PASSENGER AND LUGGAGE WEIGHT MONITORING SYSTEM BASED ON SENSING TECHNOLOGY: A CASE OF ZAMBIA

by

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DECLARATION

I, the undersigned, declare that the work in this dissertation has not been previously submitted in candidature for any degree. This dissertation is the result of my own work and investigations, except where otherwise stated. Other sources are acknowledged by given explicit references. A complete list of reference is given.

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ABSTRACT

The prevalence of *overloading*, which is exceeding the maximum load weight, on public transport especially buses in Zambia is very rampant. This is attributed mainly to the fact that there is currently no system to measure and monitor load weight particularly at bus stations apart from few weighbridges on few selected roads located far away from the loading points. The phenomenon of overloading leads to damage to road pavements which in turn lead to compromise in road safety, damage to vehicle, higher fuel consumption, and reduces the lifespan of both the motor vehicles and the road infrastructure.

The aim of this study was to design, develop, and implement a model prototype of passenger and luggage weight monitoring system to mitigate the challenge of overloading on public buses. To achieve this, a baseline study was conducted to appreciate the challenges of the current system being experienced in the management of passengers and luggage load weight on public buses at bus stations to avoid overloading. It was revealed from the study that the challenge of overloading on public buses was mainly due to luggage at 96 percent while that of passengers was only at 7 percent. It was also revealed that there was a direct proportional relationship between the causes of overloading and risk factors contributing to causes of road traffic accident, and these were the *human factors*. The risk factors considered to contribute to compromised road safety leading to road traffic accidents were also established from all stakeholders and the following were the outcomes: 54 percent human, 39 percent road/environmental, 6 percent vehicle and 1 percent was attributed to other factors.

The results of the baseline study were then used as a basis to design and develop a Load Weight Monitoring System (LWMS) based on sensing technologies of weight and motion. Other emerging technologies like Web-based Mobile Communication, Internet of Things (IoT), and Cloud Computing concepts where also utilized to automate the data capturing and transmission to the main server. The proposed LWMS model prototype employed Load Cells and Motion Sensors to capture the load weight and direction respectively. The data captured by the sensors was then computed by the Arduino microcontroller before sending it to the central data centre for onward forwarding to relevant stakeholders.

Keywords:

Overloading; Load Weight; Sensing Technologies; Emerging Technologies; Load Weight Management System.

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DEDICATION

This work is dedicated to my family; Dad and Mum, Wife and Children, and Grandchildren.

DEFINITIONS OF KEYWORDS

A brief description of the main concepts dealt with in the study is presented below. Different scholars have defined them in different ways. However, in this study they will mean as defined below:

Accuracy:	The precision of measurement made by a weighing system and it is expressed in terms of error as a percentage of (i) the specified value (e.g., 10 volts ±1%), (ii) a range (e.g., 2% of full scale), or (iii) as parts (e.g., 100 parts per million).
Amplifier:	An electronic device that magnifiers a small electric signal to some significant signal able to be measured.
Analog Scale:	Is a scale that mostly is mechanical in nature and has some moving parts in it, and has no electronic devices or components attached to it.
Automobile Dependency:	Use of automobile in relation to a variety of advantages such as on demand mobility, comfort, status, speed, and convenience.
Axle Load:	The weight transmitted onto the road by an axle bearing two tyres or more.
Calibration:	The process by which a scale is set in order to check for accuracy and any errors in measurement, that is, adjustment for accuracy;
Cloud Computing:	Is the on-demand delivery of compute power, database, storage, applications, and other IT resources via the internet (the Cloud) with typically pay-as-you-go pricing for the cloud services used only thereby helping lowering operating costs, more efficient utilization of infrastructure and flexible utilization according to business needs.
Congestion:	It is particularly linked with motorization and the diffusion of the automobile, in which the demand for transport infrastructures has increased but the supply of infrastructures has often not been able to keep up with the growth of mobility demands at a specific point in time and in a specific section of the transport system.

Core Road Network: The bare minimum network that is required to be maintained continuously and on a sustainable basis in order to realize its social and economic potential.

Digital Scale: Is a scale that incorporates electronic circuit components, has devices like Liquid Crystal Display (LCD) Screens and can often be computer networked.

Error: The algebraic difference between the reading of the measurement and true value of the load being measured.

Gauge Factor: The ratio of fractional change in electrical resistance to the fractional change in length (strain) and is different sensitivity of strain possessed by each strain gauge expressed quantitatively.

Gross Vehicle Mass: The net weight of a motor vehicle or trailer together with such weight of goods or passengers or both.

Gross Weight: The weight of goods and the maximum number of passengers that may be carried on a public service vehicle shall be determined by a vehicle examiner in the prescribed manner, and, together with such other particulars as may be prescribed, shall be described on the certificate of fitness for the vehicle issued and shall be legibly painted in a conspicuous position on the vehicle in such manner as may be prescribed.

Internet of Things: The system of physical objects or things hooked up with hardware, software, sensors, and system connectivity which empowers these objects to gather and alternate information and it makes use of different kinds of protocols to work with exclusive objects.

Load Cell: A transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured or a transducer that converts the physical force into measurable, quantifiable electric energy and it is the active and key component used in a *digital scale*.

Load Weight: The total weight of the passengers and luggage carried on public bus at any given time.

Luggage: The bags, suitcases, etc. that contain possessions of the passenger and loaded on the bus when on a journey travelling

Motor Omnibus: A public service vehicle which carries or is intended to carry passengers and their luggage, goods and merchandise or other loads and is licensed to carry more than seven passengers excluding the driver.

Motor Vehicle: Any mechanically propelled vehicle intended or adapted for use on roads.

Passenger: A person who is travelling in an automobile, bus, train, airplane, or other conveyance, especially one who is not the driver, pilot, or the like.

Platform Scale: Also known as *Flat Electronic Scale*, is a special scale used to measure bulky objects like suitcases (luggage) at bus stations and airport terminals.

Public Service Vehicle: A motor vehicle used for carrying passengers, goods, merchandise or other loads for hire or reward, whether at separate and distinct fares for their respective places or not.

Public Transport: Also known as Public Transportation, Public Transit, or Mass Transit, is a shared passenger transport service which is available for use by the general public.

Scale: A device that is used for weighing, comparing and determining the weight or mass of an object or material.

Vehicle Overloading: A phenomenon resulting from either exceeding the permissible maximum axle load or the maximum Gross Vehicle Mass (GVM).

Weighbridges: Scales used to measure very large objects like trucks, where the truck drives onto a special stripe of the road that is connected to a Digital Scale, then the operator reads off the truck’s weight in tonnes.

Weigh-in-Motion: Also referred to as Weighing-in-Motion (WIM), is a device that is designed to capture and record the *axle weights* and *gross vehicle weights* as vehicle drive over a measurement site.

Wheatstone Bridge: An electronic circuit used to take small changes in resistance and turning it into something formidable to be measured using a number of resistors.

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LIST OF ABBREVIATIONS AND ACRONYMS

The abbreviations and acronyms used in this dissertation are presented below:

ADC	Analog to Digital Convertor
ALCP	Axle Load Control Programme
AVL	Automatic Vehicle Location
COMESA	Common Market for Eastern and Southern Africa
CRN	Core Road Network
DCaaS	Data Centre as a Service
EAC	East African Community
EC	European Commission
ED	Event Detection
EMI	Electromechanical/Electromagnetic Interference
GDP	Gross Domestic Product
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GVM	Gross Vehicle Mass
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle
HLC	Hydraulic Load Cell
ICT	Information and Communications Technology
ICT	International Consultants and Technocrats
IEEE	Institute of Electrical and Electronics Engineers
IJACSA	International Journal of Advanced Computer Science and Applications
IoT	Internet of Things
IR	Infra-Red
LWMS	Load Weight Monitoring System

MAC	Medium Access Control
N	Newton
NORAD	Norwegian Agency for Development Cooperation
PELC	Piezo-Electric Load Cell
PHP	Hypertext Preprocessor
PIR	Passive Infra-Red
PLC	Pneumatic Load Cell
POI	Phenomenon of Interest
PSV	Public Service Vehicle
PT	Public Transport
RDA	Road Development Agency
REC	Regional Economic Communities
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
ROADSIP	Road Sector Investment Programme
RSN	Remote Sensor Network
RTSA	Road Transport and Safety Agency
SADC	Southern African Development Community
SGLC	Strain Gauge Load Cell
SI	Statutory Instrument
SPE	Spatial Process Estimation
TO	Timeout
TOC	Tracker of the Chip
TRB	Transportation Research Board
TRL	Transport Research Laboratory
US$	United States of American Dollar
USB	Universal Serial Bus
VWMS	Vehicle Weight Management System
WIM	Weigh In Motion
WSN	Wireless Sensor Network

ZMK Zambian Kwacha

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In this chapter we introduce the research study. We look at the background, motivation and significance of the research. The scope, problem statement and aim of the study are then highlighted. This is then followed by the objectives, research questions and the research contributions, and finally, the organization of the dissertation and summary are presented.

1.2 Background to the Research

The prevalence of overloading passengers and luggage, that is, *load weight*, on public buses in Zambia is rampant. Currently, at the source points, that is, at the bus stations, the bus crews have neither means nor ways to establish how much *load weight* is loaded onto the bus, resulting in exceeding the prescribed maximum *load weight* of the bus. The only points where the bus weight is measured is at designated weighbridges on few selected roads far away from the source points. This challenge leads to overloading which leads to compromised road safety and in turn to increase in road traffic accidents, damage to road pavements, damage to vehicle, higher fuel consumption, among many others. The road traffic accidents have robbed the country of its merger resources like human capital, infrastructure and property damage, while frequent road repairs exerts financial pressure on the national budget and hence adversely affecting the national gross domestic product (GDP).

Since the *load weight* loaded on the buses is not known, the bus owners or operators also do not have any means to obtain detailed accurate data on how much load weight is carried on their buses, apart from relying just on passenger tickets to calculate expected income and apparently getting very little or nothing from luggage.

According to the Road Development Agency (RDA)'s Road Maintenance Strategy for 2015 to 2024, most of the roads in Zambia were constructed after independence between 1964 and late 1970's [1]. The roads were built to very high standards, and at the time, the heaviest truck rarely exceeded 20 tonnes (truck and trailer). Over time, there had been tremendous increase in the carrying capacities of busses and heavy goods vehicles (HGVs) due to the advancement in technology which had partly been cited as one of the causes of vehicle overloading [2].

Vehicle overloading is a phenomenon resulting from either exceeding the permissible Maximum Axle Load or the Maximum Gross Vehicle Mass (GVM). Axle load is defined as the weight transmitted onto the road by an axle bearing two tyres or more, while GVM is defined as the net weight of a motor vehicle or trailer together with such weight of goods or passengers or both. The maximum permissible load limits take into account the road design capacity and vehicle tyre ratings among other things [3]. The adverse effects of vehicle overloading leads to the rapid deterioration of the road pavement infrastructure, leading to rutting, fatigue cracking, and in certain cases structural failure, leading to high road maintenance costs [4]-[7]; compromises road safety leading to higher road traffic accidents [8],[9]; decrease in vehicle performance, namely, dynamic stability, braking and handling gradient [10],[11]. A study conducted by the International Road Dynamics Inc., found that 10 percent increase in weight can accelerate pavement damage by over 40 percent [12]. Therefore, the damage caused by overloading rises exponentially with each additional ton of axle load, and this reduces the life of a road substantially [13]. Other notable effects of overloading are compromised road safety leading to road traffic accidents; damage to vehicle and increase in fuel consumption leading to high operational costs; among many others. Thus, overloading has an adverse effect on the national Gross Domestic Product (GDP) [14].

The Metrology Act for Zambia Metrology Agency in reference to the National Measurement Units states that "a person shall not, without reference to the standard unit of measurement, in relation to any goods and services quote a price or charge; issue or exhibit a price list, invoice or other document; state a quantity in an advertisement, poster or document; or indicate the net quantity of a commodity on a package" [15]. Unfortunately, the current situation at our bus stations in Zambia, is such that the loaders will load the luggage on the bus and even prescribe a charge without any reference to any standard unit of measurement.

According to Road Transport and Safety Agency (RTSA), among the several most probable cause of road traffic accidents are Excessive Speed, Misjudging Clearance Distance, Driving under Influence of Alcohol/Drugs, Un-road Worth Vehicle condition, and Failure to Observe Road Traffic Rules [16], among others. No mention of Overloading is mentioned, probably, it is due to the fact that there is no means of establishing load weight apart from weighbridges.

1.3 Motivation and Significance of the Research

The theoretic framework of this study is based on the premise of the knowledge of Sensing Technology of weight and motion using Load Cells and Passive Infra-Red (PIR) sensors. Other existing and emerging technologies such as Wireless Sensor Network (WSN), Internet of Things (IoT), Cloud Computing and Mobile Communication could also be adopted. This is to facilitate the implementation of an automatic embedded system of load weight data capturing and collection; measuring and analyzing; and storage and transmission.

There are several pieces of legislation which provide legal guidelines to deal with vehicle load weight regulation in Zambia. The Roads and Road Traffic Act [17] and the Public Roads Act [18] provides guidelines on the prescribed permissible *load weights* for public vehicles. Also the Metrology Act prescribes the National Standard Unit to be used for charging any item which is measured and weighed [15]. One common acronym states that "If you cannot measure it, then you cannot manage it." Therefore, the need to come up with a system to help the facilitation of enforcement of various pieces of legislature on one hand and need to exploit technological solutions on the other hand necessitated this research.

The significance of this study is that it will create a forum for further discussions on policy, regulation, enforcement and best practices to implement systems to enhance *load weight* management from the source, that is, from the bus station, that will help to reduce road damage and improve road safety by using the proposed *load weight* monitoring system and wireless sensor network to capture and provide accurate data on *load weight* on buses.

1.4 Scope

This research involved a baseline study that was conducted in Lusaka province of Zambia to establish the challenge of overloading on Public Services Vehicles (PSV) at Intercity Buses

Terminus. The key stakeholders targeted included Institutions and Agencies; Bus Operators or Owners; Bus Crew (Manager, Drivers, Conductors, Inspectors and, Loaders). An Automatic Load Weight Monitoring model and the software prototype based on Sensor Technology principles and other emerging technologies [19] model was implemented in this study. The results of the baseline study were statistically analysed to give a position from all different stakeholders on the need to curb overloading on public buses and provided the requirements in the design of the proposed system.

The detailed implementation was based on Sensing Technologies of Weight and Motion. Other technologies employed were Mobile Digital Communication, Cloud Computing for Data Capture and Storage at Centralised Database centre using and Internet of Things (IoT) [19], which are beyond the scope of this study work.

1.5 Problem Statement

The failure to adhere to the prescribed maximum *load weight* eventually results in increased road traffic accidents, high road maintenance costs and high operation costs among other several adverse effects. The road traffic accidents have robbed the country of its merger resources like human capital, increased medical expenses, infrastructure damage, while frequent road repairs exerts financial pressure on the national budget and hence adversely affecting the national gross domestic product (GDP). Lack of appropriate and modern means to measure and establish the total *load weight* on public bus poses the challenge of overloading both passengers and luggage. This leads to damage of road pavements which in turn leads to compromised road safety.

1.6 Aim

To develop a passenger and luggage weight monitoring system, in order to mitigate the challenge of overloading on public buses and enhance road safety.

1.7 Objectives

(i) To conduct a baseline study to establish if bus operators and crew adhere to prescribed maximum *load weight* of buses.

(ii) To design an automatic system model to monitor the load weight of passengers and luggage loaded on public buses based on Weight and Motion Sensing Technologies.

(iii) To develop, test and implement a prototype model based on the proposed design in (ii).

1.8 Research Questions

(i) To what extent do the bus operators and crew adhere to the prescribed maximum *load weight* of buses?

(ii) How can we design a modern automated weight monitoring system model of passengers and luggage on public buses to mitigate the challenge of overloading?

(iii) How can we develop and implement an Automatic *Load Weight* Monitoring System prototype model for public buses based on the outcome of *research question (ii)*?

1.9 Research Contributions

The research contributions came from the baseline study which was carried out which highlighted the challenges of public buses transporters in Zambia. A model was developed based on sensor technologies together with existing and emerging technologies. Finally, a prototype program was also developed to test and validate the model

The establishment of a *load weight* monitoring and management system on public buses from the source will lead to adherence and compliance observation of the maximum load weight leading to improved road safety and hence less road traffic accidents, less damage road pavements, and less expenses on road maintenance. The current up-hazard manner of handling passengers and luggage will be improved.

Extending the same principle of load weight monitoring to other commercial service vehicles could contribute to reduction and ultimately eliminate the vice of overloading on roads, thereby improving road safety by reduced road damage and also reduced road maintenance costs.

Part of the results of this work were published in a peer review and shared with the research community through the publication which appeared in the International Journal of Advanced Computer Science and Applications (IJACSA), Vol.10, No.6, 2019, [20].

1.10 Organisation of the Dissertation

The work done in this thesis is organised into five chapters. Chapter 1 is the Introduction to the Research. In this chapter, we give a brief overview of the work in this thesis. We also give the motivation and significance, scope, problem statement, aim, objectives and contribution of this research study. This chapter concludes by the giving an outline of the thesis.

Chapter 2 discusses the literature review and the related works. In this chapter, we begin by providing a comprehensive review of Public Transport System, theory of Scales, Electronic Scales, Weighbridges, Wireless Sensor Networks, Motion Sensors and Cloud Computing. Next we look at the related works regarding vehicle weight management systems.

The research methodology is given in Chapter 3. In this chapter, we look at the methods used to conduct the baseline study and implementation of the proposed system.

In Chapter 4, we present the research findings of the baseline study and the proposed system implementation. Finally, Chapter 5 discusses the findings, draws the conclusions and gives the recommendations of the study.

1.11 Summary

In this chapter, we looked at the background to the research. We begin by looking at the challenge of exceeding the maximum permissible load weight on public buses caused by overloading in Zambia. The motivation, significance and scope of the work in this study are then outlined. Finally we give the problem statement, stated the aim, objectives, the research contributions and we close this chapter with an organization of the dissertation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature of most related works to this research study are reviewed. Firstly, an extensive review of Public Transport (PT) and the related Public Service Vehicles (PSVs) regulations are reviewed. This is followed by the different types and modes of public transport, the causes of accidents and challenges of public transport.

This is followed by a brief review of Scales, Electronic Scales and a detailed review of Load Cells, Wireless Sensor Networks and Cloud Computing. Also, a review of the software development approaches is presented in the following section. Lastly, this chapter closes by looking at related works of automated load weight monitoring and management system.

[Source: Field Image Captured at Lusaka Intercity Bus Terminus, 2018]

Figure 2.1: Image of Typical Example of Public Transport in Zambia – Euro Bus Services

2.2 Public Transport

Public Transport, also known as Public Transportation, Public Transit, or Mass Transit, is a shared passenger transport service which is available for use by the general public. This is distinct contrast to other modes such as Private Car, Taxi Cab, Car Pooling, or Hired Buses which are not shared by strangers without private arrangement. A vehicle specifically designated to be used for public transport is usually referred to as a "public service vehicle" [17] [18].

According to the Roads and Road Traffic Act [17], the *gross weight* of a public service vehicle, the weight of goods and the maximum number of passengers that may be carried on a public service vehicle shall be determined by a vehicle examiner in the prescribed manner, and, together with such other particulars as may be prescribed, shall be described on the certificate of fitness for the vehicle issued and shall be legibly painted in a conspicuous position on the vehicle in such manner as may be prescribed:

(i) Provided that, notwithstanding the provisions of above subsection and of any regulations which may be made prescribing the manner in which the number of passengers that may be carried in a public service vehicle shall be determined, the Commissioner may, in his/her discretion, by Gazette notice, authorise, subject to such conditions as he may specify in such notice, the carriage of standing passengers in such omnibuses or classes of omnibuses as he may so specify.

(ii) If there be found in any public service vehicle more passengers than the vehicle is permitted to carry, then the conductor of the vehicle, if any, or, if no conductor is carried, the driver, shall be guilty of an offence and liable upon conviction, to a fine of two hundred penalty units in respect of every passenger carried in excess of the permitted number of passengers.

(iii) If any person being requested by the conductor or driver of a public service vehicle not to enter the vehicle enters or attempts to enter the vehicle when it is carrying the full number of passengers which it is permitted to carry, he shall be guilty of an offence.

(iv) For the purposes of this section, a child apparently under five years of age and not occupying a seat shall not be counted as a person, and three children apparently over five years of age and under ten years of age shall be counted as two persons.

(v) Maximum laden weight and axle weight of vehicles:

   a) The maximum laden weight of a vehicle or trailer shall not exceed the manufacturer's permitted gross weight of such vehicle or trailer or 6,500 kilograms, whichever is less.

b) The maximum weight carried on any axle of a vehicle or trailer shall not exceed the manufacturer's permitted axle weight or 4,500 kilograms, whichever is less.
c) If, upon a vehicle or trailer being weighed or tested as aforesaid, it is found that the laden weight of such vehicle or trailer or the weight carried on any axle thereof exceeds the limit specified in any law applicable to the road in question for the time being in force or in any exemption granted in terms of regulation 58, a police officer or road traffic inspector may direct that the load be reduced or re-distributed, as the case may be, so as to comply with such law or such exemption, and may detain such vehicle or trailer until the person in charge thereof has complied with such direction.
d) If, when the vehicle or trailer is weighed, it is found to have a laden weight exceeding the maximum permitted weight, a fine of five penalty units per kilogram above the maximum permitted weight shall be paid.

2.2.1 Types and Modes of Public Transport

The types and mode of Public Transport (PT) varies greatly depending on the level of development of an area or country, with the corresponding advancement in the basic support infrastructure. In developed countries, public transport include city buses; trolley buses; trams (or light rail) and passenger trains; rapid transit (metro/subways/underground trains); and ferries. In between cities, public transport is dominated airlines, coaches, and inter-city rail, sometimes with high-speed trains in some instances. Most of this public transport is characterised to offer a headway service, that is, scheduled timetabled, say every 5 minutes, as opposed to being scheduled for ant time of the day. Para-transit is sometimes used in areas of low-demand and for people who need door-to door service [21].

In developing and sub-Saharan countries, especially in Africa, the research into PT undertaken by Transport Research Laboratory (TRL) has shown that PT vehicles in African and Asian countries are frequently poorly maintained and often overloaded, whilst the drivers themselves receive inadequate training. Public transport in many African cities is provided not only by the conventional bus but also by Para-transit vehicles such as Mammy wagons (converted trucks) and Matatu (converted vans in Kenya and the like) [22]. Such forms of public transport are poorly regulated and controlled, with many operating illegally. These vehicles currently have a reputation of being particularly dangerous and pose a lot of safety hazards on the roads.As a typical example, one important mode of transport in many cities in Indonesia is known as the Angkutan Kota which has 12-14 passenger seats and is classified as Para-transit.

This mode shares 61.24 percent of the total public transportation available in Bandung, Indonesia. This minivan operates around 46 percent of the total public transportation in many cities in Indonesia, and 52 percent of the total public transportation in the Province of West Java. Many people depend on this transport mode, especially students and people from the middle to low economic strata. Although the existence of Para-transit has been accused as the main cause for traffic disturbance, its important role in providing mobility for captive riders cannot be neglected [23].

Other forms of public transport in Africa, particularly in Zambia are Mini-buses and Taxis. These offer on-demand services in many parts of the urban cities and the services are mostly not scheduled as they have to wait until the vehicle is full before it starts off [24].

