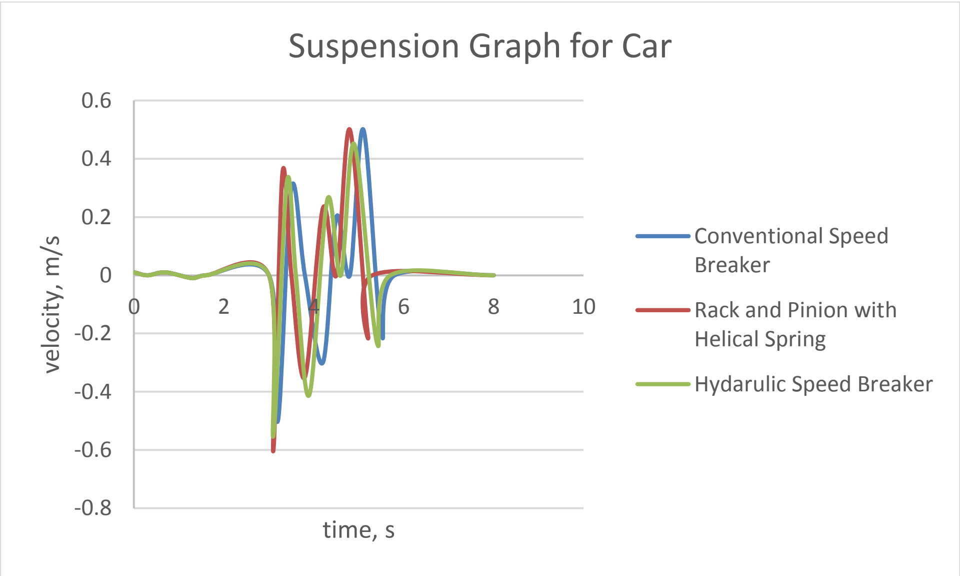


Figure 4.7: Suspension Graph of Car

Based on the suspension graphs of car for different types of speed breakers obtained from the simulation results, it is clear that the shapes of the graphs are the same. However, the velocities of the suspension during certain time are different and this will result in different accelerations experienced by the car. From the graph, we can deduce that the car experienced most acceleration when it is passing through hydraulic speed breaker while the car experienced a little more acceleration when it is passing through rack and pinion with helical speed breaker as compared to conventional speed breaker.

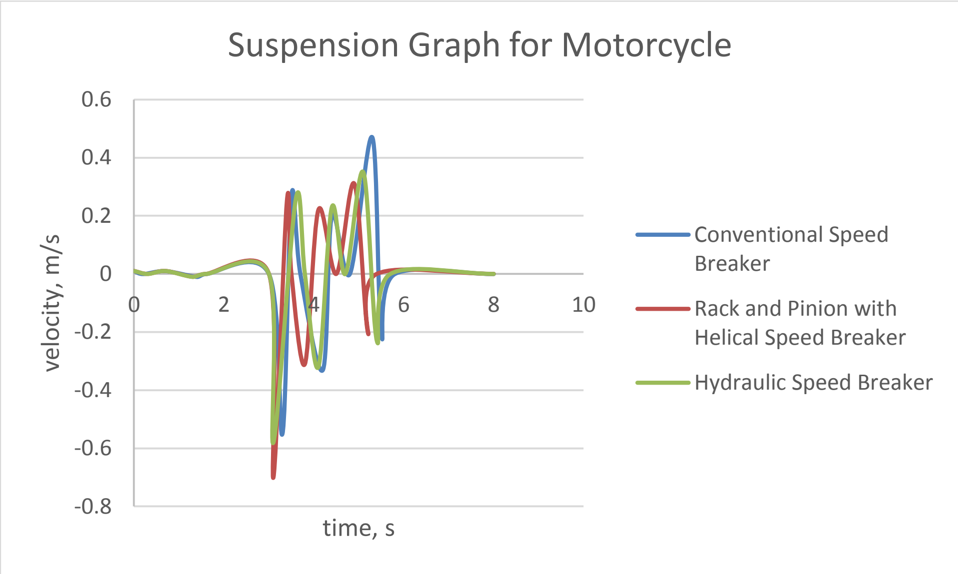


Figure 4.8: Suspension Graph for Motorcycle

As for the suspension graphs of motorcycle for different types of speed breakers, the shapes of the graphs are also the same as compared to each other. However, identical to the suspension graphs of car, the velocities of the suspension during certain time are different which will result in different accelerations. From the graph, we can deduce that the motorcycle also experienced most acceleration when it is passing through hydraulic speed breaker and the motorcycle experienced a little extra acceleration when it is passing through rack and pinion with helical speed breaker as compared to conventional speed breaker. Therefore, it is concluded that the smart speed breaker will affect the suspension of the vehicle however the impact is not that significant as it only produces a small amount of differences in the acceleration of the suspension of the vehicles.

