Investigate the impact of tyre inflation pressure on road vehicle operation: a case study of the Wonji-shoa sugar factory

Joher Jeyilan Seid

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Material Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

August, 2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master's Thesis entitled "INVESTIGATE THE IMPACT OF TYRE INFLATION PRESSURE ON ROAD VEHICLE OPERATION: A CASE STUDY OF THE WONJI-SHOA SUGAR FACTORY" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "INVESTIGATE THE IMPACT OF TYRE INFLATION PRESSURE ON ROAD VEHICLE OPERATION: A CASE STUDY OF THE WONJI-SHOA SUGAR FACTORY" prepared under my guidance by Joher Jeyilan Seid submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Automotive Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

____________________________	________________	______________
Major Advisor	Signature	Date

APPROVAL

I, the advisors of the thesis entitled “INVESTIGATE THE IMPACT OF TYRE INFLATION PRESSURE ON ROAD VEHICLE OPERATION: A CASE STUDY OF THE WONJI-SHOA SUGAR FACTORY” and developed by Joher Jeyilan Seid, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Joher Jeyilan read and evaluated the thesis entitled “INVESTIGATE THE IMPACT OF TYRE INFLATION PRESSURE ON ROAD VEHICLE OPERATION: A CASE STUDY OF THE WONJI-SHOA SUGAR FACTORY” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Automotive Engineering.

Chair Person	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

TABLE OF CONTENT

CONTENTS **PAGE**

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURE

ACRONYMS

A/C	Air Condition
RTIs	Road Traffic Injuries
GDP	Growth Domestic Product
TPMS	Tyre Pressure Monitoring Systems
OEM	Original Equipment Manufacturer
ABS	Antilock Braking System
CPU	Central Processing Unit
GPS	Global Positioning System
CP	Cornering Power
FESD	Field Equipment Service Division
MERF	Mean Equivalent Rolling Force
NEDC	North East Development Commission
QSS-TB	Quasi Static Simulation Toolbox
DOF	Degree Of Freedom
RRC	Rolling Resistance Coefficient
ODE	Ordinary Differential Equations
FT	Tractive Force
FN	Normal Force
FRR	Rolling Resistance Force

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ABSTRACT

A tyre is an important part of a road vehicle which transfers static and dynamic forces of a vehicle to the road. The load on the tyre is supported by forcefully filed compressed air and its body structure. The aim of this study was to investigate the impact of tyre inflation pressure on vehicle operations at the Wonji Shoa sugar factory. Different works of literature are reviewed to disclose the contribution of other scholars concerning the impact of tyre inflation pressure on vehicle operation. Mat lab Simulink software, Quasi-Static Simulation Toolbox (QSS TB), vehicles with 205/70R16 tyres and Microsoft Excel are the materials used in this study work. Data from Wonji Shoa sugar factory vehicles are collected by direct interview. Mathematical models and simulations are developed in Mat lab Simulink and QSS TB to capture the influence of tyre inflation pressure on vehicle operation from the viewpoint of fuel consumption, vehicle handling and ride comfort. The bouncing acceleration of the sprung mass is higher at higher tyre inflation pressure and the bouncing displacement of the sprung mass becomes higher at lower tyre inflation pressure results are obtained. It was also revealed that fuel consumption was increased by about 4.9% as tyre inflation pressure reduced from 3 to 2 bars. From the data collected, more than 73% of Wonji Shoa sugar factory vehicles are operating with at least one tyre deflated more than 25%. Therefore Wonji Shoa sugar factory loses about 207,324.5 liters of fuel per year in addition to 4,231,111 liters of planned fuel due to incorrect tyre inflation pressure. To tackle this problem tyre pressure monitoring system was recommended to enable live tyre condition monitoring.

Keywords: Tyre inflation pressure, Mat lab simulation, QSS TB library, Car model, Degree of freedom, Vehicle operation, Vehicle handling, Ride comfort

CHAPTER ONE
INTRODUCTION

1.1. Background

Tyre is an important parts of a road vehicle. It was conveyed all static and dynamic forces to the road through a very small contact patch. Tyre was made of rubber and a series of synthetic materials such as fiber, textile, and steel cords. It possesses three distinct structural such as rubber matrix, cords and steel beads. A rubber matrix which contains the air and provides abrasion resistance and road grip. A cord (textile, steel) provides a tensile reinforcement for the rubber and carry most of the load applied to the tyre. Steel bead was circumferentially connected a tyre to the wheel of a car (Freund & Bray, 2009). It was made up of the body constituents such as inner liner, body plies, bead bundle, belts, sidewalls, and tread. Bead bundle is a ring of high strength steel cable coated with rubber which provides the strength a tyre needs to stay seated on wheel rim and transfer forces from a tyre to its rim. Inner layers are made up of plies of different fabrics such as polyester cord. A tope layers of a tyre is called plies. Cap plies are polyester fabric that help hold everything in place. Inner liner is special compounds of tyre used to make gastight and protects loses of air pressure from tubeless tyre. A tyre belt is used to reinforce the body plies. Belt reduces squirm to improve tread wear and resist damage from impacts and penetration. A tyre carcass was built of rubber glazed steel or other high strength cords tied to bead bundles. It supports a tension forces generated by tyre air pressure. A number of carcass plies on a tyre often describes the strength of a tyre. Side wall of tyre protects a tyre body plies, provide lateral stability and protecting air pressure escaping. Tyre tread is a part of tyre that comes in contact with the road and made up of a mixture of different kinds of natural and synthetic rubbers. A tyre tread patterns were made up of tread lugs and tread voids. A lug (slot/block/void) is sections of rubber that make contact with the road and void is spaces located between a lugs.

A tyre was supported a vehicles load by using compressed air to create tension in its carcass plies. A carcass are a series of cords that have a high tension strength, and almost no compression strength. Besides vertical load carrying, a tire must transmit acceleration, braking, and cornering forces to the road. These forces are transmitted to the rim in a similar manner. Acceleration and braking forces also depend on the friction between the rim and the bead. A tyre also acts as a spring between the rim and the road. Tyres are divided in to radial and non-radial depending on the angle between carcass metallic cords and the tyre plane. Each type of tyre construction has its own set of characteristics that are the key to its performance. A radial tyre is constructed with reinforcing steel cable belts that are assembled in parallel and run side to side, from one bead to another bead at an angle of 90^0 to the circumferential centerline of the tire. This makes the tire more flexible radially, which reduces rolling resistance and improves cornering capability. Non radial (Bias or cross-plies) in plies are layered diagonal from one bead to other bead at about an angle. The ends of the plies are wrapped around the bead wires, anchoring them to the rim of the wheel.

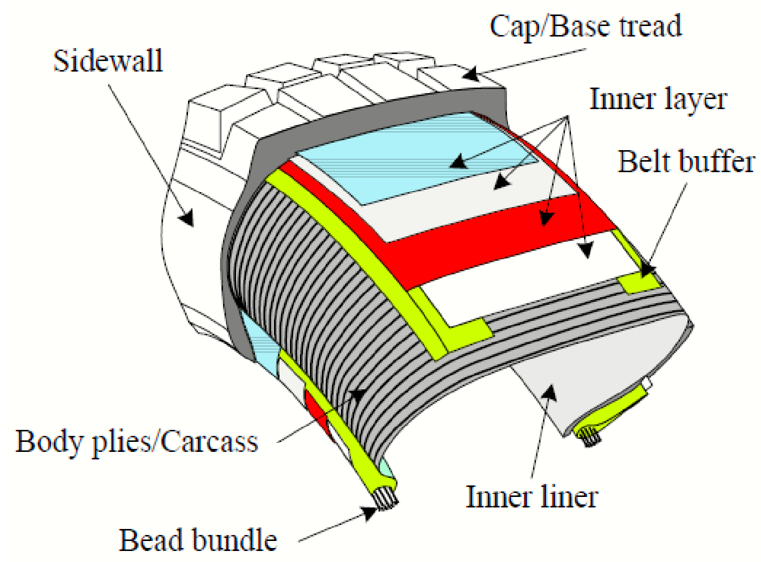

Figure 1.1. Radial tyre components and its arrangement (Reza N., 2008)

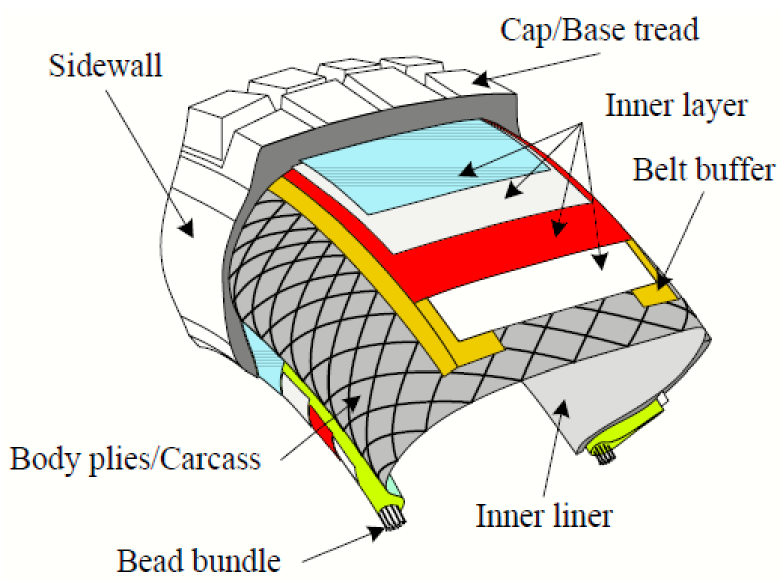

Figure 1.2. Bias or cross plies tyre components and arrangement(Reza N., 2008)

Transportation is a back bone of any economic development for a countries of the world which used for transporting goods and passengers from place to place. Vehicles are one of the most important means of transportation which easily moves on different types of road and weather condition. Driving Safety, vehicle handling and controlling, lack of occupant comfort, fuel consumption and maintenance cost as function of deterioration, manufacturing defect and operation condition lead to vehicles components failure. This is an important things to be controlled and improved to enhance safety, comfort and cost of transportation. Different scholars had being studded and developed a numbers of improvement on road vehicle to enhance better comfort and safety and cheaper operational and maintenance costs.

Road accident and economic loses may happened because of vehicle technical problems, the pedestrian way of moving aside the road, drivers' lack of knowledge, skill and attitude required to drive the vehicle. But skill and attitude required driving the vehicle and the pedestrian's way of moving aside the road is minimized by providing training and legal legislation. On the other hand the vehicle technical problem is not as such easy to make free from road accident due to system of the vehicle directional controlling mechanisms come upon with some kinds of failures as a function of time due to manufacturing and maintenance defect, operating harshness, depreciation and etc. So if this failure will not monitored and corrected or controlled, the vehicle may failed and results in catastrophic accidents which results in a loss of life's and properties. Monitoring of vehicle technical condition may be carried out by visual inspection while vehicles at stationary position by smelling unusual odor that disseminated from defected machine elements, by hearing noisy sound received from defected parts or system and by installing some kind of electronically controlled monitoring mechanisms while the vehicle driving or stopped. Over load, loses of pressure, wrong tyre size and construction and tyre wear are some of the tyre defect which affects tyre performance.

Increasing fuel price, harm full gases emission, driving stability and ride comforts are the main driving factors for continuous development of automotive industry from time to time. The major objective of vehicle power transmission design is minimizing of fuel consumption, emission and component costs while ensuring adequate drivability and reliability performance over specified drive cycles. These improvements are measured and certified the car makers by cross checking with either software simulation data or laboratory tests. A quality and standard assuring through a mathematical modeling, simulation and laboratory testing institution currently on work to check and certify a road vehicle operation requires improvement. A laboratory test services used to measure vehicle tyre dynamic performance is not yet given in our country research institution. Because of this short coming a different operational quality insuring of dynamic vehicle tyre was performed by different software modeling and simulation and the results of the analysis was compared with quality assurance parameters set by different world class certified quality assurance institution.

Fundamentally they are two approaches for simulating longitudinal vehicle motions. These are forward dynamic and backward quasi-static approaches. The forward dynamic approach typically consists of dynamic models consisting of a set of ordinary differential equations (ODEs). This approach uses a driver's commands such as throttle, brakes, and steering wheel, as inputs to calculate the vehicle dynamics. Because this approach requires a control system for tracking a drive cycle it is more suitable to control design and validation purposes, once that the overall powertrain architecture has been correctly sized.

But backward quasi-static simulations use speeds and accelerations provided by the drive cycle. The quasi-static simulations essentially to check whether or not all subsystems that composes powertrain are able to provide the required actions within their physical and operative limits. A torque and speed required at the wheels is computed from the speed profile defined in the drive cycle. The computation then goes backward through the driveline chain by computing the generating variables that finally produce the given torque and speed. This model is used to compute the required torque, speed and acceleration at the wheels and a computation goes back through a driveline up to estimate the amount of primary energy (chemical, electrical or both) that must be used to accomplish such a drive cycle.

Therefore tyre is an important component of a road vehicle that determines the operation performance of road vehicle. It serves as transmitting means of tractive, braking and steering forces between vehicle and road. To do this a tyres needs to be erected by material structure made from and forcefully filled compressed pneumatic air. But a forcefully filled pneumatic air of a tyre may be drop blow or filled above recommended amount of air to erect the tyre and this situation is referred to as wrong tyre inflation pressure.

1.2. Statement of the problem

The profit of any profit seeking companies are governed by the way they control their operational loses. One of the operation carried out in sugar factory is input and out material transportation. These vehicles are serve as a means of transportation and field work supervision. To do this the company utilizes different vehicles. But these vehicles are exposed to different losses when transporting those commodities. These loses are exited from different sources in the forms of maintenance and operational cost introduced by premature failure of its components like tyres.

Operational cost of a vehicle in sugar industry to produce one kilogram of sugar in Ethiopia were increasing from time to time. This increase vehicle operational cost makes dramatically raising of sugar production cost in recent few years. Vehicle maintenance and operational cost requirement of Wonji-shoa sugar factory has been increasing from year to year. The money required for sugar production operation in this factory was exceeds the sale of actual sugar produced per year in recent time. This was happened because of the increases of production cost. Maintenance and operational cost are some of the components of production cost. The defect introduced on these cost makes the increases in production cost of the factory. One of the components of sugar production operation is vehicle maintenance which service as a means of transportation and field work supervision which is a back bone of the industry. Even if the money required to maintain those vehicle is high, the money allocated by factory was less than the required because the factory yearly budget allocation was governed by the amount of products and its sales. This situation makes the number of vehicles allocated for operation less than the number required because others vehicle downed for awaiting of maintenance and operational inputs delayed due to shortage of money. Since the vehicle required for operation is not as per required standards field operation was being disturbed reduces the total industry production. To tackle this problem it needs the identification of the point of operation loses like operational and maintenance costs.

Tyre is one of the components of a vehicle which venerable to different static and dynamic forces, operation condition and operating temperature. It service as intermediate parts between vehicle and road to transfer different forces including driving and allow directional controlling for the operator of the vehicle. A tyre was filled with compressed air to deliver this above mentioned function. Filling of air under and above the amount recommended by tyre and vehicle manufacturer affects the function of a tyre. But in nature tyre are gradually loses its pressure when serving on vehicle. This things show that tyre is a very important machine elements of a vehicle. So the purposes of this study was to will investigate the impact of tyre inflation pressure on vehicle operation to will answer the question:

- What are the dynamics of vehicle affected by tyre inflation pressure?
- What is the impacts of tyre inflation pressure on vehicle operation?
- What is the impacts of tyre impacts of tyre inflation pressure on Wonji-shoa sugar factory vehicle’s?

1.3. Objectives

1.3.1. General objective

The main objective of this study was to be investigate the impact of tyre inflation pressure on road vehicle operation.

1.3.2. Specific objective

The Specific objectives of this study works are:-

- To develop mathematical model to investigate the impact of tyre inflation pressure on vehicle operation
- To develop mat lab Simulink to investigate the influence of tyre inflation pressure on road vehicle operation
- To simulate the effects of tyre inflation pressure on road vehicle operation
- To compare the results of simulation against standards and laboratory tests

1.4. Significance of the study

According to data from Wonji shoa sugar factory, vehicles operational cost are increasing from time to time. Consumable material and maintenance cost may made vehicles operational cost increment if not identified and controlled. Perhaps tyre is one of the vehicle comports that determines vehicle health operation. Tyre is a vehicle component that transfers forces between a road and a vehicle. A tyre was performed its function if and only if it was erected by material structure made from and forcefully filled compressed pneumatic air. This compressed pneumatic air may drops blow and rises above a recommended amount due to leakage and wrong filings.

The study finding helps Wonji shoa sugar to pick up the impacts of tyre inflation pressure their vehicle operation. It was also helps our country to identify loses and damage caused by improper tyre inflation pressure and its remedy. This study was intended to contribute to the adoption and development of technologies to enhance the efficiency of transport sector. The outcomes of will inspire more a transport sector and vehicle assembly institution.

1.5. Delimitation (scope)

Since a vehicle tyre is an interacting point of road vehicle through which forces are transmitted between a vehicle and a road. The activity of transmitting forces between a vehicle and a road determines the operational performance of a vehicle. Out vehicle operational performance a vehicle this study was mainly focused on the impact of tyre inflation pressure on vehicle operation. These operational difficulty are imposed in forms of energy loses, stability loses, ride comfort loses, emission of environmental pollutant gases, emission of noisy and harshness, increment of maintenance cost and etc. This study was only focused on tyre inflation pressure impact on vehicle fuel consumption, handing and ride comfort. In addition to this the impact of this tyre inflation pressure study was carried out on Wonji shoa sugar factory vehicles.

There are many sources of energy losses on road vehicles which influences fuel consumption of a vehicles. Those Losses are imposed due to vehicle aerodynamic, inertia and road gradient, rolling resistance. From these parameters of vehicle energy loses this study was limited to tyre rolling resistance which influenced by tyre inflation pressure. It also includes the survey of the effects of tyre inflation pressure on vehicle transport operation and existing vehicle wheel condition monitoring system are included. This study focused on investigation of the influence of tyre inflation pressure on vehicles of Wonji-shoa sugar factory. The analysis was performed through mathematical modeling and simulation to extract the impacts of tyre inflation pressure on vehicle operation performance using mat lab Simulink and qss tb as per vehicles tyre data collected from Wonji- shoa sugar factory and analyzing the result of simulation and the influence it have on the factories operation.

1.6. Beneficiaries of the study

The study is aimed at investigation of the impact of tyre inflation on road vehicle operation. The results of this study will show vehicle operation performance inefficiency introduced by improper tyre inflation pressure. After the impact of this tyre inflation pressure was identified the mitigating mechanism will recommended. Therefore the beneficiaries of this study are Wonji shoa sugar factory, environmental protector, vehicle users and assembly plants, research institution, traffic management institution, road user/pedestrians in Ethiopia.

1.7. Limitation

In this thesis work, the limitations are global pandemic disease COVID-19 and the war in introduced in northern and other parts of our country makes sudden inflation and too high increment cost of material, and unavailability of some study material on local markets. Since I’m self-sponsored and due to forced repeating and longtime coving field works are greatly influenced on my concentration and material access to finish my work on time.

1.8. Organization of the this thesis

This study comprises of five chapters. **Chapter one** contains introduction of the study, Statement of the problems, Objectives, Beneficiary, Significance of the study, Delimitations (scope), Limitations, and Organization of the thesis. **Chapter two** comprises of literature review including different journals of previous study, working manual, books and standards. It also a research gabs identified from literature review. **Chapter three** presents the methodology and material required to study and analysis the influence of tyre inflation pressure on vehicle operation. **Chapter four** presents results and discussion of the study. **Chapter five** contains conclusion and recommendations of the study. Reference and appendix also given at the end of the chapter five.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

Tyre is the most influential component of a vehicle that interacts with a road. Tyres position was maintained relative to each other and body by axle. The axles of a vehicle deal with the weight a vehicle, acceleration, braking and steering force. These forces were transmitted longitudinal, lateral and vertically between the vehicle and road (Crolla, 2009). A wheel is the assembly of tyre and rim inflated with air pressure that supports the weight of the vehicle (Ramalingam, 2009). The assembly provides ride quality, load carrying capacity and vehicle handling characteristics. A rim is a metallic cylindrical part on which a tyre is installed. Tyre is the casing and tube assembled on a vehicle wheel to provide pneumatically cushioned contact and traction with the road (Wong, 2001). Tyre is a means of transmitting power and torque between vehicle and road to make a vehicle to propel, slowing down during braking and ensure safe maneuvering during steering.

Tyres lack of proper maintenance, depreciation, difficulty of measuring or monitoring before the failure exceeds repair limits, manufacturing defects, utilizing and operating faults are some causes of failure. Road vehicles are used pneumatic tyre to transfer acceleration, braking and cornering forces between vehicle and road. It was introduced some sort of defects because of manufacturing, operational and maintenance defects. Manufacturing defects are not economical to correct for already manufactured tyres. Operational and maintenance defects are corrected by identifying the causes of the defects and taking the necessary measures.

Different operation defects are happened on a vehicle. These defects are operational, production and service life out dated. A failure was happened on a vehicle or its components because of above mentioned defects which may increases vehicle operation and maintenance cost. In addition to this it may affects fleet management because of a failed vehicle and/or its components made specific vehicle to be out of operation. These things are made the total company production or services disordered and finally their profit might be lost or score loses.

Tyres are the most expensive maintenance items for fleets and common vehicle related defect cited in crash reports after brakes. Tyre deficiencies are the second-ranked reason for commercial vehicles to be cited for defects during roadside inspections. The overall performance of a vehicle is particularly influenced by the characteristics of its tyres. Tyres have an effect on a vehicle's handling, traction, ride consolation, and fuel consumption (Clark, 1981). Vehicles could maneuver only by longitudinal, vertical, and lateral force systems generated under the tyres. Properly inflated tyre provide comfortable, safe and efficient vehicle driving (NXP, 2014).

2.2. Tyre development

The rubber tire interacts with the hard road surface by deforming under load, thereby generating the forces responsible for traction, cornering, acceleration, and braking. History of tyre development is started by innovations and improvements in tyre designs, materials and manufacturing techniques. There are three major periods of tyre development. Those periods are early tyre developments, midcentury developments and modern radial era. Charles Goodyear invented the rubber mixing and curing process known as vulcanization in 1840s which is important for making of natural rubber. John Boyd Dunlop patented the pneumatic tyre for use on bicycles in the 1880s. Michelin in France, Goodrich in the United States, and others had adapted the pneumatic tyre to the automobile at the end of 19th century. After a few years a brand company such as B. F. Goodrich, Firestone, General, Goodyear, and U.S. Rubber in the United States and Continental, Dunlop, Michelin, and Pirelli in Europe are starting to make tyres. During World War I, tens of thousands cars, trucks, and buses were being mass produced each year in the United States, which created a burgeoning demand for tyres and many other rubber products such as hoses, belts, and gaskets. A rapid changes in automobile technologies, new road surfaces and faster and more frequent driving created new demands on tyres. These fast changing of environment forced tyre manufacturing companies to learn much about tyre design and construction by invest more in research and development. Tyre's fatigue life was greatly extended during this time from the foundation they got by replacing the rubber coated and cross-woven canvas in the tire's casing with plies of rubberized and directionally oriented fabric. Reinforcing agents such as carbon black powders are founded and added to natural rubber is greatly increased its resistance to abrasion and allowed tires to operate thousands of miles, rather than hundreds, before wearing out. This gain is accompanied by the gains in operational performance understanding grew about the tyre's central role in vehicle steering, handling and braking. Because of improvements in tyre molds and rubber compounding, tyre makers introduced better gripping and more durable tread patterns during this period.

At the beginning of the World War II, USA estimated that rubber production could be sustained to meet wartime needs for only about 3 years because Japan gained control of Asian rubber plantations. Because of this nation's chemical companies and research institutions called as to accelerate an introduction and development of synthetic rubbers made from petroleum and natural gas. From this annual hundreds of thousands of tons synthetic rubber produced. Because of gained experience with synthetics rubber on (Cl.ark, 1971) military tyres, tire producing companies are adapted this to passenger tyres after the war. By the 1950s, more than two-thirds of the rubber used in tires was synthetic. After World War II steel-belted radial-ply tyre and its commercial introduction in Europe by Michelin. The radial ply tyre offered a much more stable tread foundation and a more flexible sidewall. These gives for a tyre longer tread life, better wet and dry traction, improved puncture resistance, and reduced rolling resistance and energy consumption (Tomkins, 1981).

Since American motorist began to use foreign vehicles, some home made vehicles were equipped with radial tyre during 1970s to satisfy the beginning demand of radial ply tyre. By the beginning of the 1980s, radial tires had become the standard construction type for both OE and replacement tires. Radials accounted for about 60 percent of passenger tire shipments in 1980, 97 percent by the end of the 1980s, and 99 percent in 2005. Tyre wear life was a key selling point for radials, because average tire wear life increased by thousands of miles. In addition, tyre companies marketed "all-season" tyres made possible by the stability of the steel belt as a structural foundation, which prevented tread cracking in the required cross-groove pattern for winter traction. This development brought an end to the practice among many North American motorists of switching to specialized snow tyres during the winter months. Radials also offered improved handling, which led to a growing array of tyres designed and marketed as performance, high performance, and ultra-high performance. Starting in the 1980s, tire manufacturers started rating more tires in North America according to their designed maximum operating speed. The desired speed rating affected the choice of materials and construction of the tyre. For instance, tyres with higher speed ratings required stronger steel belts and belt compounds covered by a nylon cap ply (French, 1989).