PT comes in various forms and types; each type distinguished by the technology and infrastructure it uses. For example, railways use trains running on metal rails, buses use the main road network, and airplanes use the sky, canoes, boats, ferries and ships uses waterways also referred to as marine, and so on. Some types may blur the boundaries a little, for example, trams are a form of 'light rail' using lighter-than-normal train vehicles which typically run on metal rails embedded into public roads although may also have sections of dedicated track.

The distinctions can be even more subtle, for example, buses and coaches, which both use motor vehicles on the public road network, however coaches tend to be bigger, and used for longer distances with fewer stops. Whilst it may be tempting to try and come up with definitions for these different types, ultimately, maps are most useful if they match with people's expectations. So, when choosing which type a particular public transport service falls into, it is generally best to go with whatever the users of that service general understanding of it would be [25] - [27].

The modes of PT can be categorized by the different means it is achieved and the main ones include surface (road, railways), marine (water), air (aviation).

Around the world, interest in urban and metropolitan passenger and goods movements is increasing because they account for a substantial share of traffic and economic activity in urban and metropolitan areas. In this context, many city administrators have implemented measures to mitigate the negative effects of PT [28] - [30].

2.2.2 Road Network in Zambia

Roads are predominantly a preferred mode of PT and travel, typically carrying over 80 percent passengers and goods. The public road network in Zambia is among the most important public national infrastructure asset with an estimated value of US$ 8.3 billion, representing 31 percent of the country’s gross domestic product (GDP) as of 2014. Certainly, it could be estimated that the value of the asset road network in Zambia is on the increase, considering the massive investments in road infrastructure through numerous road projects the government had embarked on in the recent past, inter alia, the Link Zambia 8000, Pave Zambia 2000, L400 and C400, among others. The Second Road Sector Investment Programme (ROADSIP) II document defined the Core Road Network (CRN) as the barest minimum network that is required to be maintained continuously and on a sustainable basis in order to realize its social and economic potential [31].

The following were adopted as the designations of various roads in Zambia by the RDA [31]:

(i) Trunk Roads (T) as Inter-Territorial main roads connecting Zambia to neighboring countries;

(ii) Main Roads (M) as Territorial main roads connecting provincial centers and major towns within and among provinces, such as the (M009) from Lusaka to Mongu;

(iii) District Roads (D) as roads connecting districts and major settlements within the districts, such as the (D769) connecting Mumbwa and Itezhi-Tezhi;

(iv) Feeder Roads (U) are Primary, Secondary or Tertiary roads, before 1998 Feeder Roads Reclassification exercise, these were referred to as Rural District Roads (RD), or Rural Roads, and Branch/Estate Roads (B); and

(v) Urban or Township Roads are road within urban areas and townships, they do not bear any designation and are identified by individual names.

The RDA also reported that Zambia had a total classified network of public roads of 67,671km comprising of Trunk, Main, District, Primary, Secondary and Tertiary Feeder, Urban and Park Roads. However, owing to the vast size of the network and limited resources, RDA has concentrated its efforts on a rationalized the network of 40,454km deemed as the *Core Road Network* (CRN) of which 3,116km were *Trunk Roads*. The CRN is defined as the bare minimum network that is required to be maintained continuously and on a sustainable basis in order to realize its social and economic potential. Table 2.1 gives a breakdown of the CRN.

Table 2.1: Breakdown of the Core Road Network in Zambia [31]

No.	**Road Type**	**CRN (Km)**
1	Trunk (T)	3,116
2	Main (M)	3,701
3	District (D)	13,707
4	Urban	5,597
5	Primary Feeder (PF)	14,333
TOTAL		**40,454**

The map showing the Core Road Network (CRN) in Zambia is given in Figure 2.2 below.

Figure 2.2: Map of the Core Road Network in Zambia [Source: RDA, 2014]

The six Trunk Roads in Zambia are shown in Table 2.2.

Table 2.2: Trunk Roads in Zambia

No.	Name	Connected Points	Approx. Length (Km)
1	T1	Kafue Turnpike to Livingstone Border	417.0
2	T2	Chirundu Border to Nakonde Border	1150.0
3	T3	Kapiri Mposhi to Kasumbalesa Border	203.9
4	T4	Lusaka to Chipata Mwami Border	607.2
5	T5	Chingola to Mwinilunga Jimbe Border	677.2
6	T6	Katete to Chanida Border	60.9

TOTAL	**3116.2**

The map showing the six Trunk Roads in Zambia is given in Figure 2.3 below.

Figure 2.3: Map of Zambia showing Trunk Roads [42].

2.2.3 Causes of Road Traffic Accidents on Public Transport

Road accidents occur chiefly as the result of one the three main factors, namely, Human Factors; Vehicle Factors; and Road and Environment Factor. Human Factors describes that which the person did, or did not do at the time of the accident. It includes the following characteristics: over speeding, inappropriate speed for the circumstance, road traffic rules violations, alcohol, drugs, negligence, driver error and age. Vehicle Factors refers to design or mechanical faults of a vehicle, which includes a lack of maintenance and exceeding the prescribed vehicle capacity rating by the manufacturer. Road and Environmental Factors describes all aspects of road infrastructure design, construction, maintenance, weather conditions, road traffic signage and lighting, among others [32].

Figure 2.4 shows the contribution of different factors, the most notable being the Human Factors, which, in conjunction with the other two factors, contributes to 95% of all accidents, followed by 28% for Road and Environment Factors, and least by 8% for Vehicle Factor [33] – [40].

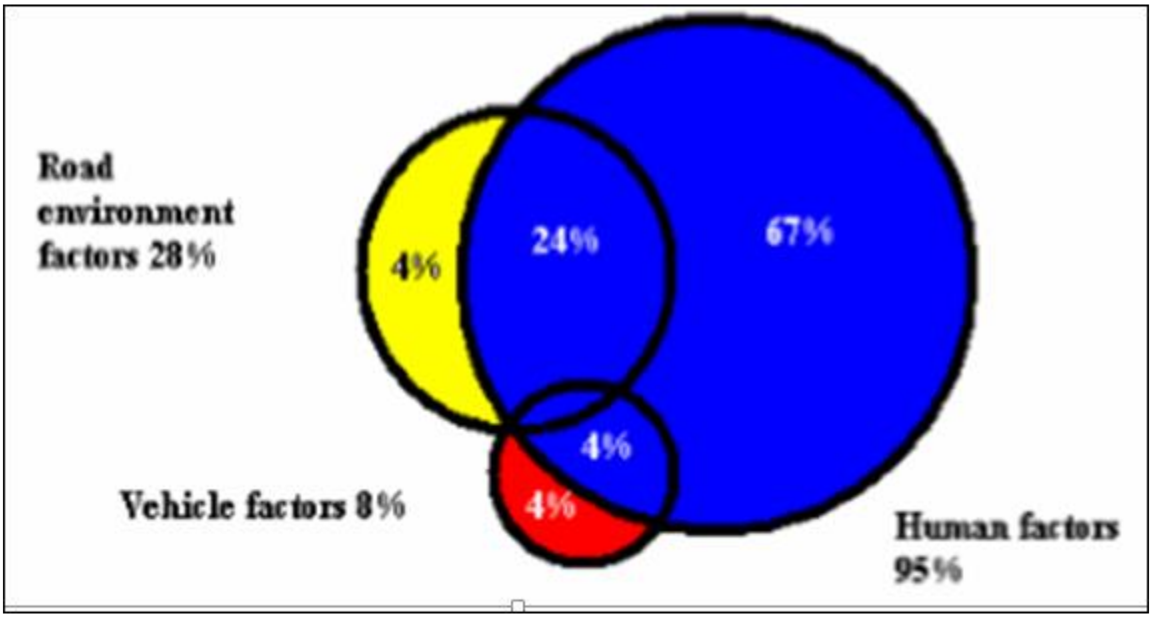

Figure 2.4: The Three Factors that Contribute to Road Accidents [Source: Austroads, 1994]

2.2.4 Vehicle Population and Overloading on Public Transport in Zambia

The vehicle population in Zambia increased from 183,701 in 2006 to 696,474 in 2016. The vehicle population growth rate, as reported by the Road Transport and Safety Agency (RTSA) in 2015, was about 45,000 vehicles per year. The increase in vehicle population and the dominance of road transport had increased pressure on the road network. Heavy goods that were traditionally transported by rail were instead, transported on roads which were not designed to carry such heavy loads hence resulting in over-stressed pavements and damage roads [41]. According to the RDA's Road Maintenance Strategy for 2014 to 2024, most of the roads in Zambia were constructed after independence between 1964 and late 1970's. The roads were built to very high standards, and at the time, the heaviest truck rarely exceeded 20 tonnes truck and trailer. Over time, there had been tremendous increase in the carrying capacities of busses and heavy goods vehicles (HGVs) due to the advancement in technology which had partly been cited as one of the causes of vehicle overloading [42].

Vehicle overloading is a phenomenon resulting from either exceeding the permissible maximum axle load or the maximum gross vehicle mass (GVM). Axle load, is defined as the weight transmitted onto the road by an axle bearing two tyres or more. Further, GVM is defined as the net weight of a motor vehicle or trailer together with such weight of goods or passengers or both. The maximum permissible load limits take into account the road design capacity and vehicle tyres rating [43] among other things.

Vehicle overloading results in rapid deterioration of the pavement structures [44]. A study conducted by the International Road Dynamics Inc., cited by Kishore and Klashinski (2000), found that 10 percent increase in weight can accelerate pavement damage by over 40 percent [45]. Therefore, the damage caused by overloading rises exponentially with each additional tonne of axle load, and this reduces the life of a road substantially [46]. The various reasons for overloading includes [47]:

(i) Transport Operators' desire to maximize on profits;
(ii) Lack of information on Axle Load Regulations;
(iii) Bad roads causing movement of load weight;
(iv) Poor distribution of load weight on the vehicle;
(v) Inadequacies in other public modes of transport;
(vi) Increased demand for road transport and increase in vehicle carrying capacities;
(vii) Lack of effective controls and highway patrols; and
(viii) Carrying of additional unauthorized passengers and luggage along the way.

In order to mitigate the challenge of vehicle overloading, other modes of transportation such as railways, which has high capacity of load bearing, need to be exploited [48]. Apart from vehicle overloads, factors responsible for failure of roads include poor geotechnical properties of the soil, topography and drainage, climate, geology, poor design, construction materials and poor construction technologies [49]. Tables 2.3 shows the maximum permissible loads in Zambia based on Gross Vehicle Mass (GVM) limit [43].

Table 2.3: Maximum Gross Vehicle Mass Limits in Zambia [43]

No.	Vehicle Description	Permissible GVM (Kg)
1	Two axle vehicle	18,000
2	Three axle vehicle	26,000
3	Four (or more) axle vehicle	28,000
4	Vehicle and semi-trailer with 3-axles (articulated)	28,000
5	Vehicle and semi-trailer with 4-axles (articulated)	36,000
6	Vehicle and semi-trailer with 5-axles (articulated)	44,000
7	Vehicle and semi-trailer with 6-axles (articulated)	50,000
8	Vehicle and draw-bar trailer with 4-axles	37,000
9	Vehicle and draw-bar trailer with 5-axles	45,000
10	Vehicle and draw-bar trailer with 6-axles	53,000
11	Vehicle and draw-bar trailer with 7-axles or more	56,000
12	Any interlink with 6-axles	53,000
13	Any interlink with 7-axles or more	56,000

The Norwegian Agency for Development Cooperation (NORAD) and the European Commission (EC), committed itself, in March 2004, to undertake an Axle Load Control Programme (ALCP) in Zambia with the objective of "Establishing a robust and efficient control system with capacity to protect all the CRN against illegal overloading". The ALCP was guided by two principal statutes, namely, the Public Roads Act No. 12 of 2002 and the principal regulation, Statutory Instrument (SI) No. 28 of 2007 which was amended twice in 2015 alone. The statutes stipulated the legal axle load and GVM limits of vehicles plying on public roads.

The enforcement of these statutes was conducted at the eight gazetted fixed weighbridges on the CRN and using portable or mobile weighbridges. Portable weighbridges were randomly stationed on roads that did not have fixed weighbridges and at times near the fixed weighbridges as a supplement or to verify the operations of the fixed weighbridges.

The ALCP for Zambia was launched in April 2004, with a budget of US$ 7.2 million and was an integral part of ROADSIP II. The ALCP had the target of reducing the rate of overloading from greater than 20 percent to five percent or less, for the axles or in relation to the GVM from greater than 55 percent to less than five percent [50]. This target had been achieved with the figures for 2014 indicating the average overload on both axles and GVM to be 2.38 percent of the total number of 780,690 HGV weighed at the eight fixed weighbridges.

However, this might not be so representative of what was obtaining on the entire length of Trunk Roads considering the non-uniform spread of weighbridges which makes it impossible to capture the entire traffic on Trunk Roads. It was also a common scenario to see overloaded vehicles off-loading part of their loads a few kilometers before the weighbridge which they loaded back after passing through the weighbridge. Of course, overloaded vehicles that completely bypassed the weighbridges or use alternative routes could not be accounted for. Table 2.4 shows the maximum permissible loads in Zambia based on Axle Load Limits [43].

Table 2.4: Maximum Axle Load Limit in Zambia

No.	Type of Axle/Group of Axles	No. of Tyres	Max. Load (Tonnes)	Configuration
1	Single Steering Drive Operated	2	8	F1
2	Two Steering Drive Operated	4	14	F11
3	Single Steering Draw-Bar Controlled	2	8	T1
4	Single Steering Draw-Bar Controlled	4	9	T2
5	Single Non-Steering	2	8	A1
6	Single Non-Steering	4	10	A2
7	Tandem Non-Steering	4	12	A11
8	Tandem Non-Steering	6	15	A12
9	Tandem Non-Steering	8	18	A22
10	Tandem Non-Steering (Dolly)	8	16	T22
11	Triple Non-Steering	10	21	A212
12	Triple Non-Steering	12	24	A222
13	Triple Super Single Tyres	6	24	B111
14	Triple Single Non-Steering	6	15	A111

As already stated, the ALCP in Zambia was guided by two principal statutes, the Public Roads Act No. 12 of 2002 and SI No. 28 of 2007. Part I, Section 3 of SI No. 28 of 2007 stated that the regulation applied to vehicles with a GVM of 6.5 tonnes and above.

This implied that all vehicles with a GVM of 6.5 tonnes and above were required by law to pass through a weighbridge. Part V, Section 35 subsection 1 and 2 provided that "*An overload shall be determined by comparing weights found by weighing axles, combination of axles or GVM to the defined authorized limits*," and Part VI stipulated the procedures for fines and payments for overload. In particular, it provided that an HGV that exceeded the authorized axle load limit after the additional five percent tolerance or weigh more than the GVM legal limits was considered overloaded and was charged for overload compensation accordingly. The overload compensation was calculated separately on each axle or group of axles and GVM according to the schedules set out in the regulation. The compensation was structured in such a way as to deter would be offenders at the same time enough to compensate for the damage caused to the road infrastructure. In a case where a driver of a HGV with a GVM of 6.5 tonnes and above avoided a weighbridge, a charge of US$ 2,000.00 was levied for absconding. A driver who refused to have his/her HGV weighed was charged an obstruction fee of 50,000 penalty units which translated to ZMK 10,000.00 (US$ 1000 at exchange rate of US$ 1= ZMK 10) at the prevailing rate of ZMK 0.20 per penalty unit [43].

The ALCP Training Manual of 2007 indicated that for an overloaded vehicle carrying an abnormal load that exceeded the prescribed maximum dimensions and was indivisible, the driver must carry a special (abnormal load) permit for the specific transport. The permit must contain a specification of the starting point and destination and the route to be followed and the axle-loads and GVM to be used. If the abnormal load was beyond the contents in the permit, the load had to be unloaded on the spot. If the driver was not in the possession of such a permit, the vehicle was to be detained at the expense of the owner until a permit was provided and the relevant fee is paid [43].

According to the report on the Economic Impact of Enforcing Axle Load Regulation – A Case of Zambia [51], the following were highlighted:

(i) The annual average saving in the cost of road maintenance from effective ALCP was estimated to be of the order of US$ 4 to 4.1 million per year.

(ii) The estimated increase in the annual cost of haulage due to GVM was in the order of US$ 12 to 13 million, that is, about three times the saving in road maintenance. The approved GVM of 56 tonnes was thought to be low and expensive for Zambia in terms of transport costs but it was acknowledged that the GVM limits were set regionally by SADC.

(iii)It was impossible to evaluate the optimal GVM for Zambia due to the scarcity of information on the strength of bridges in Zambia.

2.2.5 Challenges Associated with Public Transport

Generally, PT in developing countries is confronted with numerous challenges, one of the most crucial being the insufficient and inadequate transport infrastructures. This results in a struggle for survival due mainly to the costs to be borne by the operators in order to continue the activity of offering public transportation service. The difficulty in securing vehicle spare parts combined with recurrent breakdowns frequently leads the operators to resort to other means, including overloading. The challenges in PT in developing countries are adequately covered by Dr. Jean-Paul Rodrigue in his book entitled "Urban Transport Challenges" and he states that "*the most important transport challenges are often related to urban areas and take place when transport systems, for a variety of reasons, cannot satisfy the numerous requirements of urban mobility"* [52]. Most salient challenges are highlighted below.

2.2.5.1 Urban Transportation at the Crossroads

Cities are locations having a high level of *accumulation* and *concentration* of economic activities and are complex spatial structures that are supported by transport systems. The larger the city, the greater its complexity and the higher the potential for disruptions, particularly when this complexity is not effectively managed. The most important transport problems are often related to urban areas and take place when transport systems, for a variety of reasons, cannot satisfy the numerous requirements of urban mobility. Urban productivity is highly dependent on the efficiency of its transport system to move labor, consumers and freight between multiple origins and destinations. Figure 2.5 shows the paths of urban transport development.

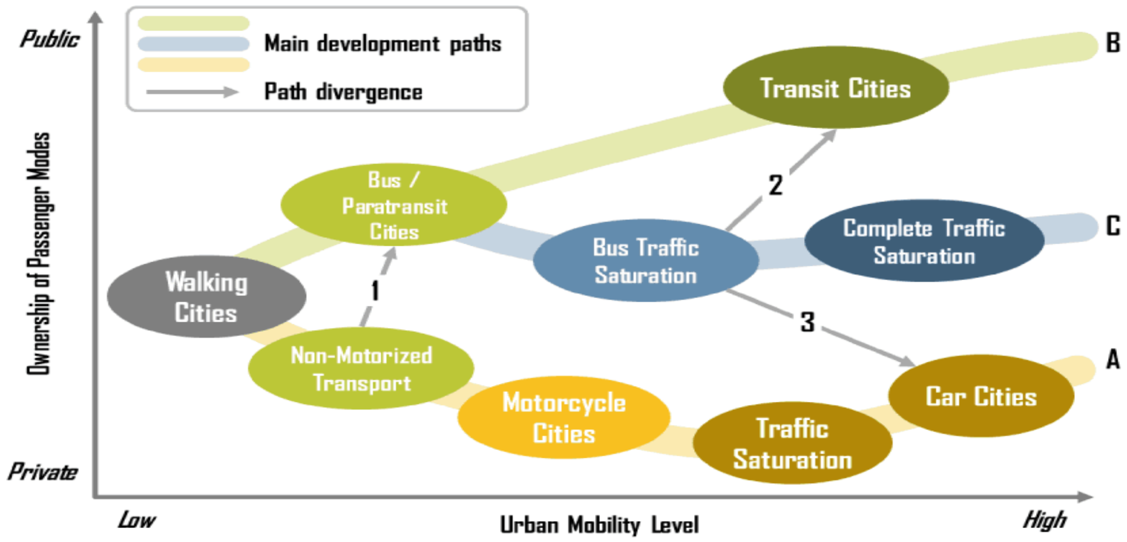

Figure 2.5: Urban Transport Development Paths [53]

The important transport terminals such as ports, airports, and rail-yards are located within urban areas, contributing to a specific array of problems. Some problems are ancient, like congestion (which plagued cities such as Rome), while others are new like urban freight distribution or environmental impacts [53] – [56].

The most notable urban transport problems are:

(i) **Traffic Congestion and Parking Difficulties**: Congestion is one of the most prevalent transport problems in large urban areas. It is particularly linked with motorization and the diffusion of the automobile, which has increased the demand for transport infrastructures. However, the supply of infrastructures has often not been able to keep up with the growth of mobility. Since vehicles spend the majority of the time parked, motorization has expanded the *demand for parking space*, which has created space consumption problems particularly in *central areas*; the spatial imprint of parked vehicles is significant. Congestion and parking are also interrelated since looking for a parking space (called "cruising") creates additional delays and impairs local circulation. In central areas of large cities cruising may account for more than 10 percent of the local circulation as drivers can spend 20 minutes looking for a parking spot. This practice is often judged more economically effective than using a paying off-street parking facility as the time spent looking for a free (or low cost) parking space as compensated by the monetary savings. Also, many delivery vehicles will simply double-park at the closest possible spot to unload their cargo.

(ii) **Longer Commuting**: On par with congestion people are spending an increasing amount of *time commuting* between their residence and workplace. An important factor behind this trend is related to residential affordability as housing located further away from central areas (where most of the employment remains) is more affordable. Therefore, commuters are trading time for housing affordability. However, long commuting is linked with several social problems, such as isolation, as well as poorer health (obesity).

(iii) **Public Transport Inadequacy**: Many public transit systems, or parts of them, are either over or under used. During peak hours, crowdedness creates discomfort for users as the system copes with a temporary surge in demand. Low ridership makes many services financially unsustainable, particularly in suburban areas. In spite of significant subsidies and cross-financing (e.g. tolls) almost every public transit system cannot generate sufficient income to cover its operating and capital costs. While in the past deficits were deemed acceptable because of the essential service public transit was providing for urban mobility, its financial burden is increasingly controversial.

(iv) **Difficulties for Non-Motorized Transport**: These difficulties are either the outcome of intense traffic, where the mobility of pedestrians, bicycles and vehicles is impaired, but also because of a blatant lack of consideration for pedestrians and bicycles in the physical design of infrastructures and facilities.

(v) **Loss of Public Space**: The majority of roads are publicly owned and free of access. Increased traffic has adverse impacts on public activities which once crowded the streets such as markets, agoras, parades and processions, games, and community interactions. These have gradually disappeared to be replaced by automobiles. In many cases, these activities have shifted to shopping malls while in other cases, they have been abandoned altogether. Traffic flows influence the life and interactions of residents and their usage of street space. High traffic impedes social interactions and activities like walking and cycling.

(vi) **High Maintenance Costs:** Cities with an aging of their transport infrastructure are facing growing maintenance costs as well as pressures to upgrade to more modern infrastructure. In addition to the involved costs, maintenance and repair activities create circulation disruptions. Delayed maintenance is rather common since it conveys the benefit of keeping current costs low, but at the expense of higher future costs and on some occasion the risk of infrastructure failure. The more extensive the road and highway network, the higher the maintenance cost and the financial burden.

(vii) **Environmental Impacts and Energy Consumption:** Pollution, including noise, generated by circulation has become a serious impediment to the quality of life and even the health of urban populations. Further, energy consumption by urban transportation has dramatically increased and so the dependency on petroleum. These considerations are increasingly linked with peak mobility expectations, where high energy prices incite a shift towards more efficient and sustainable forms of urban transportation, namely public transit.