4.3 Vehicular Discomfort

4.3.1 Calculation Results for Vehicular Discomfort

The RMS acceleration of the vehicles and the VDV values are calculated using the values obtained from the suspension graphs simulated.

4.3.1.1 RMS Acceleration for Car for Conventional Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.0333)^2 + (0.0143)^2 + (-0.0333)^2 + (0.0333)^2 + (-2.5)^2 + (2.67)^2 + (-1)^2 + (-0.75)^2 + (1.67)^2 + (-0.67)^2 + (1.67)^2 + (-1.75)^2 + (0.67)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 1.3723ms^{-2}$$

4.3.1.2 RMS Acceleration for Car for Rack and Pinion with Helical Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.0333)^2 + (0.0143)^2 + (-0.0333)^2 + (0.0333)^2 + (-6)^2 + (4.75)^2 + (-1.75)^2 + (-1.167)^2 + (1.45)^2 + (-0.77)^2 + (1.67)^2 + (-1.75)^2 + (2)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 2.41ms^{-2}$$

4.3.1.3 RMS Acceleration for Car for Hydraulic Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.0333)^2 + (0.0143)^2 + (-0.0333)^2 + (0.0333)^2 + (-5.5)^2 + (2.9)^2 + (-1.6)^2 + (-1.367)^2 + (1.675)^2 + (-0.87)^2 + (1.5)^2 + (-1.36)^2 + (0.77)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 1.9895ms^{-2}$$

4.3.1.4 VDV value for Car for Conventional Speed Breaker

$$VDV = (\frac{1}{3}[(-0.0333)^4 + (0.0143)^4 + (-0.0333)^4 + (0.0333)^4 + (-2.5)^4 + (2.67)^4 + (-1)^4 + (-0.75)^4 + (1.67)^4 + (-0.67)^4 + (1.67)^4 + (-1.75)^4 + (0.67)^4)^{\frac{1}{4}}$$

$$VDV = 2.4965ms^{-1,75}$$

4.3.1.5 VDV value for Car for Rack and Pinion with Helical Speed Breaker

$$VDV = (\frac{1}{3}[(-0.0333)^4 + (0.0143)^4 + (-0.0333)^4 + (0.0333)^4 + (-6)^4 + (4.75)^4 + (-1.75)^4 + (-1.167)^4 + (1.45)^4 + (-0.77)^4 + (1.67)^4 + (-1.75)^4 + (2)^4)^{\frac{1}{4}}$$

$$VDV = 4.987ms^{-1,75}$$

4.3.1.6 VDV value for Car for Hydraulic Speed Breaker

$$VDV = (\frac{1}{3}[(-0.0333)^4 + (0.0143)^4 + (-0.0333)^4 + (0.0333)^4 + (-5.5)^4 + (2.9)^4 + (-1.6)^4 + (-1.367)^4 + (1.675)^4 + (-0.87)^4 + (1.5)^4 + (-1.36)^4 + (0.77)^4)^{\frac{1}{4}}$$

$$VDV = 4.2868ms^{-1,75}$$

4.3.1.7 RMS Acceleration for Motorcycle for Conventional Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.05)^2 + (0.02)^2 + (-0.0286)^2 + (0.05)^2 + (-1.833)^2 + (4.1)^2 + (-1.35)^2 + (-0.66)^2 + (2.65)^2 + (-0.5)^2 + (0.94)^2 + (-3.4)^2 + (0.7)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 1.811ms^{-2}$$

4.3.1.8 RMS Acceleration for Motorcycle for Rack and Pinion with Helical Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.0333)^2 + (0.025)^2 + (-0.0333)^2 + (0.0333)^2 + (-7)^2 + (3.167)^2 + (-2.5)^2 + (-1.0333)^2 + (1.767)^2 + (-0.55)^2 + (0.775)^2 + (-1.7)^2 + (1)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 2.39ms^{-2}$$