2.3. Tyre dynamics and static forces

The power and torque developed by a drive train was transmitted to road through tyre. A tractive effort reached at a tyre used to propel a vehicle. A tyre slows down the vehicle during braking. It also provides a means of vehicle maneuvering and cornering mechanism. A tyre-road interface force necessary for braking, acceleration and cornering is governed by tyre-road interface friction level and the normal force on a tyre. The forces transmitted to the road depend on the parameters of the vehicle and its movement. The uneven tyre pressure changes the stiffness of the tyres both radial and longitudinal and transverse, as well as changing wheel rolling and load resistance provided by the vehicle to the ground. The normal force on a tyre includes any load transfer effects and aerodynamic forces.

$$F = \mu N \tag{2.1}$$

Where F is tyre- road force, μ is interface friction coefficient and N is normal force

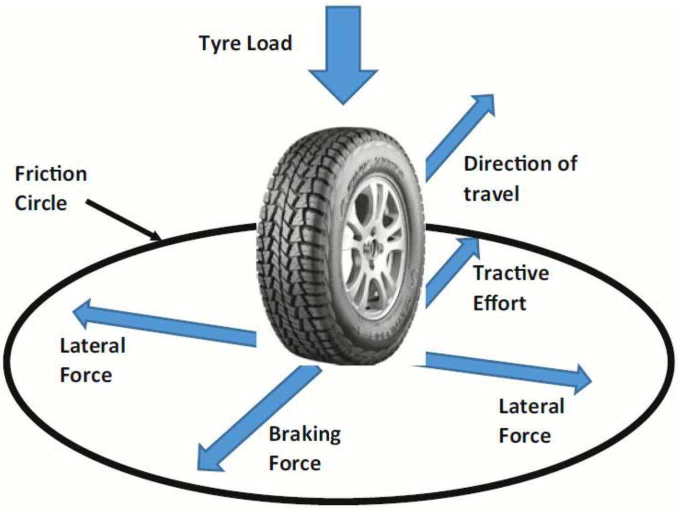

Figure 2.1. Friction circle of tyre(Barton & Fieldhouse, 2018)

Under normal operation tyre-road force needs to be sufficient to provide a combination of braking and cornering or acceleration and cornering resulting in a safe operating locus. This is referred to as the friction Circle. In reality the circle is more elliptical rather than circular as the lateral force is influenced by the non-linear cornering force/tyre load characteristic of the tyre for differing slip angles. In general, the friction Circle will provide a first order estimate of the tyre/road adhesion available (Barton & Fieldhouse, 2018).

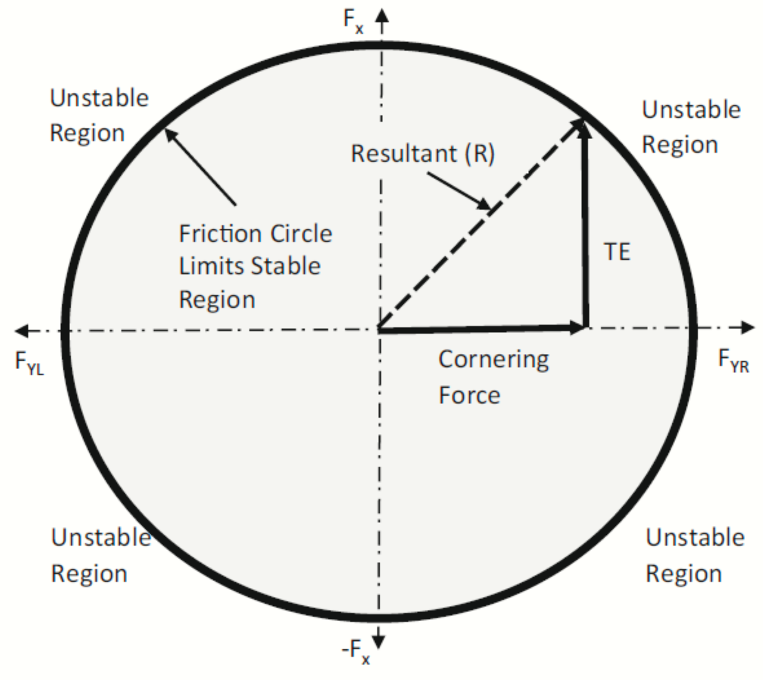

Figure 2.2. Tyre resultant force calculated from the friction circle (Barton & Fieldhouse, 2018)

$$R = \sqrt{F_X^2 + F_Y^2} \qquad 2.2$$

Where F_X is braking force or tractive effort, F_Y is cornering including side winds and R is resultant forces. Resultant force may possibly not exceeds tyre-road force. If a combination of lateral and longitudinal force which gives a resultant force exceeds Vertical load N times tyre/road interface friction coefficient μ then the tyre will slide or spin. The minimum tyre/road interface friction to avoid gross tyre slip for a particular resultant force is given by:

$$R = \mu N \qquad 2.3$$

Tyres are made with different sizes, designs, materials, and construction types. But casing, bead, and tread band are structural elements that are common to all tyres (Pacejka, 2006). Tyre casing is called a carcass which is structural frame of a tyre. Carcass is comprises of directionally oriented cords which is banded together by a rubber into layers, called plies, which give the tire strength and stiffness while retaining flexibility. Tyres are divided in to radial and bias plies types depending on the orientation of plies (K. & N., 2003). Bias plies tyre is a tyre type on which its plies are oriented diagonally. Radial plies tyre is a tyre in which plies are oriented from side to side. The number of plies is determined by tire type, size, inflation pressure, and intended application. An inflated tyre to retain on its rim its plies are anchored around circumferential hoops called bead which made of multiple strands of fine, high-tensile wire located at the inner edges of the two sidewalls where they mate with the rim. A tyre beads are pressed against the rim flange by inflation pressure, thereby seating and sealing the tire on the rim. A tyre is encircled by a tread which is thick band of rubber that forms the tire surface, from its crown (its largest radius) to its shoulders. Tyre tread is the only parts that contacts with the road surface during normal driving (Lindemuth, 2005).

The force system that a tyre gets from the ground is thought to be placed on the middle of the tyre print and can be decomposed along x, y, and z axes. Therefore, the interplay of a tyre with the road generates a three-D force device such as 3 forces and three moments (Cordoş et al., 2017). A vehicle can accelerate, decelerate, bounce up and down, or acquire an angular velocity, such as yaw, pitch, or roll. This is achieve by wheel which provides interaction between vehicle and the road surface. Wheel is the combination of metallic rime and tyre filled with pressured air to convey inaction forces between vehicle and road. Pneumatic tyres are the most common way of creating contact between a land vehicle and the road. Tyre a common way of creating contact between land vehicle and road. It combine the elastic properties of rubber and compressed air to accomplish a tasks such as:

- Generate a vertical forces (wheel loads) to support the weight of the vehicle;
- Generate tractive forces that accelerate and decelerate the vehicle;
- Generate lateral forces that provide steering control and directional stability which enable the vehicle to take a turn or to resist a side force;
- Provide cushioning and absorb forces due to road imperfections, such as bumps and potholes; and
- Provide aligning torque and camber that improve stability.

Tyre offer sufficient longitudinal traction, lateral traction and directional stability. For a tyre to carry out its meant work on cars inflation pressure and thread depth are essential factors in making certain precise tyre functioning. A compromise in either aspect will lead to upsurge braking distances, much less directional stability and extended consumption levels due to reduced tyre traction. It is clear that car with such tyre faults have comparatively poorer managing and reduced road protecting, which will therefore growth their chances to be concerned in road injuries. A compromised tyre pressure regularly causes a discounted tyre touch patch geometry which results in loss of traction endangering automobile safety.

Particularly, at some point of excessive-velocity driving, emergency braking, and fast cornering maneuvers, the tyres attain their adhesion limits quickly and the corresponding tyres with compromised touch patch geometry can also easily free grip affecting the vehicle's directional balance (Solmaz, 2019).

A tyre generates a vertical, lateral and longitudinal force that enables the vehicle to maneuver. Tyre is a main components of a vehicle which interacting with a road. Tyre affects Vehicle traction, handling, fuel consumption and ride comfort. These forces are decomposed along x, y, and z axes. The interaction of a tire with the road generates a 3D force system including three forces and three moments.

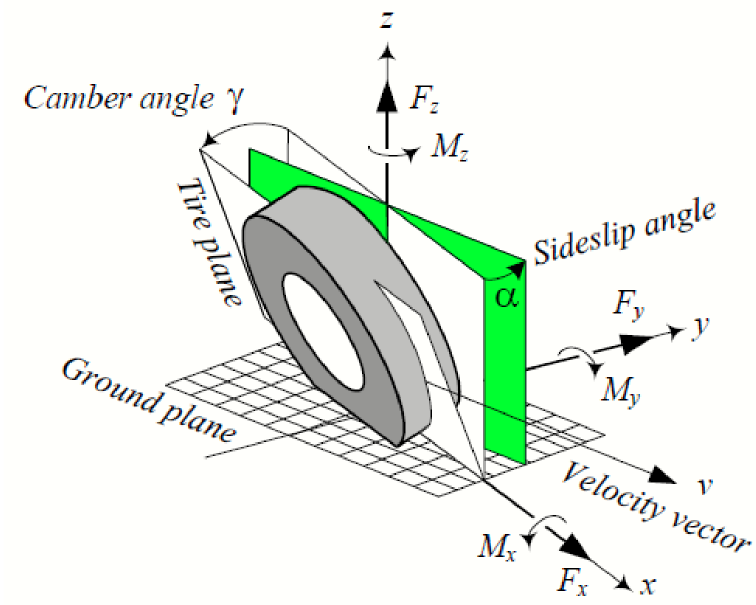

Figure 2.3. SAE tire coordinate system (Reza N., 2008)

- Normal force Fz is a vertical force and normal to the ground plane.
- Lateral force Fy is a force, tangent to a ground and orthogonal to both Fx and Fz.
- Longitudinal force Fx is a force acting along the x-axis.
- Pitch moment (rolling resistance torque) My is a lateral moment about the y-axis.
- Roll moment Mx is a longitudinal moment about the x-axis.
- Yaw moment Mz. It is an upward moment about the z-axis.

As a tyre rotates underneath the burden of a car, it stories repeated cycles of deformation and recovery, and it dissipates strength loss as warmness. Such a behavior is a common belongings of hysteretic fabric and is referred to as hysteresis. So, hysteresis is a characteristic of a deformable material including rubber, that the power of deformation is greater than the strength of restoration. The quantity of dissipated power relies upon at the mechanical characteristics of the tyre.

Hysteresis is a material property that results in loss of energy because the force versus deflection curve is different for loading and unloading (or for expansion and restitution). The area inside the loop is the lost (or dissipated or unrecoverable) energy. Hysteresis is energy losses of a tyre in the form of heat because of a continuous deforming and reforming of tyre while a vehicle is moving. Therefore hysteresis is a main reason why tyres heat up while driving. Hysteresis also generates a rolling resistance which increases vehicle fuel consumption as well.

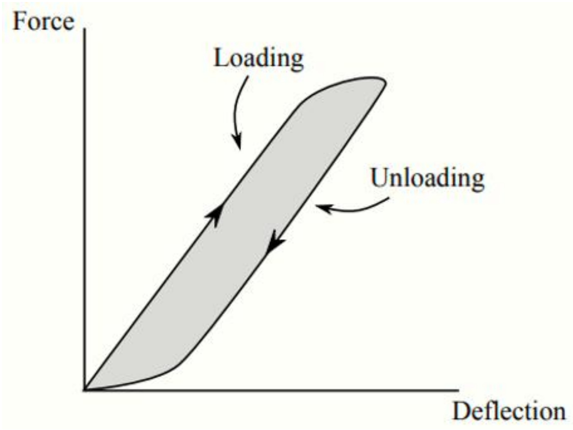

Figure 2.4. Hysteresis loss within a tyre during loading and unloading(Barton & Fieldhouse, 2018)

The hysteresis effect causes a loaded rubber no longer to rebound absolutely after load elimination. Hysteresis stage of tyres inversely have an effect on the preventing distance. A high hysteresis tyre makes the preventing shorter, however, it wears hastily and has a shorter life time. Vehicle handling performance is directly related to the tyre-street touch. Adhesion force come from the intermolecular bonds between the tyre rubber and aggregate in the road surface. This intermolecular bonds between the tyre rubber and aggregate results in some amount of sticking between the tyre and road. On a dry road, adhesion contributes more to friction (shear stresses) than does hysteresis (normal stresses). But on a wet road tyre friction is mainly due to hysteresis.

Deformation friction takes place when the rubber in the contact patch deforms from its original shape and assumes the shape of the irregularities on the road surface. This increases the friction between the tyre and road. Wear friction is due to the large stresses that the rubber in the tyre experiences. If high stress exceeds beyond the elastic limit the tips of the rubber tread.

In the longitudinal (travel) x direction: Tractive force FT, due to acceleration or braking; rolling resistance force FRR, due to energy loss at contact pitch. In the lateral (y) direction: Lateral force FL (cornering force), due to taking a turn or reaction to a lateral force, such as wind gust or force of gravity on a banked road, as well as camber thrust (lateral force due to having camber). In the vertical (z) direction: Normal force FN , also known as wheel load, which results from the weight carried by the tyres and forces generated due to road imperfections, such as bumps.

The tyres transfer the horizontal and vertical forces acting on the vehicle as a result of steering, braking and driving in combination with possible road disturbances or external disturbances like aerodynamic forces (Reiter et al., 2013). There are three forces (F) and moments (M) acting on the tyre from the floor. Tractive force (longitudinal pressure), is a component in the X direction of the ensuing pressure exerted on the tyre through the street. Lateral pressure, is a component in the Y path, and regular pressure, is a part in the Z direction. Overturning moment, is the moment about the X axis exerted on the tyre via the street. Rolling resistance moment is the moment about the Y axis, and aligning torque is the moment approximately the Z axis.

There are three forces (F) and moments (M) acting at the tyre from the floor. Tractive pressure (longitudinal force), is part within the X path of the resultant force exerted at the tyre by way of the street. Lateral force, is part inside the Y route, and ordinary pressure, is part in the Z course. Overturning second is the instant about the X axis exerted on the tyre by the street. Rolling resistance moment is the instant approximately the Y axis, and aligning torque is the instant approximately the Z axis.

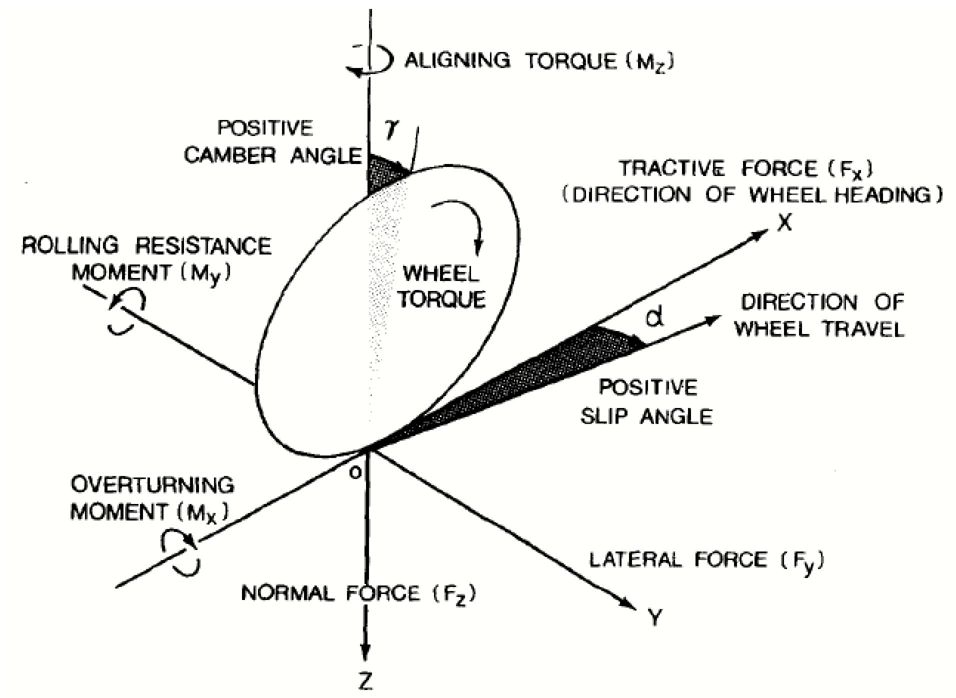

Figure 2.5. Wheel axis systems (T. D., 1990)

Slip attitude α and camber perspective γ are the two essential angles associated with a rolling tyre. Slip angle is formed by the path of wheel journey and the road of intersection of the wheel aircraft with the street surface. Camber perspective is the attitude shaped among the XZ aircraft and the wheel aircraft. Factors affect the rolling resistance of a pneumatic tyre are structure of the tyre (production and materials) and its running conditions (surface situations, inflation pressure, pace, temperature, and so on.). Slip attitude α and camber angle γ are the 2 crucial angles associated with a rolling tyre. Slip angle is the mind-set shaped among the path of wheel excursion and the road of intersection of the wheel plane with the street floor. Camber perspective is the attitude usual between the XZ aircraft and the wheel plane. Factors these have an effect on the rolling resistance of a pneumatic tyre are structure of the tyre (introduction and substances) and its operating situations (floor conditions, inflation strain, velocity, temperature, and so forth).

Inflation pressure influences the flexibility of the tyre. Depending at the deformability of the ground, the inflation pressure affects the rolling resistance of the tyre in one-of-a-kind manners. On difficult surfaces, the rolling resistance normally decreases with the growth in inflation strain. This is because, with higher inflation strain, the deflection of the tyre decreases, with consequent decrease hysteresis losses (Wong, 2001).

2.4. Tyre pressure monitoring

Properly inflated vehicle tyre provides comfortable, safe and efficient driving (NXP, 2014). A tyre can lose up to half of its air pressure without appearing to be under inflated. Due to this a sudden vehicle tyre failure may results in serious consequences, especially if it occurs when the vehicle is operating at highway high speeds. Vehicles tyre pressure drop can results in reduction of mileage, tyre life, vehicle safety and performance. To reduce this problem different experts are developed TPMS to take continuous readings of tyre pressure to pick whether a pressure is within proper inflation or not (Mathai & Vanaja Ranjan, 2015). Improper tyre pressure is a safety issue that is usually ignored on a road vehicles. To tackle such problems automotive electrical and electronics industry made improvements on vehicles' driving safety from time to time. Since tyre is a vehicle machine element that contact with road it affects traction, handling, steering, stability and braking of the vehicle if it is not properly inflated.

Tyre defects can include under-inflation, over-inflation, or insufficient tread, as well as an actual blowout. Tyre pressure monitoring systems (TPMS) is an electronic system that monitor the tyre pressures on individual wheels on a vehicle, and alert the driver when the pressure goes below a warning limit. There are several types of designs to monitor tyre pressure. Some actually measure the air pressure, and some make indirect measurements, such as gauging when the relative size of the tyre changes due to lower air pressure. Tyre pressure monitoring system is an automotive electrical and electronics system that measures the amounts of air pressure inside a vehicle tyres and alerts the driver by displaying the real pressure and/or warning the driver if the tyre pressure is out of safe limits (Salunkhe et al., 2017). TPMS is an electronic protection device which used to display the pressure in the tyres of a car and provide the driver with a caution signal (Wagh et al., 2018). Tyre Pressure Monitoring System (TPMS) is a device geared up on a vehicle that can evaluate the pressure of the tyres or the variant of pressure over time and transmit corresponding statistics to the user at the same time as the car is strolling. Without TPMS a car drivers are unable to take tyres for granted and right inflation (NXP, 2014). Automated TPMS provide a means of reliable and continuous monitoring of the vehicle tyre pressure and are designed to increase safety, decrease fuel consumption and improve vehicle performance. Depending on the methods of measuring tyre pressure monitoring system divided in to two types, namely direct and indirect tyre pressure monitoring.

2.4.1. Direct tyre pressure monitoring

Direct tyre pressure measurement provides actual tyre pressure measurement in a given wheel. The problems of direct tyre pressure monitoring system is the need of inserting pressure sensor in airline. Because of this the system need the uses of power sources for the sensor and transmitter in the form of batteries, inductive or kinetic energy scavenging solutions (Hill & Turner, 1992)(Wang et al., 2012). The addition of sensor and transmitter adds eccentric weight to the wheel and hence needs counteract weight addition which achieved by applying weights in opposite to the added mass. Model-based methods are not well understood or used outside of research institutions such as universities and engineers because OEM are not trust this type of technology (Forssel, 2009). Non-intrusive direct measurement is a type of direct tyre pressure measurement system that is not depends battery power. The electrical power is harvested from conversion of the road disturbance input and rotational energy of the wheel.

The other type of direct tyre pressure monitoring system is tyre cap system which is inexpensive aftermarket solution for vehicle without OEM TPMS. It is simple to install on wheel. The multi colored indicator is encapsulated in the valve cap and indicates critical (yellow), low (red) and normal (green) pressure. The flashing lamp type activates once a pressure threshold has been transgressed. This system has no mechanism for driver to reach and read the condition of tyre pressure during a vehicle is in motion. It is aimed at avoiding the low pressure tyre condition rather than warning the driving of an imminent fault whilst on a journey.

2.4.2. Indirect tyre pressure monitoring

Indirect tyre pressure monitoring system used information from accelerometers, suspension height and wheel speed sensors (Ersanilli, Reeve, et al., 2009)(Ersanilli, Burnham, et al., 2009).

i. Model based parameter estimation tyre pressure monitoring system

This approach attempts to a vehicle quarter car model representation by using a signal of acceleration, suspension deflection or axle acceleration with the input from the road to estimate the parameters of a transfer function model. This function parameter related to tyre spring physical constants. Perhaps it is possible to make a diagnosis of the condition of the suspension based on this parameter deviations. Therefore the parameters will be changing according to what is changing in the system. The shortcoming of this approach is that the system would never know the input and so it needs to be reconstructed or estimated from what is known about the system. Therefore suspension constants and the output are known, using these two it is possible to estimate the input. In parameter estimation result there is also non-linear nature of vehicle suspension will cause parameter deviations even in the absence of a fault and needs to be addressed before a correct diagnosis can be made (Ersanilli & Burnham, 2012).

ii. Tyre pressure monitoring by wheel speed sensor

In this approach a tyre radius varies as a function of vehicle weight and tyre pressure. The major contribution attributed to the tyre pressure (Pacejka, 2006). These properties have a marked effect on the angular velocity of the wheel. Vehicles equipped with an antilock braking system (ABS) automatically provide the angular velocity, ω, of each tyre to a CPU. A straightforward algorithm based on monitoring of the inflation measure β defined by:

$$\beta = \left| \frac{(\omega_{LF} + \omega_{RR}) - (\omega_{RF} + \omega_{LR})}{\omega_a} \right| \qquad 2.4$$

$$\omega_a = \frac{\omega_{LF} + \omega_{RR} + \omega_{RF} + \omega_{LR}}{4} \qquad 2.5$$

is used to predict tyre under inflation, where ω_{LF}, ω_{RF}, ω_{LR}, ω_{RR} denote left front, right front, left rear, and right rear wheel angular velocities, and ω_a is the average angular velocity. For normal tyre inflation pressure β is close to zero. For a vehicles equipped with speed sensor such ABS, the system requires only software to build indirect TPMS (Velupillai & Güvenç, 2007). Even if wheel speed signal detection approach is used for indirect TPMS there some short comings associated with it (Umeno et al., 1994).

- It is not measures the actual tyre pressure rather it reports the estimates value.
- The system does not warn when two tyres on the same side or same axle equally underinflated and all tyre are equally underinflated.
- The system generates false reading during cornering curve, driving on slip or low friction surfaces such as ice and wet leaves (Umeno, 2002).
- The system works when inflation pressure drops below 25%.

Tyre radii estimation using a marginalized particle filter and Bayesian parameter estimation approach utilizes individual wheel angular velocity measurements and absolute vehicle position from a global positioning system (GPS) to estimate tyre radius. The radius deviation from its nominal value is modelled as a Gaussian random variable and included as noise components in a simple vehicle motion model. The novelty lies in a Bayesian approach to estimate online both state vector and the parameters on behalf of the process noise statistics using a demoted particle filter (Lundquist et al., 2014). This solution, which builds on the work is appealing due to the high level of estimation accuracy of the tyre radii and hence tyre deflation, tested according to. This approach relies upon wheel speed information in order to operate. Like other indirect approaches, this technique does not provide actual pressure measurements and only works when the vehicle is in motion.

iii.Diffusion deflation detection using wheel angular velocity signals

Diffusion deflation detection approach is used to overcome the problems of all wheel tyre pressure deflation and defilation of tyres on same axle at a time. The researchers have shown that the tyre rolling radius rate of change in the deflated condition (140 kPa) is smaller than that in the normally inflated condition (200kPa) over a wide range of tyre aspect ratio (70% to 50%). During cornering, acceleration and deceleration detection of all tyre diffusion deflation is possible by comparing the tyre rolling radius change rate under cornering, acceleration or deceleration between a normally inflated tyre and a deflated tyre due to load shift (Yanase, 2005). Like other indirect TPMS no additional sensor is required. Wheel angular velocity is detected by the wheel speed sensor of ABS if equipped. In order to exited and make analysis the vehicle required to be in motion.

iv. Tyre pressure monitoring with wavelet transform

The approach differs from the observation of absolute differences between individual wheel speeds in that, due to the mass-spring-damper properties of the wheel system, there is a frequency component of the signal that is dependent on the tyre pressure. The property of interest in this work is the Eigen frequency which is dependent on the physical properties of the system which is a tyre. Any change in the physical constants, such as tyre pressure, mass or damping, will have a measureable effect on the Eigen frequency. Since mass and damping can reasonably be assumed to be constant, it is proposed that the frequency shift is due to tyre spring rate, which is a linear function of tyre pressure (Heißing & Ersoy, 2011).

v.Pressure monitoring by radial directional frequency and damping ratio

A radial way modal parameters of tyres subjected to exclusive degrees of inflation strain have been determined by means of the use of a frequency reaction characteristic technique. To obtain the theoretical herbal frequency and mode form, the plane vibration of a tyre has been modelled because it were a round beam. The theoretical results have been determined through assuming angular speed, tangential stiffness, radial stiffness and tension forces are due to tyre inflation stress. Those parameters are shift the natural frequency and damping ratio (Kim et al., 2007).

vi. Tyre pressure monitoring by estimation of a virtual transfer function

In this approach a tyre pressure monitoring is developed using chassis acceleration signals. This approach describes the relationship between the front and rear wheels on a given side of the vehicle (bicycle model) where developed. Like other indirect tyre pressure monitoring it does not require knowledge of the road input to make a diagnosis and wheel angular velocity information. Despite this it requires accelerometer on all corner and accuracy which adds a significant cost to vehicle. Because of some limitation four wheel diffusion cannot be detected using this approach, which suggests that it is not able to meet (UNECE, 2010) regulation requirements.