(viii) **Accidents and Safety:** Growing traffic in urban areas is linked with a growing number of accidents and fatalities, especially in developing countries. As traffic increases, accidents also increases and people feel less safe to use the streets than when there is less traffic. The diffusion of information technologies leads to paradoxical outcomes. While users have access to reliable location and navigation information, portable devices create distractions linked with a rise of accidents for drivers and pedestrians alike.

(ix) **Land Consumption:** The territorial imprint of transportation is significant, particularly for the automobile. Between 30 percent and 60 percent of a metropolitan area may be devoted to transportation, an outcome of the over-reliance on some forms of urban transportation. Yet, this land consumption also underlines the strategic importance of transportation in the economic and social welfare of cities.

(x) **Freight Distribution:** Globalization and the materialization of the economy have resulted in growing quantities of freight moving within cities. As freight traffic commonly shares infrastructures with the circulation of passengers, the mobility of freight in urban areas has become increasingly problematic. City logistics strategies can be established to mitigate the variety of challenges faced by urban freight distribution.

Many dimensions to the urban transport challenge are linked with the dominance of the automobile, which are dealt with as the next challenge item of *Automobile Dependency*.

2.2.5.2 Automobile Dependency Challenge

Automobile use is obviously related to a variety of advantages such as on demand mobility, comfort, status, speed, and convenience. These advantages jointly illustrate why automobile ownership continues to grow worldwide, especially in urban areas. When given the choice and the opportunity, most individuals will prefer using an automobile. Several factors influence the growth of the total vehicle fleet, such as sustained economic growth (increase in income and quality of life), complex individual urban movement patterns (many households have more than one automobile), more leisure time and suburbanization. Therefore, rising automobile mobility can be perceived as a positive consequence of economic development. The acute growth in the total number of vehicles also gives rise to congestion at peak traffic hours in business district areas [57] – [61].

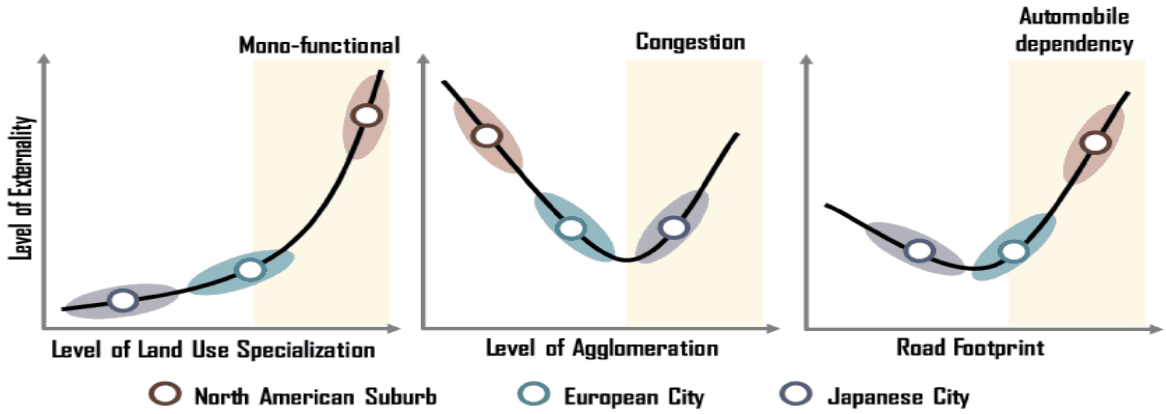

Figure 2.6: Geographical Paradoxes behind Urban Transport Challenges [53]

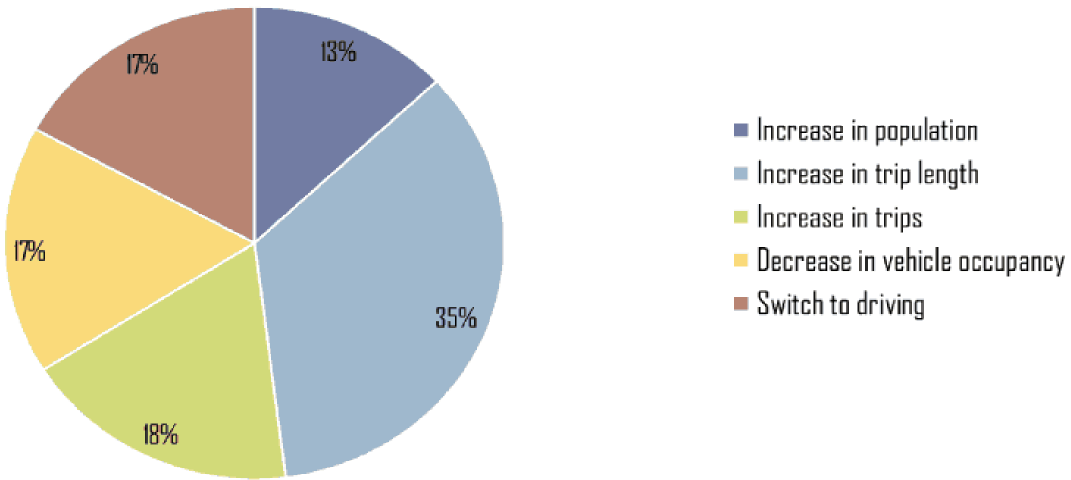

Figure 2.7: Factors Contributing to the Growth of Driving in the United States [53]

Cities are important generators and attractors of movements, which have created a set of geographical paradoxes that are self-reinforcing. For instance, specialization leads to additional transport demands while agglomeration leads to congestion, as shown in Figure 2.6. Over time, a state of automobile dependency has emerged which results in a declining role of other modes, thereby limiting still further alternatives to urban mobility. In addition to the factors contributing to the growth of driving as shown in Figure 2.7, the two major factors contributing to automobile dependency are:

(i) **Underpricing and Consumer Choices:** Most road infrastructures are subsidized as they are considered a public service. Consequently, drivers do not bear the full cost of automobile use. Like the "Tragedy of the Commons", when a resource is free of access (road), it tends to be overused and abused (congestion). This is also reflected in consumer choice, where automobile ownership is a symbol of status, freedom and prestige, especially in developing countries. Single home ownership also reinforces automobile dependency.

(ii) **Planning and Investment Practices:** Planning and the ensuing allocation of public funds aim towards improving road and parking facilities in an ongoing attempt to avoid congestion. Other transportation alternatives tend to be disregarded. In many cases, zoning regulations impose minimum standards of road and parking services and de facto impose a regulated automobile dependency.

There are several levels of automobile dependency, ranging from low to acute, with their corresponding land use patterns and alternatives to mobility. Among the most relevant indicators of automobile dependency are the level of vehicle ownership, per capita motor vehicle mileage and the proportion of total commuting trips made using an automobile as shown in Figure 2.8 and Figure 2.9 respectively.

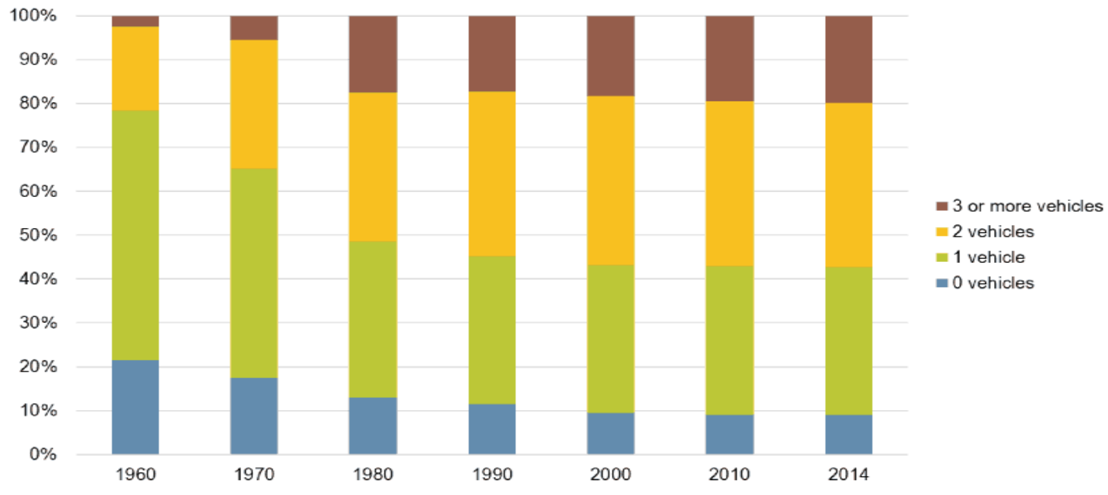

Figure 2.8: Percentage of Households by Number of Vehicles in USA, 1960-2014 [53]

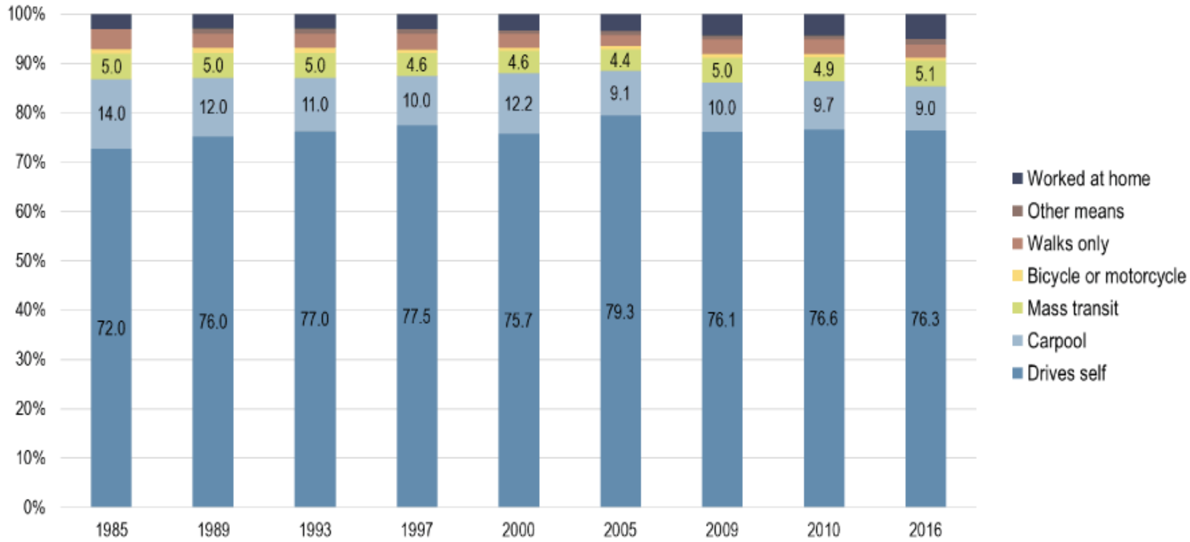

Figure 2.9: Home-to-Work Trips Modes, United States, 1985-2016 [53]

A situation of high automobile dependency is reached when more than three quarters of commuting trips are done using the automobile, see Figure 2.10. For USA, this proportion has remained around 88 percent over the recent decades. Automobile dependency is also served by a cultural and commercial system promoting the automobile as a symbol of status and personal freedom, namely through intense advertising and enticements to purchase new automobiles. Not surprisingly, many developing countries perceive motorization as a condition for development.

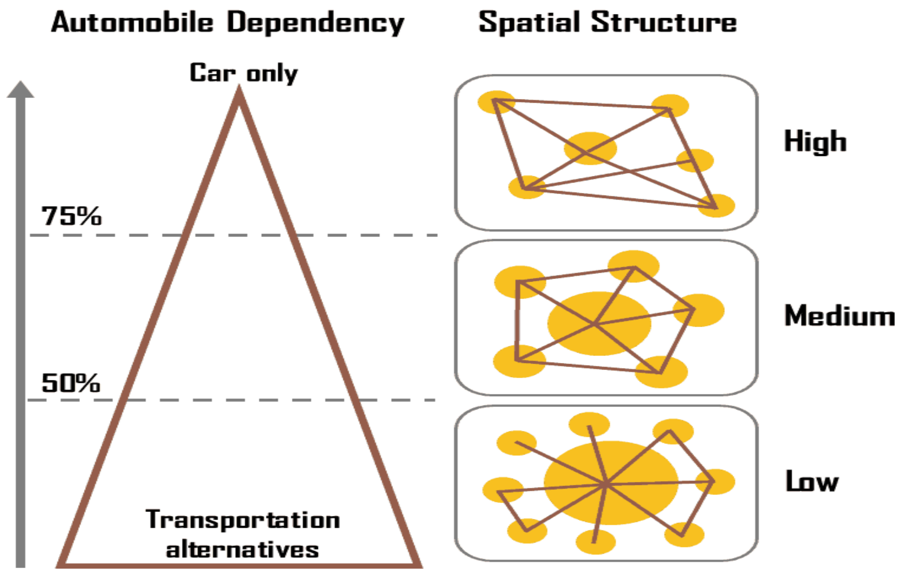

Figure 2.10: Levels of Automobile Dependency [53]

Even if the term automobile dependency is often negatively perceived and favored by market distortions such as the provision of roads, its outcome reflects the choice of individuals who see the automobile more as an advantage than an inconvenience. The second half of the 20th century saw the adaptation of many cities in North America and Europe to automobile circulation. Motorized transportation was seen as a powerful symbol of modernity and development. Highways were constructed, streets were enlarged, and parking lots were set often disrupting the existing urban fabric with the creation of motorized cities. However, from the 1980s, *motorization started to be seen more negatively* and several cities implemented policies to limit automobile circulation, at least in specific areas, by a set of strategies including:

(i) **Dissuasion:** Although automobile circulation is permitted, it is impeded by regulations and physical planning. For instance, parking space can be severely limited and speed bumps placed to force speed reduction.

(ii) **Prohibition of Downtown Circulation**: During most of the day the downtown area is closed to automobile circulation but deliveries are permitted during the night. Such strategies are often undertaken to protect the character and the physical infrastructures of an historical city. They do however, like most policies, have unintended consequences. If mobility is restrained in certain locations or during certain time periods, people will simply go elsewhere (longer movements) or defer their mobility for another time (more movements).

(iii) **Tolls:** Imposing tolls for parking and entry (congestion pricing) to some parts of the city has been a strategy being considered seriously in many areas as it confers the potential advantage of congestion mitigation and revenue generation. Most evidence underlines however that drivers are willing to bear additional toll costs for the convenience of using a car, especially for commuting since it is linked with their main source of income.

Tentative solutions have been put forth such as transport planning measures (synchronized traffic lights, regulated parking), limited vehicle traffic in selected areas, the promotion of bicycle paths and public transit. In Mexico City, vehicle use is prohibited according to license plate numbers and the date (even-uneven). Affluent families have solved this issue by purchasing a second vehicle, thus worsening the existing situation. Singapore is the only country in the world which has successfully controlled the amount and growth rate of its vehicle fleet by imposing a heavy tax burden and purchasing permits on automobile owners. Such a command-based approach is unlikely to be possible in other contexts.

There is a growing body of evidence underlining that a *peak level of car mobility* is unfolding, at least in developed countries. Higher energy prices, congestion, less economic prospects and the general aging of the population are all countervailing forces to car dependency. For instance, since 2006 the number of vehicle-miles travelled in the United States has *peaked*, a process associated with higher energy prices and an economic recession. There are many alternatives to automobile dependency such as inter-modality (combining the advantages of individual and collective transport), carpooling (strengthened by policy and regulation by the US government) or non-motorized transportation (walking and cycling). These alternatives can only be partially implemented as the automobile remains on the short and medium terms the prime choice for providing urban mobility. A significant potential change remains the development of mobile car sharing applications enabling a better utilization of vehicle assets. Although this would not reduce the level of automobile dependency, it can offer enough flexibility for some users not to require the ownership of an automobile [57] – [61].

2.2.5.3 Congestion Challenge

Congestion occurs when *transport demand exceeds transport supply* at a specific point in time and in a specific section of the transport system. Under such circumstances, each vehicle impairs the mobility of others.

Congestion can be perceived as an unavoidable consequence of the usage of scarce transport resources, particularly if they are not priced. The last decades have seen the extension of roads in urban areas, most of them free of access. Those infrastructures were designed for speed and high capacity, but the growth of urban circulation occurred at a rate higher than often expected. Investments came from diverse levels of government with a view to provide accessibility to cities and regions. There were strong incentives for the expansion of road transportation by providing high levels of transport supply. This has created a vicious circle of congestion which supports the construction of additional road capacity and automobile dependency. Urban congestion mainly concerns two domains of circulation, often sharing the same infrastructures [62]:

(i) **Passengers**: In many regions of the world incomes have significantly increased; one automobile per household or more is becoming common. Access to an automobile conveys flexibility in terms of the choice of origin, destination and travel time. The automobile is favored at the expense of other modes for most trips, including commuting. For instance, automobiles account for the bulk of commuting trips in the United States. The majority of automobile related congestion is the outcome of time preferences in the usage of vehicles (during commuting hours) as well as a substantial amount of space required to park vehicles. About 95 percent of the time an automobile is idle.

(ii) **Freight**: Several industries have shifted their transport needs to trucking, thereby increasing the usage of road infrastructure. Since cities are the main destinations for freight flows (either for consumption or for transfer to other locations) trucking adds to further congestion in urban areas. The "*last mile*" problem remains particularly prevalent for freight distribution in urban areas. Congestion is commonly linked with a drop in the frequency of deliveries tying additional capacity to insure a similar level of service.

It is important to emphasize that congestion in urban areas is dominantly caused by *commuting patterns* and little by truck movements. On average, infrastructure provision was not able to keep up with the growth in the number of vehicles, even more with the total number of vehicles-km. During infrastructure improvement and construction, capacity impairment (fewer available lanes, closed sections, etc.) favors congestion. Important travel delays occur when the capacity limit is reached or exceeded, which is the case of almost all metropolitan areas. In the largest cities such as London, road traffic is actually slower than it was one hundred years ago. Marginal delays are thus increasing and driving speed becomes problematic as the level of population density increases.

Once a population threshold of about one million is reached, cities start to experience recurring congestion problems. This observation must be nuanced by numerous factors related to the urban setting, modal preferences and the quality of existing urban transport infrastructures. Large cities have become congested most of the day, and congestion was getting more acute in the 1990s and 2000s and then leveled off in many cases. For instance, average car travel speeds have substantially declined in China, with many cities experiencing an average driving speed of less than 20 km/hour with car density exceeding 200 cars per km of road, a figure comparable to many developed countries. Another important consideration concerns parking, that consumes large amounts of space and provide limited economic benefits. In automobile dependent cities, this can be very constraining as each land use has to provide an amount of parking space proportional to their level of activity. Parking has become a land use that greatly inflates the demand for urban land. Urban mobility also reveals congestion patterns. Daily trips can be either "mandatory" (workplace-home) or "voluntary" (shopping, leisure, visits). The former is often performed within fixed schedules while the latter complies with variable and discretionary schedules. Correspondingly, congestion comes in two major forms [63]:

(i) **Recurrent congestion**: The consequence of factors that cause regular demand surges on the transportation system, such as commuting, shopping or weekend trips. However, even recurrent congestion can have unforeseen impacts in terms of its duration and severity. Mandatory trips are mainly responsible for the peaks in circulation flows; implying that about half the congestion in urban areas is recurring at specific times of the day and on specific segments of the transport system.

(ii) **Non-recurrent congestion**: The other half of congestion is caused by *random events* such as accidents and unusual weather conditions (rain, snowstorms, etc.), which are unexpected and unplanned. Non-recurrent congestion is linked to the presence and effectiveness of incident response strategies. As far as accidents are concerned, their randomness is influenced by the level of traffic as the higher the traffic on specific road segments the higher the probability of accidents.

Behavioral and response time effects are also important as in a system running close to capacity, simply breaking suddenly may trigger what can be known as a *backward traveling wave*. It implies that as vehicles are forced to stop, the bottleneck moves up the location it initially took place at, often leaving drivers puzzled about its cause.

The spatial convergence of traffic causes a surcharge on transport infrastructures up to the point where congestion can lead to the total immobilization of traffic. Not only does the massive use of the automobile have an impact on traffic circulation and congestion, but it also leads to the *decline in public transit efficiency* when both are sharing the same roads [64].

2.2.5.4 The Urban Transit Challenge [65] – [70]

As cities continues to be more dispersed, the *cost of building and operating PT systems increases*. For instance, as of 2015 about 201 urban agglomerations had a subway system, the great majority of them being in developed countries. Furthermore, dispersed residential patterns characteristic of automobile dependent cities makes public transportation systems less convenient to support urban mobility. In many cities, additional investments in public transit did not result in significant additional ridership.

Unplanned and uncoordinated land development has led to rapid expansion of the urban periphery. Residents, by selecting housing in outlying areas, restrict their potential access to public transportation. Over-investment (when investments do not appear to imply significant benefits) and under-investment (when there is a substantial unmet demand) in public transit are both complex challenges. Urban transit is often perceived as the most efficient transportation mode for urban areas, notably large cities. However, surveys reveal a stagnation of public transit systems, especially in North America.

The economic relevance of public transit is being questioned. Most urban transit developments had *little, if any, impacts to alleviate congestion* in spite of mounting costs and heavy subsidies. This *paradox* is partially explained by the spatial structure of contemporary cities which are oriented along servicing the needs of the individual, not necessarily the needs of the collective mass. Thus, the automobile remains the preferred mode of urban transportation. In addition, public transit is publicly owned, implying that it is a politically motivated service that provides *limited economic returns*.

Even in transit-oriented cities, transit systems depend massively on government subsidies. Little or no competition is permitted as wages and fares are regulated, undermining any price adjustments to changes in ridership. Thus, public transit often serves the purpose of a social function ("public service") as it provides accessibility and social equity, but with limited relationships with economic activities. The most difficult challenges facing urban transit are:

(i) **Decentralization**: Public transit systems are not designed to service low density and scattered urban areas that are increasingly dominating the landscape. The greater the decentralization of urban activities, the more difficult and expensive it becomes to serve urban areas with public transit. Additionally, decentralization promotes long distance trips on transit systems causing higher operating costs and revenue issues for flat fare transit systems.

(ii) **Fixity**: The infrastructures of several public transit systems, notably rail and subway systems are fixed, while cities are dynamical entities, even if the pace of change can take decades to develop. This implies that travel patterns tend to change and that a transit system built for servicing a specific pattern may eventually face "spatial obsolescence".

(iii) **Connectivity**: Public transit systems are often independent from other modes and terminals. It is consequently difficult to transfer passengers from one system to the other.

This leads to a paradox between the preference of riders to have direct connections and the need to provide a cost-efficient service network that involves transfers.

(iv) **Automobile Competition**: In view of cheap and ubiquitous road transport systems, public transit faced strong competition and loss ridership in relative terms and in some cases in absolute terms. The higher the level of automobile dependency, the more inappropriate the public transit level of service. The public service being offered is simply outpaced by the convenience of the automobile.

(v) **Financing and Fare Structures**: Historically, most public transit systems have abandoned a distance-based fare structure for a simpler flat fare system. This had the unintended consequence of discouraging short trips for which most transit systems are well suited for, and encouraging longer trips that tend to be costlier per user than the fares they generate. Information systems offer the possibility for transit systems to move back to a more equitable distance based fare structure, particularly with the usage of smartcards that enable to charge according to the point of entry and exit within the public transit system.