4.3.1.9 RMS Acceleration for Motorcycle for Hydraulic Speed Breaker

$$a_{RMS} = (\frac{1}{13}[(-0.0333)^2 + (0.025)^2 + (-0.0333)^2 + (0.0333)^2 + (-5.8)^2 + (1.68)^2 + (-1.3)^2 + (-1.067)^2 + (1.833)^2 + (-0.767)^2 + (0.875)^2 + (-1.933)^2 + (0.767)^2)^{\frac{1}{2}}$$

$$a_{RMS} = 1.9152ms^{-2}$$

4.3.1.10 VDV value for Motorcycle for Conventional Speed Breaker

$$VDV = (\frac{1}{3}[(-0.05)^4 + (0.02)^4 + (-0.0286)^4 + (0.05)^4 + (-1.833)^4 + (4.1)^4 + (-1.35)^4 + (-0.66)^4 + (2.65)^4 + (-0.5)^4 + (0.94)^4 + (-3.4)^4 + (0.7)^4)^{\frac{1}{4}}$$

$$VDV = 3.5592ms^{-1,75}$$

4.3.1.11 VDV value for Motorcycle for Rack and Pinion with Helical Speed Breaker

$$VDV = (\frac{1}{3}[(-0.0333)^4 + (0.025)^4 + (-0.0333)^4 + (0.0333)^4 + (-7)^4 + (3.167)^4 + (-2.5)^4 + (-1.0333)^4 + (1.767)^4 + (-0.55)^4 + (0.775)^4 + (-1.7)^4 + (1)^4)^{\frac{1}{4}}$$

$$VDV = 5.4055ms^{-1,75}$$

4.3.1.12 VDV value for Motorcycle for Hydraulic Speed Breaker

$$VDV = (\frac{1}{3}[(-0.0333)^4 + (0.025)^4 + (-0.0333)^4 + (0.0333)^4 + (-5.8)^4 + (1.68)^4 + (-1.3)^4 + (-1.067)^4 + (1.833)^4 + (-0.767)^4 + (0.875)^4 + (-1.933)^4 + (0.767)^4)^{\frac{1}{4}}$$

$$VDV = 4.4442ms^{-1,75}$$

4.3.2 Discussion for Vehicular Discomfort

From the results obtained, the following figure is generated using Microsoft Excel.

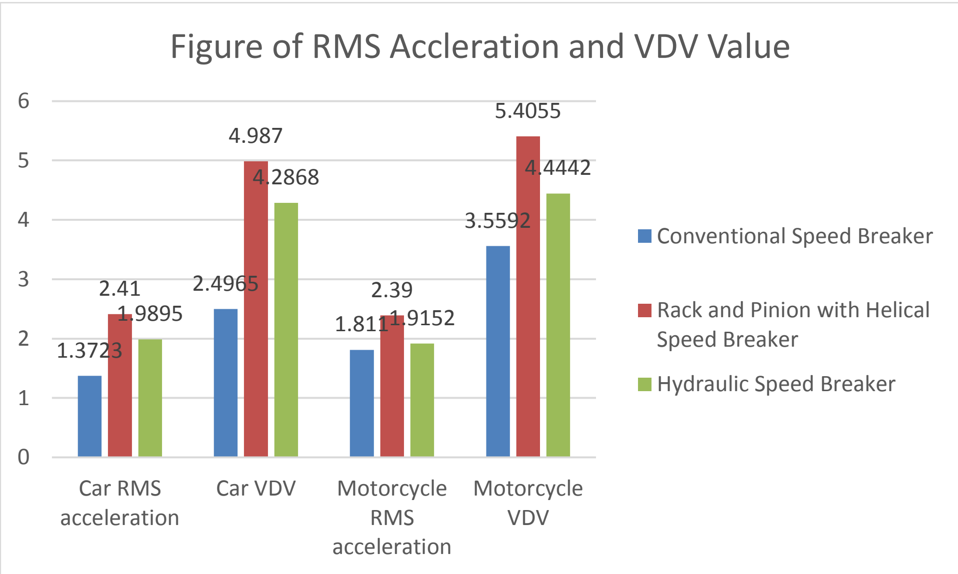


Figure 4.9: Figure of RMS Acceleration and VDV value

By comparing the calculated results with the RMS table for comfort level, the passenger of the car is found to be uncomfortable when it is passing through conventional speed breaker while the passenger of the car is found to be highly uncomfortable when it is passing through the hydraulic speed breaker and the passenger of the car is found to be extremely uncomfortable when it is passing through the rack and pinion with helical speed breaker. As for the VDV value, none of the VDV calculated reaches $8.5ms^{-1,75}$ which will trigger medium discomfort.

As for the motorcycle part, the user of the motorcycle will be highly uncomfortable when it is passing through the hydraulic speed breaker while the use of the motorcycle will be extremely uncomfortable when it is passing through the rack and pinion with helical speed breaker. As for the VDV value, it is same with the results of the car which is none of the VDV calculated reaches $8.5ms^{-1,75}$.