2.5. Effect of tyre pressure on wheel alignment

Wheel alignment is the process of positioning the wheels and suspension of a vehicle to Original Equipment Manufacturer specifications. The goal is to meet or exceed the expected tyre life, vehicle handling, ride quality and performance characteristics intended by the vehicle manufacturer. Major wheel alignment parameters that affects vehicle dynamics are camber, toe, caster and trust angle (Reza N., 2008). Wheel alignment have great influence on traveling safety and driving stability of vehicle operational performance (Chatur, 2015). Front wheel swinging all through traveling, fast tyre wear, lowering of the directional stability after steerage and steerage wheel vibration are a cars problem as a result of wheel misalignment. Tyre wear caused by wheel misalignment is a part of uneconomic, fuel consumption and air pollution. Therefore wheel alignments inspection and adjustment is carried out regularly so as to achieve vehicle travelling stability, travelling safety and other performance (Patil & Kadlag, 2016).

Vehicle's dynamical properties is related to three essential motions. Longitudinal motion (driving and braking), Lateral motion (guidance and steering) and Vertical motion (suspension and damping)(Popp & Schiehlen, 2010). All these forces are induced on vehicle wheels. Loss of stability or control of a vehicles are among a reasons for a vehicle road accidents. This type loss of vehicle control is due to a change in wheel alignment of a vehicle. Vehicle integrated wheel alignment alert system is a mechanism that used to monitor if there is a change in wheel alignment due to physical fitting or tyre direction. By maintaining the wheel alignment not only avoids collision of vehicles, it also increases the fuel efficiency of the vehicle and reduces the tyre and bolt wear of the vehicle. Out of vehicle wheel parameters camper and toe are measured and displayed on dashboard by utilizing hardware and software (Balakrishnan et al., 2016).

Today vehicle wheel alignment inspection system implement various electronic monitoring and inspection technology to reduce pre mature wear of the system. Properly adjusted wheel alignment keeps vehicle steering and suspension system in good condition and results in less wear and tear. Wheel alignment consists of adjusting of angles of the wheels so that they are perpendicular to the ground and parallel to each other (Kalita, 2016).

Vehicle wheels are the only machine element in contact with the ground and undertake the functions of steering, braking, load carrying, driving, etc... Wheel alignment parameters are the parameters relating to the movement and size. Wheels a moving vehicles are affected by six components of forces. Those forces are normal force, longitudinal force, yawing force, aligning torque, turning torque and rolling resistance moment. Vehicle suspension system and steering system are affected by the wear, collision, deformation, replacement and tyre pressure changes, causing the change of wheel alignment parameters and many malfunctions further, such as small aligning torque, steering wheel flutter, driving deviation, and the wear and puncture of tyre. When vehicle leaves the producing factory, wheel alignment parameters are sated but during the usage of a vehicle, a maintenance work shop or testing organizations may adjust the car with inaccurate alignment parameters according to standard limiting value. Problems caused by wheel misalignment are Excessive tyre wear, increased fuel consumption caused by increased rolling resistance, unsafe vehicle handling characteristics, driver fatigue and driver retention and premature suspension component wear (Hunter Engineering Company, 2017).

2.6. The influence tyre inflation pressure on steering

A fundamental requirement of all modern-day steering systems is to attach each advised wheels on an axle to make sure they remain at a few associated function to each other irrespective of flip angle that is here's a need to make certain a kinematic relationship between the two wheels. Each wheel is attached to a knuckle or upright that's related to the chassis through some swivel mechanism. Each of the knuckles is then linked to a track-rod the use of ball joints in order that, when a lateral pressure is applied to this music-rod, both wheels flow collectively, rotating/rolling about their applicable pivot and so converting the vehicle path.

The force along the track rod may be applied by mechanical, hydraulic or electrical means or any combination of these. Such a basic system connects the wheels during steering but does not provide for the wheels to satisfy the Ackermann angle requirements. This Ackermann criteria requires each of the steered wheels to be rotated by a different amount so that they are orientated to trace a true rolling radius about a common turning point.

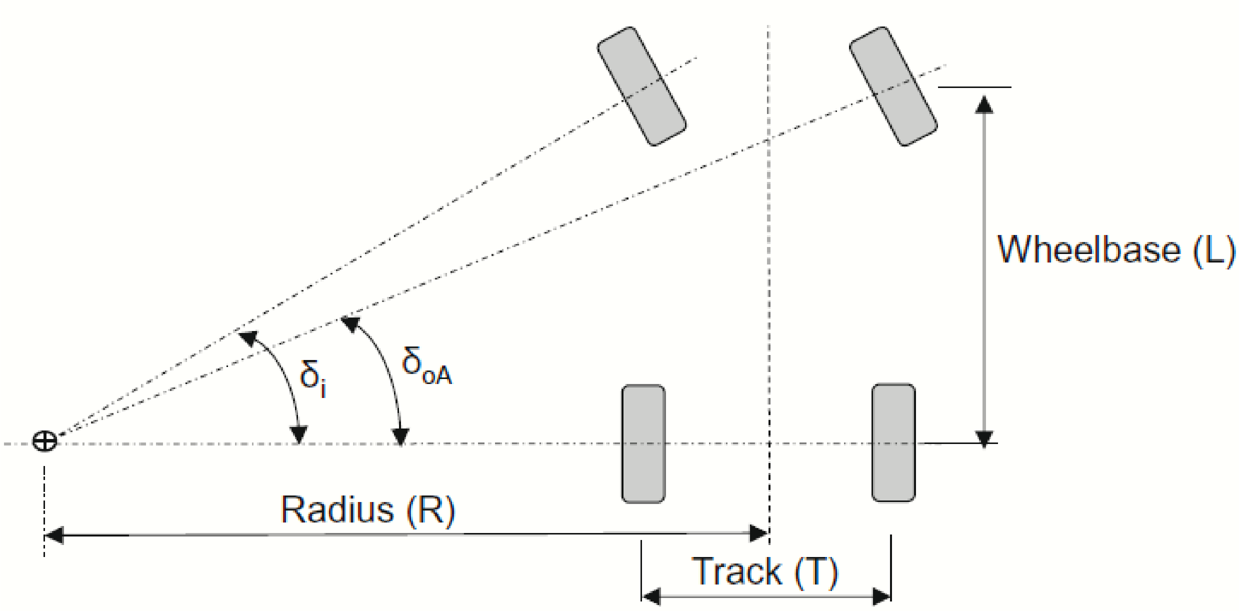

Figure 2.8. Ackermann steering geometry (Barton & Fieldhouse, 2018)

$$\tan\delta_i = \frac{L}{[R - T/2]} \tag{2.6}$$

$$an\delta_A = \frac{L}{[R + T/2]} \tag{2.7}$$

Where δ_i inner wheel angle and δ_A outer wheel angle

The theoretical track turning circle diameter D_S as measured at the suspension intercept at the ground is then given by the following equation:

$$\mathrm{Sin}\delta_A = \frac{L}{D_S/2 - d} \tag{2.8}$$

$$D_S = 2\left(\frac{L}{\sin\delta_A} + d\right) \tag{2.9}$$

If the curb to curb turning diameter was needed, then the theoretical turning diameter would be given by the equation:

$$D_S = 2\left(\frac{L}{\sin\delta_A} + d + \frac{\text{tyre tread width}}{2}\right) \tag{2.10}$$

The ideal situation would be to have the wheels rotating around a true arc with zero tyre scrub. These errors are due to general compliance and operational characteristics such as tyre slip, compliance in the mechanical system (elastomeric components) and set-up (geometric) errors. To improve vehicle handling the designer will understand these irregularities and included them in the design strategy.

When side force applied to a current tyre which is not hard, the wheel will take a different path to the direction the wheel points even though the wheel is still pointing in the original direction. The angle between the path the wheel is actually taking and the plane of the wheel is termed as slip angle (α). The slip angle is produced by the deflection of the side wall and tread. It is proportional to the side force acting on the tyre. The greater the tyre aspect ratio (tyre wall height to width) the greater the slip. As such, low aspect ratio tyres have less slip than high aspect ratio tyres.

$$\text{Cornering power} = \frac{\text{Side force}}{\text{Slip angle}} \tag{2.11}$$

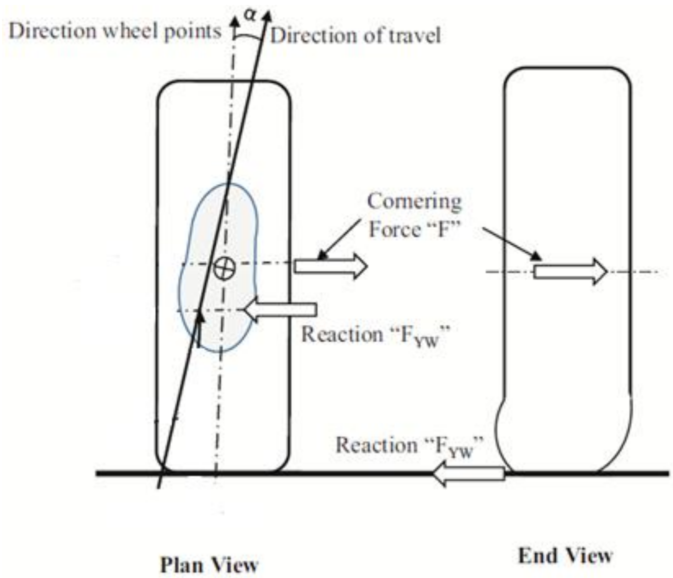

Figure 2.9. Tyre tread contact patch distortion (Barton & Fieldhouse, 2018)

The cornering power (CP) of a tyre is governed by:

- Inflation pressure—an increase raises the CP.
- Tyre construction—a radial-ply tyre has a higher CP than a diagonal-ply tyre.
- Tyre size—a low-profile tyre has a smaller wall so a higher CP is achieved.
- Camber (tilt) of wheel—tilting the wheel away from the side force increases the CP.
- Load on the wheel—if the load is increased from the normal value then CP will increase.

2.7. Elastokinematics (compliance)

Elastokinematics is a deformation of elastomeric elements within the steering and suspension system as a result of wheel forces exited from road and wheel tyre interface. It also called compliance steer. Elastokinematics is pseudo-bearings in which two connected parts are allowed to move relative to each other. They are used to enhance driving comfort. Elastokinematics are degraded with age and affect vehicle handling performance.

2.8. Influences of tyre inflation pressure on vehicle operation

2.8.1. Vehicle Operational cost

Unlimited and uncontrolled vehicle tyre pressure is imposes a number of problems on vehicle operation in terms maintenance cost, fuel consumption, vehicle handling, driving comfort and vehicle down time. Keeping a proper tyre inflation pressure is the most serious aspect of tyre on vehicle operation. Most of vehicle crashes records indicated that the causes of accidents are driver error. But after some investigations are made out of all crashes there is any mechanical flaw that might contributed. Among all possible mechanical factors tyre was responsible for 21% of all reported crashes that were caused by a vehicle defect.

Tyre is a main contributor of vehicle maintenance cost. Increasing tyre monitoring and maintenance was decreases tyre damage and it's replacing frequency by increasing service life of a tyre and reducing vehicle fuel consumption. As rubber product tyre is get in to fatigue and generates heat and weaken its structure and shorten its life as a function of the tyre pressure reduction and load on it. A tyre Operating with inflation pressure reduced by about 20% its service life will be reduced by about 30% (Kreeb et al., 2003) (Masseie & Campbell, 1996).

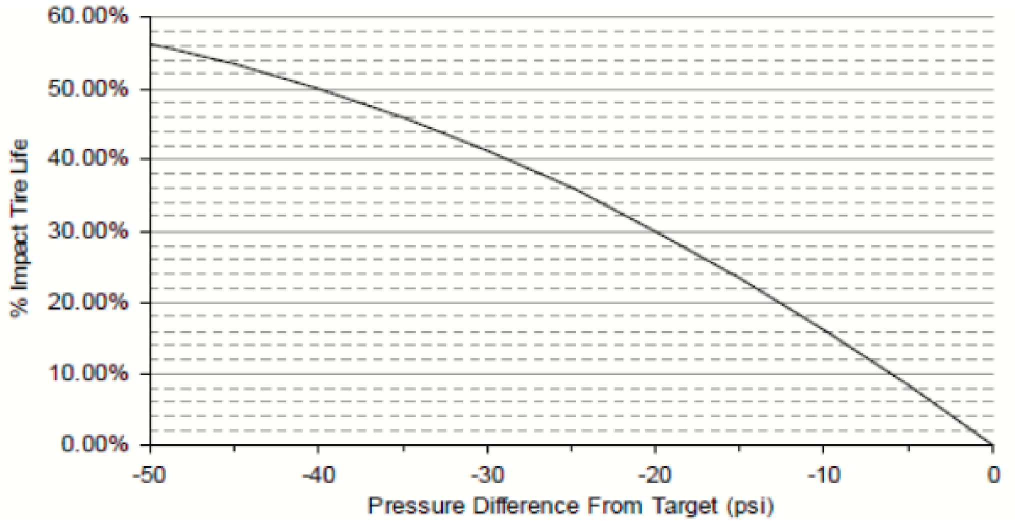

Figure 2.10. The impact of tyre inflation (Kreeb et al., 2003)

Good year tyre manufacturer supposed that for every 0.0689 bar tyre inflation pressure reduction results in 1.2% tyre tread life reduction. Improper tyre pressure inflation was includes over and under tyre pressure inflation that lead to abnormal wear accountable for early tyre removing. 10% to 30% of tyres are removed from the vehicle because of regular long-term put on, while 40% to 60% tyres are replaced for "odd wear" motives, 5% to 10 % are changed with not anything is found and the remaining 20% are eliminated for other motives.

The quantity of fuel consumed by a vehicle over a distance traveled is affected by the efficiency of a vehicle in converting a chemical energy in a fuel into mechanical energy and transmitting to the axles to drive the wheels. About two- third energy in a vehicles fuel tank is lost in converting heat into mechanical work at the engine much of it unavoidably (Das, 2014). Only about 12% to 20% of energy in a fuel is ultimately transmitted to vehicle's driveline as mechanical energy to turn the wheels. A majority of energy in a fuel is dissipated as unrecoverable heat from engine combustion and friction in the engine, driveline, axles, and wheel bearings. Some energy output from the engine is used to power vehicle accessories. Rolling resistance consumes about one-third of mechanical energy output. At a normal operating condition rolling resistance consumes 4% to 7% of the total energy expended by the vehicle. Reduction of 10% of rolling resistance will increase 1 to 2 % increase in fuel economy. A number of tyre operating conditions that affects rolling resistance are load, inflation pressure, and temperature (Friedrich, 2002). Inadequate tyre inflation pressure affects vehicle fuel economy. The lesser the tyre inflation pressure the higher the higher tyre foot print and increases fuel consumption.

There are several factors that make contributions to the overall fuel consumption of a vehicle. Those elements may be widely labeled into aerodynamic drag losses, power loss from tyres, and automobile inertia in the course of acceleration or deceleration. However, this thesis will only focuses on effect of tyres air pressure and the influence it has on overall fuel consumption contribution on vehicle. Tyre rolling resistance is a force required to maintain the forward motion of a loaded pneumatic tyre in a straight road, on a flat road, at a constant automobile speed whilst no wind resistance is exist (Barton & Fieldhouse, 2018). The tyre rolling resistance may be attributed to three generally categorized mechanisms (E. M., 2010) (K. & N., 2003):

- Aerodynamic drag of the rolling wheel
- Friction or scrubbing between tyre and roadway and
- Hysteretic loses of tyres due to cyclic stressing of the rubber compound.

The rolling resistance (RR) is a force that should be triumph over to reason a car to move at constant velocity over a horizontal surface and assuming aerodynamic force is zero and a vehicle journeying on immediately and clean avenue. Rolling resistance arises from main sources that are continuous deformation of the tyres during rolling and frictional consequences in the mechanical driveline components. Rolling tyres go through a persistent cyclical deformation because the tyre passes continuously via the touch place vicinity. This reasons deformation of the sidewalls and tread place and, because it isn't always a perfectly elastic manner, a few power is lost over hysteresis. If a normal tyre is inflated to the appropriate strain, the rolling resistance reduces and vehicle economy increases. If the tyre is below-inflated, the rolling resistance will increase due to immoderate tyre wall deformations. If excessive over-inflation happens then car coping with is affected (Barton & Fieldhouse, 2018).

$$\mathrm{R_R = N.C_R} \qquad 2.12$$

Where RR rolling resistance, CR coefficient of rolling resistance and N normal force perpendicular to the floor on which the automobile is shifting. The tyre/street interface pressure necessary for acceleration, braking and cornering is dependent on the tyre/road interface friction level and the normal force at the tyre. The normal force on the tyre must consist of any load switch effects and aerodynamic forces.

$$\mathrm{F = \mu N} \qquad 2.13$$

Where F is tyre or road force, μ is interface friction coefficient and N is normal force on tyre. There is gab between officially reported fuel consumption and the one experienced by the vehicle user. A given current certification results does not consider a variety of different real world operating conditions. These varieties of different operating conditions are investigated in order to identify a real factors that affecting fuel consumption. Auxiliary systems, Aerodynamics, Weather conditions, Driving behavior and Vehicle condition are the main factors affecting vehicle fuel consumption and environmental pollution. Auxiliary systems refer vehicle accessories and elements that improve driving safety and comfort. Those accessories and elements are air cleaner, A/C (Huhn, 2008), Lighting, Wipers, electric windows, brake assistance and collision warning and avoidance (Dudenhöffer & John, 2009) (Reif & Dietsche, 2011). The use of auxiliary device requires an increased in mechanical or electric deliver and increases engine energy demand and gasoline consumption. Aerodynamics refers to the form and layout of the auto. Shape adjustments will boom the aerodynamic resistances resulting in multiplied fuel intake (Agency), 2014). Ambient conditions check with the outside conditions together with wind, temperature and barometric pressure. They have an effect on vehicle fuel consumption overall performance as they influence the engine operation (e.g. Motor oil viscosity, engine consumption air-glide, etc.). They might also affect driving, as the driving force has to adjust his riding pattern therefore. Driving conduct refers to the driving patterns person motive force follows, like acceleration and top velocity. Aggressive using can growth fuel consumption dramatically by way of up to 24 %, at the same time as eco-using can offer envisioned advantages within the order of 6 to 8 % as compared to conventional real-world operation with sure resources raising.

Vehicle condition refers to the state of the vehicle in terms of maintenance such as engine lubricant viscosity and tyre rolling resistance. Inflation pressure determine tyre stiffness, which has a giant have an effect on the touch region of the tyre and pressure distribution over the touch surface and tyre rolling resistance. Therefore, as pressure inside the vehicle tyre is reduced, the rolling resistance will increase over the street due to the fact the surface touch vicinity and virtual hill peak is expanded. When the rolling resistance is improved it takes greater strength (gas) to get the auto to go the equal distance. The relationship between tyre pressure, rolling resistance, and fuel economy is complex and dynamic and is dependent on several other factors, including vehicle type and load, road and environmental conditions (Friedrich, 2002) (Calwell et al., 2003).

2.8.2. Road safety and accident

Road accident depends on the relation between the system components. This system includes man, vehicle and road components. Road safety is ensured when these components relations are satisfy certain natural regulated limits. Vehicle accident is one of the top causes of death on the world. Even though vehicles are designed to help people, they also kill the man make them because of different reason. (Ali et al., 2019) (World Health Organization, 2013) described that road vehicle accidents are the third cause of death in the world. Studies reveal that about 1.24 million individuals die each year as a result of traffic accidents. Majority of these deaths (85%) occur in poor countries. The resolution encourages all member states to set their own national road traffic casualties reduction goals for the decade and to carry out road safety activities, particularly in the areas of road safety management, road infrastructure, vehicle safety, road user behavior, traffic safety education, and post-crash response. Road traffic injuries (RTIs) are significant public health challenges and are projected to be the fifth leading contributor to the global burden of disease by 2030(Josephine et al., 2012). However, accidents are unfortunate and frequently occur on the road and cause death (Aldegheishem et al., 2018), infrastructures damage, and human health injuries. Majority of the countries lose 3% of their GDP due to road accidents. Besides having a huge emotional impact on the quality of life, road crashes also pose a very significant socio-economic burden (Wim, 2020) on the country. Medical costs, loss of productive capacity, property damage, administrative expenditures and human costs are all achieved at the expense of traffic deaths. The causes of road traffic accidents (RTA)s are multifaceted and can be divided into three categories: driver factors, vehicle factors, and highway factors (Olemo, 2016). Numerous elements have been identified through empirical research, most of which are connected to drivers, vehicles, roads, and the environment. Road traffic accidents are predictable and preventable but good data is important to understand the ways in which road safety interventions can be effective. Cost-effective preventive measures can be designed to address this global problem. Existing studies of automobile accidents had focused primarily on injuries caused by driver’s error and road-related factors (Zhou et al., 2020). Surprisingly, limited effort has been devoted to identifying factors that increase the rate of accidents caused by vehicle systems. Road Traffic Police report indicates that causes of accidents are the real fault of the system "man - vehicle - road" interactions (Bureika et al., 2012). These systems may not directly be the cause of the accident but, can indirectly influence the causation of an accident. Most accident researchers are based on post-data to analyses the situations of traffic accidents. The fact that most researchers or reporters don't say much about their contribution may stem from the fact that, they lack adequate information on how they might have caused or influence the accident (Panagiota et al., 2009). Different information deals with the technical cause of road accidents, but vehicle failure accounts 2 – 15% for the main cause of an accident (Duboka, 2017). Vehicle accident research has primarily focused on past tragedies to develop and implement policies to combat this pandemic.

2.8.3. Vehicle dynamic control

The main problems of operation of road transport vehicles are related to safety, economy and environmental impact. The performances by vehicles are closely linked to tyres, their selection and the quality of their operation. The main purpose of the tyre is to cushion the impact on the car chassis due to rough road, to provide a reliable grip between the wheels and the road surface, to transmit traction and braking forces to the road surface (P. & H., 2019) (V et al., 2016). Braking performance is a measure of how much effective and stable a vehicle is under braking (Gillespie, 1992).

Researchers like (M. K. M. et al., 2002) conducted a sequence of test on unique vehicles and concluded that ABS braking performance is most desirable near the producer encouraged tyre pressure and barely low both above and beneath this nominal pressure. From the research conducted on vehicle braking efficiency by (Ajami et al., 2020) stated that decreasing tyre air pressure from two to one bar and applying a brake at vehicle moving at 100km/h decreases vehicle stopping distance by12 %. In addition to this decreasing tyre inflation pressure from two to one bar again and applying a brake at vehicle driving at 90km/h decreases vehicle stopping distance by15 %. Overall stiffness of a tyre and weight carrying capability is determined with the aid of the air in it. This inflation pressure can drastically have an effect on the general vehicle overall performance. Almost all developed tyre models are both ignored the effects of tyre stress or could not sufficiently validate the outcomes received from it. Tyre pressure influences on three important handling parameters of tyres. Those parameters are longitudinal force, lateral pressure and aligning moment. Tyre's average stiffness increases with growth in air pressure thereby reducing the tyre deformation and in flip its contact patch duration. A discount in contact patch period consequences in decrease cornering stiffness. Cornering stiffness is better for high stress tyres at higher vertical loads. The explanation provided earlier for the first trend breaks down at excessive vertical loads (J., 2005). Increase in inflation pressure results in an increase in tyre stiffness which in turn results in the decrease in contact patch length. Decrease in contact length is followed by decrease in moment arm of the self-aligning moment, thereby exhibiting a lower peak value.

2.8.4. Ride safety and comfort

Vehicle ride comfort gives a guiding standards for the powerful manage of vehicle frame excitations and vibrations that causes passenger discomfort and car components failure. Human body preferred a responds to specific vibration frequencies in distinct approaches. A vehicle is subjected to vibrations from a number of special sources. Some of the primary resources are avenue floor irregularities, engine and driveline vibrations, aerodynamic forces and mass imbalances inside the rotating additives. In this report only the low frequency avenue surface excitations will be considered and the opposite resources of vibration and noise can be excluded. Vertical stiffness of a tyre is stimulated via numerous parameters such as inflation pressure, load, speed, camber and many others (Jacobsson, 2012) (T. et al., 2004).

2.9. Research gab

Vehicles operational performances are disturbed as a function of its component defects. Tyre is one of the components of vehicle which transfers forces between a vehicle chassis and road. A tyre provides this function if and only if its structure and inflation pressure are kept at a normal value and condition. From literature review it was revealed that tyre inflation pressure affects vehicle operational cost, directional vehicle handling, vehicle ride comfort and traffic accidents. Rolling, aerodynamic, rotary parts of vehicle inertia and climbing resistance are a resistance forces applied on moving road vehicles. Those resistance are considered and determined during designing face and manufacturing period before dispatched to the end user for particular vehicle brand and model. This values are affected by defects introduced to the vehicle components from different sources such as operational and maintenance faults. The defect introduced to vehicle components are added extra burden beyond the value given during designing and manufacturing. A tyre is one of the components of a road vehicle which vulnerable to operational and maintenance defects. Tyre inflation pressure, wear and tear and service life are tyre faults which affects vehicle operation. Minimum and unavoidable amount of vehicle operational defects are considered during designing at a vehicle normal operating and load condition. This value is changed due to improper operation, maintenance and load condition.

Different studies are revealed that tyre inflation pressure affects vehicle power loses, vehicle directional control, ride comforts and reduces vehicle component service life. The effects of tyre inflation pressure on vehicle directional control was identified on literature review concerning tyre inflation pressure on braking efficiency and steering. But it is not clearly identified by how much tyre inflation pressure affects this value is not clearly identified. In addition causes of traffic accidents are happened because of faults of man - vehicle – road interactions. But which vehicle parts are responsible for the accident not clearly identified rather than general conclusion given. 10% to 30% of tyres are removed from the vehicle because of regular long-term service, 40% to 60% are replaced for odd wear motives, 5% to 10 % are changed with not anything is found and the remaining 20% are eliminated for other motives. But again the effect of tyre inflation pressure effect on tyre life is not clearly identified.

CHAPTER THREE
MATERIAL AND METHOD

3.1. Introduction

This chapter presents material and method used to build mathematical vehicle model and simulation that enables to capable of drawing the impact of tyre inflation pressure on vehicle operation in the form of handling, ride characteristics and fuel consumption. To do this three vehicle models are built by using mat lab Simulink software. A vehicle has three basic functional domains. These functional domains are longitudinal dynamics (propulsion, braking and tyres), vertical dynamics (springing, damping and tyres) and lateral dynamics (steering, braking, propulsion, tyres). Those functional domain models and simulations are developed. At each phase of study the result obtained will compared to experimental data and standards obtained from the literature.