(vi) **Legacy Costs**: Most public transit systems employ unionized labor that have consistently used strikes (or the threat of a strike) and the acute disruptions they create as leverage to negotiate favorable contracts, including health and retirement benefits. Since public transit is subsidized these costs were not well reflected in the fare systems. In many transit systems, additional subsidies went into compensation or to cover past debt, and not necessarily into performance improvements or additional infrastructure. As most governments are facing stringent budgetary constraints because of social welfare commitments, public transit agencies are being forced to reassess their budgets through an unpopular mix of higher fares, deferred maintenance and the breaking of labor contracts.

(vii) **Self-driving Vehicles**: Development in information technologies let anticipate in the coming years the availability of self-driving vehicles. Such a development would entail point to point services by on demand vehicles and a much better utilization level of such assets. This system could compete directly with transit systems due to its convenience, comfort and likely affordability.

Public transit systems are therefore challenged to *remain relevant to urban mobility* or to *increase its market share*. The rise in petroleum prices since 2006 has increased the cost of vehicle ownership and operation, but it still remains affordable. A recent trend concerns the usage of incentives, such as point systems (monthly pass) to further promote the use of public transit and to influence consumer behavior in order to lower the cost advantage of public transit over the automobile to change in a significant way [67] – [70].

2.3 Scales

A *scale* is a device that is used for weighing, comparing and determining the weight or mass of an object or material. The scientific word for how much an object or material weighs on a scale is "*mass*". The words "*weight*" and "*mass*" are most often used interchangeably, probably because both are often commonly used in everyday language. Almost every weighing scale uses the same basic principle of the gravitational force exerted by an object or material divided by the area the force is applied on. For commercial and industrial weighing scales, they are designed to do a lot more because they handle heavier loads, often in different environmental and physical conditions [71]. Basically there are two main categories of scales namely Analog or Digital scales.

An *Analog Scale* is one that mostly is mechanical in nature and has some moving parts in it, and has no electronic devices or components attached to it while *Digital Scale* is a scale that incorporates electronic circuit components, has devices like Liquid Crystal Display (LCD) Screens and can often be computer networked. Important terminologies applied to weighing scales are *Calibration, Accuracy* and *Error* [71]:

(i) *Calibration* is the process by which a scale is set in order to check for accuracy and any errors in measurement, that is, adjustment for accuracy;

(ii) *Accuracy* is the precision of measurement made by a weighing system and it is expressed in terms of error as a percentage of: (a) the specified value (e.g., 10 volts ±1%), (b) a range (e.g., 2% of full scale), or (c) as parts (e.g., 100 parts per million); and,

(iii) *Error* is the algebraic difference between the indicated value and the true value of the load being measured.

There are different types of scales in use to measure different types of objects and materials and below are some examples [72]:

(i) *Analog* or *Digital Scales* can be used to measure to measure a person's weight, measuring from 0 to 150 kg, and usually shows units in kilograms and grams like 63.6 kg;

(ii) *Flat Electronic Scales,* also called *Platform Scales,* can be used to measure bulky objects like suitcases (luggage) at bus stations;

(iii) *Weighbridges* are scales used to measure very large objects like trucks, where the truck drives onto a special stripe of the road that is connected to a Digital Scale, then the operator reads off the truck's weight in tonnes.

For the purpose of technological application and this research, a *digital scale*, more often referred to as an *electronic scale*, is more ideal because of its adaptability due to its active component, the load cell, which is easily adaptable and compatible to be used with a computer.

2.3.1 Electronic Scales

The design and operation principle of the Electronic Scale is based on the principle and operation of the *Load Cell* (discussed in details in ***Section 2.4***). An Electronic Scale can be made in several forms but typically includes one or more load cells that support (or suspend) a weigh vessel or platform, a junction box, and a weight controller.

When a load is applied to a weigh vessel or platform, a portion of the load is transmitted to each of the load cell. Each load cell then sends an electrical proportional to the load it senses via a cable to the junction box. The load cell signals are summed in the junction box and sent via one larger cable to a weight controller, which converts the summed signal to a weight reading. It is important to note that the weight reading's accuracy can be affected by the system components' quality, system's installation and operation in the local environment [73].

As already stated, one of the most key important parameter of any weighing system, particularly the Electronic Scale, is its *Accuracy*, which can be achieved by ensuring right choice of components suitable for the application, initial calibration and frequent re-calibration, and taking steps to control environmental and other factors affecting the entire weighing system [74]. To help choose high quality weighing system components, it is recommended to take advantage of the expertise of professional renowned weighing system equipment supplies. Other key important aspects are determining how the system will be installed and what factors can affect its operation once it is up and running in the particular local area.

2.3.2 Determinants of Electronic Scale's Accuracy

Five important factors that can affect the Electronic Scale's accuracy are: Load Cell Accuracy, Load Factors, Environmental Forces, Interference with Signal Transmission, and Instrumentation and Control [75].

2.3.2.1 Load Cell Accuracy

Selecting a top-quality load cell for the Electronic Scale is the first step in obtaining weighing accuracy. The load cell (also called a *load sensor* or *transducer*) is a piece of machined metal that bends with the load's mechanical force and converts the mechanical force into an electrical signal. The bend does not exceed the metal's elasticity and is measured by strain gauges bonded at points on the cell. As long as the load is applied to the proper spot on the load cell, the strain gauges provide a proportional electrical signal.

The six key specifications for a load cell that will provide accurate weight information are:

(i) Nonlinearity: ±0.018 % of the load cell's rated output.
(ii) Hysteresis: ±0.025 % of the load cell's rated output.
(iii) Nonrepeatability: ±0.01 % of the load cell's rated output.
(iv) Creep: ±0.01 % of the load cell's rated output in 5 minutes.
(v) Temperature Effect on Output: ±0.0008 % of the load per degree Fahrenheit.
(vi) Temperature Effect on Zero: ±0.001 % of the load cell's rated output per degree Fahrenheit.

Although every specification will not necessarily apply, it is important to understand each specification to determine the load cell's combined accuracy. The load cell's response time is another factor to consider for some applications. The typical load cell behaves like a stiff spring that oscillates, so to achieve an accurate weight reading, the load cell must settle, that is, stop oscillating, in less time than the required weighing period. While load cell response time is typically not important for a batching application, a high-speed check-weighing or rotary filling machine requires fast-responding load cells.

Such load cells dampen their own natural oscillating frequency when a load is applied to them. However, the load cells do not reject vibrations applied to them from outside sources, such as nearby equipment, so there is still need to isolate the load cells from such vibration sources (covered in more details under *Environmental Forces*) [76].

2.3.2.2 Load Factors

It is important to ensure that the load is applied to each load cell in the Electronic Scale as specified by the manufacturer. An improperly applied load, such as a twisting load, causes the strain gauges in the cell to experience strain and send a signal change proportional to the twisting rather than the load's weight. For accurate weighing, the load cells alone must support all the weight to be measured. For example, rigid conduit connections and rigidly mounted piping on a weigh vessel will support some of the load and prevent the total load from being transmitted to the load cells. To avoid this problem, use flexible connections that will not support part of the load. And if bumpers or check rods are used to keep the weigh vessel from swinging and swaying, make sure that they do not support any of the load.

Correctly align each load point assembly, that is, each load cell and its mounting hardware, to ensure that the mounting hardware channels the load directly through the load cell. For example, for compression-mounting load cells under a hopper, align each load point assembly directly under the hopper leg to avoid pulling or pushing between assemblies on the other legs. Each load cell should be level, and all should be on the same plane to ensure that they share the load equally.

Ensure that the floor or structure under the load cells is strong enough to bear the weight of the vessel and its contents, as well as the weight of other equipment resting on the same floor or structure, without flexing. This will ensure that the load point assemblies remain level ±0.5 percent from zero to full load and prevent unwanted side loads on the load cells that can impair the weighing system's accuracy.

If the weigh vessel has long spindly legs, the legs can spread apart as material is loaded into the vessel. This introduces side loads to the load cells and can cause system binding, which prevents the load cells from sensing the full load. The weight accuracy may be preserved by adding cross bracing to the legs to strengthen the structure [77].

2.3.2.3 Environmental Forces

Ensure that *only* the weight force is transmitted to each load cell. Other forces, including environmental forces such as wind loading, shock loading, vibration, large temperature changes, and pressure differentials, can produce errors in the load cell signal.

Wind loading: Wind loading can affect an outdoor weighing system or a low-capacity indoor system. For example, outdoors, a 30-mph crosswind on a weigh vessel exerts forces on the load cells that have nothing to do with weight, causing the windward cells to sense a lighter load and the leeward cells to sense a heavier load. In such a case use higher-capacity load cells to prevent overloading the leeward cells. Indoors, an active overhead air conditioning vent can also create inaccurate small-increment (such as 1-ounce) measurements on a low-capacity weighing system, such as a small platform scale. A Plexiglas cover over the platform scale can be used to block or divert the stray air currents.

For accurate weighing, the load cells alone must support all the weight to be measured.

Shock loading: Shock loading occurs when heavy material is dumped onto a weighing system, causing forces greater than the system's rated capacity and damaging the system. You can use higher-capacity load cells that can handle this shock loading, but this will degrade the system's resolution (the smallest increment that the system can weigh). Controlling the material flow onto the weighing system with a feeder, specially designed loading chute, or other device can prevent shock-loading damage.

Vibration: Vibration from process equipment and other sources near the weighing system can cause the load cells to measure the weight of material as well as vibration that's transmitted to them, which the cells sense as mechanical noise. You can reduce or prevent vibration effects by isolating the weighing system from vibration sources when possible or using weighing system instrumentation with algorithms that remove vibration effects.

Large Temperature Changes: Whether your weigh vessel is indoors or outdoors, large temperature changes can cause it to expand or contract. This causes errors in the weight reading and can damage the load cells. If your weighing system is exposed to large temperature shifts, install load cells and mounting hardware that can handle the vessel's expansion and contraction.

Pressure differentials: A pressure differential can create weighing errors by applying unwanted forces to the weighing system. A pressure differential can occur, for example, when a weigh vessel is installed between a pressurized plant floor and another floor at ambient pressure. To minimize weighing errors, calibrate the load cells to the pressurized floor's constant pressure level. If the pressurization isn't constant, install the weigh vessel elsewhere.

A pressure differential can create weighing errors by applying unwanted forces to the weighing system.

Another form of pressure differential is created in an unvented weigh vessel: When material flows quickly into a closed weigh vessel, it displaces a volume of air equal to the material volume. If the air cannot escape from the vessel through a vent, the flexible connections that attach the material inlet and outlet piping to the weigh vessel will expand as the undisplaced air floods into it, and this expansion will apply side forces to the load cells, creating weighing errors. To prevent this problem, the weigh vessel must be properly vented [78].

2.3.2.4 Interference with Signal Transmission

In addition to ensuring that the load cells measure only the desired weight, it's equally important to ensure that the weight controller measures only the load cell electrical signal. Radio frequency interference (RFI), electromechanical interference (EMI), moisture, and temperature can all interfere with this electrical signal.

RFI and EMI: Just as vibration is mechanical noise (that is, interference) to a load cell, RFI and EMI are electrical noise to the load cell signal sent from the cells to the weight controller. RFI and EMI sources include lightning, portable two-way radios, large power lines, static electricity, solenoids, and electromechanical relays. One major step toward preventing these electric noise sources from affecting your weighing accuracy is to isolate the load cell low-voltage signal (typically equal to 1 millionth of a penlight battery's output) in a shielded cable and then route the cable in a conduit separate from other cables. But be aware that the load cell cable shield can also be an open door for electrical noise. To prevent the noise from affecting the load cell function, properly ground the shield by tying it at only one end to a true ground, which will prevent the shield from forming a ground loop.

Moisture: Moisture that enters the weighing system's junction box can wick itself into the cables to each load cell and reduce the capacitance between signal lines. This causes the load cell excitation lines (the lines carrying electrical energy to the cells) to couple with the signal lines (the lines carrying the cells' signals back to the junction box), creating electrical noise that can affect the weighing accuracy. To avoid this, use a waterproof NEMA 4-rated junction box and plug any unused junction box holes. If moisture is present in the environment, it is better to use load cells that are hermetically sealed at both the strain gauge area and the cable entry. The strain gauge area should be welded shut. The cable entry, which is the most vulnerable to moisture because moisture can wick up through the cable, should have a welded fitting that includes a glass-to-metal hermetic header.

Temperature: A load cell cable conduit that's subject to large temperature changes or that runs more than 50 feet from the junction box to the weight controller can be affected by temperature fluctuations, which cause resistance changes in the cable. This can cause excitation changes, in turn causing load cell signal changes. To prevent these temperature problems, a six-wire load cell cable is used, which allows the weight controller to make ratio metric readings of the load cell signal that ignore excitation-change-induced changes [79].

2.3.2.5 Instrumentation and Control

From the foregoing, it is important to ensure that the load cell signal arrives at the weight controller in the cleanest form possible. But chances are, the signal still will not be absolutely clean. Why not? Remember that the load cell transmits a signal that represents mechanical force, and vibration *is* a mechanical force. Similarly, the weight controller measures an electrical signal, and RFI and EMI *are* electrical signals. But even if the mechanical and electrical noise sources cannot be entirely eliminated, ensure to select a weight controller that helps clean up less-than-perfect weight signals and improves weighing accuracy.

A weight controller equipped with a dual-slope, analog-to-digital converter can also help digitally average other random signal fluctuations. Once the controller digitizes the signal, it can average the readings to smooth out the slow rolling and yield a representative signal. Such digital averaging is especially useful for averaging from 1 to 250 readings per weighing cycle when the weighing system is set up to take weight readings at single-unit increments (for example, at 1-pound increments rather than 5-pound increments on a system with a 200-pound range). In some applications, a weight controller that provides built-in proprietary algorithms that automatically eliminate the effects of signal fluctuations down to 0.25 hertz may be used. The weight controller requires several other features to ensure weight accuracy. The controller should have an analog-to-digital converter that can be synchronized with a 60-hertz line frequency to avoid the problem of "60-hertz hum" caused by noise from 60-hertz power lines and equipment. The controller's internal components should provide proper analog signal shielding to isolate the signal from stray interference. The controller's analog circuitry should also have high-grade electrical components to accurately process the load cells' low-voltage weight signals. Finally, three key parameters are to be considered for weight controller specifications to ensure that the weighing system is accurate:

(i) Nonlinearity: ±0.01 percent of span (i.e., the weighing system's selected operating range).

(ii) Temperature effect on zero: ±0.0027 percent of span per degree Fahrenheit.
(iii) Temperature effect on output: ±0.0027 percent of span per degree Fahrenheit.

As with a load cell, nonlinearity effects on the weight controller are negligible for small weight changes. The temperature effect on zero can be ignored if the controller tares before starting the weighing cycle [80].

2.4 Load Cells

A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. It is a transducer that converts the physical force into measurable, quantifiable electric energy. A load cell is the active and key component used in digital scales. It converts the force exerted by a load into some proportional corresponding electrical signal enabling weight measurement [81].

Load Cells are used in several types of measuring instruments such as Laboratory Balances, Industrial and Commercial Scales, Platform Scales, [82], and Universal Testing Machines [83]. Other known applications of load cells are that from 1993, the British Antarctic Survey installed load cells in glass fibre nests to weigh Albatross Chick [84], and are also used in a variety of items such as the seven-post shaker which is used to set up race cars [85].
The advantages of load cells are:
(i) Rugged and compact construction;
(ii) No moving parts;
(iii) Can be used for static and dynamic loading;
(iv) Highly Accurate; and
(v) Wide range of measurement.

However, the disadvantages of load cells are:
(i) Mounting is difficult; and
(ii) Calibration is a tedious procedure.

2.4.1 Types of Load Cells

There are various types of load cells because they are needed to operate different pieces of machinery; hence many configurations are available which mostly include *Strain Gauge*; *Piezoelectric*; *Hydraulic*; and *Pneumatic Load Cells*. Other types of load cells include *Vibrating Wire Load Cells*, useful in geo-mechanical applications due to low amounts of drift; and *Capacitive Load Cells* where the capacitance of a capacitor changes as the load presses the two plates of a capacitor closer together. A typical example of load cells is shown in Figure 2.11 [86].

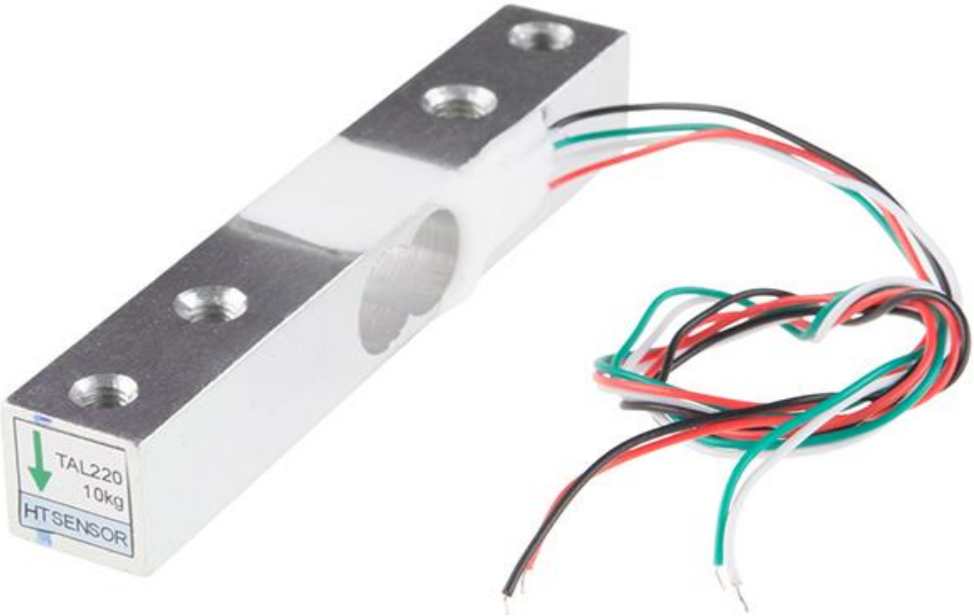

Figure 2.11: Typical Example of Load Cells [86]

2.4.2 Strain Gauge Load Cells

Strain Gauge Load Cells (SGLCs) are the most common and popular load cells in industry due to particularly being stiff, have very good resonance values, and tend to have long life cycles in application. They work on the principle that the strain gauge (a planar resistor) deforms, stretches, or contracts when the material of the load cells deforms appropriately. The output values are extremely small and are relational to the stress and/or strain that the material load cell is undergoing at the time. The change in resistance of the strain gauge provides and electrical value change that is calibrated to the load placed on the load cell.

SGLCs convert the load or force acting on them into electrical signals and it measures strain, transferring the force into electrical energy, which manifests as a unit parameter for measurement. Actually, measuring strain effects helps preserve the integrity of the unit under pressure as well as protects equipment and people nearby [87].

2.4.2.1 Operation of SGLC

The operation of SGLC is through a mechanical construction, the force being sensed deforms the strain gauge. The strain gauge measures the deformation (stain) as a change in electrical resistance, which is a measure of the strain and hence the applied force as shown in Figure 2.12.

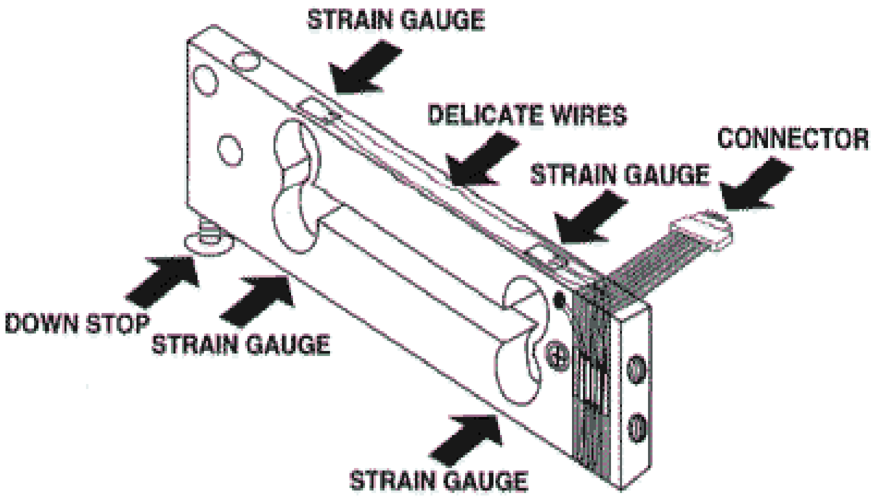

Figure 2.12: Strain Gauge Load Cell diagram [87] [Source: Scalenet.com]

The SGLC element usually consists of four strain gauges configured in a Wheatstone Bridge formation but sometimes can be two strain gauges (Half Bridge) or single strain gauge (Quarter Bridge) [46]. In the Bar SGLCs, the cell is set up in a "Z" formations so that torque is applied to the bar and the four strain gauges on the cell will measure the bending distortion, two measuring compression and two tension. When these four strain gauges are set up in a Wheatstone bridge formation, it is easy to accurately measure the small changes in resistance from the strain gauges as shown in Figure 2.13.

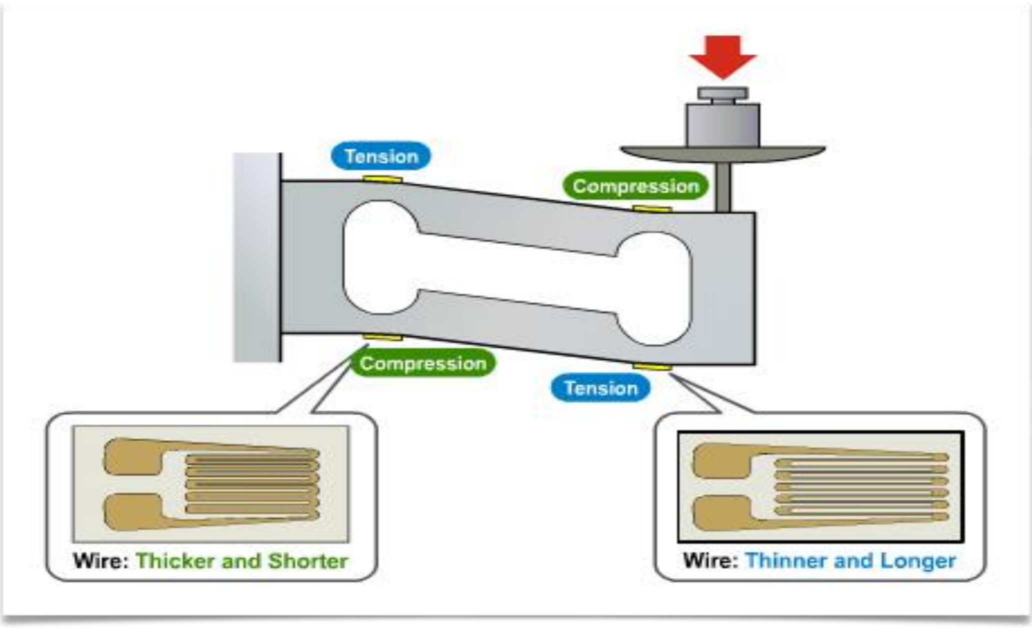

Figure 2.13: In depth diagram of Strain Gauges on Bar SGLCs when force is applied [87]

The electrical signal output is typically in the order of a few millivolts and therefore require to be amplified before it can be used. The output of the load cell can be scaled to calculate the force to the transducer. Sometimes a high-resolution Analog to Digital Converter (ADC), typically 24-bits, can be used directly.