From Figure 4.7, it is clear that hydraulic speed breaker will causes more discomfort compare to conventional speed breaker while rack and pinion with helical speed breaker will causes most discomfort compare to the other speed breakers. Therefore, it is proven that the smart speed breakers will bring more discomfort to the users than conventional speed breaker.

4.4 Fuel Consumption

4.4.1 Calculation Results for Fuel Consumption

4.4.1.1 Fuel Consumption for Car

The car model used in this research is Honda Civic Dx, which has mass of 1239kg, and the coefficient of friction of the conventional speed breaker is 0.7

$$F = 1239 \times 0 - 0.7(1239 \times 9.81)$$
$$F = -8508.213\ N$$

while F=ma, therefore

$$|-8508.213| = 1239 \times a$$
$$a = 6.867ms^{-2}$$

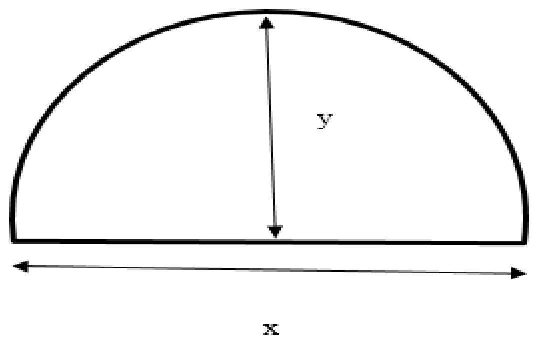


Figure 4.10: Sample Figure of Speed Breaker

$$Gradient\ for\ hydraulic\ speed\ breaker = \frac{y}{\frac{x}{2}}$$

$$Gradient\ for\ hydraulic\ speed\ breaker = \frac{0.12}{\frac{0.24}{2}}$$

$$Gradient\ for\ hydraulic\ speed\ breaker = 1$$

$$Gradient\ for\ rack\ and\ pinion\ speed\ breaker = \frac{y}{\frac{x}{2}}$$

$$Gradient\ for\ rack\ and\ pinion\ speed\ breaker = \frac{0.05}{\frac{0.1}{2}}$$

$$Gradient\ for\ rack\ and\ pinion\ speed\ breaker = 1$$

Since, the conventional speed breaker can have different dimension, the gradient of conventional speed breaker is assumed to be same as the smart speed breaker to ensure fair comparison

$$P_b = (105.47 \times 5.56) + (5.4276 \times 5.56^2) + (0.2670 \times 5.56^3) + (1.239 \times 5.56)\ (6.867 + 9.81 \times 1)$$

$$P_b = 914.98W$$

$$FCR = \frac{1(0.164 \times \frac{6000}{60} \times 1.7 + \frac{\left(\frac{0.915}{0.88} + 0.75\right)}{0.4})}{43.7}$$

$$FCR = 0.7404gs^{-1}$$

As for hydraulic and rack and pinion with helical speed breakers, since the coefficient of friction for both the speed breakers are the same which is 0.8 and the gradients are also the same which is 1. The calculation is as follows

$$F = 1239 \times 0 - 0.8(1239 \times 9.81)$$
$$F = -9723.672\,N$$

while F=ma, therefore

$$|-9723.672| = 1239 \times a$$
$$a = 7.848ms^{-2}$$

$$P_b = (105.47 \times 5.56) + (5.4276 \times 5.56^2) + (0.2670 \times 5.56^3) + (1.239 \times 5.56)\,(7.848 + 9.81 \times 1)$$
$$P_b = 921.7348W$$

$$FCR = \frac{1(0.164 \times \frac{6000}{60} \times 1.7 + \frac{\left(\frac{0.922}{0.88} + 0.75\right)}{0.4})}{43.7}$$
$$FCR = 0.7408gs^{-1}$$