3.2. Study area designation

This study was carried out at Wonji-showa sugar factory which is located in east Shewa, Oromia, Ethiopia at latitude of 8.37565 and the longitude of 39.31143 with the GPS coordinates of 08° 22′ 32.34″ N and 39° 18′ 41.14″.

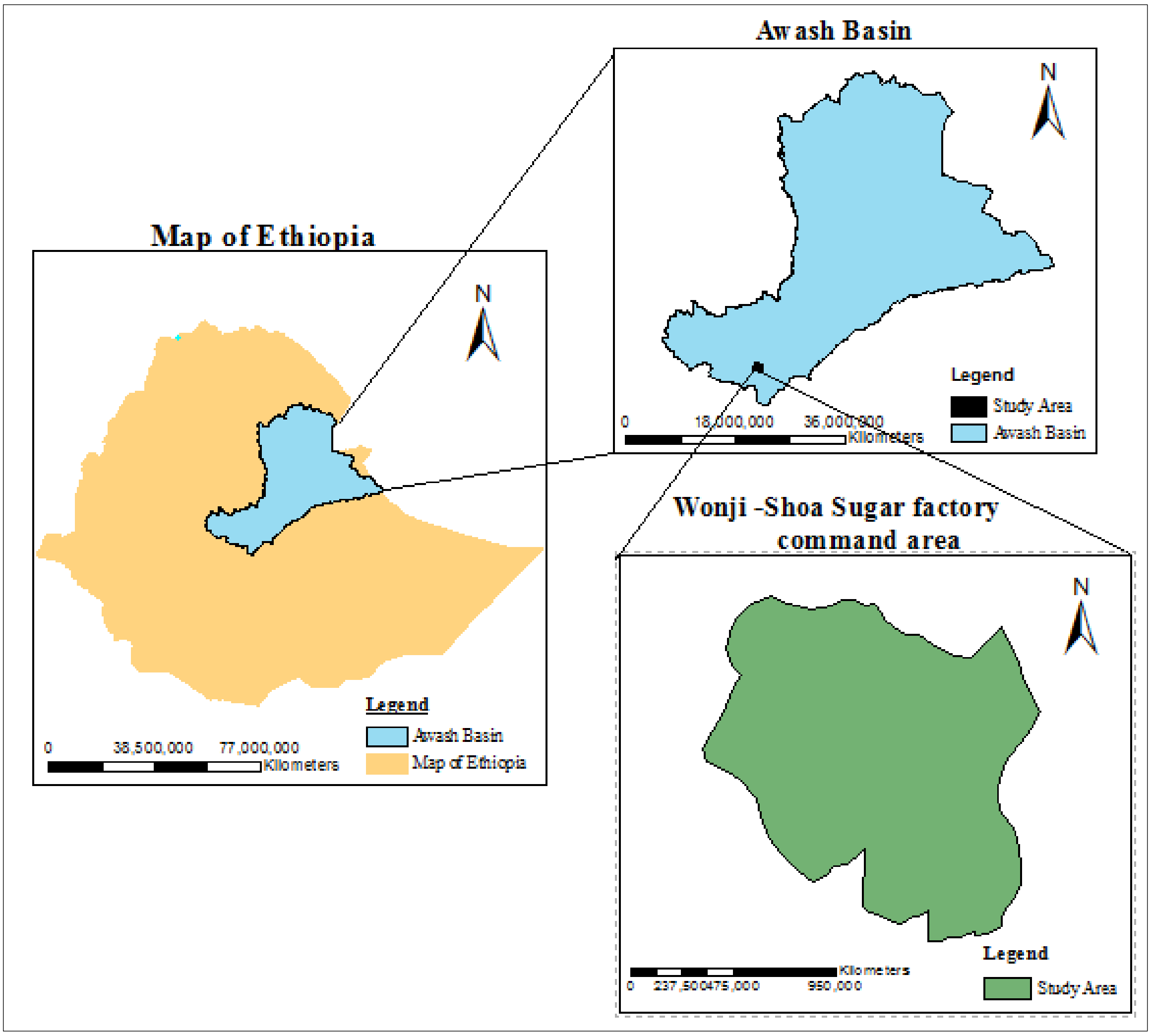

Figure 3.1. GPS location of Wonji-shoa sugar factory

3.3. Material

This chapter presents the material and methodology used to build mathematical tyre model that enable to extract the influence of tyre inflation pressure on the fuel consumption, ride characteristics and lateral handling of a vehicles at Wonji-shoa sugar factory. To do this Mat lab Simulink software was utilized for modeling and simulation of vehicle fuel consumption, vertical ride comfort and lateral handling as a function of tyre inflation pressure. The driving force for this study was the climbing of operational budget requirement of sugar factories from time to time and becoming difficult to produce sugar in our country. This increasing operation budget requirements was mainly surprising for field equipment maintenance and field operation. Vehicles are one of the equipment's of a factory maintained under this maintenance department. Perhaps factory uses different type of vehicles for land preparation, cane cultivation, cane transportation, field work supervision and etc. To accomplish these operational activities it was utilized different type of tyres to its vehicles. Therefore tyre is a parts of a road and off road vehicles. It is the only parts that transfers forces between roads and the vehicles. These tyres are exposed to different circumstances of defects. These circumstances of defects are wear and tear due to over loading, improper air pressure in the tyre, improper wheel alignment, wrong quality and etc. utilizing defective tyre on operation sets the factory maintenance repetition, increasing in maintenance costs, vehicle down hours and finally decreases factories profit. To demonstrate tyre inflation pressure impact on the factories vehicle performance passenger car was selected. Data are collected for supper vision vehicles, truck vehicle for material transportation and trailers for cane transportation which accounts the majority of sugar production expenses. To design advanced automotive power train, it required to correctly understand the energy line and rapidly identify the areas where the savings are probable. So it requires to position a simulation tools that capable of perform a precise and fast systems analysis. Vehicle model is developed in matlab Simulink using the quasi-static simulation tool box library (QSS TB) based on specification of one of the type of vehicle used in Wonji-shoa sugar factory. The QSS TB was developed by ETH Zürich for educational research purposes which permits fast and simple estimation of fuel consumption for different vehicles power transmission configurations (Guzzele & Amstutz, 2005). In general the material used for modeling and simulation of vehicle fuel consumption, vertical ride comfort and lateral handling as a function of tyre inflation pressure are:

- Mat lab Simulink software
- Quasi Static Simulation Toolbox (QSS TB)
- Pickup vehicle with 205/70R16 tyre
- Microsoft excel

3.4. Method

The research used a qualitative research approach, due to its characteristics. So that in order to achieve the general and specific objectives of the study and answer the research questions, the study followed the research model based on well-accepted elements of the design science research methodology (DSRM) process (A. & Peffers, 2007). The main reason I was select design science research methodology was because this method was well planned research design that helps to ensure my research aims, that I collect high-quality data, and that I use the right kind of analysis to answer my questions, utilizing credible sources. This allows to draw valid, trustworthy conclusions. There are several methods of tyre inflation pressure testing plat forms which could provide a well-structured tools for study its impact on vehicle operation. From those tools I selected mathematical modeling and simulating in matlab Simulink using QSS TB library. Primary data collection method is used to collect data of vehicle tyre inflation pressure at Wonji shoa sugar factory by direct interview. The collected data are summarized and manipulated using Microsoft office excel. Passenger car with tyre size 205/70R16 specification is taken from manufacture broacher. All data are inserted in to qss tb user interface and analyzed. Vehicle handling model is also developed with mat lab Simulink by half car model and ride quality model is developed with full car model in mat lab Simulink.

3.5. Data Collection

This study consists of both primary and secondary data. The nature of the data that are required to conduct this research can only be collected through the qualitative methods. Since the qualitative data collection is the best option for this research work to collect the required data and information in order to draw the best results. The option of qualitative study for this research is the outcome of a mirroring on the nature of the difficulty. Eye to eye interview methods were favor to quantitative methods as they provide intricate details of the qualitative situation. In this study, semi-structured question was observed as the richer and most important way to collect data.

The qualitative data collection techniques that were applied in this study were interviews, document analysis, and observation. Literature studies are also regarded as a data collection technique. This technique was preferred because the thesis was built on understanding views and perceptions of people, rather than on statistical comparisons among the statistical data. A researcher carrying out a study mainly through interviews, with physical involvement in action in the field as a participant, can gain the advantages of personal involvement such as in depth investigation into people and related issues and enabling observation or participation in action. Average tyre maintenance data of Wonji-shoa sugar factory transport vehicles collected from field equipment maintenance division (FEMD) tyre repair experts by direct interview in January 2022 are listed in table blow.

Table 3.1. Inflation pressure of passenger cars at Wonji-shoa sugar factory

No of tyre deflated ≥ 25%	Number of vehicles	Percent out of total 31 vehicles
0	7	26.9
1	9	34.6
2	5	19.7
3	3	11.5
4	2	7.3

Table 3.2. Inflation pressure of truck and buses at Wonji-shoa sugar factory

No of tyre deflated ≥ 25%	Number of vehicles	Percent out of total 26 vehicles
0	6	19
1	11	36
2	5	16
3	2	6
4	3	10
≥ 5	4	13

3.6. Vehicle driving resistances modeling

Under inflated tyre make a weight of vehicle supported by tyre rather than air pressure. The weight supported by a tyre enlarges a tyre print and increases friction and heat. But over inflated tyre makes too much vehicle weight was supported by tyre air pressure. Due to this a vehicle was bouncing and hard to steer because the tyre print is small and only the center portion of the tyre print is contacting. The rolling friction coefficient decreases by increasing the inflation pressure p. The effect of increasing pressure is equivalent to decreasing normal load. The following empirical equation has been suggested to show the effects of both pressure and load on the rolling friction coefficient. Reducing tyre inflation pressure increases the rolling resistance of a vehicle.

$$\mu_r = \frac{K}{1000}\left(5.1 + \frac{5.5X10^5 + 90F_Z}{p} + \frac{1100 + 0.0388F_Z}{p} v_x^2\right) \qquad 3.1$$

Where μ_r is rolling friction coefficient, F_z is normal load in N, p is pressure in MPa, V_x is tyre longitudinal velocity in m/s, and parameter K is coefficient depending on the tyre construction and equal to 0.8 for radial tyres and 1.0 for non-radial (diagonal tires) tyres. Power lost to overcome rolling resistance dependents on tyre inflation pressure(Jaza, 2009).

$$P = F_{RR} * V_x = -\mu_r * V_x * F_z \qquad 3.2$$

$$P = \frac{-K * V_X}{1000}\left(5.1 + \frac{5.5 * 10^5}{p} + \frac{1100 + 0.0388 * F_Z}{p} * V_x^2\right) * F_Z \qquad 3.3$$

Where: P is power lost in overcoming rolling resistance, F_{RR} – rolling resistance force.

Several resistive forces act on a moving car. These forces are rolling resistance, drag inertia forces, up/downhill force and tow force. Out of them some are act on the vehicle all the time and some of them may not be present in a certain driving condition. The goal of this thesis is to study the effect of vehicle wheel defects on vehicle performance I many focus on wheel rolling resistances. Vehicle driving resistances are divided into steady-state and dynamic resistance. Steady state resistance includes rolling resistance, aerodynamic drag, and climbing resistance. But vehicle accelerating is a type of dynamic resistance. The overall driving resistance is equal to required force implemented to the driven wheels which used to enable rolling movement.

$$F = F_{Req} = F_A + 4F_{RR} + F_C + F_I \qquad 3.4$$

Total driving resistance force F, Required force at the driving wheels F_{Req}, Rolling resistance of one wheel F_{RR}, Inertial resistance F_I, Aerodynamic drag F_A and Climbing resistance F_C.

3.7. Power Loss Analysis

Under real-world operating conditions, a tyre's behavior is influenced not only by the kinematic and Elastokinematics effects of the vehicle, but also by the effects of combined tangential and lateral slip, both of which are dependent on the dynamic wheel loads and resulting internal tyre pressures. These parameters are required for measurements of the rolling resistance and can have a significant effect on both the tyre's energy balance and the vehicle's fuel consumption. Sufficient information about these parameters can only be provided by a complex power loss analysis. This type of analysis determines the power loss in the tyre by subtracting the power output from the power input.

$$P_{loss} = P_{in} - P_{out} \qquad 3.5$$

In order to decompose the tyre's power loss into its individual additives, all movement parameters need to be considered. These consist of the velocities and rotational velocities in addition to the corresponding torques and forces.

$$P_{loss} = P_{loss,roll} + P_{loss,V_X} + P_{loss,V_Y} + P_{loss,V_Z} + P_{loss,W_X} + P_{loss,W_Z} \qquad 3.6$$

Where $P_{loss,\ roll}$ is rolling power loss, $P_{loss,\ vx}$, is power loss due to change camper angle, $P_{loss,vy}$ is power loss due to longitudinal slip, $P_{loss,\ vz}$ is Power loss due to tyre deformation in the vertical direction, $P_{loss, wx}$ is Power loss due to sideslip, $P_{loss, wz}$ is Power loss due to course angle change and aligning torque

The various modes of power loss considered in this equation are:

- Rolling power loss (equivalent to traditional measurements of rolling resistance)
- Power loss due to change camber angle
- Power loss due to longitudinal slip
- Power loss due to tyre deformation in the vertical direction
- Power loss due to sideslip
- Power loss due to course angle change and aligning torque.

Power loss analyses are performed using appropriately equipped test rigs which are capable of measuring the tire's rolling resistance. Depending on the operating conditions, power losses of more than 10 kW per tyre are possible. The power loss behavior of a tire can be integrated over defined cycles and operating parameters to obtain the total power loss. This can then be used to perform a more accurate energy balance than could be obtained by simply using the coefficient of rolling resistance. A comprehensive analysis of this type can be used to show how different chassis designs and axle configurations can reduce the energy consumption of the vehicle. As a visco-elastic component, the tire's behavior is heavily dependent on temperature. Temperature can affect the tyre's adhesion, durability, ride comfort, wear, and rolling resistance. It is therefore important to measure tire temperature during testing and include temperature effects in any simulations of tire behavior. There is also a direct relationship between tire temperature and the power loss in the tire. The effects listed above depend mainly on the temperature of the rubber in the tire's tread surfaces. The search for an optimal compromise between increased adhesion and reduced rolling resistance has been the main focus of tire material development for decades.

A power condition of a tyre may be included over defined cycles and working parameters to acquire the whole loss. Then after this can be used to carry out extra correct energy stability than could be received via without a doubt the use of the coefficient of rolling resistance. A complete evaluation of this type may be used to reveal how specific chassis designs and axle configurations can reduce the energy consumption of the car. As a viscos-elastic factor, the tyre's behavior is heavily depending on temperature. Temperature can have an effect on the tyre's adhesion, sturdiness, experience comfort, wear, and rolling resistance. It is consequently critical to degree tyre temperature throughout testing and include temperature results in any simulations of tyre behavior. There is likewise a right away dating among tyre temperature and the power loss inside a tyre. The results indexed above depend in particular at the temperature of the rubber inside a tyre's tread surfaces. The look for a top-quality compromise among accelerated adhesion and decreased rolling resistance has been the principle attention of tyre material improvement for many years.

3.8. Fuel Consumption modeling

In order to overcome driving resistance force and to provide a required power vehicle needs energy from some source. As a result of their high energy densities (unit energy per unit mass), the carbon-hydrogen bonds found in liquid fossil fuels are the standard energy source used for motor vehicles. Liquid fossil fuels are still cost effective to manufacture from crude oil, and are available worldwide. This may change in the foreseeable future, as the earth's oil reserves are being rapidly consumed. The specific forms of liquid fossil fuels used to power automobiles are various grades of gasoline and diesel fuels. The energy in fuel is stored in chemical form as the bonds between hydrogen atoms and carbon atoms. During combustion with oxygen, this energy is released as heat. The byproducts of this combustion reaction are H_2O and CO_2. European Union lawmakers have therefore created a mandatory fleet maximum emissions limit of 130 g/km for automakers, which is set to go into effect in the year 2012. Due to economic factors, environmental concerns, and concerns about the scarcity of resources, a main goal of automotive engineers is to develop vehicles which consume as little fuel as possible. This goal can be achieved in a number of ways, for example by optimizing a vehicle's aerodynamics or using tires with reduced rolling resistance. Methods for reducing fuel consumption also include optimizing engine internal processes and improving powertrain efficiency. In addition to these traditional methods, the use of alternative energy sources can be considered. The fuel consumption B [kg] of a vehicle can be calculated based on the energy density of a particular energy storage medium. In general, a specific fuel consumption is indicated for a vehicle. This fuel consumption is relative to the distance traveled s_x [m] and is denoted as B_e [kg/m].

$$E_{Req} = \int_0^{s_x} F_{Req}(s).\, ds = \int_0^{t_x} P_{Req}(t).\, dt \qquad 3.7$$

Where E_{Req} is energy required, F_{Req} is driving resistance force, s_x is distance traveled, P_{Req} is required power and t is time. The fuel consumption per unit distance B_e can therefore be calculated as:

$$B_e = \frac{B}{S_x} \qquad 3.8$$

The energy required to drive the wheels is determined by the driving resistances. A total driving resistance is made up of climbing and inertial resistance. The energy required at the wheels to overcome these forces is retained in the vehicle's position and state of motion as kinetic and potential energy.

3.9. Mathematical modeling

QSS TB is used with matlab Simulink to develop a complete vehicle model which is utilized for modelling a dynamic system. In traditional way dynamic systems are modelled as speed and acceleration of a system are calculated from forces acting on it. But in this approach a force acting on the system is calculated from the speed and acceleration of the system. This situation cause and effect relationships are reversed. In the quasi-static method acceleration (a_y) is a cause. But forces (F_{yL1}, F_{yR1}, F_{xL1}, F_{xR1}, F_{yL2}, and F_{yR2}) are the effect.

$$M * a_y = F_{yL2} + F_{yR2} + \left(F_{yL1} + F_{yR1}\right)\cos(\delta) + (F_{xL1} + F_{xR1})\sin(\delta) \qquad 3.9$$

Rolling resistance is a losses of energy per unit of distance travelled. From the literature review a number of parameters such as speed, load, temperature, tyre pressure, construction, size, road condition, wear, and wheel alignment are a defects of vehicles that influence overall rolling resistance of tyres. The rolling resistance coefficient is dimensionless. Rolling resistance of a tyre depends on the load applied to the tyre. Studies have suggested that a linear relationship exists between rolling resistance and tyre load, so a dimensionless rolling resistance coefficient has been formulated.

$$C_{RR} = \frac{F_{RR}}{F_Z} \qquad 3.10$$

Where C_{RR} is rolling resistance coefficient, F_{RR} is rolling resistance force and F_Z is tyre load.

Vehicles moving on the road are confronted by rolling resistance, air resistance, gradient resistance and resistance due to inertial forces. A car driving along flat road without longitudinal or lateral gradient at a regular velocity the resistance of inertial forces and a gradient resistance are theoretically equal to zero and consequently, they can be unnoticed. If a vertical element of air resistance is also overlooked, supplied that the value of horizontal aspect for a positive car shifting at given regular speed is understood, then it's far possible to calculate the value of rolling resistance through subtracting the air resistance from the overall resistance. According to rolling resistance force equation:

$$R = R_f + R_\alpha + R_a + R_i \qquad 3.11$$

Where R is rolling resistance, R_f is resistance due friction, R_α is gradient resistance, R_a is air resistance, and R_i is resistance due to inertial forces. Therefore these parameters are taken into consideration to version tyre rolling resistance forces in complete automobile model. Since it tough to govern temperature in actual global rolling resistance will no longer recollect. Using this modeled equation a tyre rolling resistance forces may be determined at specific tyre pressures based on rolling resistance forces statistics measured at a few fixed wide variety of factors.

$$F_{RR} = F_{RR0} + K_L(F_Z + F_{Z0}) + K_P\left(\frac{1}{p_i} + \frac{1}{p_0}\right) \qquad 3.12$$

Where F_{RR} is a tyre rolling resistance force at a load F_Z and pressure P_i, F_{RR0} is tyre rolling resistance force at reference load F_{Z0} and reference pressure P_0, K_L is slope of load dependency of F_{RR} at a fixed pressure P_0 and K_P is a slope of reciprocal pressure (1/P) dependency of F_{RR} at fixed load, F_{Z0}.

$$F_{RR} = F_{RR0} * \left(\frac{F_Z}{F_{Z0}}\right)\left(C_P * \frac{p_0}{p} + C_T\right) \qquad 3.13$$

This mathematical model show the influence of vehicle load, speed and tyre inflation pressure on vehicle rolling resistance. Rolling resistance force of the tyre is measured at some prearranged speeds as a tyre speed is varies from 15 km/h to 110 km/h.

$$F_{RR} = P^\alpha F^\beta(a + bv + cv^2) \qquad 3.14$$

Where V is the coast-down speed and α, β, a, b and c are constants which are depending on the pressure P and load F_Z of the tyres. The values of those constants are obtained with the aid of appearing regression analysis on the rolling resistance forces statistics acquired from the coast-down process. This model has been validated for several tyres of various sizes, throughout specific manufacturers.

$$F_{RR} = C_{RR}(Z) * Z \qquad 3.15$$

$$F_{RR} = K * P^\alpha * Z^\beta \qquad 3.16$$

Where k is constant for a given tyre $\alpha \approx -0.4$ and $\beta \approx 0.85$ for an average passenger car and $\alpha \approx -0.4$ and $\beta \approx 0.85$ for a truck tyre

$$F_{RR} = F_{RR-ISO} * \left(\frac{P}{P_{ISO}}\right)^{\alpha} * \left(\frac{Z}{Z_{ISO}}\right)^{\beta} \quad 3.17$$

Where F_{RR} is rolling resistance, F_{RR-ISO} is ISO rolling resistance, P_{ISO} is ISO pressure, Z_{ISO} is ISO load and C_{RR} is rolling resistance coefficient.

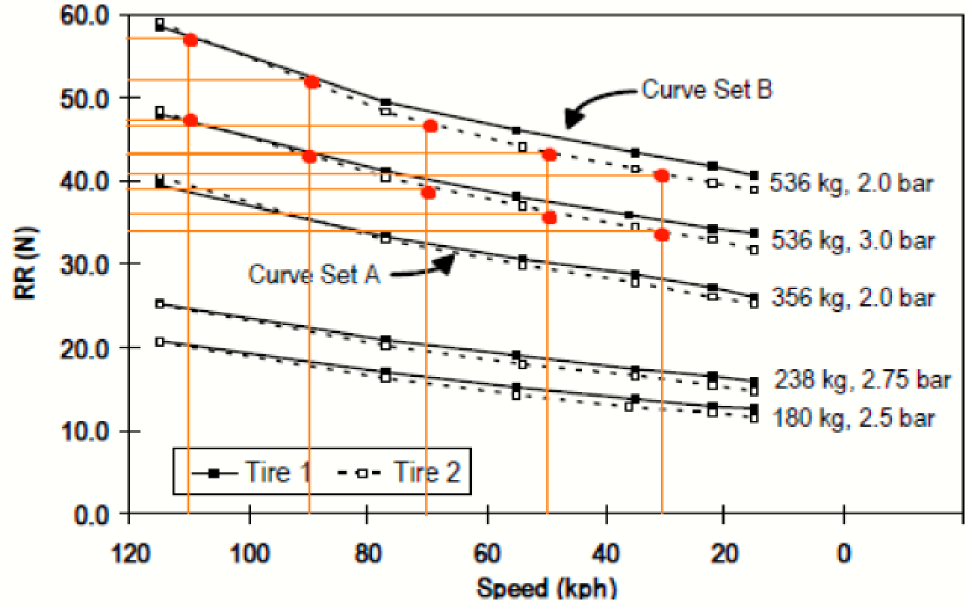

Figure 3.2. Rolling resistance force as a function of load, velocity and pressure (S. & H., 1999)

The above mentioned model presents the impact of tyre inflation pressure on rolling resistance force satisfactorily.

It is insufficient to absolutely rank tyres primarily based on traditional technique of comparing with their rolling resistance coefficient measured by test rag. Rather Mean Equivalent Rolling Resistance is used to examine the rolling resistance forces of tyres for a selected tyre and driving cycle combination. MERF is described because the average of rolling resistance pressure values of all of the individual speeds time factor in a using cycle. This is mathematically defined by equation:

$$MERF_{Cycle} = \frac{\int_{t_0}^{t_f} F_{RR} dt}{\int_{t_0}^{tt_f} dt} \quad 3.18$$

Where, $MERF_{Cycle}$ is mean equivalent rolling resistance force, F_{RR} is rolling resistance force, t_0 is cycle start time and t_f is cycle end time.

For a fixed tyre pressure and load, equation 3.18 is simplified using standard numerical integration method to equation

$$\mathrm{MERF_{Cycle}} = \frac{\mathrm{P}^{\alpha}\mathrm{Z}^{\beta}(\mathrm{at_f}+\mathrm{b}\sum_{\mathrm{i}=1}^{\mathrm{f}}\mathrm{V}+\mathrm{c}\sum_{\mathrm{i}=1}^{\mathrm{f}}\mathrm{V}^2)}{\mathrm{t_f}} \quad 3.19$$

3.10. QSS TB vehicle model

The specification of land cruiser pickup automobile is used and a complete car model is developed in matlab Simulink of Quasi static Simulation library. This library is evolved for instructional functions and has built in fashions of various vehicle's additives together with engines, transmissions, motors, batteries and so on, with which it's far possible to build a complete automobile. From information of the given brand and model car specification, it is able to predicting the gas consumption for a given driving cycle, based on a number of vehicle inputs, which includes tyre pressure. So for as identified in literature review the scope of this thesis is modeling tyre rolling resistance to study its effect on vehicle operation.

To do first tyre pressure was adjusted to the manufacturer recommended pressure of 2.2 bars. Then the model turned into simulated over a New European Drive Cycle (NEDC) metropolis using cycle to obtain its fuel consumption in liters/hundred km. The internal thermal efficiency of the engine was then modified inside suitable limits to match the fuel intake of a real vehicle (Guzzele & Amstutz, 2005). Then the model turned into simulated over a NEDC metropolis riding cycle to acquire its fuel consumption in liters/hundred km.