The strain gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. Mostly, four stain gauges are used to obtain maximum sensitivity and temperature compensation. Two of the gauges are usually in tension and can be represented as ***T1*** and ***T2***, while the other two are in compensation and can be represented as ***C1*** and ***C2***, wired with compensation adjustments. The SGLC is fundamentally a spring optimized for strain measurement. Gauges are mounted in areas that exhibit strain in compression or tension. When weight is applied to the load cell, gauges ***C1*** and ***C2*** compresses, decreasing their resistances; simultaneously, gauges ***T1*** and ***T2*** are stretched (tensioned), increasing their resistances. The change in resistances causes more current to flow through ***C1*** and ***C2***, and less current to flow through ***T1*** and ***T2***. Thus, a potential difference is felt at the output or the signal leads of the load cell. The gauges are mounted in a differential bridge to enhance measurement accuracy [47]. When weight is applied, the strain changes the electrical resistance of the gauges in proportion to the load [48]. The other types of load cells are fading into obscurity due to the SGLCs continued increase in their accuracy and lower unit costs.

2.4.2.2 Load Cell Mechanical Setup

Most strain gauge load cells work in very similar ways, but may vary in size, material, and mechanical setup, which can lead to each cell having different maximum loads and sensitivities that they can handle. Figure 2.14 shows one possible way of the load cell mechanical setup with the Bar-Type SGLC.

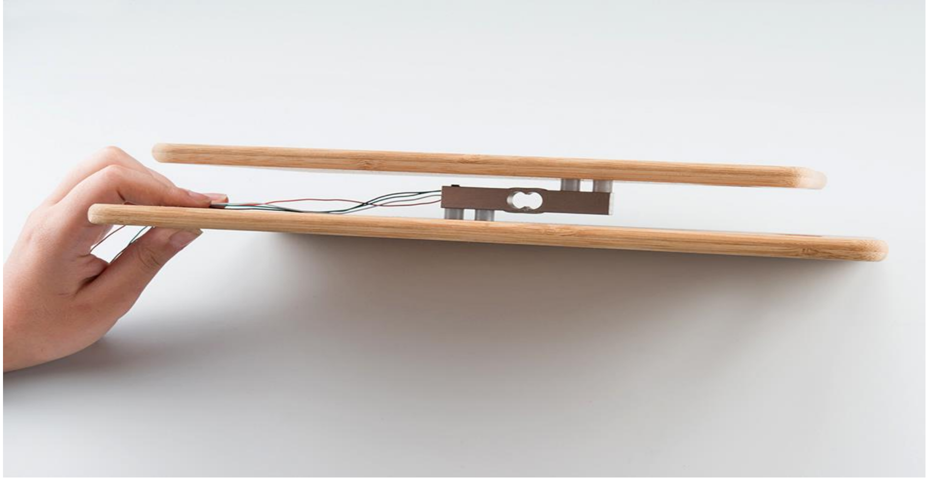

Figure 2.14: Load Cell Mechanical Setup with the Bar-Type SGLC [87]

As already stated, a strain gauge is a device that measures electrical resistance changes in response to, and proportional of, strain (pressure or force) applied to the device. The most common strain gauge is made up of very fine wire, or foil, set up in a grid pattern in such a way that there is a linear change in electrical resistance when strain is applied in one specific direction, most commonly found with a base resistance of 120Ω, 350Ω, and 1,000Ω. Each strain gauge has a different sensitivity to strain, which is expressed quantitatively as the *Gauge Factor* (GF). The Gauge Factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain). The GF for metallic strain gauges is typically around ***2***.

When a SGLC is setup to measure the change in resistance, there is *very small change in strain*, thus, strain measurements rarely involve quantities larger than a few milli-strain ($e * 10^{-3}$). Suppose a strain of **500με** is applied to the strain gauge with a GF of ***2***, the change in electrical resistance will only be:

$$2*(500*10^{-6}) = 0.1$$

For a ***120Ω*** gauge, this is a change of only ***0.12Ω***, which is a very small change, and, for most devices, cannot even be detected, let alone detected accurately. So another device is needed, though very expensive, that can either accurately measure super small changes in resistance or a device that can take that very small change in resistance and turn it into something that can be measured accurately.

2.4.2.3 Amplifier and Wheatstone Bridge

An Amplifier is an electronic device that magnifiers a small electric signal to some significant signal able to be measured. There are many examples of amplifiers like the HX711 or the NAU7802, and one such is shown in Figure 2.15.

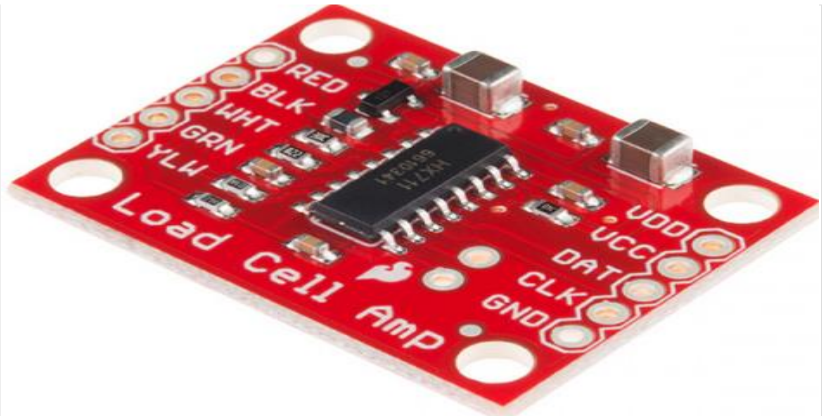

Figure 2.15: Typical Example of a Load Cell Amplifier HX711 [87]

A good way of taking small changes in resistance and turning it into something more measurable is using a *Wheatstone Bridge*, which is a configuration of four resistors with a known voltage applied as shown in Figure 2.16.

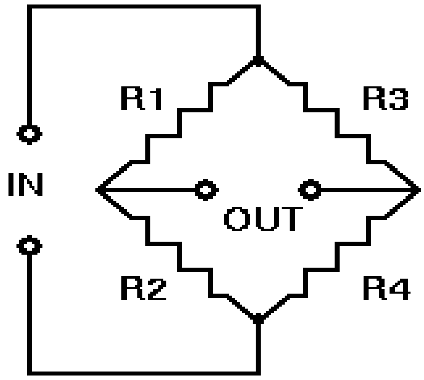

Figure 2.16: Wheatstone Bridge Circuit Configuration [87]

where: V_{in} (**IN**) is a *known constant voltage*,

V_{out} (OUT) is the *measured resultant voltage*; and

R1, R2, R3, and ***R4*** are resistors with known resistance.

If ***R1/R2*** = ***R3/R4***, then V_{out} is ***0*** (*zero)*, but if there is a change to the value of one of the resistors, V_{out} will have a resulting change that can be measured and is governed by the following equation using Ohm's law:

$$V_{out} = [(R3/(R3+R4) - R2/(R1+R2))] * V_{in} \qquad \textit{Equation 2.1}$$

By replacing one of the resistors in a Wheatstone Bridge with a Strain Gauge, the change in V_{out} can easily be measured and used to assess the force applied. Figure 2.17 shows the configuration of a Full-Bridge Strain Gauge circuit.

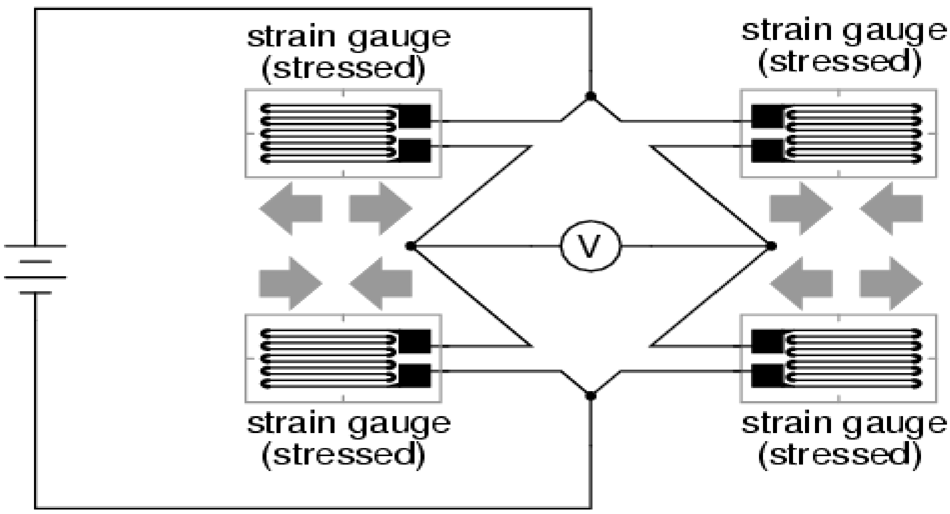

Figure 2.17: Example of a Bar Load Cell Wheatstone Bridge [87]

2.4.2.4 Shapes and Pertinent Issues of SGLC

There are several shapes of SGLC and the six common one include:

(i) **Shear Beam**: Straight block of material fixed on one end and loaded on the other;

(ii) **Double-Ended Shear Beam**: Straight block of material fixed at both ends and loaded in the center;

(iii) **Compression Load Cell**: Block of material designed to be loaded at one point or area in compression;

(iv) **S-Type Load Cell**: S-shaped block of material that can be used in both compression and tension (load links and tension load cells are designed for tension only);

(v) **Rope Clamp**: Assembly attached to a rope and measures its tension. Rope Clamps are popular in hoist, crane and elevator applications due to the ease of their installation; they have to be designed for a large range of loads, including dynamic peak loads, so their output for the rated load tends to be lower than of the other types;

(vi) **Loadpin**: Used for sensing loads, for example, on axles.

Some pertinent issues of SGLCs among many others include:

(i) **Mechanical Mounting**: The cells have to be properly mounted. All the load force has to go through the part of the load cell where its deformation is sensed. Friction may induce offset or hysteresis. Wrong mounting may result in the cell reporting forces along undesired axis, which still may correlate to the sensed load, confusing the technician.

(ii) **Overload**: Within its rating, the load cell deforms elastically and returns back to its shape after being unloaded. If subjected to loads above its maximum rating, the material of the load cell may *plastically deform*; this may result in a signal offset, loss of linearity, difficulty with or impossibility of calibration, or even mechanical damage to the sensing element (e.g. delamination, rupture).

(iii) **Wiring Issues**: The wires to the cell may develop high resistance, e.g. due to corrosion. Alternatively, parallel current paths can be formed by ingress of moisture. In both cases the signal develops offset (unless all wires are affected equally) and accuracy is lost.

(iv) **Electrical Damage**: The load cells can be damaged by induced or conducted current. *Lightning* hitting the construction, or *Arc Welding* performed near the load cells, can overstress the fine resistors of the strain gauges and cause their damage or destruction. For welding nearby, it is suggested to disconnect the load cell and short all its pins to the ground, nearby the cell itself. High voltages can break through the insulation between the substrate and the strain gauges.

(v) **Nonlinearity**: At the low end of their scale, the load cells tend to be nonlinear. This becomes important for cells sensing very large ranges, or with large surplus of load capability to withstand temporary loads or shocks, for example, the Rope Clamps. More points may be needed for the calibration curve when performing the calibration to ascertain the accuracy.

The other important issues worth noting when using the SGLCs are:

(i) **Wiring of SGLC**: The full-bridge cells come typically in four-wire configuration. The wires to the top and bottom end of the bridge are the excitation (often labelled ***E***+ and ***E***−, or ***Ex***+ and ***Ex***−), the wires to its sides are the signal (labelled ***S***+ and ***S***−).

(ii) **Excitation and Rated Output of SGLC**: The bridge is excited with stabilized voltage (usually 10V, but can be 20V, 5V, or less for battery powered instrumentation). The difference voltage proportional to the load then appears on the signal outputs.

The cell output is rated in millivolts per volt (***mV/V***) of the difference voltage at full rated mechanical load. Thus, a ***2.96 mV/V*** load cell will produce ***29.6 millivolt*** signal at full load when excited with ***10 volts***. Typical sensitivity values are ***1*** to ***3 mV/V***. Typical maximum excitation voltage is around ***15 volts***. Ideally, the voltage difference between ***S+*** and ***S-*** is ***0*** (zero) under zero load, and grows proportionally to the load cell's mechanical load. Sometimes a six wire configuration is used, where the two additional wires are "*sense*" (***Sen+*** and ***Sen-***), and are connected to the bridge with ***Ex+*** and ***Ex-*** wires, in a fashion similar to *four-terminal sensing*. With these additional signals, the controller can compensate for the change in wire resistance due to instance of temperature fluctuations.

One or more load cells can be used for sensing a single load if the force can be concentrated to a single point, for example, small scale sensing, ropes, tensile loads and point loads, then a single cell can be used. For long beams, two cells at the end are used. Vertical cylinders can be measured at three points and rectangular objects usually require four sensors. More sensors are used for large containers or platforms, or very heavy loads. If the loads are symmetrical guaranteed, some of the load cells can be substituted with pivots; this significantly saves on cost of load cells but compromises accuracy. Load cells can be connected in parallel; in this case, all the corresponding signals are connected together (***Ex+*** to ***Ex+, S+*** to ***S+,*** ...), and resulting signal is the average of the signals from all sensing elements. This is often used in personal scales, or other multipoint weight sensors [87] – [88].

2.4.3 Piezo-Electric Load Cells

Piezo-Electric Load Cells (PELCs) work on the same principle of deformation as the SGLCs, but a voltage output is generated by the basic basic *piezoelectric* material, proportional to the deformation of load cell. PELCs are useful for dynamic/frequent measurements of force. Most applications for piezo-based load cells are in the dynamic loading conditions, where strain gauge load cells can fail with high dynamic loading cycles. It must be remembered that the piezo-electric effect is dynamic, that is, the *electrical output of a gauge is an impulse function and is not static*. The voltage output is only useful when the strain is changing and does not measure static values.

However, depending on conditioning system used, "*quasi static*" operation can be done. Using a so called "*Charge Amplifier*" with "*Long*" time constant allow accurate measurement lasting many hours for large loads to many minutes for small loads. Another advantage of PELCs, conditioned with a *Charge Amplifier*, is the wide measuring range that can be achieved. Users can choose a load cell with a range of hundreds of kilo-Newtons (kN) and use it for measuring few Newtons (N) of forces with the same Signal/Noise ratio, again this is possible only with the use of a "*Charge Amplifier*" conditioning [87].

2.4.4 Hydraulic Load Cells

The Hydraulic Load Cells (HLCs) uses conventional piston and cylinder arrangement to convey a change in pressure by the movement of the piston and a diaphragm arrangement which produces a change in the pressure on a Bourdon tube connected with the load cells. The piston is placed in a thin elastic diaphragm. The piston does not actually come in contact with the load cell. Mechanical stops are placed to prevent over strain of the diaphragm when the loads exceed certain limit. The load cell is completely filled with oil. When the load is applied on the piston, the movement of the piston and the diaphragm results in an increase of oil pressure. This pressure is then transmitted to a hydraulic pressure gauge via a high pressure hose. The gauge's Bourdon tube senses the pressure and registers it on the dial. Because this sensor has no electrical components, it is ideal for use in hazardous areas. Typical HLC applications include tank, bin, and hopper weighing. By example, a HLC is immune to transient voltages (lightning) so these type of load cells might be a more effective device in outdoor environments. This technology is more expensive than other types of load cells. It is a more costly technology and thus cannot effectively compete on a cost of purchase basis [89] – [90]. Figure 2.18 shows a diagram of a HLC.

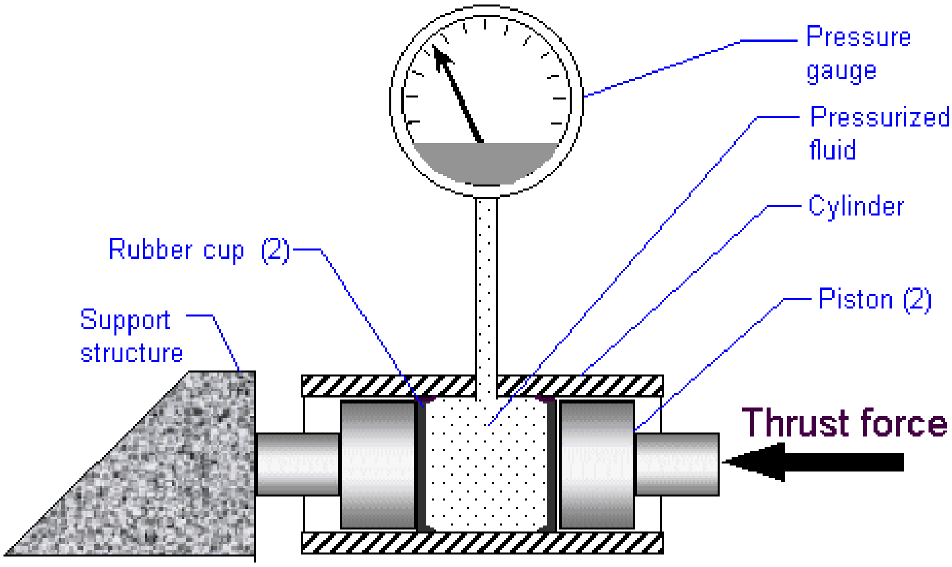

Figure 2.18: Diagram of a Hydraulic Load Cell [89] [Source: Nikka's Rocketry]

2.4.5 Pneumatic Load Cells

The Pneumatic Load Cell (PLCs) is designed to automatically regulate the balancing of pressure. It uses air pressure applied to one end of a diaphragm, and it escapes through the nozzle placed at the bottom of the load cell, which has a pressure gauge inside of the load cell.

A pressure gauge is attached with the load cell to measure the pressure inside the cell. The deflection of the diaphragm affects the airflow through the nozzle as well as the pressure inside the chamber. Refer to Figure 2.19 [87].

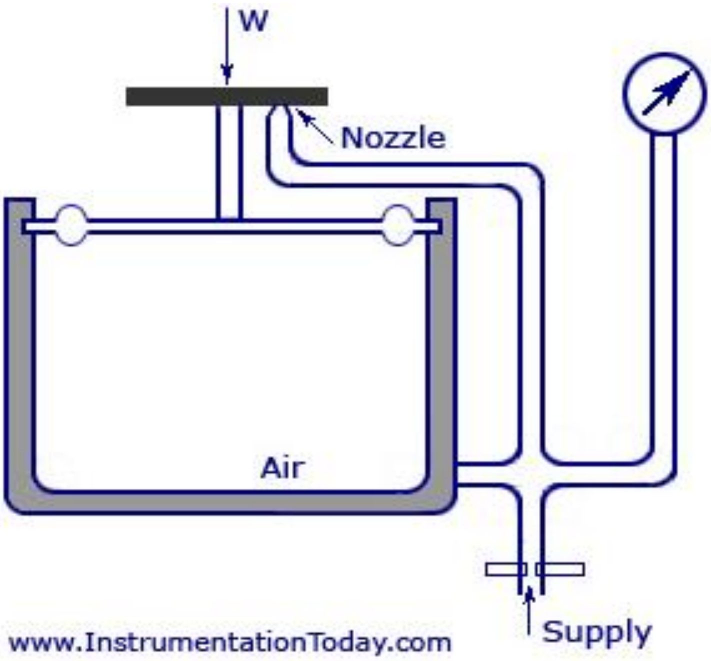

Figure 2.19: Diagram of a Pneumatic Load Cell [87] [Source: Instrumentation Today]

2.4.6 Ringing of Load Cells

Every load cell is subject to "ringing" when subjected to abrupt load changes. This stems from the spring-like behavior of load cells. In order to measure the loads, they have to deform. As such, a load cell of finite stiffness must have spring-like behavior, exhibiting vibrations at its natural frequency. An oscillating data pattern can be the result of ringing. Ringing can be suppressed in a limited fashion by passive means. Alternatively, a control system can use an actuator to actively damp out the ringing of a load cell. This method offers better performance at a cost of significant increase in complexity [88].

2.4.7 Applications of Load Cells

Load cells are necessary for many load-bearing applications, both to maintain structural integrity and, in so doing, ensure the safety of people and environment. Large buildings, which sway in wind and contract and expand in different seasons, are huge, pressure-dependent structures housing hundreds to thousands of people, and under unsafe conditions, accidents can happen.

Virtually any structure of similar type needs to be monitored to keep on an even keel. Most buildings are designed to withstand impacts and natural disasters, and load cell strain gauges are set in place so as to monitor these conditions. For instance, brick structures, which are composed of interlaced building materials, require load cell strain gauges to see if anything has shifted too much to pose a hazard.

Although mankind has implemented innovational technology to decrease the likelihood of this happening, looking at any old ruins of a castle or wall can show the types of dangers brick structures can pose. In large skyscrapers, the many support beams and structural components often use load cells for similar reasons. Many buildings have such units to keep the building under observation.

Other load-bearing applications include freight vehicles and docking locations which must sustain incredibly heavy loads on a day to day basis. The load cell might be monitored less in a vehicle, which is on the go and not subjective to constant analysis, but fixed-place applications like docks will undergo status checks frequently [87] – [90].

2.5 Existing and Emerging Technologies

2.5.1 Wireless Sensor Network

A Wireless Sensor Network (WSN) can be defined as a network of devices, denoted as *nodes*, which can cooperatively sense and may control the environment enabling interaction between persons or computers and the surrounding environment, and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links. The data is forwarded, possibly via multiple hops, to a *sink* (sometimes denoted as *controller* or *monitor*) that can use it locally or is connected to other networks (e.g., the Internet) through a *gateway*. The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous or not.

Figure 2.20(a) i.e., left part, shows a traditional Single-Sink. Almost all scientific papers in the literature deal with such a definition. This single-sink scenario suffers from the lack of scalability: by increasing the number of nodes, the amount of data gathered by the sink increases and once its capacity is reached, the network size cannot be augmented. Moreover, for reasons related to Medium Access Control (MAC), routing aspects and network performance cannot be considered independent of the network size [91] – [101].