4.4.1.2 Fuel Consumption for Motorcycle

The motorcycle model used in this research is Kawasaki Ninja 650R which has mass of 186kg and the coefficient of friction of the conventional speed breaker is 0.7

$$F = 186 \times 0 - 0.7(186 \times 9.81)$$
$$F = -1277.262\,N$$

while F=ma, therefore

$$|-1277.262| = 186 \times a$$
$$a = 6.867ms^{-2}$$

$$P_b = (53.47 \times 5.56) + (3.326 \times 5.56^2) + (1.3 \times 5.56^3) + (0.186 \times 5.56)(6.867 + 9.81 \times 1)$$

$$P_b = 640.802W$$

$$FCR = \frac{1(0.108 \times \frac{6000}{60} \times 1.5 + \frac{\left(\frac{0.641}{0.9} + 0.77\right)}{0.43})}{43.7}$$

$$FCR = 0.44959gs^{-1}$$

As for hydraulic and rack and pinion with helical speed breakers, since the coefficient of friction for both the speed breakers are the same which is 0.8 and the gradients are also the same which is 1. The calculation is as follows

$$F = 186 \times 0 - 0.8(186 \times 9.81)$$

$$F = -1459.728\,N$$

while F=ma, therefore

$$|-1459.728| = 186 \times a$$

$$a = 7.848ms^{-2}$$

$$P_b = (53.47 \times 5.56) + (3.326 \times 5.56^2) + (1.3 \times 5.56^3) + (0.186 \times 5.56)(7.848 + 9.81 \times 1)$$

$$P_b = 641.817W$$

$$FCR = \frac{1(0.108 \times \frac{6000}{60} \times 1.5 + \frac{\left(\frac{0.642}{0.9} + 0.77\right)}{0.43})}{43.7}$$

$$FCR = 0.44965gs^{-1}$$

4.4.2 Discussion for Fuel Consumption

From the results obtained, the following figure is generated using Microsoft Excel.

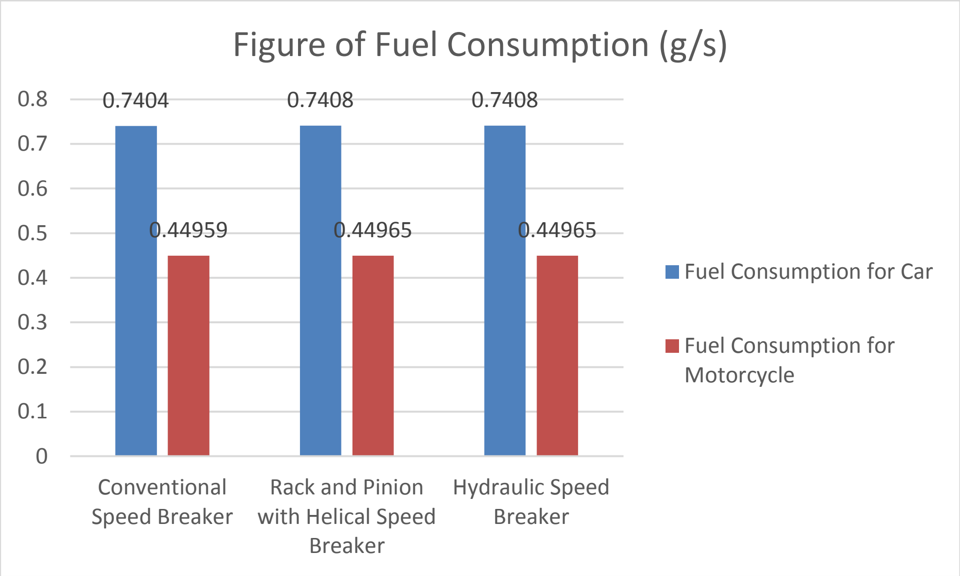


Figure 4.11: Figure of Fuel Consumption

From the calculated results, it is proven that the fuel consumption of a vehicle passing through smart speed breakers is indeed higher than the fuel consumption of a vehicle passing through conventional speed breaker. However, the difference is very small can be said that to be insignificant especially for the fuel consumption of a motorcycle travelling through the speed breakers. From Figure 4.9, it is clear that there are slight differences between the fuel consumption for car while travelling through smart speed breakers and conventional speed breaker while as for the differences in the fuel consumption for motorcycle while travelling through smart speed breakers and conventional speed breaker is very hard to be noticed as the differences is too small.

4.5 Tyre Wear Rate

4.5.1 Calculation Results for Tyre Wear Rate

4.5.1.1 Fuel Consumption for Car

$$Normal\ Forces\ on\ Tyre = \frac{1239 \times 9.81}{4}$$

$$Normal\ Forces\ on\ Tyre = 3038.6475N$$

Malaysia air mass density is given as 0.924kgm^{-3}

$$F_a = 0.5 \times 0.924 \times 0.9 \times 0.32 \times 2.3 \times 5.56^2$$

$$F_a = 9.4605N$$

$$F_g = 1239 \times 1 \times 9.81$$

$$F_g = 12154.59N$$

$$F_c = \max\left(0, \quad \frac{\left(\frac{1239 \times 5.56^2}{3000} - 1239 \times 9.81 \times 0\right)^2}{4 \times 43} \times 10^{-3}\right)$$