Table 3.3. Sampled vehicle spessification

No	Parameter	Value
1	Engine specifications	6-cylinder
2	Maximum torque [Nm @ r/min]	280 @ 2200
3	Maximum power [hp @ r/min]	131@ 3800
4	Curb weight [Kg]	2245
5	Wheelbase [m]	2.73
6	COG to front axle [m]	1.150
7	COG to rear axle [m]	1.525
8	Aerodynamic drag coefficient [-]	0.29
9	Rolling resistance coefficient [-]	0.0089
10	Gear ratios [1st-5th, Reverse]	[4.313, 2.33, 1.436, 1.00, 0.838, 4.22]

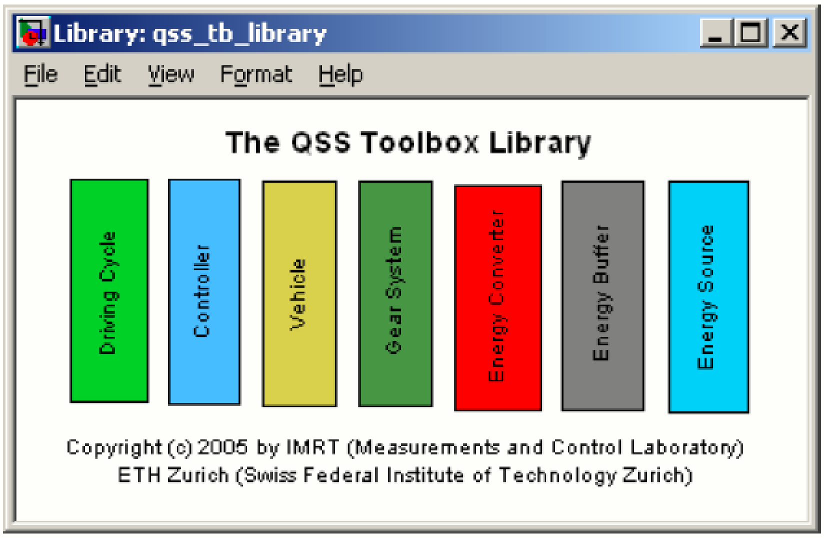

Figure 3.3. QSS TB Library top Level

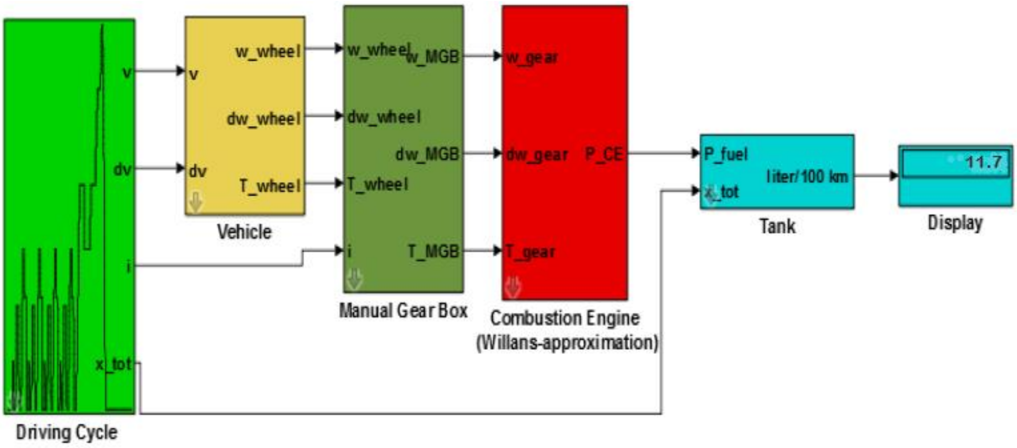

Figure 3.4. QSS vehicle model showing fuel consumption in L/100 km

A Qss tb driving Cycle is a user interface mask where parameter such as a cycle and step size are inserted.

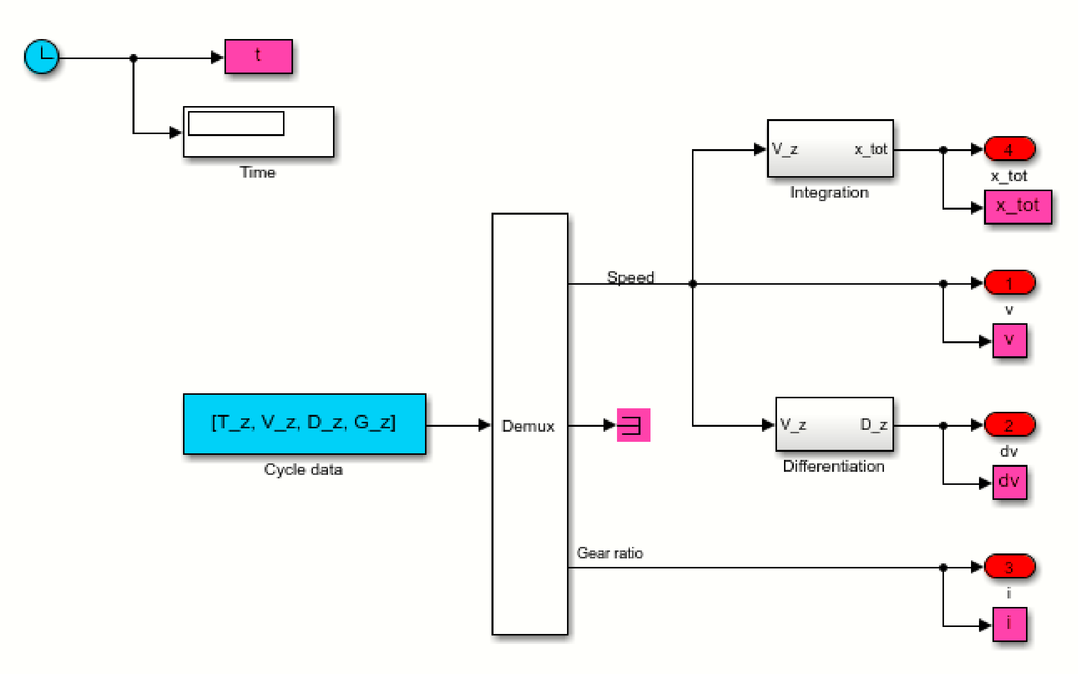

Figure 3.5. Drive cycle

Vehicle a qss tb user interface mask in which the total mass of the vehicle, rotating mass, vehicle cross section, wheel diameter, drag coefficient and rolling friction coefficient are inserted.

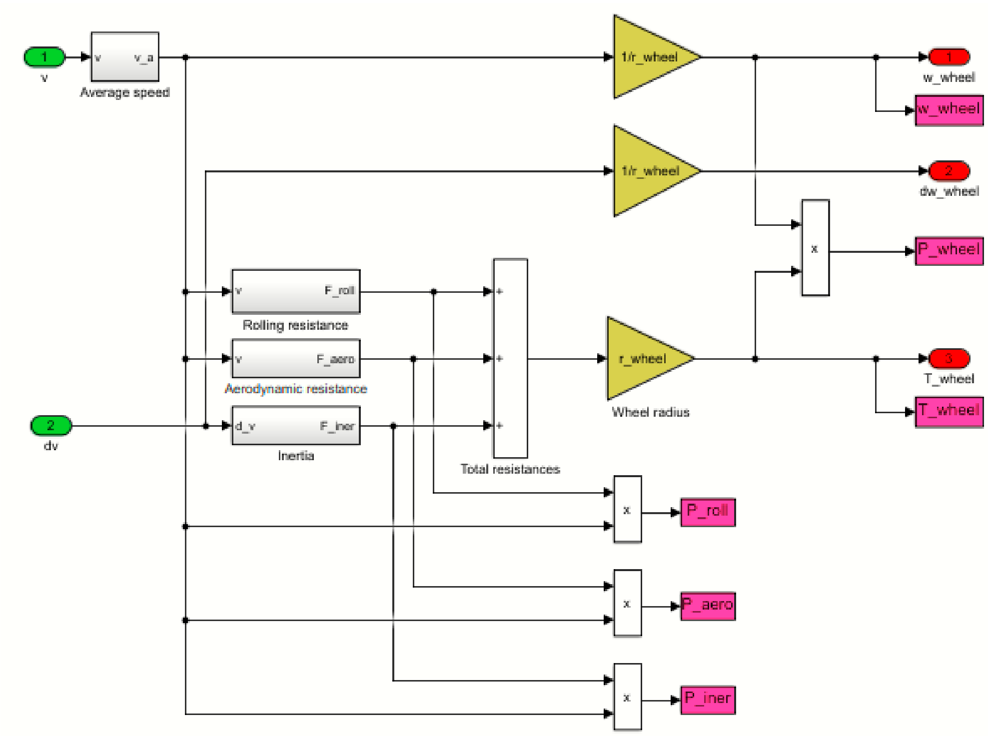

Figure 3.6. Vehicle

Manual Gear Box is a place where gear ratio of all gear train including first to fifth gear, deferential gear ratio, idling loses, efficiency and minimum wheel speed are inserted to user inter face(mask) of qss tb.

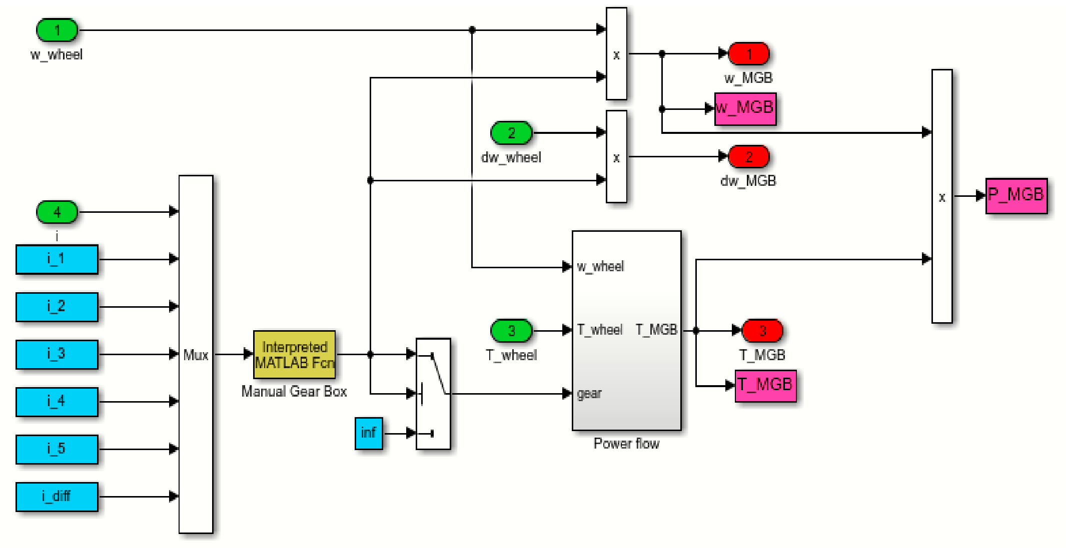

Figure 3.7. Manual transmission (Gear system)

Combustion engine is qss tb user interface mask at which engine data such as engine type displacement, engine scaling factor, engine inertia, engine speed at idle, engine power at idle, power required by auxiliaries, enable fuel cutoff, engine torque at fuel cutoff, engine power at fuel cutoff are inserted.

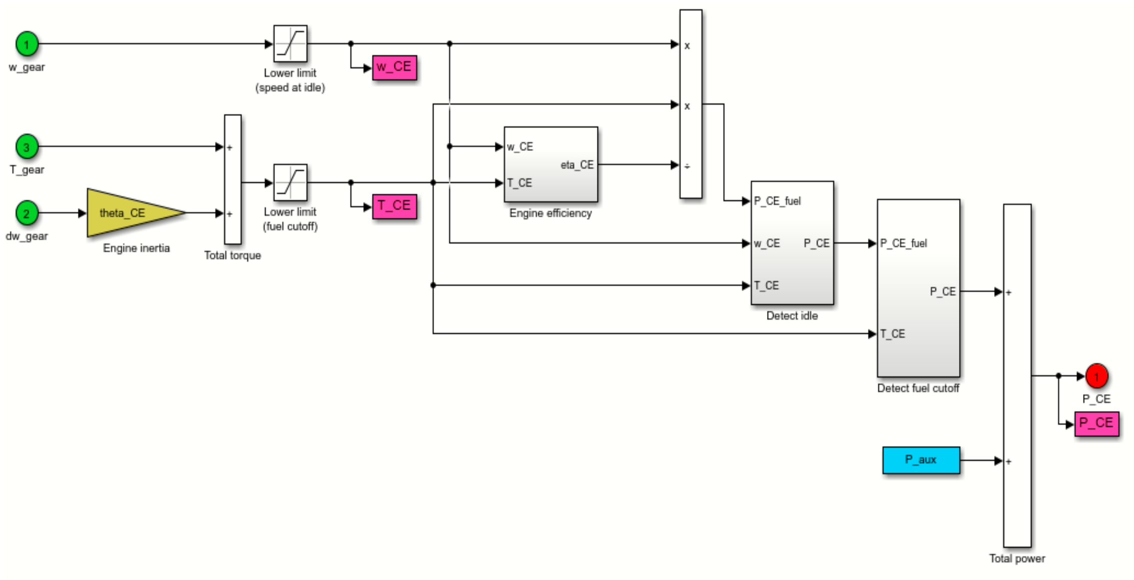

Figure 3.8. Combustion engine (Energy convertor)

Tank is qss tb user interface mask at which fuel and include cold start losses are inserted.

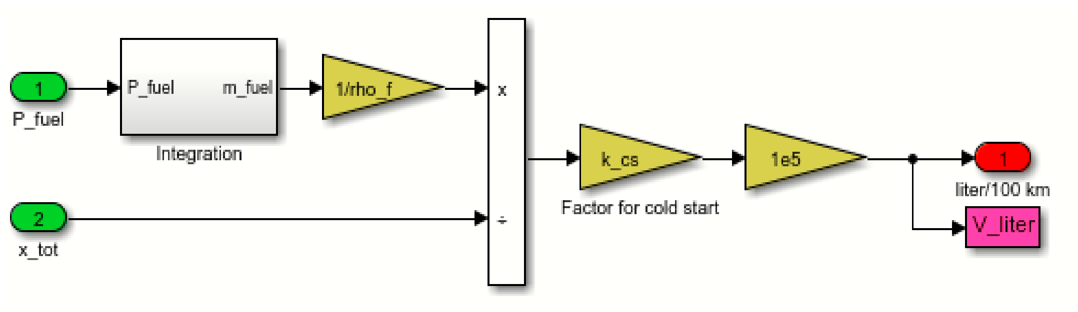

Figure 3.9. Tank (Energy source)

Driving Cycle block passes the velocity and acceleration statistics to the vehicle block as shown on figure 3.5. In the vehicle block figure 3.6 the overall resistance forces acting on the car is calculated and converted to required torque on the wheel middle. This block then passes the angular speed, angular acceleration and torque at the wheels to the manual gear box block figure 3.7. This lock in flip calculates the angular velocity, angular acceleration and torque, on the crank shaft of the engine based totally on the device choice records furnished by the usage of cycle block, at particular speeds. These values are then passed on the combustion engine block as shown in figure 3.8, that's an engine model that makes use of Williams's approximation to offer sensible simplifications to engine torque and overall performance characteristics.

Friction loss in engine block was modeled by means of semi empirical friction model which is developed by Zurich institute of technology. This model accounts for losses due to addition of supercharger/ turbochargers/, coolant and oil pumps. From this combustion engine block calculates mechanical power required from engine torque and speed at the crank shaft. This block finally calculates the entire energy gained from combustion of fuel by dividing power by engines internal thermodynamic efficiency coefficient and passed to the tank block a place where fuel consumption was calculated from the total distance travelled and displayed in liter/100km. Rolling resistance force of a vehicle is calculated using a simple linear relationship between rolling resistance and load in Vehicle block in QSS library.

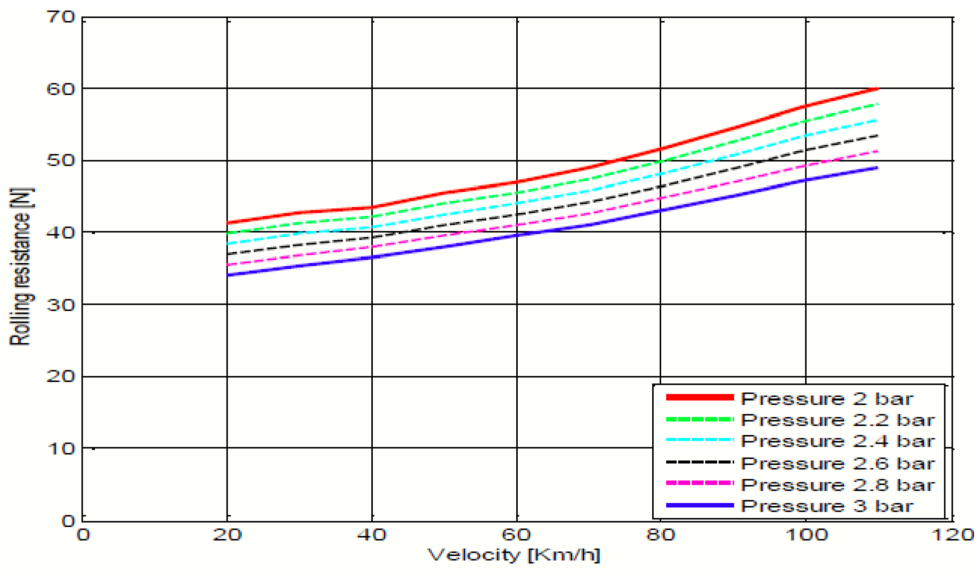

Figure 3.10. Rolling resistance as a function of velocity and pressure

3.11. Vehicle rolling resistance combined model

By using mat lab Simulink a block representation of the combined model is developed. The input parameters of this model are radius (R), longitudinal Velocity (Vx), normal Load (N), section Width (W) and tyre inflation Pressure (P). The out puts are rolling resistance coefficient (RRC) and rolling resistance force (RR).

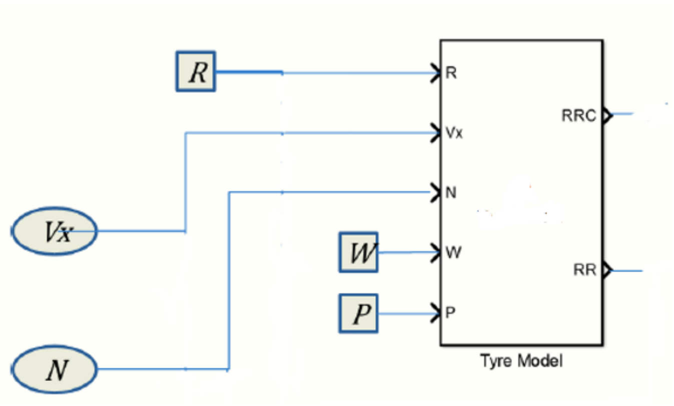

Figure 3.11. Combined model in mat lab Simulink

3.12. Vehicle handling characteristics modeling

Vehicle handling is the vehicle's reaction defined by its motion to both a driver actions and disturbances act on the vehicle during its longitudinal motion. A vehicle handling is subject to numerous and diverse requirements. The factors which determine vehicle safety are controllability on poor road surfaces

- Braking distance and brake force control
- Controllability while cornering
- Controllability at high speeds
- Controllability on slippery road surfaces
- Tolerant behavior when pushed to the limit
- Wheel slip control systems
- Predictability of vehicle behavior
- Feel for the road
- Driver assistance systems

Vehicle coping with is can range from one driving force to different. It is a driving force's belief of a vehicle's reaction to inputs forces which includes steerage, braking and acceleration. In different phrase it refers to a bodily response of the car to lateral forces. It is take a look at the automobile's behavior from the driving force's perspective. It gives the improvement of a two-song car version to observe the influence of tyre pressure on the coping with traits of the car. The reliability of effects obtained from a vehicle version is great as dependable because the tyre model utilized in it to outline the tyre forces and moments. In this understand, the tyre is one of the most crucial additives in a car, which thru its interaction with the street generates forces and moments required to maneuver a vehicle.

Vehicle handling and stability control was built in Mat lab Simulink according to vehicle power train. This model includes tyre pressure and vehicle dynamic model by 7 DOF. In a typical driving condition selected a vehicle handling simulation as per change in tyre pressure is considered. The influence of tyre pressure levels was studied. Theoretical dynamic model of a 7DOF vehicle was built. To build this model the influence of tyre inflation pressure were considered. Depending on built 7DOF vehicle dynamic model vehicle stability change with tyre inflation pressure change was simulated and analyzed.

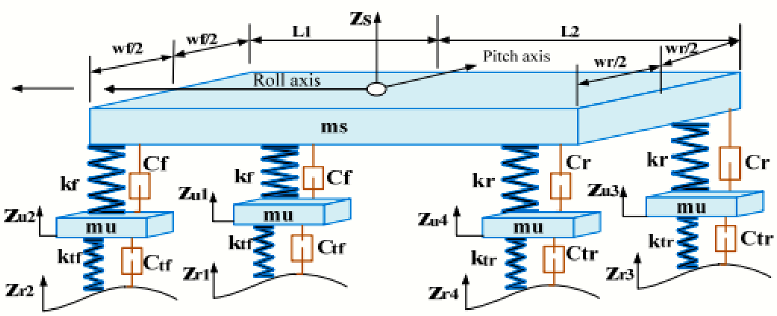

Figure 3.12. Full vehicle models

Where m_s is Sprung mass in kg, m_u is unsprang mass in kg, L_1 is distance from front wheel to the car CG in m, and L_2 is distance from rear wheel to the car CG in m, K_f is stiffness of front spring in N/m, k_r is stiffness of rear spring in N/m, K_{tf} is stiffness of front tyres in N/m, k_{tr}, is stiffness of rear tyres in N/m, C_f is front damper coefficient in Nm/sec, C_r is rear damper coefficient Nm/sec, C_{tf} is front tyre damping coefficient in Nm/sec, C_{tr} is rear tyre damping coefficient in Nm/sec, W_f is front vehicle width in m, and W_r is rear vehicle width in , Z_s displacement of the vehicle body in m, Z_{u1}, Z_{u2}, Z_{u3}, Z_{u4} are displacement of each wheel in m, Z_{r1}, Z_{r2}, Z_{r3}, and Z_{r4} are road excitation at all wheel.

$$\begin{aligned} m_s\ddot{z}_s = {} & k_f(z_{u1}-z_{s1})+k_f(z_{u2}-z_{s2})+k_r(z_{u3}-z_{s3})+k_r(z_{u4}-z_{s4})+c_f(\dot{z}_{u1}-\dot{z}_{s1}) \\ & +c_f(\dot{z}_{u2}-\dot{z}_{s2})+c_r(\dot{z}_{u3}-\dot{z}_{s3}) \\ & +c_r(\dot{z}_{u4}-\dot{z}_{s4}) \end{aligned} \qquad 3.20$$

For pitching moment of inertia of sprung mass

$$\begin{aligned} I_p\ddot{\theta}_s = {} & k_fI_1(z_{u1}-z_{s1})+k_fI_1(z_{u2}-z_{s2})-k_rI_2(z_{u3}-z_{s3})-k_rI_2(z_{u4}-z_{s4}) \\ & +c_fI_1(\dot{z}_{u1}-\dot{z}_{s1})+c_fI_1(\dot{z}_{u2}-\dot{z}_{s2})-c_rI_2(\dot{z}_{u3}-\dot{z}_{s3}) \\ & -c_rI_2(\dot{z}_{u4}-\dot{z}_{s4}) \end{aligned} \qquad 3.21$$

For rolling motion of the sprung mass

$$\begin{aligned} I_r\ddot{\varphi} = {} & \frac{k_fw_f}{2}(z_{u1}-z_{s1})-\frac{k_fw_f}{2}(z_{u2}-z_{s2})+\frac{k_rw_r}{2}(z_{u3}-z_{s3})-\frac{k_rw_r}{2}(z_{u4}-z_{s4}) \\ & +\frac{c_fw_f}{2}(\dot{z}_{u1}-\dot{z}_{s1})-\frac{c_fw_f}{2}(\dot{z}_{u2}-\dot{z}_{s2})+\frac{c_rw_r}{2}(\dot{z}_{u3}-\dot{z}_{s3}) \\ & -\frac{c_rw_r}{2}(\dot{z}_{u4}-\dot{z}_{s4}) \end{aligned} \qquad 3.22$$

For each wheel motion in vertical direction

$$\begin{aligned} m_{uf}\ddot{z}_{u1} = {} & -k_f(z_{u1}-z_{s1})-c_f(\dot{z}_{u1}-\dot{z}_{s1})+k_{tf}(z_{r1}-z_{u1}) \\ & +c_{tf}(\dot{z}_{r1}-\dot{z}_{u1}) \end{aligned} \qquad 3.23$$

$$\begin{aligned} m_{uf}\ddot{z}_{u2} = {} & -k_f(z_{u2}-z_{s2})-c_f(\dot{z}_{u2}-\dot{z}_{s2})+k_{tf}(z_{r2}-z_{u2}) \\ & +c_{tf}(\dot{z}_{r2}-\dot{z}_{u2}) \end{aligned} \qquad 3.24$$

$$\begin{aligned} m_{ur}\ddot{z}_{u3} = {} & -k_r(z_{u3}-z_{s3})-c_r(\dot{z}_{u3}-\ddot{z}_{s3})+k_{tr}(z_{r3}-z_{u3}) \\ & +c_{tr}(\dot{z}_{r3}-\dot{z}_{u3}) \end{aligned} \qquad 3.25$$

$$\begin{aligned} m_{ur}\ddot{z}_{u4} = {} & -k_r(z_{u4}-z_{s4})-c_r(\dot{z}_{u4}-\ddot{z}_{s4})+k_{tr}(z_{r4}-z_{u4}) \\ & +c_{tr}(\dot{z}_{r4}-\dot{z}_{u4}) \end{aligned} \qquad 3.26$$

Table 3.4. Definition of equation variables and parameters

No	Variables	Definitions
1	m_s = 2,155 Kg	Sprung mass
2	M_f = 90 Kg, m_r = 85 Kg	Unsprang mass
3	I_r = 5340 Kgm^2, I_p = 6430 Kgm^2	Roll and pitch of moment of inertia
4	L_1 =2.13 m, L_2 = 2.0 m	Distance from front and rear wheel to the car
5	K_f =36297 N/m, k_r = 19620 N/m	Stiffness of front and rear spring
6	K_{tf}, k_{tr} = 182470 N/m	Stiffness of tyres
7	C_f =3924, c_r = 2943 Nm/sec	Front and rear damper coefficient for
8	W_f = 1.74 m, w_r = 1.70 m	Front and rear vehicle width
9	Z_s in m	Displacement of the vehicle body
10	Z_{u1}, Z_{u2}, Z_{u3}, Z_{u4} , in m	Displacement of each wheel
11	θ, φ, rad	Roll and pitch angles

The model was validated using experimental data collected when the vehicle was being driven, at a speed of 8km/h, over Bump 1 (located within the premises of The University of Huddersfield). From simulation result as shown on figure 3.14 decrease in tyre pressure results in increasing the amplitude of the relative displacement of the vehicle body.