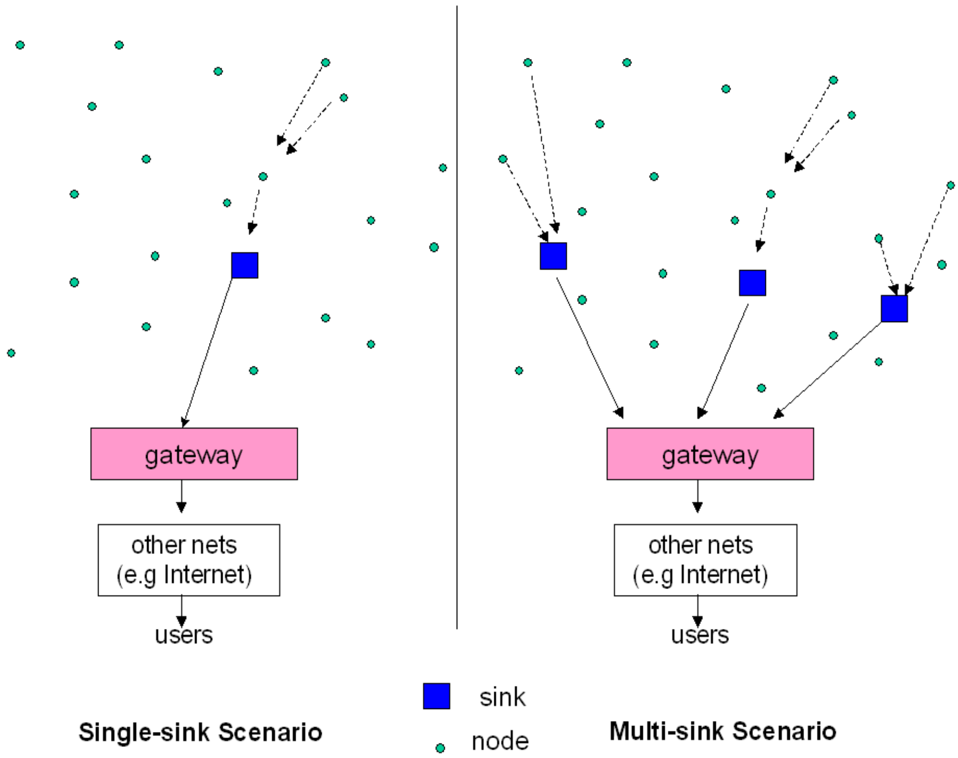

Figure 2.20: (a) Left Part: Single-Sink WSN. (b) Right Part: Multi-Sink WSN [102]

A more general scenario includes Multiple-Sinks in the network, Figure 2.20(b), i.e., right part. Given a level of node density, a larger number of sinks will decrease the probability of isolated clusters of nodes that cannot deliver their data owing to unfortunate signal propagation conditions. In principle, a Multiple-Sink WSN can be scalable (i.e., the same performance can be achieved even by increasing the number of nodes), while this is clearly not true for a Single-Sink network. However, a Multi-Sink WSN does not represent a trivial extension of a Single-Sink case for the network engineer. In many cases nodes send the data collected to one of the sinks, selected among many, which forward the data to the gateway, toward the final user, Figure 2.20(b), i.e., right part. From the protocol viewpoint, this means that a selection can be done, based on a suitable criteria that could be, for example, minimum delay, maximum throughput, minimum number of hops, and so on. Therefore, the presence of Multiple-Sinks ensures better network performance with respect to the Single-Sink case (assuming the same number of nodes is deployed over the same area), but the communication protocols must be more complex and should be designed according to suitable criteria [102] – [103].

2.5.1.1 Application of Wireless Sensor Networks

The variety of possible applications of WSNs to the real world is practically unlimited, from environmental monitoring [104], health care [105], positioning and tracking [106], to logistic, localization, and so on. It is important to underline that the application strongly affects the choice of the wireless technology to be used. Once application requirements are set, the designer then selects the technology which allows to satisfying these requirements. Thus, the knowledge of the features, advantages and disadvantages of the different technologies is fundamental. For the purpose of applications classification, one possible way is to distinguish applications according to the type of data that must be gathered in the network. Almost any application, in fact, could be classified into two categories: Event Detection (ED) and Spatial Process Estimation (SPE) [105].

In the ED case, sensors are deployed to detect an event, for example a fire in a forest, a quake, position, tracking, and so on. Signal processing within devices is very simple, owing to the fact that each device has to compare the measured quantity with a given threshold and to send the binary information to the sink(s). The density of nodes must ensure that the event is detected and forwarded to the sink(s) with a suitable probability of success while maintaining a low probability of false alarm. The detection of the phenomenon of interest

(POI) could be performed in a decentralized or distributed way, meaning that sensors, together with the sink, cooperatively undertake the task of identifying the POI. However, unlike in classical decentralized detection problems, greater challenges exist in a WSN setting. There are stringent power constraints for each node, communication channels between nodes and the fusion center are severely bandwidth-constrained and are no longer lossless (that is, fading, noise and, possibly, external sources of interference are present), and the observation at each sensor node is spatially varying. In the context of decentralized detection, cooperation allows exchange of information among sensor nodes to continuously update their local decisions until consensus is reached across the nodes [106] – [109].

In SPE case, the WSN aims at estimating a given physical phenomenon (e.g., the atmospheric pressure in a wide area, or the ground temperature variations in a small volcanic site), which can be modelled as a bi-dimensional random process (generally non-stationary). The main issue is to obtain the estimation of the entire behavior of the spatial process based on the samples taken by sensors that are typically placed in random positions. The measurements will then subject to proper processing which might be performed either in a distributed manner by the nodes, or centrally at the supervisor. The estimation error is strictly related to nodes density as well as on the spatial variability of the process. Higher nodes density leads to a more accurate scalar field reconstruction at the expense of a larger network throughput and cost [110] – [113].

In the recent literature, different works addressed the estimation of a scalar field using random WSNs. As an example, is a distributed algorithm able to estimate the gradient of a generic smooth physical process (energy constraints and nodes failure are not considered there); in the relationship between the random topology of a sensor network and the quality of the reconstructed field is investigated and some guidelines on how sensors should be deployed over a spatial area for efficient data acquisition and reconstruction are derived. Distributed source coding techniques can be successfully exploited to reduce the amount of data to be transmitted and hence to improve the network energy efficiency [114].

There exist also applications that belong to both categories. As an example, environmental monitoring applications could be ED-based or SPE-based. To the first category belong, for example, the location of a fire in a forest, or the detection of a quake, and so on, as shown in Figure 2.21. Alternatively, the estimation of the temperature of a given area belongs to the second category. In general, these applications aim at monitoring indoor or outdoor environments, where the supervised area may be few hundreds of square meters or thousands of square kilometers, and the duration of the supervision may last for years [114].

Natural disasters such as floods, forest fires and earthquakes may be perceived earlier by installing networked embedded systems closer to places where these phenomena may occur. Such systems cannot rely on a fixed infrastructure and have to be very robust, because of the inevitable impairments encountered in open environments. The system should respond to environment changes as quick as possible. The environment to be observed will mostly be inaccessible by the human all the time. Hence, robustness plays an important role. Also security and surveillance applications have some demanding and challenging requirements such as real-time monitoring and high security [114].

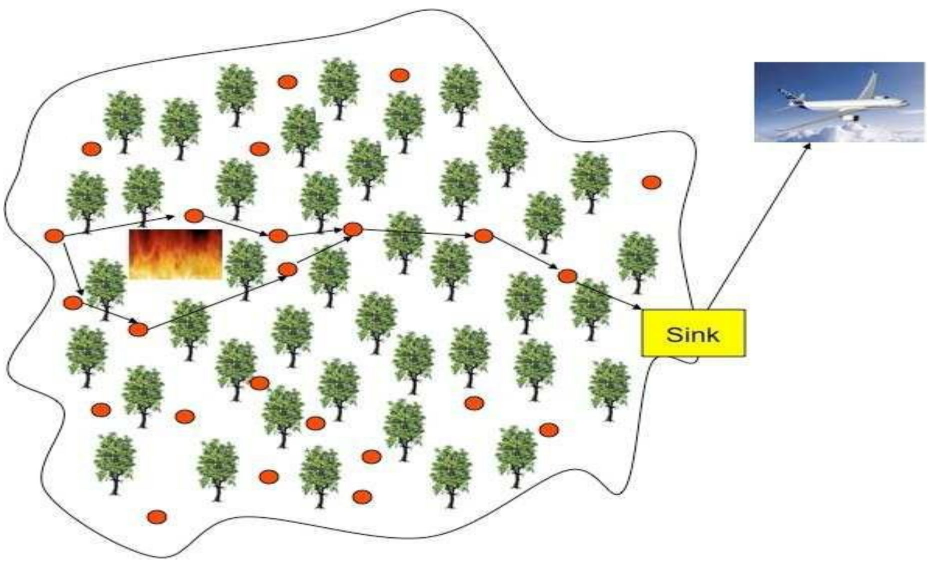

Figure 2.21: Event detection application [105].

Another application that could belong to both the above defined categories is devoted to the realization of energy efficient buildings. In this application, in fact, sensor nodes could aim at estimating a process (SPE), but also events (ED). In this case the WSN is distributed in buildings (residential or not) to manage efficiently the energy consumption of all the electric appliances. Consequently, nodes have to continuously monitor the energy consumed by all appliances connected to the electrical grid. Therefore, sensors have to estimate a process, that is the energy consumption which varies with time, but in some cases, they could be used to detect some events. As an example, sensors could detect the arrival of a person in a room to switch on some electrical appliances [115].

2.5.1.2 Main Features in WSN's Design

The main features of WSNs are: scalability with respect to the number of nodes in the network, self-organization, self-healing, energy efficiency, a sufficient degree of connectivity among nodes, low-complexity, low cost and size of nodes.

The protocol architectures and technical solutions providing such features can be considered as a potential framework for the creation of these networks, but, unfortunately, the definition of such a protocol architectures and technical solutions is not simple, and therefore, more research work is still needed on this subject.

The massive research on WSNs started after the year 2000. However, it took advantage of the outcome of the research on wireless networks performed since the second half of the previous century. According to some general definitions, *wireless ad hoc networks* are formed dynamically by an autonomous system of nodes connected via wireless links without using an existing network infrastructure or centralized administration. Nodes are connected through "ad hoc" topologies, set up and cleared according to user needs and temporary conditions [101]. Apparently, this definition can include WSNs. However, this is not true. This is the list of main features for wireless ad hoc networks: unplanned and highly dynamical; nodes are "smart" terminals (laptops, and so on); typical applications include real time or non-real time data, multimedia, voice; every node can be either source or destination of information; every node can be a router toward other nodes; energy is not the most relevant matter; capacity is the most relevant matter [101].

Apart from the very first item, which is common to WSNs, in all other cases there is a clear distinction between WSNs and wireless ad hoc networks. In WSNs, nodes are simple and low-complexity devices; the typical applications require few bytes sent periodically or upon request or according to some external event; every node can be either source or destination of information, not both; some nodes do not play the role of routers; energy efficiency is a very relevant matter, while capacity is not for most applications. Therefore, WSNs are not a special case of wireless ad hoc networks. Thus, a lot of care must be used when considering protocols and algorithms which are good for ad hoc networks, and using them in the context of WSNs [101].

2.5.2 Cloud Computing Technology

With the spread of broadband internet across the globe, more emphasis has been placed on how to effectively and efficiently utilize and allocate all the available computing, processing and storage capacity available globally[116].

Resource sharing has enabled concepts such as Software as a Service, Platform as a Service and Database as a Service where the end user does not need to worry about the technical requirements of systems, software and the technical specifications of the database but just focuses on service usage.

Cloud computing has made it possible for emerging companies to rollout their services at a much faster pace as the cost of data centres is slowly becoming a non-factor with cloud based solutions such as Data Centre as a Service (DCaaS). Cloud computing has brought about novel ideas where a computer is no longer viewed as a standalone entity but can span multiple hardware platforms and multiple geographical locations [117].

2.5.3 Internet of Things

Internet of Things (IoT) is defined as “the system of physical objects or things hooked up with hardware, software, sensors, and system connectivity which empowers these objects to gather and alternate information”. IoT makes use of different kinds of protocols to work with exclusive objects [118].

In another study, it adds that IoT is a network of ordinary objects which are embedded with technologies that helps to communicate and engage inside themselves and exterior environment, this in-turn affords Intellect to the objects thereby making people’s lives convenient. IoT also provides networking to connect people, things, applications, and data through the Internet to enable remote control, management, and interactive integrated services [119].

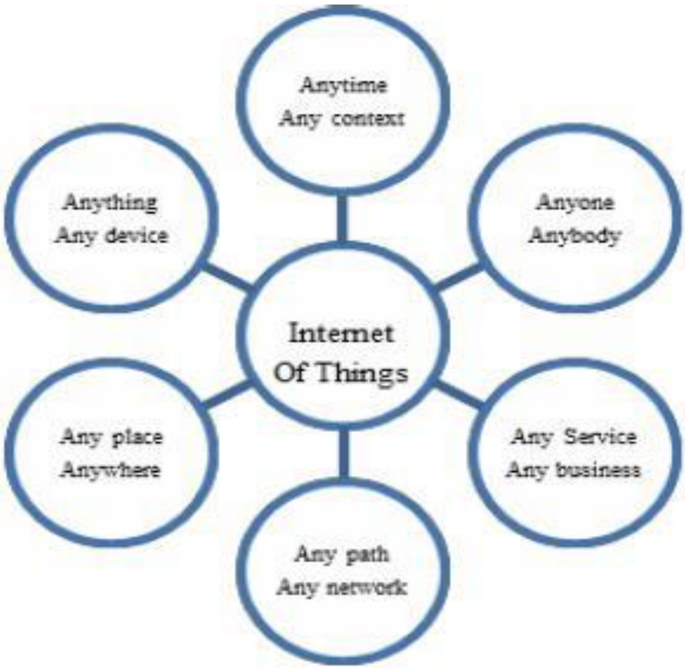

Figure 2.22: IoT Definition/Concept [119] [120]

Table 2.5: Internet of Things Smart Applications and Services [120]

No.	Application of Internet of things	
	Service Domain	***Services***
1	Smart Home	Entertainment, Internet Access
2	Smart Office	Secure File Exchange, Internet Access, VPN, B2B
3	Smart Retail	Customer Privacy, Business Transactions, Business Security, Business Security, B2B, Sales & Logistics
4	Smart City	City Management, Resource Management, Police Network, Fire Department Network, Transportation Management, Disaster Management
5	Smart Agriculture	Area Monitoring, Condition Sensing, Fire Alarm,
6	Smart Energy and Fuel	Pipeline Monitoring, Tank Monitoring, Power Line Monitoring, Trespassing & Damage Management
7	Smart Transport	Road Condition Monitoring, Traffic Status Monitoring, Navigation Support, Smart Car support, Traffic Information Support, Intelligent Transport System (ITS)

IoT also provides networking to connect people, things, applications, and data through the Internet to enable remote control, management, and interactive integrated services [121].

Figure 2.22 and Table 2.5 shows a summary of the definition or concept of IoT and the numerous applications of IoT among others, respectively.

2.5.4 Remote Sensor Network

Remote Sensor Network (RSN) have traditionally relied on four components, a sensor to collect the data, an aggregator to centralize the collection of data, an uplink network to relay the data and a server to which the data is to be sent. Wireless Sensor Network (WSN) can be further broken down into two main components, RSN and Uplink. The RSN is that part of the network that is composed of the sensors which have energy sources and some kind of personal area network used for localized communication [122]. The network may also comprise a collaboration algorithm which may determine its work mode. The three main work modes that enable collaboration in a WSN are: Star, Mesh or Ring Networks. The remote sensors basically sense, process and send the data either individually or through an Aggregator [123].

2.6 Sensing Technologies

In our study two types of sensing technologies, the Motion Sensing and the Weight Sensing, are employed and are of paramount importance worth to be covered in details. The Weight Sensing has already been covered in *Section 2.4*.

2.6.1 Motion Sensing Technology

The proposed LWMS requires a means by which the system can track the motion of passengers as they enter or exit the vehicle. The tracking is required so as to keep track of the current passenger weight within the vehicle. If a passenger is determined to have entered the vehicle, the passenger's weight is to be added to the total current passenger weight in the vehicle. If a passenger is determined to have exited the vehicle, the passenger's weight is to be subtracted from the total current passenger weight registered in the vehicle.

The above described scenarios require the use of motion tracking technology, such sensors should be sensitive, in order to track even the slightest movements, highly responsive, to track multiple movements that occur sequentially within a short period of time and the motion sensors should have a means of determining the direction of motion, this is crucial in order to determine whether the system should add the passenger weight or subtract the current weight. Below is the review of current advancements in motion sensing as well as tracking.

2.6.2 Types of Motion Sensing Technology

Motion sensing technology often refers to a means of determining an object pose or position through changes in electromagnetic fields, waves or physical forces it emits around it and converting these to electrical signals [124]. Motion sensing technologies are plenty in varieties and are application specific, meaning that there is no single motion device that exhibits *all* of the traits of a perfect motion sensor as described by the IEEE as the Tracker of the Chip (TOC). The TOC would possess all of the following traits [125]: (i) Tiny; (ii) Self-Contained; (iii) Accurate; (iv) Complete; (v) Cheap; (vi) Immune to Occlusions; (vii) Fast; (viii) Robust; and (ix) Tenacious.

Motion Sensing Technologies are classified as follows: Mechanical; Acoustic; Magnetic; Optical; and, Microwave Radio Sensing [124] – [126].

2.6.2.1 Mechanical Sensing

Mechanical sensors are typically constructed from joint pieces that are connected to transducers. The pieces form a physical linkage between the object whose motion is to be detected and the environment in which the object resides. As the object moves, its movements are converted from the physical distance in which the motion takes place to electrical signals by the transducer. Mechanical sensors are the simplest form of sensors, however mechanical sensors would be inappropriate for our particular application.

2.6.2.2 Acoustic Sensing

Acoustic sensing systems are capable of detecting sound waves and their transmission through a medium. The sound waves are used to detect the position of objects and therefore the difference in motion.

2.6.2.3 Magnetic Sensing

Just as important as the motion sensing technology used is the position of said motion sensing technology. This is no trivial matter, the motion sensors should be positioned so as to be in view of all passenger entry and exit but not in a position in which the sensors may detect in consequential movement.

2.6.2.4 Optical Sensing

This is the sensor type of choice for the proposed system, optical motion sensors are small, cheap, fast and robust; to provide the quality necessary for the proposed system demonstration. Optical sensors have two components to them, a source of light and a sensor to detect the light.

2.6.2.5 Microwave Radio Sensing

These are sensors that can operate with signals in the microwave radio spectrum radio frequency. The Doppler Theory which states that a constant frequency signal reflected off an object with a periodically varying displacement will result in a reflected signal at the same frequency, but with a time varying phase, employs the microwave radio sensors.

2.6.3 Motion Sensing with Adaptive Timing for Lighting Fixtures

Many households, commercial, industrial and government facilities contain many rooms, each of which requires one or more light fixtures for normal operation. These light fixtures consume a lot of power during their operation.

To reduce the amount of power consumed, a lot of these facilities employ the use of Lighting Control Systems, as shown in the Figure 2.23 [127].

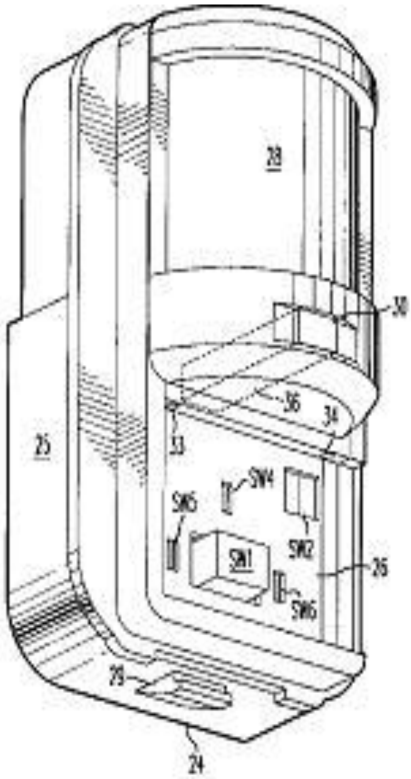

Figure 2.23: An Excerpt from Patent US6151529A Detecting the Lighting System [127]

This patent [127] pertains to one such invention and it is composed of four main components, namely:

(i) A relay configured to provide a circuit between a power line and load (e.g., a lighting fixture) when in a closed position, and to interrupt the path when in an open position;

(ii) A processing device connected to the relay for controlling when the relay is in an open position and when the relay is in a closed position;

(iii) A memory device associated with the said processing device for storing program code and parameters, one or more of which can be specified by a system user, the processing device being able to control the relay in accordance with the program code and the parameter; and

(iv) A sensor for detecting when an occupant has entered an area, which can be illuminated by the lighting fixtures, and providing an output signal to the processing device; wherein the processing device is programmable to close the relay in response to the output signal for a period of time, the duration of which is determined automatically by the processing device.

The lighting control system operates by detecting the presence or absence of occupants in a room, through the use of a motion sensor (the object of interest) within the device connected to a processing device. Once the motion sensor detects a presence in the room, it outputs a signal to the processing devices which in turn closes the relay and allows the lighting fixture to switch ON. This lighting control system different from the others because it overcomes a significant drawback that other systems possess because they use motion sensors. However, the drawback of this lighting control system is the presence of a timeout (TO) period, that is, the amount of time that the lighting fixture remains on after the last detection of motion. For example, if the fixed TO period is too long, the wall switch does not realize maximum energy and cost savings. If the fixed TO period is too short, the wall switch powers down lighting fixtures while an occupant is still in the lighted area. This lighting system overcomes this through the data analysis by the processing device of light triggering events (events that cause the lighting fixture to 'switch ON') and time settings, to determine room occupants active and non-active periods and adjust the TO value accordingly [20].

The manner in which the Light Detection System handles the TO delay of the motion sensors is of significant interest to our Load Weight Monitoring System (LWMS) as this may affect the detection of steps into and out of the vehicle. Secondly the use of a processing device in the lighting system is a design that will be borrowed for the LWMS through the use of the Arduino Microcontroller Development board, this will also allow for the programming of the motion sensor using the Arduino IDE in order to accurately determine the TO period.

2.7 Weighbridge Technology

Weighbridges are the standard means of measuring the weight of a vehicle. Weighbridges contain a set of scales that are usually mounted on a concrete or steel base. In order for them to be flush with the road surface they are set up on; they are either pit mounted, including the weighing device which is placed within the pit or they are mounted on the surface. For the latter a ramp is included for vehicles to drive onto.

Weighbridges require the vehicle meant to be weighed to be driven onto a fixed platform on which load cells measure the weight of the vehicle at the four points of contact on which the vehicle meets the platform, the points typically are the tires of the vehicle. The problem with using the weighbridge is sometimes inaccurate measurements are recorded due to the difference in impedances of the load cells used to weigh the vehicle [128]. Secondly, weighbridges are fixed, that is, they cannot be relocated or moved to different locations, this implies that a vehicle may increase its load during transit and the excess load will not be tracked or accounted for by the weighbridge [129]. This method does not completely prevent the overloading of vehicles.

2.8 Axle Load Control in Zambia

It has been established that effective enforcement of overload control measures is one way of reducing vehicle overloading. Vehicle overloading control in Zambia was previously enforced in terms of the Roads and Road Traffic Act, CAP. 464, which was amended several times making it difficult to obtain a high level of understanding of the legal framework. The enforcement of overload control was done at weighbridges and the first eight (8) fixed weighbridges were installed on the Zambian road network between 1970 and 1980. All of these weighbridges were, at the time, of a mechanical type, the Avery 58H 20, with a capacity of 30 tonnes but have since transformed into electronic ones except for Kafulafuta and Mwami weighbridge. The first eight (8) weighbridge stations were at Livingstone, Kafue, Kapiri Mposhi, Kafulafuta, Mpika, Nakonde, Mwami and Solwezi. Seven of these weighbridges were still operational and an additional weighbridge had been constructed at Kazungula. From the information gathered, the Nakonde weighbridge was under private hands and was used on a commercial basis rather than for enforcement [130] - [132].