$$F_c = \max(0,\ 0.07423 \times 10^{-3})$$

$$F_c = 0.07423 \times 10^{-3}N$$

$$b_{11} = 37 \times 0.508 = 18.796$$

$$b_{12} = \frac{0.064}{0.508} = 0.126$$

$$b_{13} = \frac{0.012 \times 4}{0.508^2} = 0.186$$

IRI for conventional speed breaker is 2.5mkm^{-1}

$$CR_2 = 0.5(0.5 + 0.02 \times 1.3 + 0.1 \times 2.5 + 0 \times 1)$$

$$CR_2 = 0.388$$

$$F_r = 0.388 \times \left(18.796 \times 4 + 1(0.126 \times 1239 + 0.186 \times 5.56^2)\right)$$

$$F_r = 91.9746N$$

$$Circumferentiol\ Force\ on\ Tyre = \frac{(1 + 0 \times 0) \times (9.5605 + 91.9746 + 12154.59)}{4}$$

$$Circumferentiol\ Force\ on\ Tyre = 3064.0313N$$

$$Lateral\ Force\ on\ Tyre = \frac{0.07423 \times 10^{-3}}{4}$$

$$Lateral\ Force\ on\ Tyre = 0.01856 \times 10^{-3}N$$

$$Tyre\ Energy = \frac{(3064.031)^2 + (0.01856 \times 10^{-3})^2}{3038.6475}$$

$$Tyre\ Energy = 3089.6265$$

$$Total\ change\ in\ Tread\ Wear = 0.01747 + 0.001 \times 3089.6265$$

$$Total\ change\ in\ Tread\ Wear = 3.1071$$

$$NT = \frac{3.1071}{10 \times 14}$$

$$NT = 0.02219$$

$$TWR = \frac{4 \times 0.02219}{2.4}$$

$$TWR = 0.03698\%/km$$

IRI for smart speed breaker is 2.86mkm^{-1}

$$CR_2 = 0.5(0.5 + 0.02 \times 1.3 + 0.1 \times 2.86 + 0 \times 1)$$

$$CR_2 = 0.406$$

$$F_r = 0.406 \times \left(18.796 \times 4 + 1(0.126 \times 1239 + 0.186 \times 5.56^2)\right)$$

$$F_r = 96.2415N$$

$$Circumferentiol\ Force\ on\ Tyre = \frac{(1 + 0 \times 0) \times (9.5605 + 96.2415 + 12154.59)}{4}$$

$$Circumferentiol\ Force\ on\ Tyre = 3065.098N$$

$$Tyre\ Energy = \frac{(3065.098)^2 + (0.01856 \times 10^{-3})^2}{3038.6475}$$

$$Tyre\ Energy = 3091.7787$$

$$Total\ change\ in\ Tread\ Wear = 0.01747 + 0.001 \times 3091.7787$$

$$Total\ change\ in\ Tread\ Wear = 3.1092$$

$$NT = \frac{3.1092}{10 \times 14}$$

$$NT = 0.02221$$

$$TWR = \frac{4 \times 0.02221}{2.4}$$

$$TWR = 0.03702\%/km$$

4.5.1.2 Fuel Consumption for Motorcycle

$$Normal\ Forces\ on\ Tyre = \frac{186 \times 9.81}{4}$$

$$Normal\ Forces\ on\ Tyre = 456.165N$$

Malaysia air mass density is given as 0.924kgm^{-3}

$$F_a = 0.5 \times 0.924 \times 0.8 \times 0.3 \times 1.2 \times 5.56^2$$

$$F_a = 4.1132N$$

$$F_g = 186 \times 1 \times 9.81$$

$$F_g = 1824.66N$$

$$F_c = \max(\,0\,, \quad \frac{(\frac{186 \times 5.56^2}{3000} - 186 \times 9.81 \times 0)^2}{2 \times 43} \times 10^{-3})$$

$$F_c = \max(\,0\,,\ 0.02229 \times 10^{-3})$$

$$F_c = 0.02229 \times 10^{-3} N$$

$$b_{11} = 37 \times 0.4572 = 16.9164$$

$$b_{12} = \frac{0.064}{0.4572} = 0.14$$

$$b_{13} = \frac{0.012 \times 2}{0.4572^2} = 0.1148$$

IRI for conventional speed breaker is 2.5mkm^{-1}

$$CR_2 = 0.5(0.5 + 0.02 \times 1.3 + 0.1 \times 2.5 + 0 \times 1)$$

$$CR_2 = 0.388$$

$$F_r = 0.388 \times \left(16.9164 \times 2 + 1(0.14 \times 186 + 0.1148 \times 5.56^2)\right)$$