Suspension travel is a relative displacement between the wheel and vehicle body. So suspension travel is increasing with decreasing of tyre pressure. But this should be optimized with vehicle handling and stability. Decreasing tyre inflation pressure will increase RMS value which affects ride comfort negatively. The effect of tyre under-inflation on the performance of the vehicle suspension such as ride quality, handling and stability of the vehicle are theoretically modeled by 7DOF and analyzed by using mat lab Simulink and the results were compared to the existing experimental data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Contribution of rolling resistance to fuel consumption

This chapter gives values established from the simulation of car models two-tune, QSS and the four DOF full car model. From these result the effect of tyre inflation pressure on car fuel consumption, vehicle ride and handling are discussed to extract the results. A non-public inferences are made to correlate the outcomes among the vehicle models and the actual car. Rolling resistance effort/force is defined as a linear feature of load which is F_{RR}=f (Load) and referred as RR-I. RR-I is not account for the effects of other tyre working parameters which includes vehicle speed, inflation pressure and so forth. This version is used as a reference for another model RR-II which money owed for the influence of automobile velocity, load and inflation pressure on rolling resistance of tyres.

Table 4.1. Comparison of vehicle fuel consumption of two RR models

RR model No.	Fuel consumption [L/100 km]
RR-I	11.77
RR-II	11.68

The blue curve to RR-I and red curve corresponds model RR-II. For a fixed load and inflation pressure, the rolling resistance increases with pace for RR-II even as the RR pressure is unaffected by means of speed for model RR-I. This impact of reducing rolling resistance by means of 10% at the corresponding alternate in fuel intake estimation.

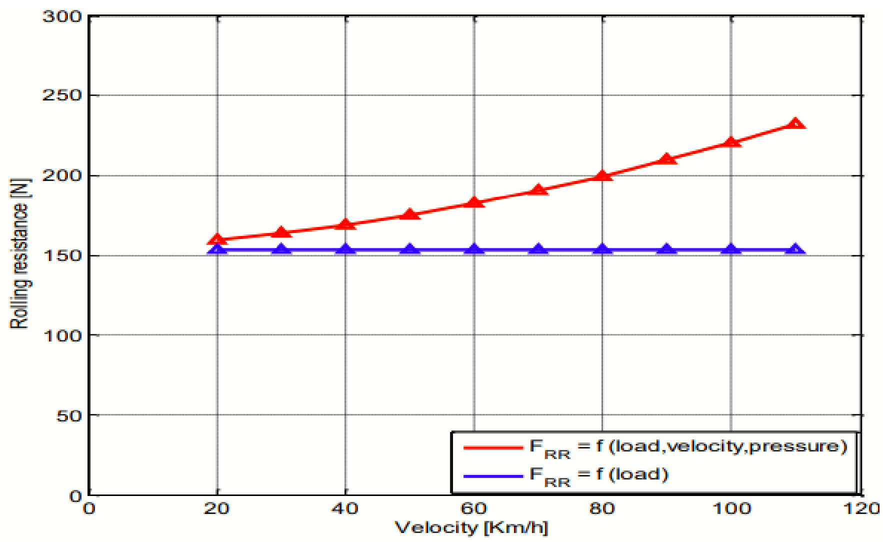

Figure 4.1. Difference between two rolling resistance models

In RR-I model fuel consumption reduced by 1.36%. Reducing 10% of rolling resistance reduces vehicle fuel consumption by 1.36% for nonlinear model RR-II as indicated in table above. But (Hall D. E. & C., 2001) stated that 10% reduction in rolling resistance can results in reduction of 2% of in vehicle fuel consumption. There is no a clear reference about whether the test is carried out at fixed speed, pressure and vertical load for model. It is important that in tyre rolling resistance can be accurately modelled for better estimation of vehicle fuel consumption. From table 4.2 using RR-II model in a full vehicle model to better estimation of fuel saving obtained.

4.2. Influence of tyre pressure on rolling resistance

As tyre inflation pressure increases its vertical deflation decreases and holds its shape firmly. Due to this deformation of rubber is smaller compared to that in a tyre with lower pressure. So hysteresis losses reduce thereby decreasing rolling resistance in case of level road surface. As inflation pressure reduces, there is a lot of bending and shearing of tyre sidewall and tread region, which amounts to losses in the rubber resulting in an increase in rolling resistance. Therefore Tyre rolling resistance decreases with increase in pressure on level road surface as other parameters are kept constant. QSS whole vehicle model used in this thesis work allows to calculate fuel consumption of a vehicle between the inflation pressures of 2 and 3 bars. It is shown by QSS model simulation that variation of rolling resistance of tyres changed with tyre inflation pressure.

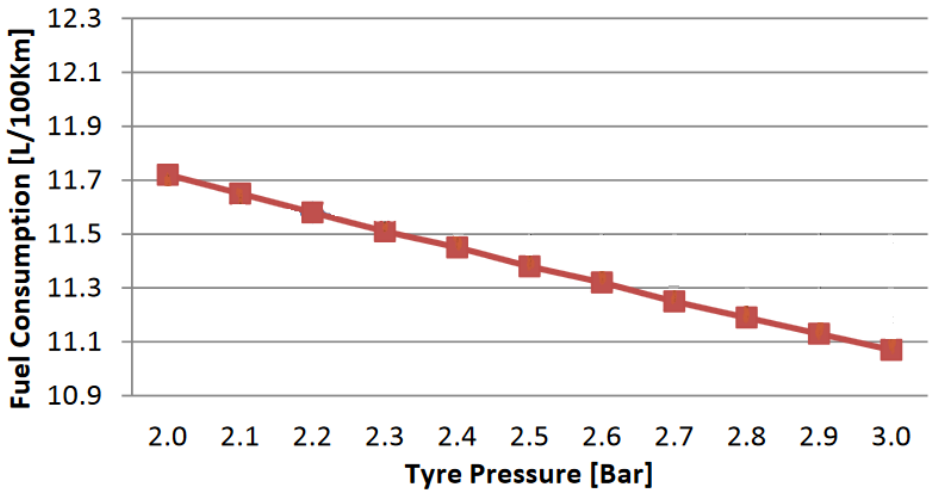

Figure 4.2 Influence of tyre pressure on fuel consumption

From the simulation blue line represents fuel consumption at nominal pressure of 2.19 bar. The red curve show the actual variation of fuel consumption with tyre inflation pressure. It is clearly seen on simulation fuel consumption is reduced with increase in inflation pressure.

Between the pressures range of two and three bar fuel reduction of around 4.9 % was observed. Bu in real station the number seen on simulation seems higher. In practical it may not possible to achieve such high value since the losses due to slippage not been included. When the tyre losses were included in the simulation for the NEDC city cycle at an inflation pressure of 2.2 bar, the fuel consumption increased from 11.58 L/100km to 11.61 L/100km, indicating an increase of only 0.25%. The reduction in fuel consumption with the increase in pressure can be observed even beyond three bars. However, this will be at the expense of reduced ride quality, poor traction and increased uneven tyre wear.

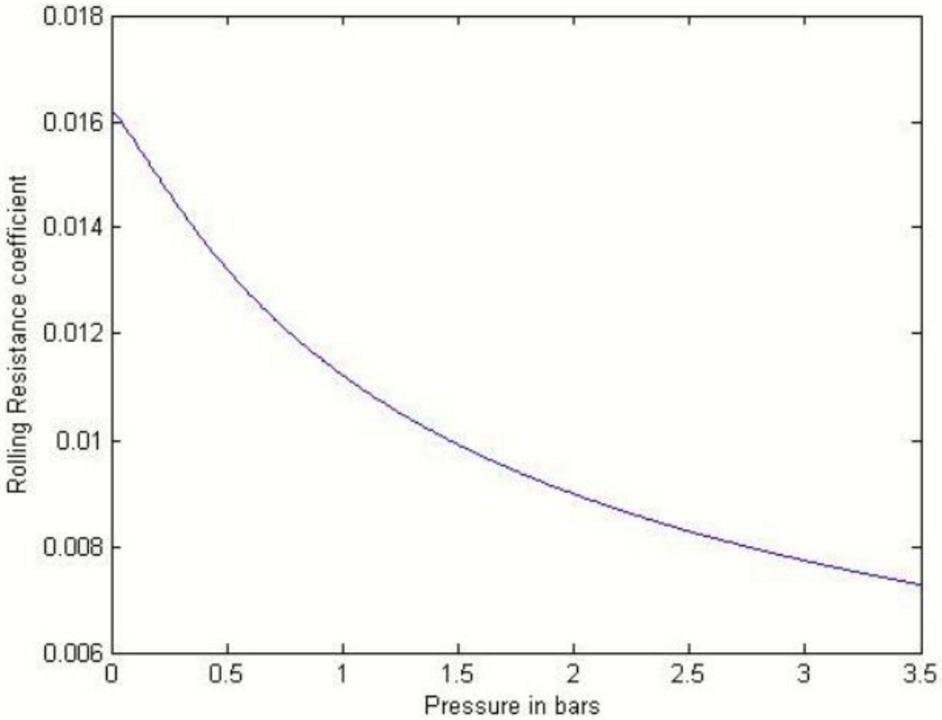

Figure 4.3. Tyre rolling resistance coefficient versus inflation pressure

Figure 4.3 shows that a plot between rolling resistance coefficient and tyre inflation pressure. The x-axis denotes tyre inflation pressure ranging from 0.5 bar to 3 bar and y-axis denotes the coefficient of rolling resistance. Decreasing of tyre inflation pressure from 2.1 bars to 1.8 bars will increases rolling resistance coefficient about 5.6%. Decreasing inflation pressure decreases increases radial deformation of tyre. The increase of radial deformation will increases hysteresis damping and causing an increasing of rolling resistance coefficient.

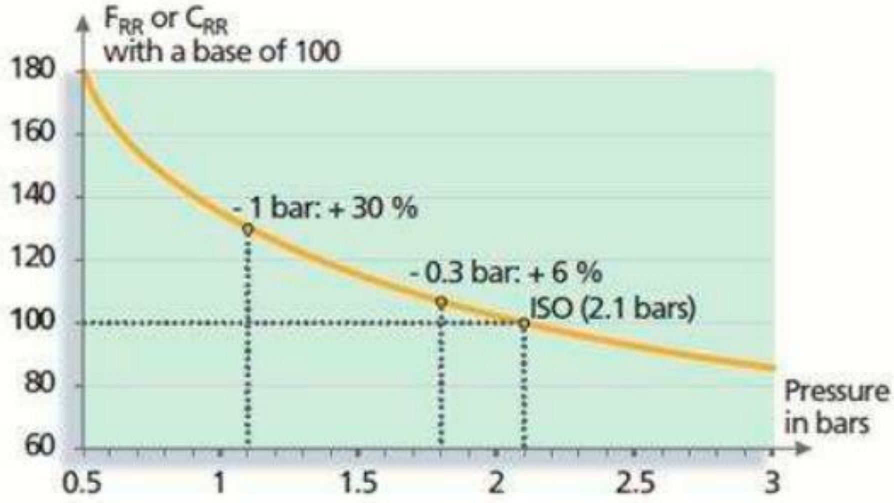

Figure 4.4. Rolling resistance measured at 2.1 bars or ISO

As shown on figure 4.4 rolling resistance coefficient and tyre inflation pressure from experimental data from Michelin. According to Michelin experiment decreasing tyre inflation pressure from 2.1 bars to 1.8 bars will decreases rolling resistance coefficient by about 6%. A combined model for analysis of rolling resistance coefficient as a function of tyre inflation pressure change is in close covenant with experimental values from Michelin for a passenger car tyre operating range. This model provides a reasonable information on the influence of tyre inflation pressure on rolling resistance coefficient.

4.3. Vehicle handling and ride comfort

The model was validated using experimental data collected when the vehicle was being driven, at a speed of 8km/h, over Bump 1 (located within the premises of The University of Hudders field). From simulation result as shown on figure 4 decrease in tyre pressure results in increasing the amplitude of the relative displacement of the vehicle body.

Suspension travel is a relative displacement between the wheel and vehicle body. So suspension travel is increasing with decreasing of tyre pressure. But this should be optimized with vehicle handling and stability. The effect of tyre under-inflation on the performance of the vehicle suspension such as ride quality, handling and stability of the vehicle are theoretically modeled by 7DOF and analyzed by using mat lab Simulink and the results were compared to the existing experimental data.

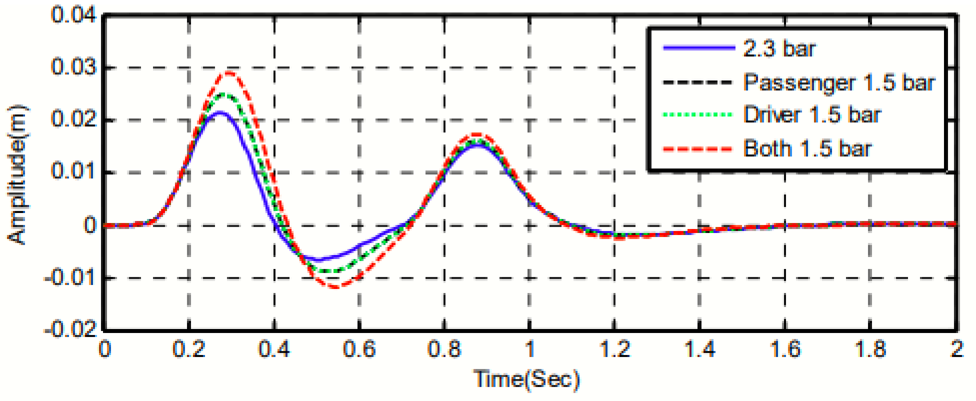

Figure 4.5. Displacement of vehicle body for different tyre pressure

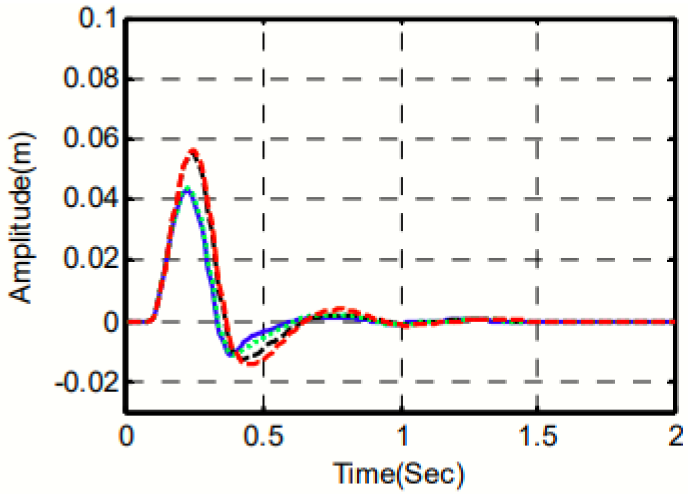

Figure 4.6. Wheel Displacement Front left

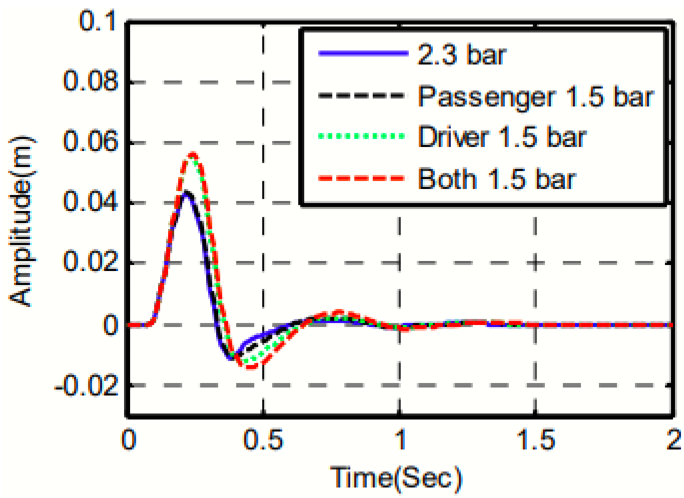

Figure 4.7. Wheel Displacement Front right

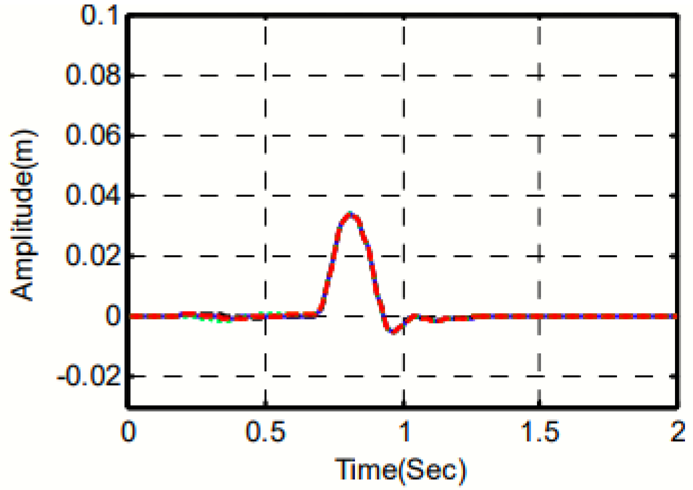

Figure 4.8. Wheel Displacement Rear left

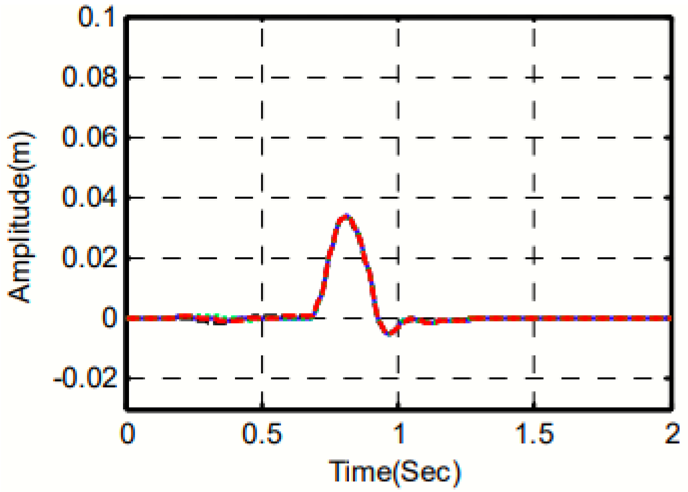

Figure 4.9. Wheel Displacement Rear right

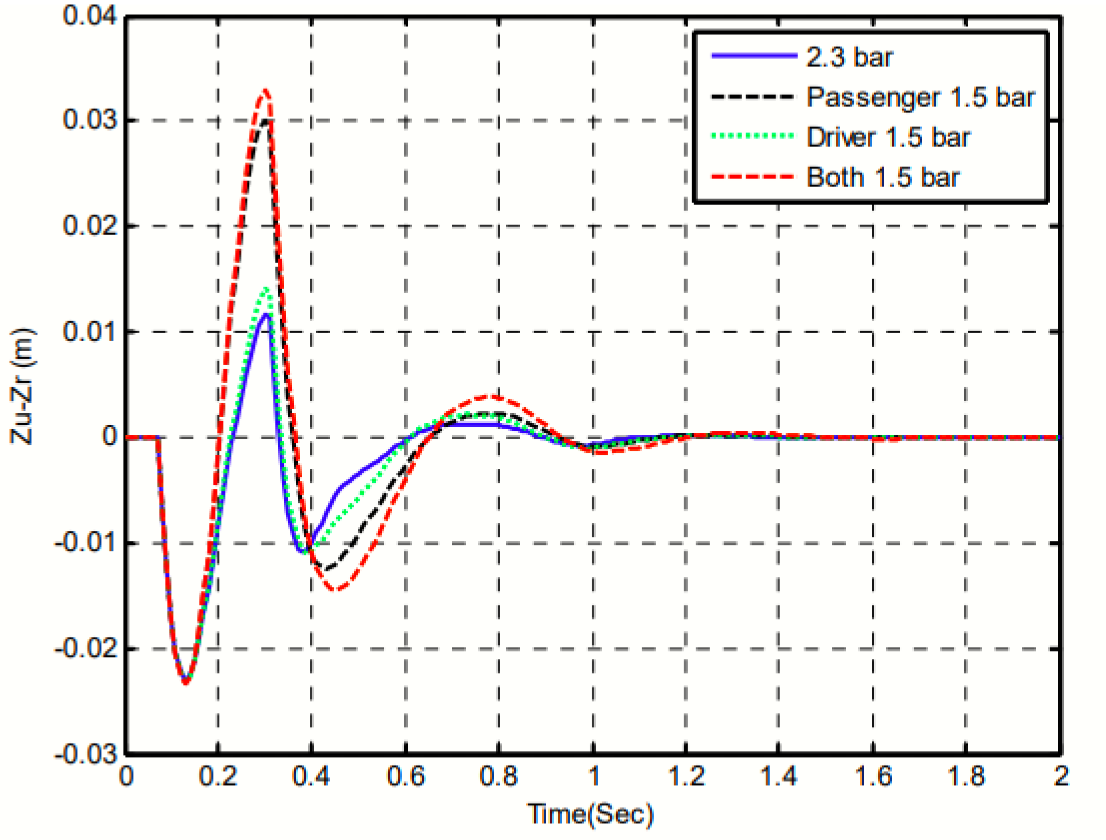

Figure 4.10. Wheel deflections for different tyre pressure

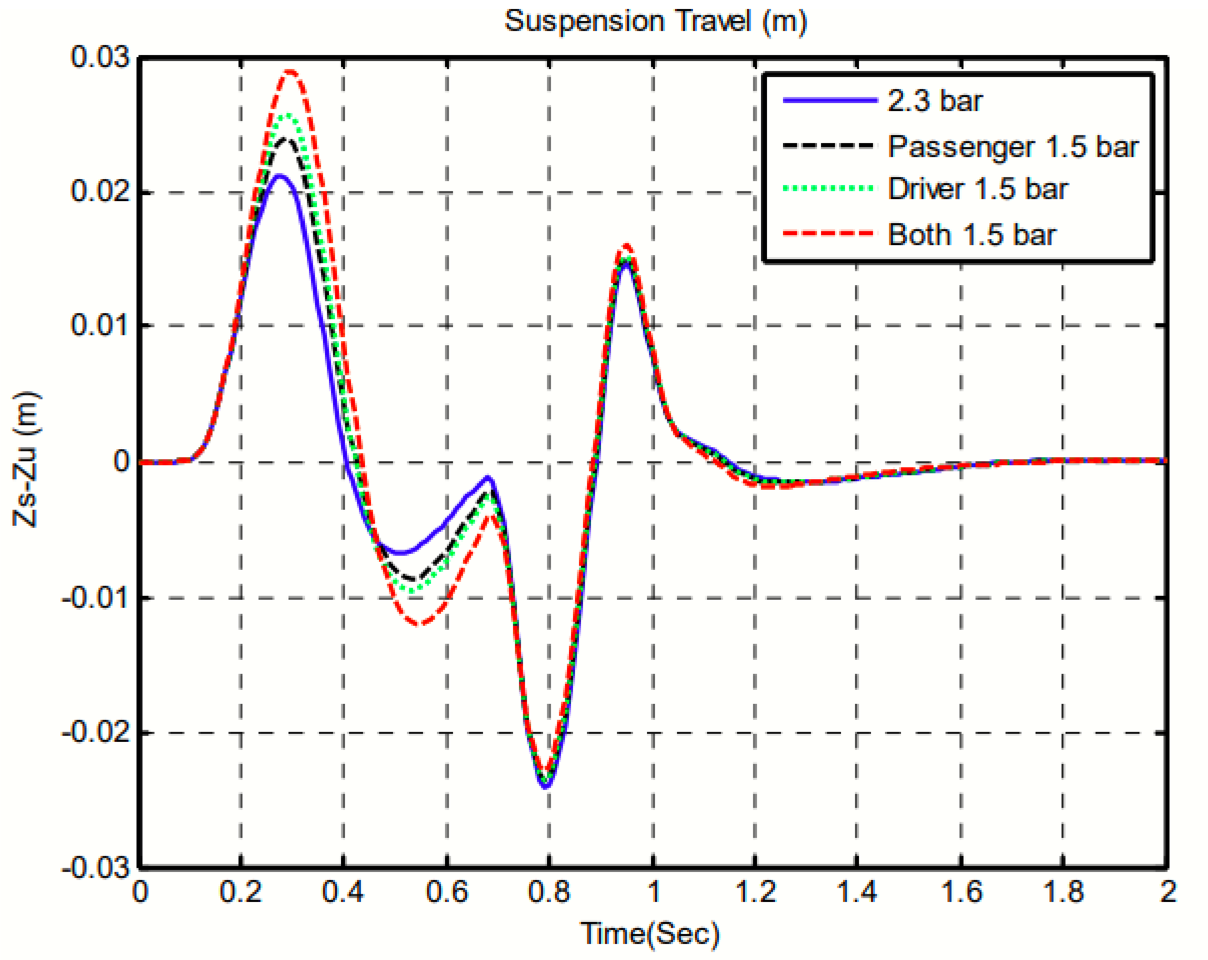

Figure 4.11. Suspension travel for different tyre pressure

At tyre inflation pressure 1.8 bar better yaw response at the first peak and reaching stability earlier than tyre inflation pressure at 2.2 and 2.8 bar. From this result it was concluded that the vehicle's over-steer stability could be improved by reducing the pressure in the four tyres.