The ALCP in Zambia was guided by two principal statutes, the Public Roads Act No. 12 of 2002 and SI No. 28 of 2007. Part I, Section 3 of SI No. 28 of 2007 stated that the regulation applied to vehicles with a GVM of 6.5 tonnes and above. This implied that all vehicles with a GVM of 6.5 tonnes and above were required by law to pass through a weighbridge. Part V, Section 35 subsection 1 and 2 provided that “An overload shall be determined by comparing weights found by weighing axles, combination of axles or GVM to the defined authorized limits”, and Part VI stipulated the procedures for fines and payments for overload. In particular, it provided that an HGV that exceeded the authorized axle load limit after the additional five percent tolerance or weigh more than the GVM legal limits was considered overloaded and was charged for overload compensation accordingly. The overload compensation was calculated separately on each axle or group of axles and GVM according to the schedules set out in the regulation. The compensation was structured in such a way as to deter would be offenders at the same time enough to compensate for the damage caused to the road 23 infrastructure. In a case where a driver of a HGV with a GVM of 6.5 tonnes and above avoided a weighbridge, a charge of US$ 2,000.00 was levied for absconding. A driver who refused to have his/her HGV weighed was charged an obstruction fee of 50,000 penalty units which translated to ZMW 10,000.00 (US$ 1000 at exchange rate of US$ 1= ZMW 10) at the prevailing rate of ZMW 0.20 per penalty unit.

The ALCP Training Manual of 2007 indicated that for an overloaded vehicle carrying an abnormal load that exceeded the prescribed maximum dimensions and was indivisible, the driver must carry a special (abnormal load) permit for the specific transport. The permit must contain a specification of the starting point and destination and the route to be followed and the axle-loads and GVM to be used. If the abnormal load was beyond the contents in the permit, the load had to be unloaded on the spot. If the driver was not in the possession of such a permit, the vehicle was to be detained at the expense of the owner until a permit was provided and the relevant fee is paid, as stated by Larsen, *et al.*, in their report on the Economic Impact of Enforcing Axle Load Regulation [133], highlighted that:

(i) The annual average saving in the cost of road maintenance from effective ALCP was estimated to be of the order of US$ 4 to 4.1 million per year.

(ii) The estimated increase in the annual cost of haulage was in the order of US$ 12 to 13 million, that is, about three times the saving in road maintenance. The increase in the cost of haulage was associated to the GVM. The approved GVM of 56 tonnes was thought to be low and expensive for Zambia in terms of transport costs but it was acknowledged that the GVM limits were set regionally by SADC.

(iii) It was impossible to evaluate the optimal GVM for Zambia due to the scarcity of information on the strength of bridges in Zambia.

Studies conducted in the United States of America (USA) revealed that if legal weight limits throughout the country were increased to 11.8 tonnes on a single axle and 20.0 tonnes on a tandem axle on all federal-aid highways, the total benefit-cost ratio would be 12:1.

Another study conducted in the USA revealed that for every dollar invested in axle load enforcement efforts; there would be US$ 4.50 in pavement damage avoided [134] – [135].

Clearly, the management and protection of the road network is necessary, while maintaining the economic base of the transport industry [136]. It had been proposed by the United States Agency for International Development (USAID) that self-regulation would be the ideal method of combating overloading but transporters ignored overloading if it did not significantly damage their vehicles [137].

Laws and regulations to control/manage vehicle overloading have been in existence in Southern African countries for more than 40 years, and have been changed and updated to reflect the changing circumstances of the road transport industry.

The International Consultants and Technocrats (ICT) Report on Axle Load Regulation and Management [138] identified the benefits of an effective overload management, as follows:

(i) It protects the investment made in roads and bridges by slowing down the load related distresses.

(ii) It thereby helps to postpone periodic maintenance of the roads and therefore results in savings that enables undertaking other road improvement works as the road budget gets further stretched.

(iii) It helps to control abrupt road damage at sharp turnings such as at round-about by reducing the tractive forces pushing the layer materials towards the edges.

(iv) By controlling overload related distress, load control enables identification of other causes of premature failure, wherever these may occur.

(v) With resultant improved riding quality of roads through axle load control, it results in reducing fuel consumption and prevents excessive and premature damage to vehicles.

(vi) The vehicles, with reduced loads and on account of better riding surfaces would benefit due to reduced operating costs, less wear and tear of vehicles and the related lower maintenance costs.

(vii) It improves on road safety as, with reduced payloads, the weight to engine power ratios gets improved and vehicle control becomes easier.

(viii) Engine power ratios get improved and vehicle control becomes easier.

2.9 Axle Load Control in Southern and Eastern Africa

Regional Economic Communities (RECs) that include SADC, the Common Market for Eastern and Southern Africa (COMESA) and the East African Community (EAC) cover the Southern and Eastern parts of Africa. In 2005, these three RECs established the Tripartite, an umbrella organization [139]. The EAC Load Control Bill [140], to harmonize the GVM limits to 56 tonnes [141], based on axle load, with the maximum for a single axle being 10 tonnes. Initially, Kenya had a maximum allowable weight of 48 tonnes; Tanzania had 56 tonnes, while Uganda, Rwanda and Burundi allowed a maximum of 52 tonnes [141]. The different limits were a source of conflict and confusion among the countries. The approved SADC/COMESA maximum allowable limits are maximum eight tonnes per single axle and 56 tonnes GVM. Plans to harmonize regulations for EAC, SADC/COMESA were underway by the three regional organizations [142].

2.10 Axle Load Control in Selected Regions of the World

Although legal axle load limits vary from country to country, they to some extent reflect the different environmental and social conditions of each country, but economic analyses have rarely, if ever, been used to justify them [143]. Most countries stipulated a maximum GVM and a maximum permitted legal axle load (usually eight, 10 or 13 tonnes for single axles). There may also be a maximum permitted axle load for multiple axles, that is, two or three closely spaced axles, usually lower than the total that would be permitted if each axle were treated separately. However, the amount of damage caused to the road by multiple axles can be either more or less than would be caused by the axles if they were to be separated, depending on the spacing of the axles and the design of the road [144].

In Malaysia [145], a weight restriction order to control the allowable axle load and GVM in Malaysia was gazetted in 1966 where the GVM was then fixed at maximum single axle load of nine tonnes. The restriction order was revised in 1989 to allow the maximum single axle load of 10 tonnes. An amendment of 2003 raised the allowable maximum single axle load to 12 tonnes, depending on the wheel base.

In Europe [146], the Heavy-Duty Vehicles (HDVs) including buses and coaches using European roads must comply with rules on weights and dimensions set out in the Directive 96/53/EC. It also stated that the directive established maximum common measures to ensure that road safety was not jeopardized and that degradation to roads, bridges and tunnels was minimal and promoted fair competition. Freight vehicle industry was working on lowering cost of doing business and lowering environmental impacts. The single axle limit in European Union (EU) was 10 tonnes and the maximum allowable GVM was 44 tonnes.

In U.S.A. [147], the Federal regulations that applied on major highways governed the weight and width of vehicles and the number of trailers that a power unit may tow is stated in the Transportation Research Board (TRB). It further stated that these regulations had important economic consequences because trucking accounted for 80 percent of expenditures on freight transportation in the U.S.A. Size and weight limits influence highway construction and maintenance costs and highway accident losses. The regulations affected international commerce as well because U.S.A. limits differed from those of Canada and Mexico and because containers shipped in international trade often were not consistent with U.S.A. regulations.

The TRB reported that, in general, the state regulations governed the following:

(i) The maximum weight on any single axle which is 10 tonnes;
(ii) The maximum weight on any group of axles on a vehicle as a function of the span of the axle group and the number of axles and does not exceed 42.5 tonnes in most states;
(iii) The maximum weight of the entire vehicle;
(iv) The maximum length, width, and height; and
(v) The maximum number of trailers.

2.11 Weigh In Motion (WIM) Sensing Systems

Weigh-in-Motion or Weighing-in-Motion (WIM) devices are designed to capture and record the *axle weights* and *gross vehicle weights* as vehicles drive over a measurement site. Unlike static scales like weighbridges, WIM systems are capable of measuring vehicles traveling at a reduced or normal traffic speed and do not require the vehicle to come to a stop. This makes the weighing process more efficient, and, in the case of commercial vehicles, allows for trucks under the weight limit to bypass static scales or inspection.

In road transport application, WIM is useful especially for big vehicles or trucks to monitor the gross vehicle weight and axle weight for different purposes including [148]:

(i) Pavement design, monitoring, and research;
(ii) Bridge design, monitoring, and research;
(iii) To inform weight overload enforcement policies and to directly facilitate enforcement; Planning and freight movement studies;
(iv) Toll by weight; and
(v) Data to facilitate legislation and regulation.

Several types of WIM are available and they are best illustrated and explained separately as:

2.11.1 Piezoelectric Systems

Piezoelectric Systems are based on a Piezoelectric Sensor, which is a device that uses the electric charge that builds up in certain solid materials such as crystals and certain ceramics in response to applied mechanical stress. This type of electric charge is known as *piezoelectricity,* it means electricity resulting from pressure of latent heat. The resultant change in pressure, acceleration of temperature is converted to an electric charge within the piezoelectric sensor. Piezoelectric WIM systems use quartz-piezoelectric sensor to detect the changes in voltage caused by the pressure exerted on the sensor by an axle and thus the weight of the axle.

When a vehicle drives over the piezoelectric based WIM system, the system obtains the dynamic load of the vehicle based on the pressure exerted on the sensor and estimates the static load using set calibration parameters. The Piezoelectric sensors are often installed perpendicular to the direction of motion of the vehicle in the traffic lane and can be permanently installed in the road or temporarily on the road surface with road tape. The most common material used for piezoelectric WIM systems is Quartz, this is due to it is durability properties. Figure 2.24 refers. [149] – [152].

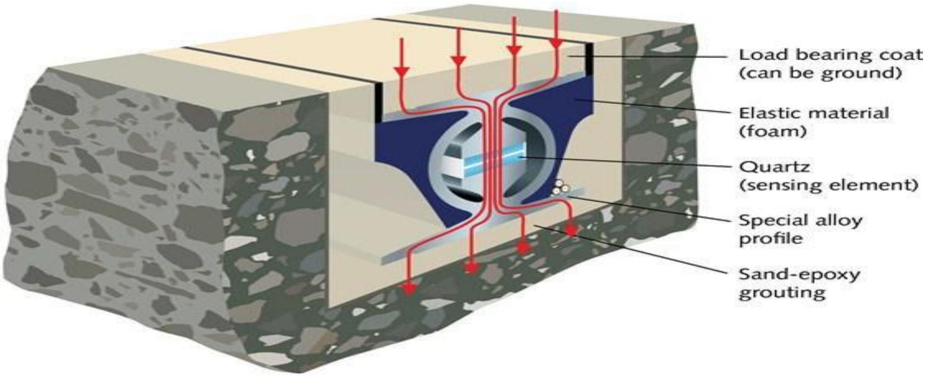

Figure 2.24: Quartz Crystal based Piezoelectric WIM Sensor. [Source: Kistler.com]

2.11.2 Capacitive Mats

Capacitive Mats are placed along the surface of the road, they are a type of WIM system that extends along the tire imprint of the vehicle. Capacitive Mats measure the change in *capacitance* due to the tyres force applied by the vehicle on the mat. Capacitance is defined as the ratio of the change in electric charge in a material to it is change in electric potential, the electric charge is stored in a device known as a capacitor. In WIM systems, Capacitive Mats usually consist of one weight sensor per lane and two inductive loops in order to cover a maximum of four traffic lanes, Figure 2.25 refers. Capacitive mats have other applications apart from their use in Road WIM systems; they can be used to measure weight in bed and other soft material unlike load sensors [153] – [156].

Figure 2.25: An Example of a Capacitive Sensor Mat [156]

2.11.3 Load Cells

In a WIM system load cells are placed in the travel lane perpendicular to the direction of traffic. Load Cell WIMs are used for *low speed* measurement of weight and are composed of a rigid weight and a series of load cells mounted between them and a support frame in order to measure the force transferred from the wheel/axle of the vehicle and then to the frame, see Figure 2.26. Load Cell WIM are accurate but expensive [157].

Figure 2.26: Load Cell WIM. [Source : International Society for WIM]

2.11.4 Bending Plates

Unlike Capacitive Mats which can be used on a soft surface, bending plates are rigid and employ the use of strain gauges. They consist of a plate supported by a frame at its edges with a stain gauge installed. The Strain gauges measure the bend of the plate as a wheel or axle crossed it. The vertical forces applied are proportional to the bend of the plate, Figure 2.27 refers. Bending plates are cheaper and less accurate than load cells [153] [156].

Figure 2.27: Bending Plate WIM [Source: International Society for WIM]

2.11.5 WIM Systems based on Load Cell Sensors [158]

WIM systems based on Load Cells uses load cells for the weight sensors. Most currently available WIM systems with load cells use strain gauge type sensors. The sensing element of these load cells typically consists of pairs of strain gages mounted to both sides of the web of a specially machined shear beam. When a force is applied to the sensing element, the strain gages measure the principal strains on the beam web, which are used to determine the applied load. The sensing element is capable of measuring high forces, is insensitive to the point of loading, and offers good resistance to side loads. One type of load cell based weight sensor used in WIM systems has a single load cell mounted to a steel frame under the center of a rectangular steel loading plate. The weighing unit employs a torque tube that transmits any weight applied to the surface of the load plate to the single load cell.

Another type of load cell based weight sensor used in WIM systems has a total of four load cells installed between a steel frame and each corner of a rectangular steel loading plate. The weight of a wheel located at any position on the loading plate is determined by summing the forces measured by each individual load cell. The rectangular load plates in these systems are approximately 30 by 72 inches, which is large enough to enable each wheel set of a given axle to be weighed individually. Load cell based systems require a reinforced concrete vault or foundation, though expensive and time consuming to construct, to support the scales.

2.12 Comparison of the WIM Sensing Technologies

When selecting a suitable technology for use, a trade-off between cost and accuracy is considered, although robustness is a factor too. The major differences between the above reviewed WIM sensing is the technology employed.

In this regard, the most accurate technology is the Load Cell based technology followed by Bending plates and then finally Piezoelectric. Load Cells measure weights within 6 percent of the actual vehicle weight for 95 percent of vehicles tested while Bending plates and Piezoelectric WIM fall to 10 percent and 15 percent respectively WIM technology is used in many places and its use continues to be popular, one will find WIM technology being used in Kentucky, Michigan and Idaho in the United States, in Europe WIM systems are used in Belgium, Namur, Zurich, Switzerland, Lulea and Sweden, and in Saudi Arabia and China too [148] – [158].

2.13 Related Works

The related works on vehicle weight tracking or monitoring systems has been implemented before by many different systems, each one of them differing in the way of its implementation. Below are the reviews of some examples of vehicle weight tracking systems and patents of vehicle weight tracking systems that share some similarities with our proposed system.

2.13.1 Vehicle Loading Status based on Analysis of Suspension Vibration Characters

This System monitors the load of a vehicle by analysis of the deformation of the vehicles suspension. Using this relationship, the System is able to detect abnormal loading of the vehicle. This System is comprised of Load monitoring device that converts the effects of the load on the suspension into an electric signal which is calibrated to match load status values.

The device is made up of a *guyed* displacement sensor, a plate for joining bodywork, steel wire for joining sensor, overload protection structure, L-shaped plate for joining axle, and clamper for overload protection device. The device monitors static as well as dynamic load, however, it cannot prevent overloading. Actually, it is this is drawback that the proposed system aims to overcome as passenger weights and luggage weights are loaded onto the bus and then logged into the vehicle database in real time thereby stating whether the vehicle is overloaded or not [159].

2.13.2 Vehicle Load Sensing System [160]

The Vehicle Load Sensing System, designed by David Carruthers and Ernie Di Rollo, shares a number of similarities with our proposed system. It comprises of Load Cells placed either on the axles of the vehicle or on the floor mounted on the bottom of the vehicle. This system is capable of detecting changes in the vehicle weight consistently and contains a method of monitoring the current vehicle weight via a display to be possessed by the driver.

The difference between this system and our proposed system is the positioning of the load cells, as well as the intended application of the load sensing system. Carruthers and Di Rollo's system is designed for general vehicle use, however our proposed system is application specific for inter-city passenger vehicles (buses), hence the proposed system will possess load cells placed on the base of the luggage bay, to keep track of the current luggage weight. It also possesses the load cells and motion detectors on the steps of the bus door for entrance/exit, specifically to track the weight of passengers and their hand carry-on luggage as they embark or disembark the bus. The way our proposed system is designed easily lends itself to future upgrades and integration with emerging technologies [160].

2.13.3 Vehicle Overloading Management System [161]

The KwaZulu Natal Department of Transport was interested in obtaining more detailed analysis of their vehicle weighing data, thus a project was started in 1987 to computerize the vehicle weighing management system in order to provide the Roads Branch with a detailed weight data from their eleven (11) permanent and eleven (11) mini weighbridge sites for satisfactory analysis of vehicle overloading information.

Figure 2.28 shows a schematic diagram of the system. In order to determine the average load of overloaded axles or axle groups, legally loaded axles are not included in the calculations. Initially, all information was input manually by a data assistant, using the monthly return sheets from each weighbridge site. Subsequently, a program for upgrading the permanent weigh sites was started, which included the computerization of the weighbridges. This involved the storage of vehicle weighing data on the hard disk of the computer at the weigh site [161].

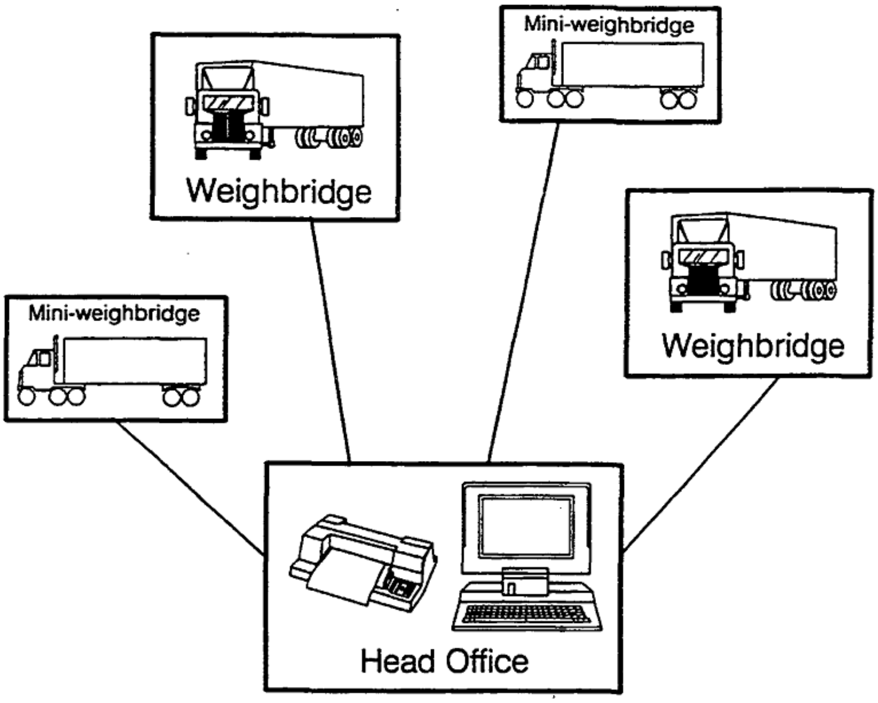

Figure 2.28: Diagrammatic Representation of the Vehicle Overloading Management System [161]

2.13.4 Automatic Weight Monitoring using RFID and Load Cells [162]

RFID tags are used for gathering the information of the vehicle which is installed in vehicle through RFID reader, information such as vehicle number, driver information, receiver address are obtained through RFID reader, IR sensor installed in field around the Two corner of vehicle which helps in positioning the vehicle after positioning the gate is closed, for weighting load to gather information regarding the imported load.

After positioning the vehicle, camera is invoked by IR sensor and the front image of the vehicle is captured and the details such as weight, receiver address, and the vehicle details with image is stored in the computer and sent to the receiver through mail with the received information the cross verification in receiver side is made possible [162].

Figure 2.29 shows a block diagram model of an Automatic Vehicle Weight Monitoring System using RFID and Load Cells.

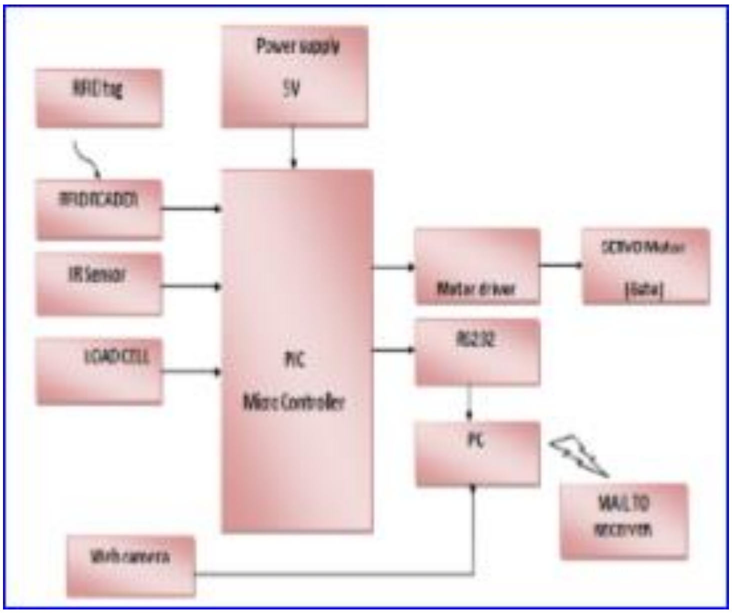

Figure 2.29: Block Diagram of RFID and Load Cell Model [162]

2.13.5 Novel Sensor System for Measuring Wheel Loads of Vehicles on Highways [184]-[185]

Accurate measurement of vehicle static axle or wheel loads has long been a major objective of highway engineers. The static weight of a vehicle is used to provide a basis for pavement analysis and design. Traditionally, these weights have been collected by pulling the vehicles off the roadway and weighing them at weigh stations while the vehicles are at rest. The static weighing of vehicles in highways has several disadvantages, including being time consuming, expensive, and dangerous on heavily travelled roads. With the development of the highway transportation and business trade, vehicle Weigh-In-Motion (WIM) technology has become a key technology for measuring traffic loads.

WIM is the process by which the static weights of vehicles are determined by measuring wheel load while the vehicles are in motion. There are several advantages of weighing vehicles while they are in motion rather than at rest which include savings in time and cost, and being safer to operate on busy roads. A novel WIM system based on monitoring of pavement strain responses in rigid pavement was investigated. In this WIM system multiple low cost, light weight, small volume and high accuracy embedded concrete strain sensors were used as WIM sensors to measure rigid pavement strain responses.

In order to verify the feasibility of the method, a system prototype based on multiple sensors was designed and deployed on a relatively busy freeway. Field calibration and tests were performed with known two-axle truck wheel loads and the measurement errors were calculated based on the static weights measured with a static weighbridge. This enables the weights of other vehicles to be calculated from the calibration constant. Calibration and test results for individual sensors or three-sensor fusions are both provided. Repeatability, sources of error, and weight accuracy are discussed. Successful results showed that the proposed method was feasible and proven to have a high accuracy. Furthermore, a sample mean approach using multiple fused individual sensors could provide better performance compared to individual sensors.

Current WIM systems are mainly based on three types of sensors: bending plate, piezoelectric and single load cells. All three sensors must be located in the path of the vehicle. The sensors register the vertical dynamic tire forces provided by the passing vehicles. Two sets of calculations must be performed on the WIM measurements to determine pavement loading under dynamic traffic conditions:

(i) The measurements are used first to estimate the static weight of the axle. Accurate estimates of the axle load require continuing calibration of the WIM station.

(ii) The axle load estimates are then used to obtain the actual dynamic load that the pavement experiences.