$$F_r = 24.6076N$$

$$Circumferentiol\ Force\ on\ Tyre = \frac{(1 + 0 \times 0) \times (4.1132 + 24.6076 + 1824.66)}{2}$$

$$Circumferentiol\ Force\ on\ Tyre = 926.6904N$$

$$Lateral\ Force\ on\ Tyre = \frac{0.02229 \times 10^{-3}}{2}$$

$$Lateral\ Force\ on\ Tyre = 0.01115 \times 10^{-3} N$$

$$Tyre\ Energy = \frac{(926.6904)^2 + (0.01115 \times 10^{-3})^2}{456.165}$$

$$Tyre\ Energy = 1882.5537$$

$$Total\ change\ in\ Tread\ Wear = 0.00639 + 0.0005 \times 1882.5537$$

$$Total\ change\ in\ Tread\ Wear = 0.9477$$

$$NT = \frac{0.9477}{10 \times 11}$$

$$NT = 0.008615$$

$$TWR = \frac{2 \times 0.008615}{2.4}$$

$$TWR = 0.007179\%/km$$

IRI for smart speed breaker is 2.86mkm^{-1}

$$CR_2 = 0.5(0.5 + 0.02 \times 1.3 + 0.1 \times 2.86 + 0 \times 1)$$

$$CR_2 = 0.406$$

$$F_r = 0.406 \times \left(16.9164 \times 2 + 1(0.14 \times 186 + 0.1148 \times 5.56^2)\right)$$

$$F_r = 25.7492N$$

$$Circumferentiol\ Force\ on\ Tyre = \frac{(1 + 0 \times 0) \times (4.1132 + 25.7492 + 1824.66)}{2}$$

$$Circumferentiol\ Force\ on\ Tyre = 927.2612N$$

$$Tyre\ Energy = \frac{(927.2612)^2 + (0.01115 \times 10^{-3})^2}{456.165}$$

$$Tyre\ Energy = 1884.8735$$

$$Total\ change\ in\ Tread\ Wear = 0.00639 + 0.0005 \times 1884.8735$$

$$Total\ change\ in\ Tread\ Wear = 0.9488$$

$$NT = \frac{0.9488}{10 \times 11}$$

$$NT = 0.008625$$

$$TWR = \frac{2 \times 0.008625}{2.4}$$

$$TWR = 0.007188\%/km$$

4.5.2 Discussion for Fuel Consumption

From the results obtained, the following figure is generated using Microsoft Excel.

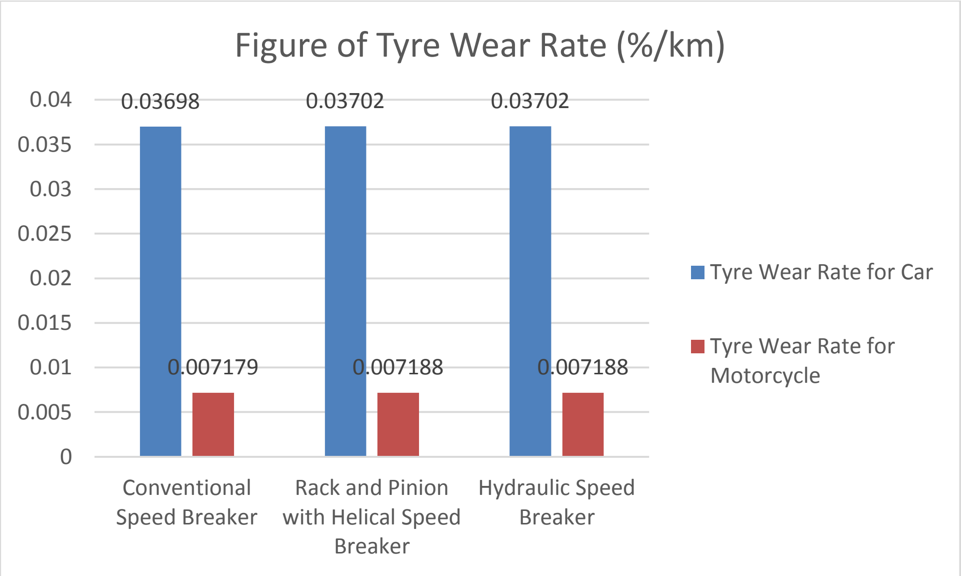


Figure 4.12: Figure of Tyre Wear Rate

From the calculated results, it is proven that the tyre wear rate of a vehicle passing through smart speed breakers is indeed higher than the tyre wear rate of a vehicle passing through conventional speed breaker. However, the difference is very small can be said that to be insignificant especially for the tyre wear rate of a motorcycle travelling through the speed breakers. From Figure 4.10, it is very hard to notice the slight differences between the tyre wear rate for car while travelling through smart speed breakers and conventional speed breaker and the situation is the same for the tyre wear rate for motorcycle while travelling through smart speed breakers and conventional speed breaker.