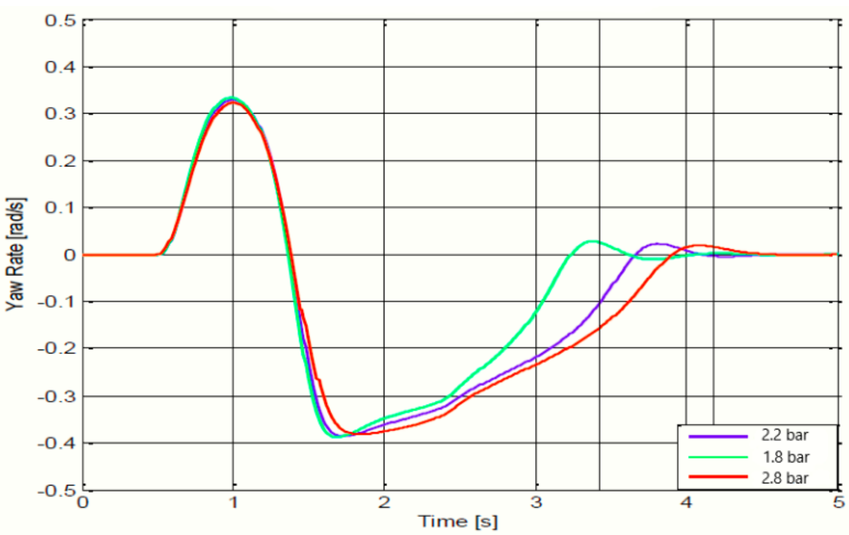

Figure 4:12. Yaw rate versus time for vehicle maneuver

4.4. Bounce acceleration

The bounce acceleration response of a car sprung mass to a set input for at a different three cases and at a step size of 0.025 meters and vehicle speed at 60 km/h model where developed. The first peak corresponds to the response of front axle passing over the step and the second peak, to that of the rear axle. Closer look at the peaks reveal that the bounce acceleration experienced is higher at higher pressures. Bouncing acceleration is higher at higher pressure and lower at a lower pressure. Therefore higher bouncing acceleration at higher pressure affects the comfort of passengers.

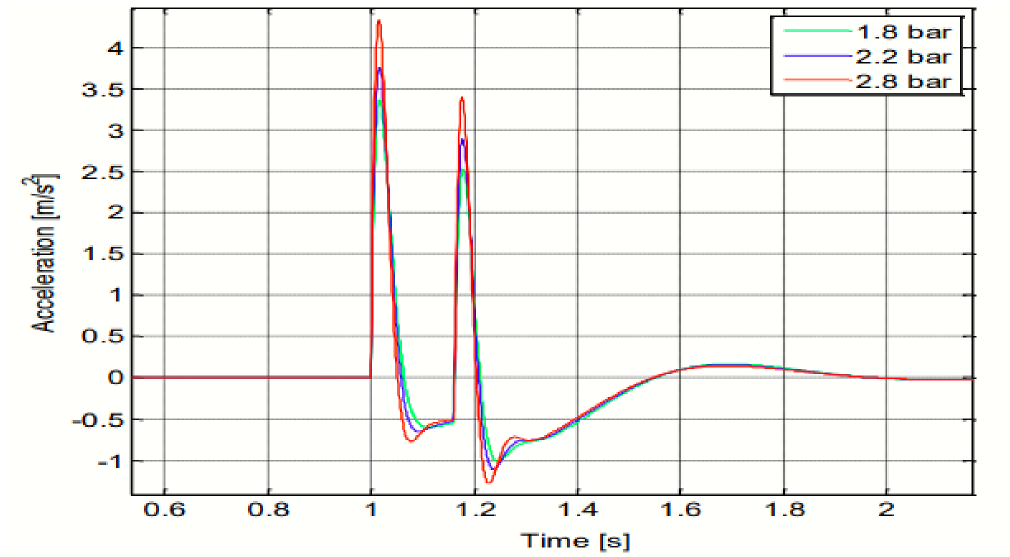

Figure 4.13. Bounce acceleration of the sprung mass at different pressures

4.5. Bounce displacement

Bounce displacement of the sprung mass to a step input at different inflation pressures is modeled and simulated. Increasing in tyre pressure the vertical displacement is reduced as seen in simulation result. This condition is absolutely opposite that observed for bouncing acceleration. A vertical displacement is reduced with increased tyre inflation pressure. This condition is absolutely opposite to that observed for bouncing acceleration.

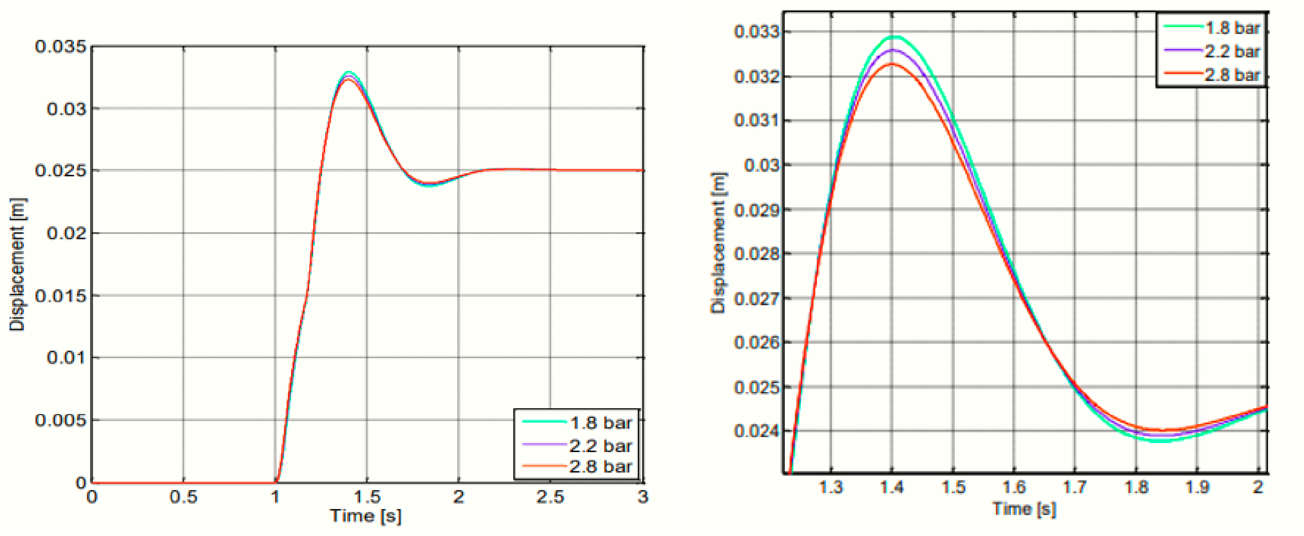

Figure 4.14. Bounce displacement of the sprung mass at different pressures

The effect of vehicle tyre defects on vehicle are studied. The pushing factor to study the effects of tyre defect on vehicle is the current headache of operation and maintenance cost imposed on sugar industry in Ethiopia. Because of different factors sugar factories are get in to saver situation to run the operation smoothly and effectively. Due to this I attracted to know the causes which sets this industry in to the current situation. In my opinion a big activities that required to reduce loses and generates profit if controlled in companies maintenance and production cost. Tyres and bearings are the upper maintenance parts of sugar industry in Ethiopia. To tackle this problem of tyre maintenance and proper storage takes the upper position. Wonji sugar factory utilizes different type vehicles for goods and passenger transportation. Out of total vehicle the company have 146 are different type of vehicles used for transportation are taken as a sample and tyre inflation pressure data are collected at FEMD of tyre repair team on January 2021 and the collected data are summarize according tyre inflation pressure.

- Normally inflated tyre vehicles are 26
- One tyre deflated more than 25% are 67
- Two tyre deflated more than 25% are 27
- Three tyres are deflated more than 25% are 14
- Four tyres are deflated more than 25% are 12

According to collected data at list one tyre is deflated more than 25% for about 120 vehicles out of 146 vehicle taken as a sample. Considering this data as input, the influence of tyre pressure and alignment are studied and analyzed using mat lab Simulink software. As indicated from simulation tyre inflation pressure is a critical parameter for performance of a vehicle. Underinflated tyres have higher rolling resistance which causes increases in vehicle fuel consumption. Over inflation pressure deteriorate driving handling characteristics. Tyre inflation pressure affects operational and maintenance costs of Wonji shoa sugar factory. More than 73% vehicles of Wonji shoa sugar factory are operating with at list one tyre are deflated more than 25%. Only about 27% of their vehicles are operating with all tyre inflated. Interims of fuel consumption Wonji Shoa sugar factory operation costs 207,324.5 litter of fuel per year in addition to 4,231,111 litter of planned fuel due incorrect tyre inflation pressure.

Table 4.2. Wonji-shoa sugar factory 2020/21 annual fuel requirement

S/N	Description of Good`s (Total offer)	Country of origine	unit	Quntity (TOTAL`S offer)	Suppliers X	
					Unit price	Total price
1	Gasoil	Suppliers is EPSE	Liter	4,231,111	18.9187	80,047,119.68
2	Furnace		Liter	500,000	16.3996	8,199,800.00
2	Gasoil ine (Petrol)		Liter	147,002	21.7687	3,200,042.44
					TOTAL DDP	91,446,962.11

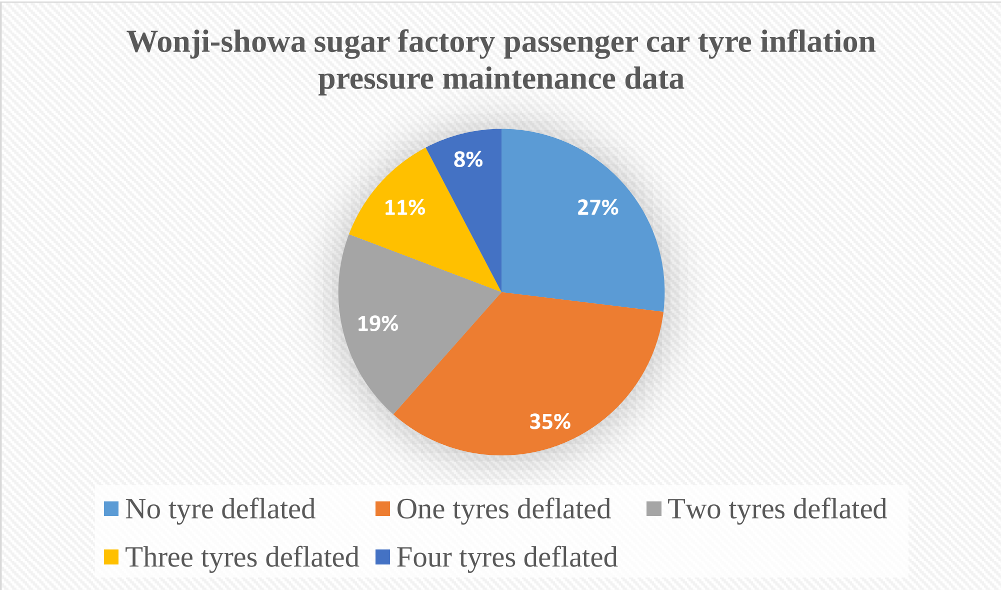

Figure 4. 15. Passenger car tyre inflation pressure maintenance data

Buses and trucks used for transportation work in that factory was also shown that 19% of their vehicles are operating with no tyre deflated. But 81% of their heavy transport vehicles are operating at least one tyre is deflated more than 25% deflated.

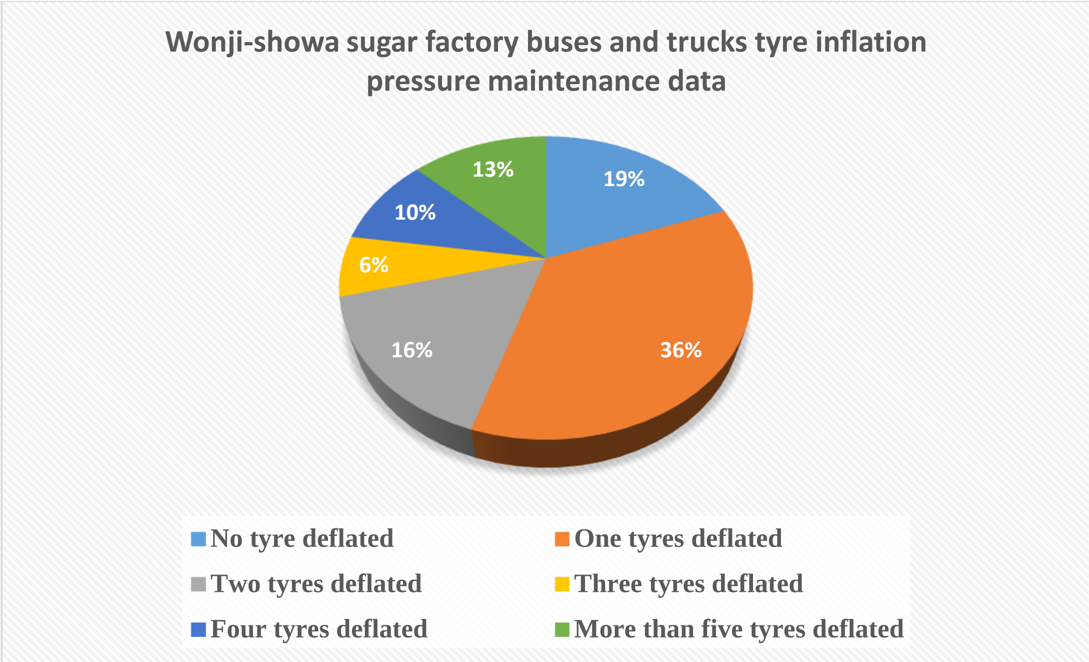

Figure 4. 16. Buses and trucks tyre inflation pressure maintenance data

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main objective of this study work is to investigate the effect of tyre inflation pressure on road vehicle operation at Wonji-shoa sugar factory. From literature review and data collected from the factory the main defects of tyre is deflation of air pressure and wheel misalignment. The effect of these tyre inflation pressure and misalignment introduce resistance force on vehicles. As described in literature review section resistance forces on vehicle in a motion are caused by aerodynamic resistance, rolling resistance, inertia resistance, inclination resistance. These resistance forces are considered during vehicle design and it was cost high to reduce beyond designed amount. But this study intention was investigate the effect of tyre problem on road vehicle operation. The problem identified is tyre inflation pressure and wheel alignment which boosts the rolling resistance of vehicle. Increased in rolling resistance of tyre will increase the energy required to drive a vehicle with the same load and operating condition. Simulation results are indicated that tyre inflation pressure is a critical parameter for performance of a vehicle.

Vehicle handling was modeled and simulated using Simulink. Vehicle response was evaluated at three different velocity for seven cases. It was observed that low tyre pressure gave better yaw reaction and higher lateral acceleration. At tyre inflation pressure 1.8 bar better yaw response at the first peak and reaching stability earlier than tyre inflation pressure at 2.2 and 2.8 bar. From this result it was concluded that the vehicle's over-steer stability could be improved by reducing the pressure in the four tyres. The corresponding lateral displacement with respect to longitudinal displacement turned into also marginally higher, especially at higher vehicle speeds. It was concluded that reducing tyre pressure in all wheels, vehicle became capable of regain yaw stability whilst it turned into on the verge of over-guidance.

The influence of tyre pressure on vehicle ride characteristics was modeled using half car model using mat lab Simulink. When the vehicle is subjected to a step input of 0.025 meters at a speed of 60 km/h, it was observed that the peak bounce acceleration of the sprung mass was higher at higher tyre pressures. Peak acceleration was determined at center of gravity increased by nearly 0.5 m/s^2 at a nominal tyre pressure of 2.2 and 2.8 bar. Bounce displacement of the sprung mass showed higher peak value at lower tyre pressures. The peak displacement measured at the vehicle's center of gravity reduced by only 0.005 meters when the tyre pressure was reduced from 2.2 bars to 1.8 bars. It was observed that the tyre was most likely to lose contact with the road at higher inflation pressures. Vertical acceleration changed into calculated at three frequencies; four hertz, six hertz and eight hertz.

A complete vehicle model of a pick-up is developed in Simulink by using QSS TB toolbox to study the effect of tyre inflation pressure on fuel consumption. First tyre rolling resistance force was mathematically modelled as a linear function of vertical tyre load by keeping other parameter such as tyre inflation pressure constant. Another model was developed by substituted with another model which takes speed, load and tyre inflation pressure into account. Rolling resistance data was taken from regression analysis which is already prepared and provided. Fuel consumption due to change in rolling resistance deeming parameters such as tyre inflation pressure generates fuel consumption in liter/100 km. It was witnessed that the fuel consumption reduced when the tyre pressure was increased from tyre inflation pressure of 2 bar to 3 bar and a reduction of up to 4.9 % was observed. These results are consistent with the findings is literature review.

Underinflated tyres have higher rolling resistance which causes increases in vehicle fuel consumption. Over inflation pressure deteriorate driving handling characteristics. Tyre inflation pressure affects operational and maintenance costs of Wonji shoa sugar factory. More than 73% vehicles of Wonji shoa sugar factory are operating with at list one tyre are deflated more than 25%. Only about 27% of their vehicles are operating with all tyre inflated. Interims of fuel consumption Wonji Shoa sugar factory operation costs 207,324.5 litter of fuel per year in addition to 4,231,111 litter of planned fuel due incorrect tyre inflation pressure. From the survey data gained from Wonji shoa sugar factory out of total numbers of vehicles serving in our country about 73 % are subjected to 4.9 % additional fuel consumption due to tyre inflation problem. Therefore the objective of this study was attained by specifically reviewing different literature concerning vehicle tyre defects and its impact on road vehicle operation specifically at wonji shoa sugar factory and the impact of tyre inflation pressure on road vehicle operational performance was investigated by using qss tb and mat lab Simulink.

5.2. Recommendations

Vehicle driving resistance is difficult to eliminate due to different limitation which is difficult to handle with the technology we have currently. But it was not hard to reduce by controlling operational modification on vehicle. Those modification are eliminated by maintaining the system or parts exceeds from original design parameters. So vehicle tyre is a critical parts which transfer rotational motion of vehicle between road and vehicle suspension. But this is achieved as long as the tyre inflation pressure is maintained.

Tyre maintenances are includes inflation pressure, tread depth measurements and alignment etc. Tyre inflation pressure is determines all tyre performance parameters. The rolling resistance of vehicle increases with increasing tyre inflation pressure. To keep this inflation pressure it requires frequent tyre pressure checking and needs tyre inflating compressed air every ware. Perhaps this was adds extra burden on derivers. The best method for checking tyre pressure is tyre pressure monitoring system which is currently applied in USA and Europe vehicle. In case of boosted rolling resistance partake from misalignment due to under inflated vehicle tyre also needs monitoring like that of tyre. In our country this type alignment measurements are carried out once a year for all vehicle. So it's better to install tyre pressure and wheel alignment monitoring system. Therefore I recommended further study on tyre inflation pressure impact on off road and in field vehicles operational performance by using laboratory test as to increased resolution of measurement in order to increases accuracy.

5.3. Future work

This study is carried out by using modeling and simulation software and compared with experimental results of the similar vehicle with the same tyre size. To increase the accuracy of tyre rolling resistance measurements it requires well developed rolling resistance test rig. But we have no such facility in our country the scope of this thesis limited to modeling and simulating. The results obtained from vehicle model simulations are only as accurate as the results of a tyre model. So it requires experimental study of tyre inflation pressure on vehicle rolling resistance and then its effect on vehicle operation such as fuel consumption, vehicle handling and ride characteristics.