4.6 Conclusion

The results showed that the traffic energy harvester based speed breakers did indeed brings negative impacts to the comfortability level of vehicle occupants, fuel consumption rate and the tyre wear rate. However, the impacts on the fuel consumption rate and tyre wear rate are not so significant since they only increased slightly.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

After acquiring all the results and undergo analysis, the conclusion is drawn. This chapter covers:

1) Conclusion
2) Recommendations

5.2 Conclusion

As a conclusion of the analysis on the results, the harnessing of traffic energy by using smart speed breaker does indeed causes some impacts, which are impacts on the vehicle's suspension system, vehicular discomfort of the users, increase of fuel consumption and increase of tyre wear rate. For the impacts on vehicle's suspension system, the shape of the suspension graph is the same indicates the ways of affecting the vehicle's suspension system by the smart speed breaker is the same as the conventional speed breaker and the differences in suspension graph is not that huge. As for the impacts on the increase of fuel consumption, it is very insignificant as the increase is only $0.0004gs^{-1}$ for car and $0.00006gs^{-1}$ for motorcycle, it is very small as compared to what the vehicle used during daily travels. Apart from that, the impacts on the increase of tyre wear rate is also very insignificants as the increase is only

0.00004%/km for car and 0.000009%/km for motorcycle. This kind of small increase will not really affect the lifetime of a tyre. However, a different story is on the impacts of vehicular discomfort, the smart speed breakers causes the vehicle users to be more uncomfortable as compared to the conventional speed breaker especially for rack and pinion with helical speed breaker which causes extreme discomfort when vehicle travels through it.

Thus, it is proven that the smart speed breakers will cause these four possible impacts and by comparing both rack and pinion with helical and hydraulic speed breakers, hydraulic speed breaker will produce smaller negative impacts, which is better if it can produce the same amount of electric power as the rack and pinion with helical speed breakers. Therefore, from the results obtained, the smart speed breakers can be said to be practical to be implemented in our daily lives.

5.3 Recommendations

This research is based on the focus of investigating the possible impacts of smart speed breakers by using simulation by software. Therefore, most of the parameters used are ideal parameters, which are not the case in real life. Thus, it is recommended that the real life model of the speed breakers and vehicle is used to produce actual results in real life. This will provide the most accurate results, which may prove the simulation results to be wrong. Besides that, more advanced software can be used to investigate the impacts in order to obtain results that are more accurate. Finally, a few more types of vehicles and smart speed breakers should be modelled to provide a better comparison of the impacts of harnessing traffic energy using smart speed breakers.

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APPENDICES

APPENDIX A: Table of RMS Acceleration Correspond to Comfort Level

Table 2.1: RMS Acceleration Correspond to Comfort Level

RMS Acceleration (ms^{-2})	Comfort Level
Lower than 0.315	Comfortable
Between 0.315 and 0.63	A bit uncomfortable
Between 0.5 and 1	Middling uncomfortable
Between 0.8 and 1.6	Uncomfortable
Between 1.25 and 2.5	Highly uncomfortable
Higher than 2	Extremely uncomfortable

APPENDIX B: Table of Parameters Used for Validation of Vehicle

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: Table of Parameters Used for Validation of Vehicle

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

Coefficient	≤ 2500 kg		> 2500 kg	
	Bias	Radial	Bias	Radial
$a0$	30	43	8.8	0
$a1$	0	0	0.088	0.0913
$a2$	0	0	−0.0000225	−0.0000114

Source: Bennett and Greenwood (2003b)

Table 4-11. Final parameters for rolling resistance coefficient ($CR2$) model.

Surface Type	≤ 2500 kg				> 2500 kg			
	$a0$	$a1$	$a2$	$a3$	$a0$	$a1$	$a2$	$a3$
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)	$Kcr2$	CD	AF (m^2)	WD	Tire Type	$CR1$	$b11$	$b12$	$b13$	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)