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APPENDIX

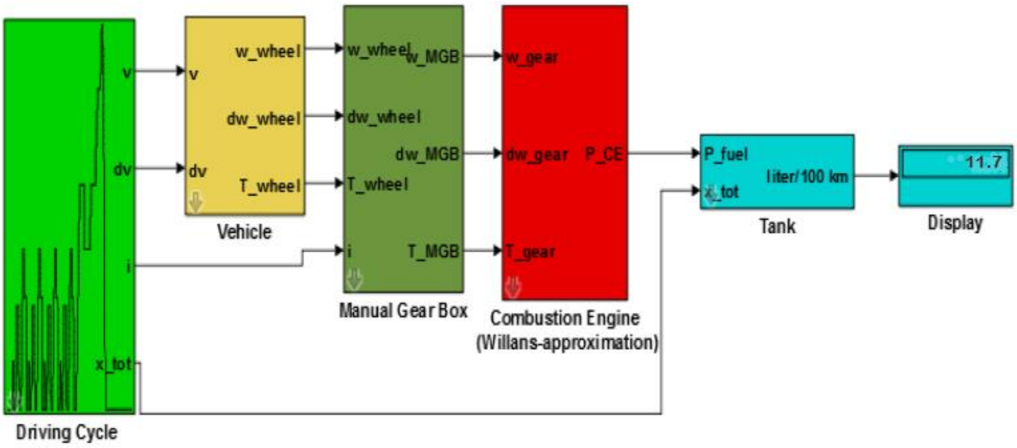

Figure A 1. QSS vehicle model showing fuel consumption in L/100 km

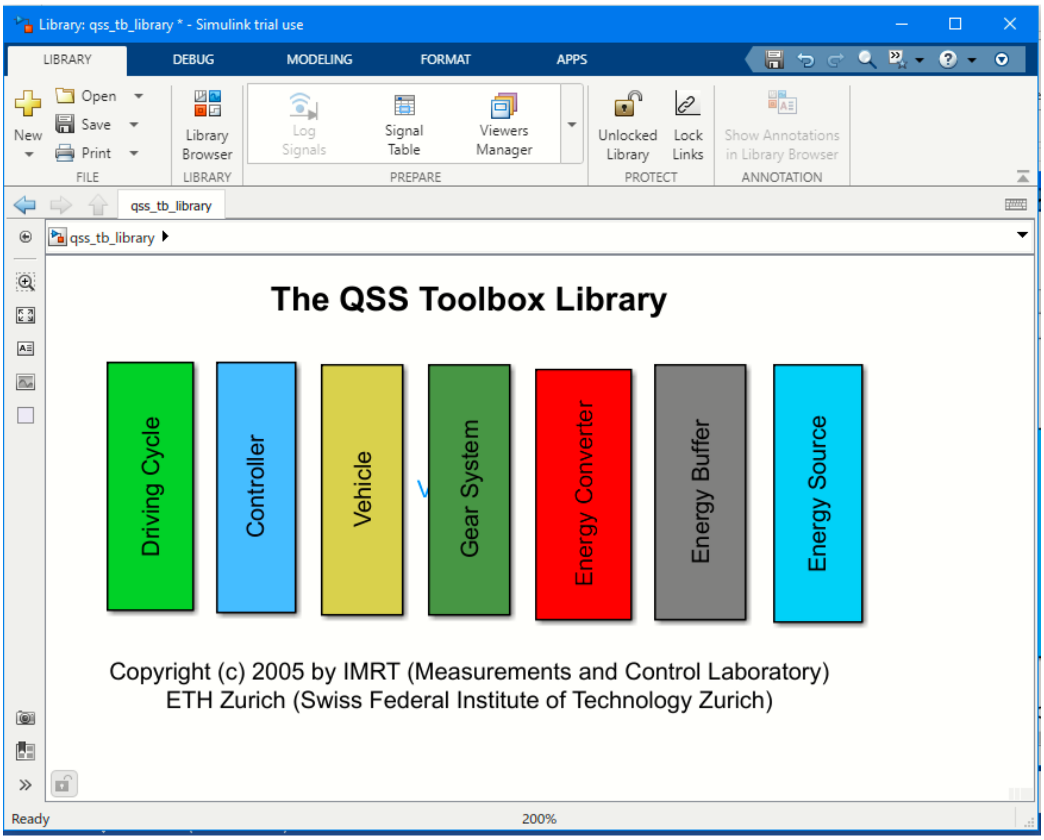

Figure A 2. Top level of the QSS Library

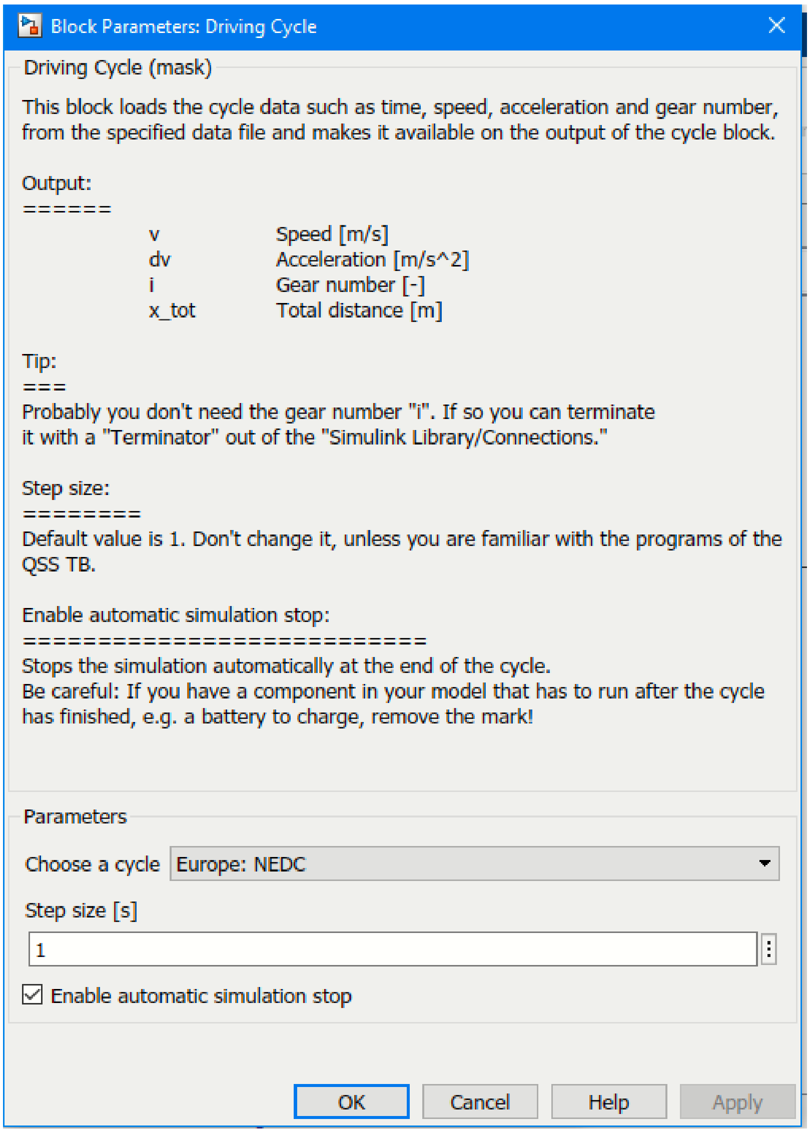

Figure A.3. The mask for the driving cycle block

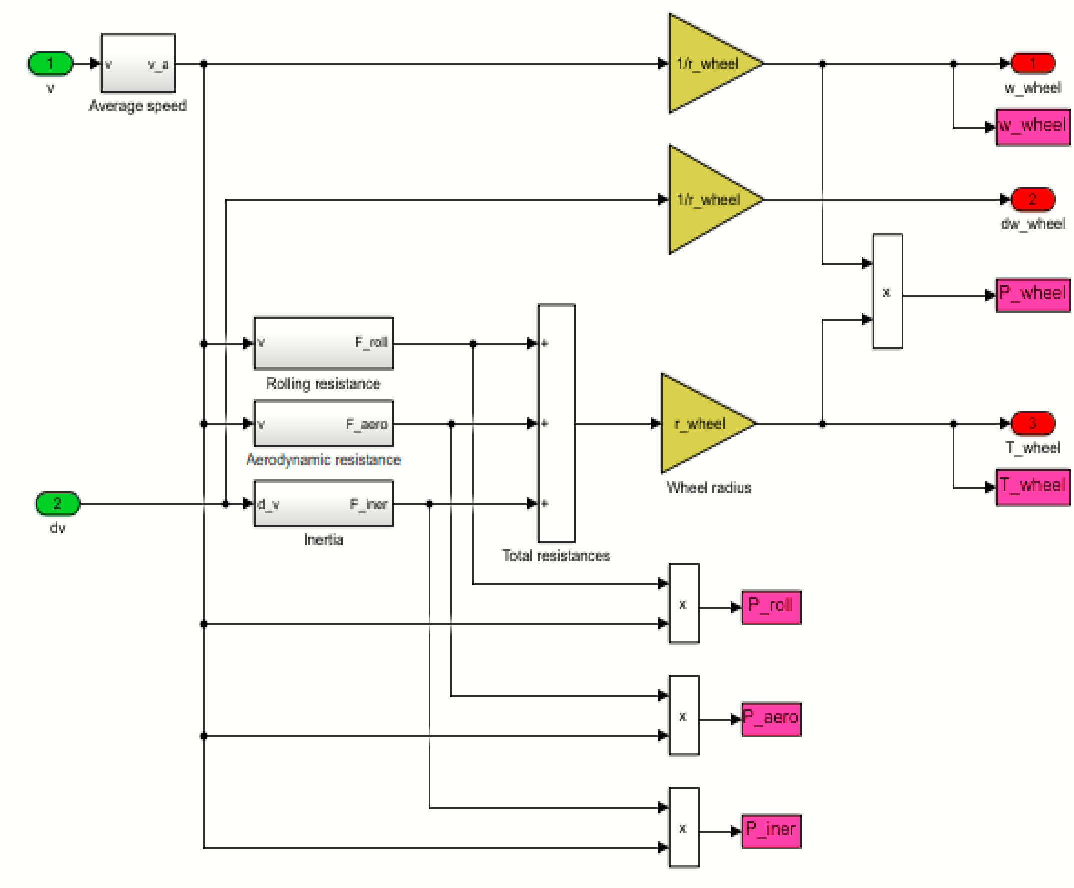

Figure A 4. Vehicle block first level

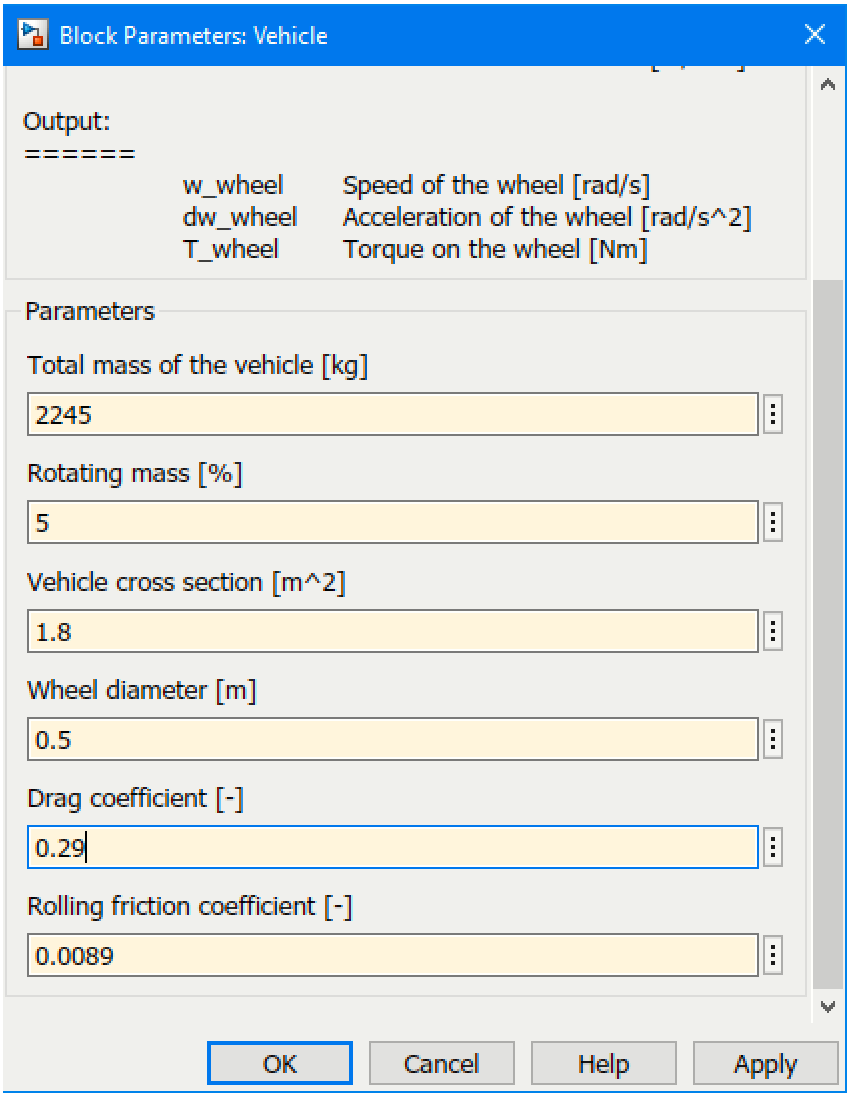

Figure A 5. The mask for the vehicle block

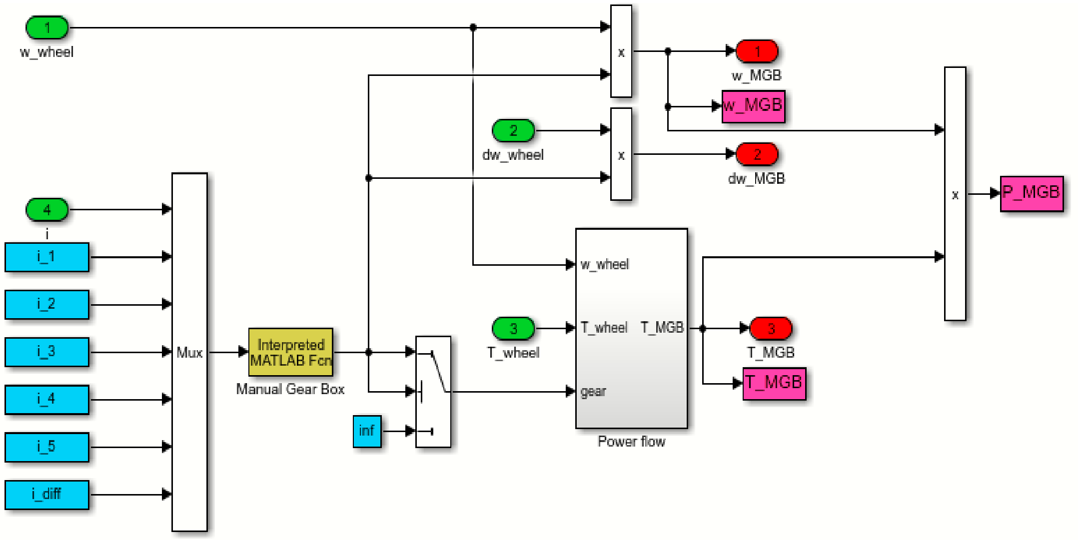

Figure A.6. Top level of the block "Manual Gear Box"

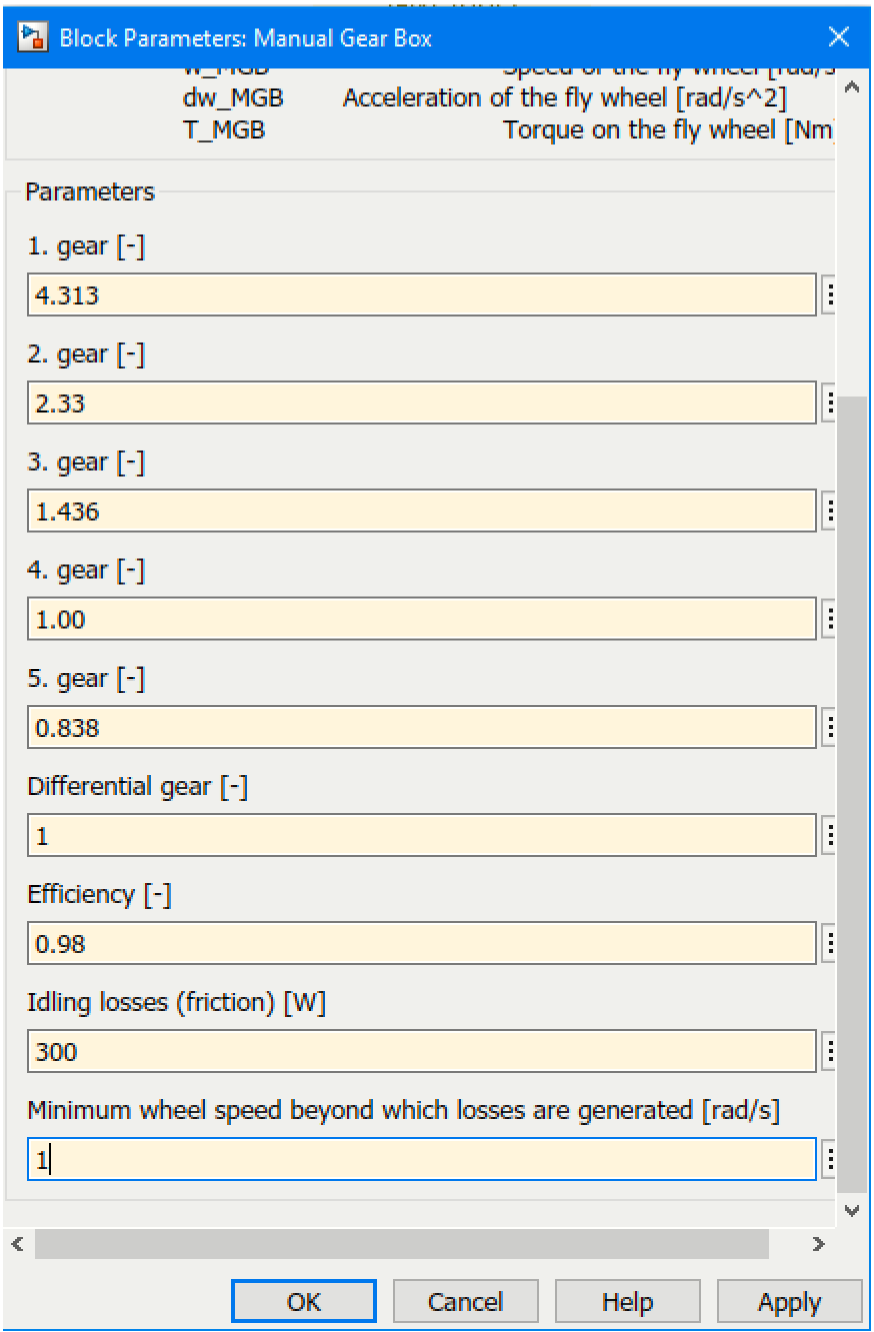

Figure A 7. The mask for the vehicle block

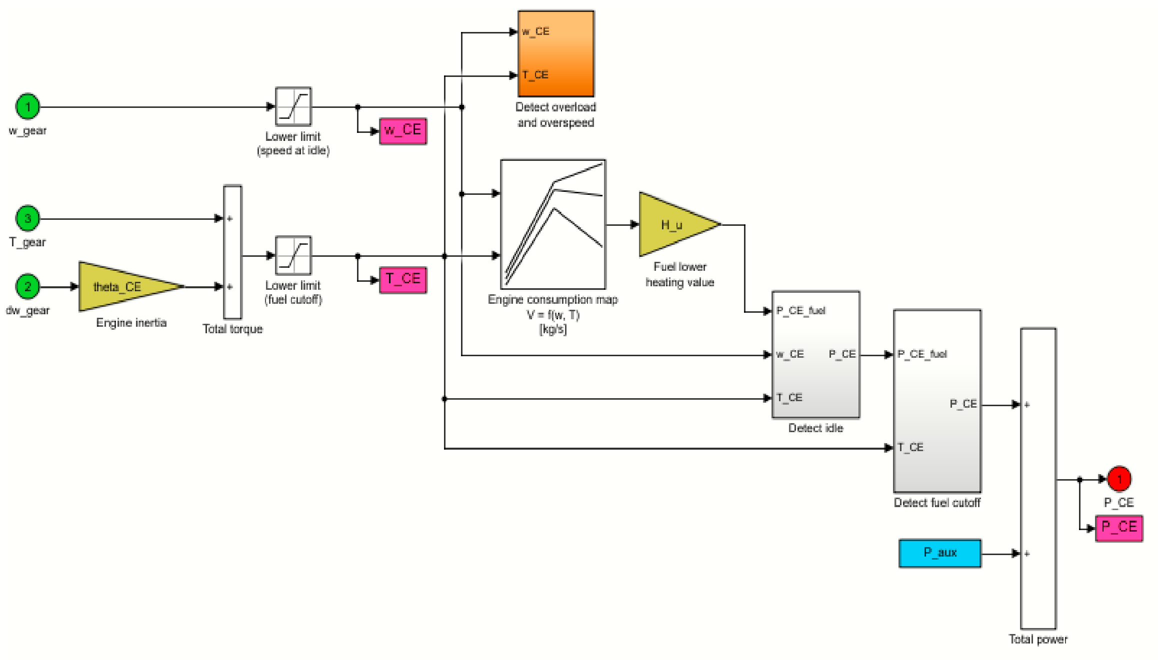

Figure A 8. Top level of the model "Combustion Engine" based on consumption map

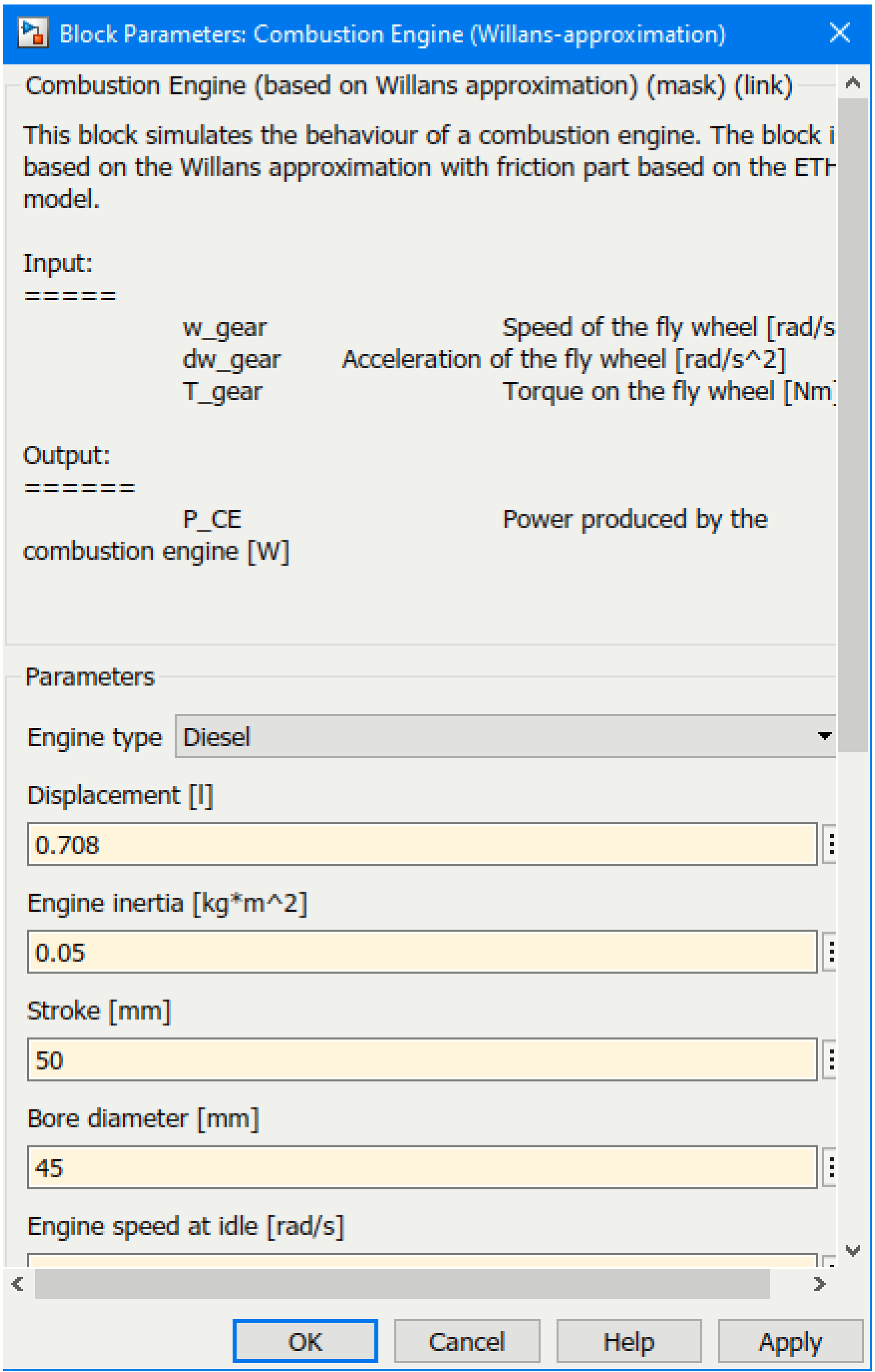

Figure A 9. The mask for the combustion engine based on consumption map block

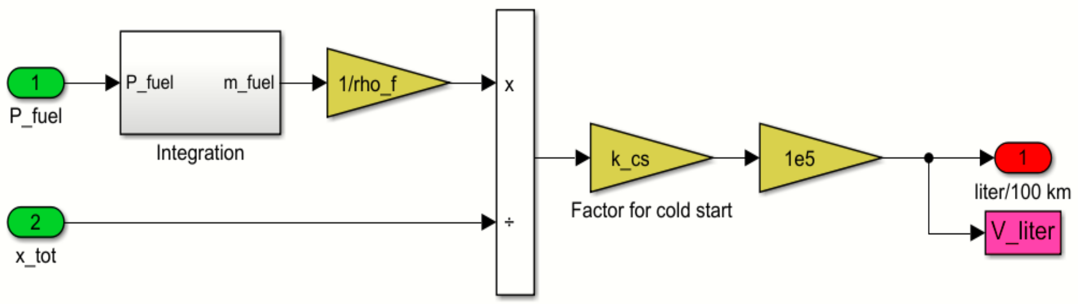

Figure A.10. Top level of the model "Tank"

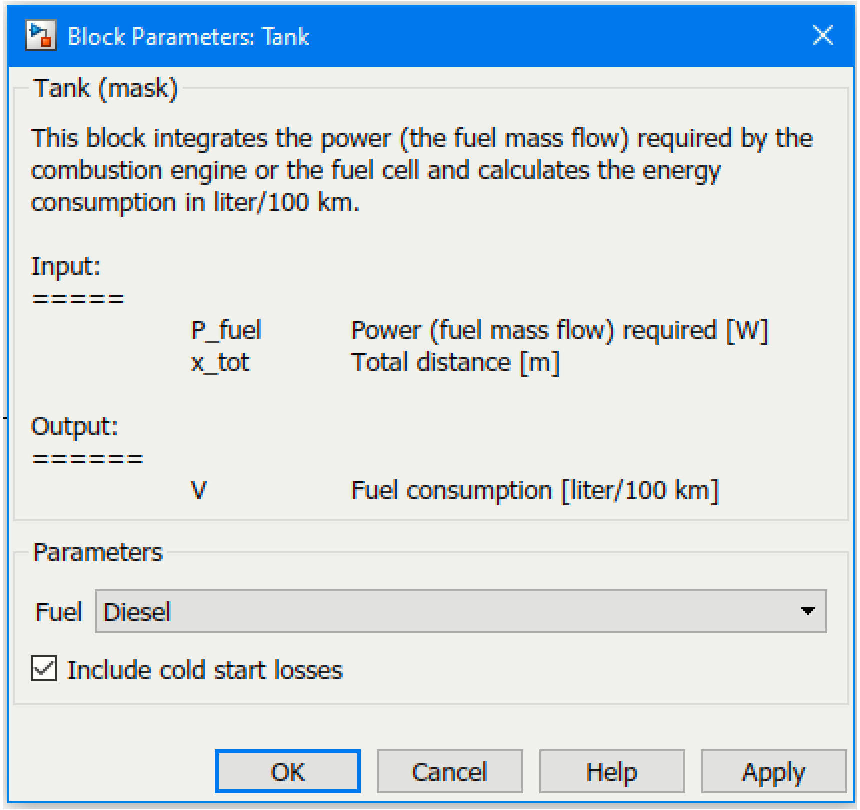

Figure A 11. The mask for the block "Tank"

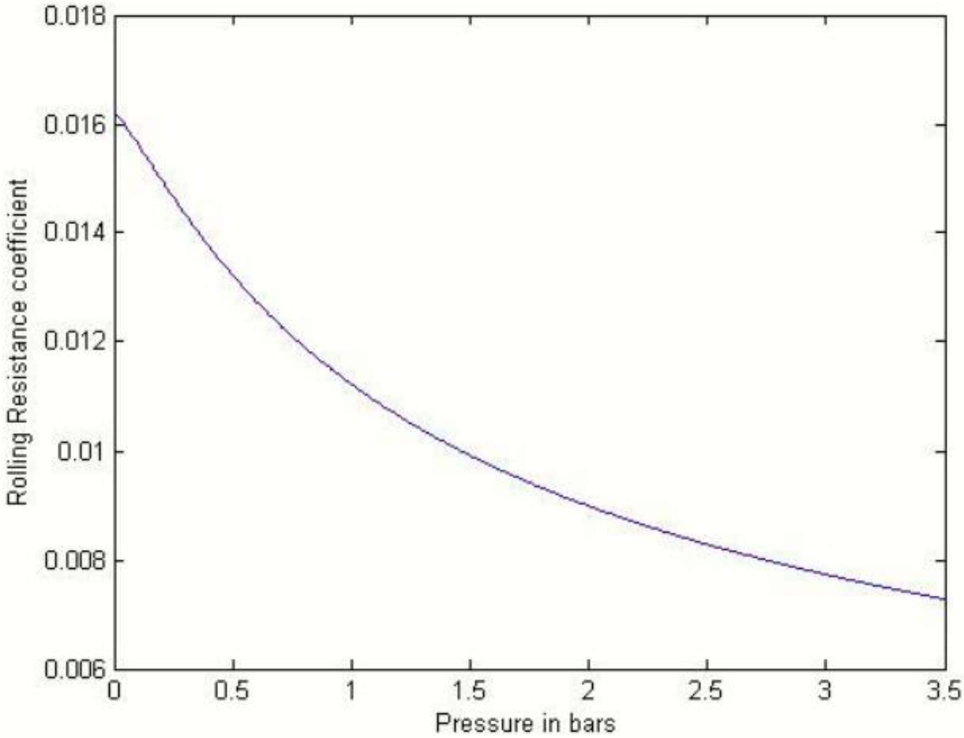

Figure A 12. Rolling resistance vs Tyre inflation pressure for 175/70 R14, V = 80 km/h, 80 % Max Load (combined model)

Table list of Wonji-shoa sugar factories road vehicles

No	Type of vehicles	Plate No	No	Type of vehicles	Plate No
1	Bus	bus-01	33	High bed	3-64810
2	Bus	3-55079	34	High bed	HBT- 15
3	Bus	3-55080	35	High bed	KV- 09
4	Bus	3-55034	36	High bed	HBT- 01
5	Bus	bus-02	37	High bed	HBT- 09
6	Daewoo cargo	3-33641	38	High bed	3-64809
7	Daewoo cargo	3-33642	39	Daewoo low bed	3-72063
8	Nissan truck	3-72078	40	Motor cycle	MB-0104
9	Sino truck	MWS-01	41	Motor cycle	MB-0101
10	Daewoo dump truck	3-36855	42	Motor cycle	MB-0050
11	Daewoo dump truck	3-37068	43	Motor cycle	MB-0108
12	Daewoo dump truck	3-37069	44	Motor cycle	MB-0094
13	Daewoo dump truck	3-36856	45	Motor cycle	MB-0083
14	Daewoo dump truck	3-37070	46	Motor cycle	MB-0131
15	Daewoo dump truck	3-36858	47	Motor cycle	ET-216
16	Daewoo dump truck	3-36861	48	Motor cycle	MB-0095
17	Toyota land cruiser	3-56117	49	Motor cycle	MB-0090
18	Toyota land cruiser	3-56112	50	Motor cycle	MB-0042
19	Toyota land cruiser	3-42075	51	Motor cycle	MB-0096
20	Toyota land cruiser	3-42078	52	Motor cycle	MB-0049
21	Toyota land cruiser	3-26844	53	Motor cycle	MB-0047
22	Toyota land cruiser	3-26846	54	Motor cycle	MB-0054
23	Toyota land cruiser	3-42076	55	Motor cycle	MB-0132
24	Toyota land cruiser	3-56120	56	Motor cycle	MB-0103
25	Toyota land cruiser	3-42073	57	Motor cycle	MB-0114
26	Toyota land cruiser	3-42077	58	Motor cycle	MB-0139
27	Toyota land cruiser	3-56115	59	Motor cycle	MB-0031
28	Toyota land cruiser	3-56121	60	Motor cycle	MB-0087
29	Toyota land cruiser	3-56113	61	Motor cycle	ET-215
30	Toyota land cruiser	3-56116	62	Motor cycle	ET-213
31	Nissan double cab	3-37291	63	Motor cycle	MB-0034
32	Nissan double cab	3-37293	64	Motor cycle	MB-0105