Calculations of the dynamic load depend on complex vehicle-pavement interaction models, which are hard to calibrate. Typically, these models are used to simulate dynamic loads. The traditional measurement method just uses the interactions between the sensor and the vehicle's tires that make the measurement inaccurate because the sensor cannot cover the whole wheel path along the driving direction.

The proposed approach differs from the traditional one in two ways:

(i) the sensing modality;

(ii) the computation of the dynamic wheel loads.

The method is based on the principle that when a dynamic force is applied by a vehicle (via its tires), the amplitude of the tensile stress at the bottom of the surface layer increases as the force increases. However, the relation between tire force and displacement of pavement depends on the shape, size, and the structure of the rigid pavement. For numerical example, the rigid pavement system is modeled using model of a plate of infinite extent on a viscous Winkler foundation subjected to moving loads with amplitude variation to investigate stress and displacement response of rigid pavement [184]. With consideration of viscous damping, the maximum deflection and stress of pavement tend to decrease with increasing frequency. The velocity effect can be negligible for moving harmonic loads within the practical range of the vehicle velocities. Actually, when the strain is not too large, rigid pavement behaves like a linear spring, which the displacement is proportional to the tires' force. In the linear range of rigid pavement response, the stress from vehicle tires is proportional to the strain (refer to Figure 2.30), i.e. εSUR = σ / E, where the longitudinal strain εSUR is induced by the vehicle wheel load, σ is the stress and E is elastic constant, called the Young's modulus. In this research, the combination of embedded concrete strain sensors is used as WIM sensor.

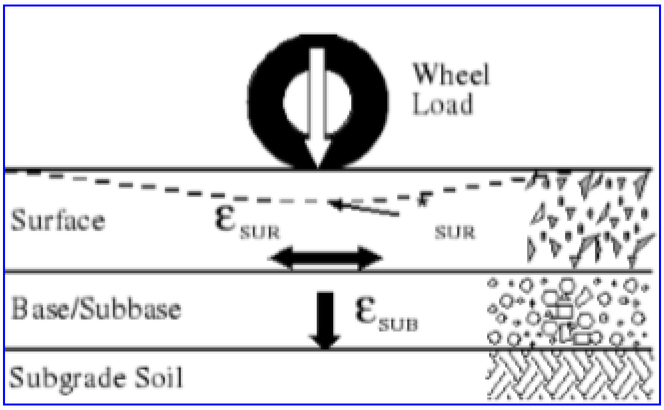

Figure 2.30: Illustration of the Strain caused by moving Wheel Loads [185]

The basic principle of the proposed WIM system is illustrated in Figure 2.31. When a vehicle passes over the WIM sensor, the vehicle wheel loads will induce a deflection of the pavement and cause the strain of strain sensors in the longitudinal direction. Since the embedded concrete strain gauge is tightly epoxied together with the strain sensor, the Piezo-resistive material of the strain gauge will produce a relative resistance change. The relative resistance change of Piezo-resistive gauges is usually measured using a Wheatstone bridge (refer to Figure 2.16). The bridge output, Equation 2.2, is zero when the balance condition, Equation 2.3, is met [185].

$$V_{out} = V_{\delta} - V_{d} \quad \text{…………… Equation 2.2}$$

$$R_1R_4 = R_2R_3 \quad \text{…………… Equation 2.3}$$

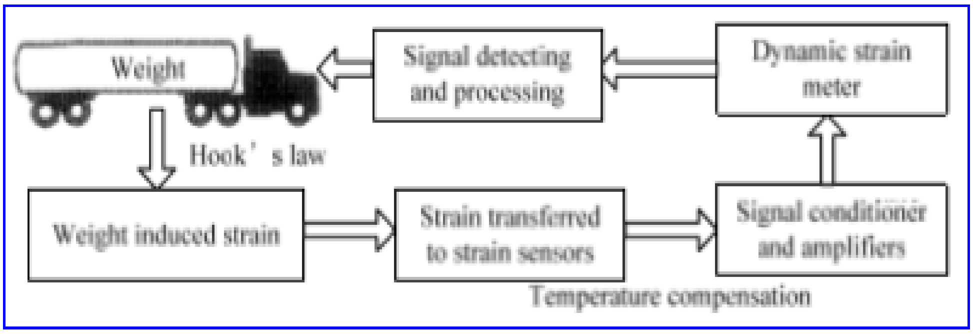

Figure 2.31: Flowchart of the proposed WIM system [185]

2.13.6 Wireless Load Weight Monitoring via a Mobile Device based on Air Suspension Pressure [186] – [189]

This system was designed and tested to measure pressure in the airbag suspension components of an over-the-road tractor trailer and use those signals to wirelessly display load weight.Three subcomponents used included: (i) Human Interface Device (HID); (ii) Two Digital Processing Units (DPUs); and (iii) Zigbee Wireless Devices for control and communication. Except for a region directly in front of the cab, the unit transmitted weights up to 45 m. Effect of number of calibration points on system accuracy was evaluated.

In order to optimize loading and comply with weight regulations, truck drivers need to be able to measure the weight of their vehicle, both total weight and individual axle weights. In many situations, e.g., field loading, fixed scales may be far away and portable scales may be impractical or too costly. A fast, real-time, cost-effective system for vehicle weighing is needed. There are current systems on the market, but some do not wirelessly transmit weight information like AirWeigh [186]; Farmtronics [187]; and TruckWeight [188]; and those that rely solely on air-spring pressure for mixed air-spring and mechanical suspension trucks are not well documented. A system is proposed which weighs the vehicle by measuring air pressure in its air-spring suspension. It can be shown that there is a linear relationship between suspension air pressure and the weight carried. The coefficients in this linear weight-pressure model can be derived via standard analysis in the static case, if the geometry is known. As it is impractical to know the geometry in all cases and because it can vary with leveling valve setting, a calibration method and least squares fitting is suggested. Note that the air-spring suspension system supports only the body and load, and not the axles or the suspension system itself. In addition, in many trucks the front steering axle is connected to a traditional spring suspension, which would require some other technology for measuring weight, e.g., load cells. It may be possible to compromise by calibrating around the missing front axle measurement using an affine linear weight-pressure model and least squares.
There are various approximations made in this work, including: all weight not support by an air spring is constant, the vehicle is sitting on flat level ground, and the vehicle is stationary. These assumptions limit the usage of the system and one would naturally like to eliminate them. When the semi-truck is empty and only the tare weight of the vehicle is being measured the approximation that there is a constant weight being supported by the non-air spring suspension components is viewed as quite good. However, as the truck is loaded a small amount of the cargo weight is transferred to these components and quickly becomes a significant source of error. Modeling this effect, to account for it in the weight estimate, is

challenging and is an unknown that requires some knowledge of how the cargo is distributed on the truck. Other small unpredictable weight variations also occur such as changes in fuel level and number of passengers.

Weight while stationary is important and useful the typical semi-truck driver. However, being able to measure weight while in motion, particular in bumpy terrain such as a farm field, would expand the usefulness of the system. To do this one can no longer make the assumption that the air-spring suspension assemblies are rigid bodies. A state-based model would need to be used to help average the pressure measurements of the dynamic in a logical way [189].

2.13.7 A Mobile Vehicle Weight Sensor and its Application in Transportation [190]

In recent years, due to the expansion of the vehicles' transportation system and concerns about the lack of accurate calculations of vehicle weight, a system that is able to calculate the vehicle's weight at any moment is necessary. Given that the transportation electronic management is related to the location and movement data of vehicles, information about movement, speed and time, traveled path, the weight sensors and fuel for the quick and timely decisions are required.

Vehicle weigh-in-motion technology has become a key technology and trend of measuring weight of the loads. Moreover, because of the strong competition between transport modes and companies, transportation management has improved, which has led to an increase in the numbers of fully loaded trucks and their gross weights. Recently, there have been a significant number of vehicles illegally overloaded and the damage vehicles cause on the road is in direct proportion to the axle weight. The overloaded transportation greatly increases the cost for the pavement maintenance and repair, shorten the service life of pavement, even affect the traffic safety and capability. So it is imperative to build a weigh station to solve these problems. Traditionally the weights of vehicles were measured and collected by placing it on the scale while the vehicle is at rest. Weight information of vehicles acquired by static weighing (i.e. does not move) was a conventional method which was used widely these days. Though the precision of this way to measure the gross weight of vehicle is very high, there are many disadvantages of the method, that is, it is not only expensive but also not possible to measure the weight of each axle separately. The most important is that it is inconvenient to weigh with stopping vehicles in some practical application. Basically there are two methods of measuring the weight of vehicle: (i) Measuring directly and (ii)

Measuring indirectly.

Measuring directly is the way which measured and collected by placing the vehicle on the scale while the vehicle is at rest. Some disadvantages of this method was mentioned but the other disadvantage is that ,the sensors which are normally used for measuring have an overload capacity and more than this capacity causes pressure on the sensor, therefore it cannot illustrate the real weight of the load. According that the loads usually fall down from high height on the vehicle, this hit on the sensor is usually 10 times more than its weight and it is natural that this amount of weight will not to be tolerated by the sensor. Therefore a system which must be considered for measuring the weight of the load, must be able to tolerate this extra pressure. This point is the main advantage of the sensor which shall be described below.

Measuring indirectly can be achieved in three ways, namely: (i) Measuring distance by Digital Ruler; (ii) Measuring Angle by Change of Spring; and (iii) Measuring Side Spring Pressure on Weight Sensor.

(i) Measuring distance by Digital Ruler: In this way the weight changes of vehicle at any moment can be measured by putting a Digital Ruler between the back chassis and axle of vehicle. This method has some problem such as: High price of Digital Ruler; and Shock and Moisture Sensitivity.

(ii) Measuring Angle Change of Spring: Spring Angle, changes with weight changes, so using an angle measurement module, the weight changes of vehicle can be measured. The problem with this method is the sensors' action is based on the magnetic changes of poles and if it is placed near power cable or metal, loses its precision can occur.

(iii) Measuring Spring Pressure on Weight Sensor: The following components are needed:

(a) A base of Weight Sensor;

(b) A weight sensor capable of weighing up 20 kilograms;

(c) A spring capable of increasing pressure up to 20 kilograms;

(d) A ball bearing placed on the spring;

(e) A device that converts the system’s resistance to 1 to 10 volt;

(f) Automatic Vehicle Location (AVL) devices;

(g) The central computer that calculates the voltage and changes it to a weight proportionate with the weight of the vehicle

(h) Communication Cables(a medium to transfer data)

(i) A data transfer system that provides communication between computer and sensor.

The operating mechanism of weight sensor device is such that the weight sensor (20 kilograms) is attached to the base of the vehicle from one side and to the spring valid for 20 kilograms from the other side. The other side of spring is placed on the flat spring of the vehicle. When the weight of the vehicle increases, the spring is jammed and it produces a power towards the weight sensor and changes the output resistance. The pivot in the device changes the sensor resistance into voltage in a way that the pivot shows 1 voltage if there is no load on chassis and it shows 10 if there is the maximum weight on the chassis .This voltage is set on the AVL and it sends to the central computer via wireless communication network such as GPRS, 3G, Local wireless, dedicated wireless network, other wireless networks to the central server. The central server estimates the weight according to a calibration chart. Figure 2.32 refers. The benefits of measuring spring pressure on weight sensor: (i) Pieces are cheap; (ii) Low depreciation of device; and (iii) Accuracy and Precision.

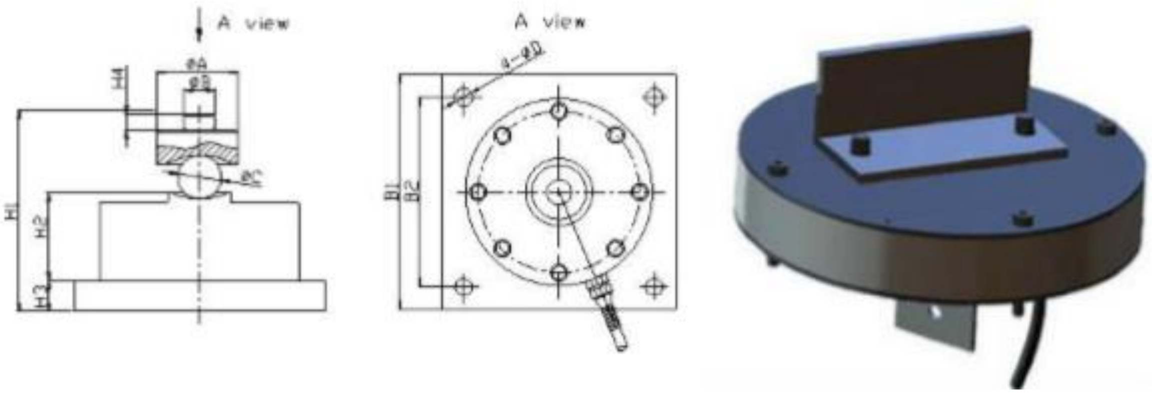

Figure 2.32: Vehicle Weight Sensor Device [190]

The Weight Sensor is installed on the back chassis and axle of the vehicle. The weight sensor measures the load/weight of the vehicle. The load/weight data obtained from the weight sensor i.e. "analog output sensor" shows the incoming pressure on the spring, of the sensor, resulted from the distance changes from the suspension system of vehicle. The load/weight data obtained from the weight sensor is transformed to the digital data by an Analog-to-Digital circuit .The system further comprises a microcontroller (central processor) for processing data received from various modules and sending or displaying the data to the users. The microcontroller receives data from the weight sensor installed in the vehicle, data from the positioning satellites and data from a dynamo of the vehicle. Refer to Figure 2.33. The positioning data are checked at regular intervals such as every minute and are consider to device configurations. These configurations are done upon differences on at-least three parameters such as but not limited to: time, angle and distance.

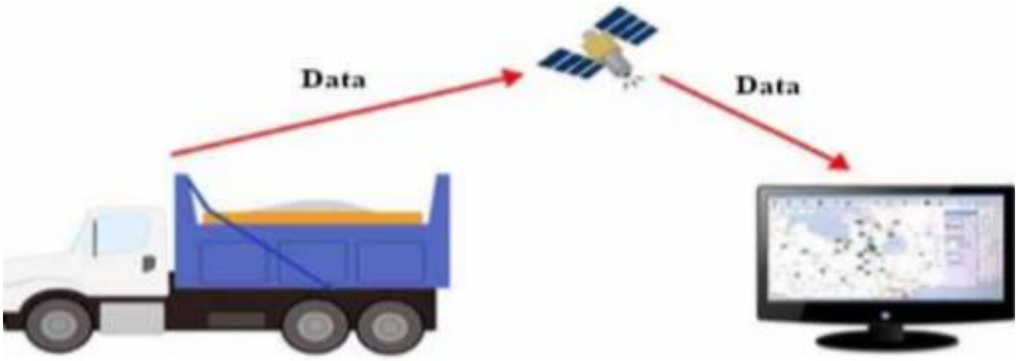

Figure 2.33: Central Computer receives the Data through the AVL System [190]

For example consider an example where time change is 30 seconds, angle change is 20 degree and distance change is 500 meters are defined for a device, then the device analyses positioning data every one second and checks differences of time, angle and distance with previous data received. If each of these differences exceeds specified data in configurations, then new data together with obtained loading weight and status of vehicle engine are packed in data packet, which are further sent to three different outputs according to applied settings on the device.

The system comprises a weight sending device attached to a base of a vehicle, and wherein the weight sensing, device is load cell, a compression spring attached to the weight sensing device and to a suspension spring of the vehicle, a voltage conversion unit attached to the weight sensing device to convert and output resistance of the load cell into a voltage, an automatic vehicle location (AVL)system connected to the voltage conversion unit to receive the output voltage from the voltage conversion unit and a central server connected to the AVL to receive location data and the vehicle load at any instant is communicated simultaneously to driver of the vehicle. A system and method is provided for measuring changes of vehicle suspension system in order to monitor changes of vehicle loading weight in various local and time situations and also checking driver's attitude toward road surface roughness.

For this purpose, this system consists of two main parts: hardware and software. Hardware part is in control of measuring changes of suspension system and processing these data in order to gain vehicle loading weight. Concluded weight could be displayed to the driver on the LCD in vehicle cabin, or together with received data from positioning module (received from positioning satellites) including speed and position of vehicle and time in the form of package is saved offline on a memory or is sent via a wireless module to server software. All these data is parsed and saved in server database software to help generate various vehicle and driver functional operation reports related to weight, position, speed and time [190].

2.13.8 Summary of Related Works

Table 2.6: Summary of Related Works in Vehicle Weight Monitoring Systems

No.	Title	Year	Author(s)	Findings	Gap
1	System for Monitoring Vehicle Overloading in KwaZulu Natal	1995	Nordengen, P.A.	Accurate analysis of data for vehicle weight management system from Weighbridges	Not Accurate because average load of axles not included in calculation.
2	A Novel Sensor System for Measuring Wheel Loads of Vehicles on Highways	2008	Zhang,W., Suo,C., and Wang, Q.	the gross weight or the axle weight of the passing vehicle can be measured dynamically by the sensors installed in or on the pavement	Inaccurate because the sensors cannot cover the whole tire patch along the driving direction.
3	Vehicle Load Sensing System	2012	Carruthers, D. Di Rollo, E.	Capable of detecting changes and current vehicle weight consistently	Position of load cell and general purpose application
4	Monitor Load Weight Wirelessly via a Mobile Device based on Air Suspension Pressure	2012	Layton, A.W., Balmos, A., Hancock, D., Ault, A., Krogmeier, J.V., Buckmaster, D.R	System that weighs the vehicle by measuring air pressure in its air-spring suspension	Linear weight pressure coefficients difficult to establish
5	Vehicle Loading Status based on Analysis of Suspension Vibration Characters	2013	Li, S., Yao, X., Yang, Z., Lilong, W. Wencas, S.	Converts effects of load on vehicle suspension into an electric signal which is calibrated to match load status values	Just shows load status but cannot prevent overloading. Not computer compatible.
6	A Mobile Vehicle Weight Sensor and its Application in Transportation with AVL	2015	Mehran, S.	System measuring measuring changes of vehicle suspension system in order to monitor changes of vehicle loading weight	Need for load weight localized need for localized sensor that can calculate amount of load on vehicle
7	Automatic Weight	2016	Lakshimi, M., Hariprasad, K.	A novel WIM method based on	Multiple sensors fusion

	Monitoring using RFID and Load Cells			pavement strain response	are expensive. Re-calibration challenges.

2.14 Load Weight Management in Airline Industry [163]

Air travel has become widespread throughout the world. Commercial aviation carries millions of passengers and cargo on tens of thousands of aircraft. Generally, the weight of a specific passenger, or the weight of their luggage, is of little consequence in the operation of a commercial jet. Over a long period of time, airlines have developed statistical information as to the average weight of the passenger and luggage. This information is used to determine safe weight loads for the specific aircraft, fuel loading requirements for specific flights, and the amount of cargo that they may be able to load on any individual flight.

Of course, significant safety margins have been built into these values. Large jets, with passenger capacities ranging from 60 to more than 400 passengers, carry the vast majority of commercial traffic. Recent increases in fuel costs have encouraged airlines to rely on the hub networks in order to reduce the number of flights. Many flights into the hubs are satisfied by smaller regional aircraft. Also, airlines are substituting the smaller aircraft as many routes as possible where they may replace larger, higher fuel consumption planes. These planes may have 20 to 45 seats. Because airlines have reduced their routes, a new type of service called Air Taxis have become more popular. Their goal is to service less popular routes. They use much smaller aircraft to supply service on demand. Depending on the route and the company, there may be between 5 and 8 available passenger seats.

While statistical information may be satisfactory for large aircraft, it may not be the best solution for a smaller plane. The statistical model must offer a high level of certainty that the plane can safely carry the load, and that there is enough fuel for the flight, with the same high built in safety margins. If there are only five passengers, it is not reasonable to automatically assume that the total weight of these passengers will be near the statistical average weight. There is some significant degree of possibility that all five will be over the average weight.

Therefore, it would only be safe to design the flight parameters based on this assumption. In order to maximize the benefit of each individual flight, it would be very useful to know the correct weight of each passenger and their baggage. In the example noted, if the five passengers in fact were equal to a statistical average, it would be possible to carry more cargo, or to reduce the amount of fuel loaded, achieving better fuel economy. Some of the Air Taxi services have begun to use electronic platform scales to accurately weigh the passengers and their luggage. The scales are designed to quickly determine a weight, and to send this weight into the custom computer application that is tracking the weight of all items going onto the plane.

The luggage and cargo may also be weighed on these scales. It is important for the platform of the scale to be large enough for any passenger to feel comfortable when standing on it. The Arlyn Scales 3200 series, as shown in Figure 2.30, is ideal for this purpose, with a platform size of 20 x 27 inches and has a very low profile, making it very easy for a passenger to step up onto the platform. With a capacity of 1000 pounds, and a readability of 0.2 pounds, all passengers will be accurately weighed. The capacity and platform size of the scale also makes it very useful for weighing cargo.

Figure 2.34: Example of Platform Scale used in Airline Industry [163]

Each Air company uses their own proprietary software program for tracking the weights. The scales are provided with USB (Universal Serial Bus) ports to transmit the data into the computer system. Arlyn Scales also provides a Windows based software utility that reads the weight from the scale. It then can target any field in the user's proprietary software. The data is automatically entered into these fields, as it is transmitted from the scale. This allows the scale to be compatible with a wide range of user applications [163].

Because the scale may be used in many different types of locations, it is provided with both a power adaptor and a rechargeable battery pack. It may be used for up to a week on a single charge. Whenever the scale is subsequently plugged into a power outlet, it will both operate the scale and automatically recharge the battery pack.

2.15 Summary

In this chapter, the literature of most related works to this research study were reviewed. Firstly, an extensive review of Public Transport (PT) and the related Public Service Vehicles (PSVs) regulations are reviewed. This is followed by the different types and modes of public transport; road network in Zambia; causes of accidents; vehicle population and overloading in Zambia; and then challenges of public transport.

This is followed by a brief review of Scales, Electronic Scales and a detailed review of Load Cells, Types of Load Cell and Application of Load Cell. This was followed by looking at existing and emerging technologies like Wireless Sensor Networks, Cloud Computing, Internet of Things, and Sensing Technologies.

Further, the chapter highlighted the management of load weight using Weighbridge Technology, Axle Load Control in Zambia, Axle Load Control in Southern and Eastern Africa, Axle Load Control in Selected Region of the World and Weigh In Motion Sensing Systems. Then descriptions of different systems of related works of Vehicle Load Weight Tracking and Monitoring Systems was given, and lastly looked at Weight Management in the Airline industry.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter is essentially divided into four (4) sections, namely, introduction, baseline study, system automation, and last summary. The baseline study describes the research design and methods, population and sample size, sampling methods, data collection, data processing and presentation, ethical consideration and limitations of the baseline study.

The system automation highlights the current situation, bus terminus, proposed system (LWMS) giving details of the system design and materials, system development and system implementation. Finally a summary of the key issues discussed in the methodology chapter is presented.

Research Methodology is defined as a systematic way of solving a problem [164]. The aim of the research methodology is to assist in understanding of not the products of scientific inquiry but the process of attaining them [165]. Also another school of thought argues that the content of the subject matter does not make it scientific, but its methodology [166].

A mixed-method approach was used through structured questionnaires to address the first objective (i); then a traditional System Development Life Cycle (SDLC) was employed to achieve the second objective (ii); and an automated Load Weight Monitoring System (LWMS) was developed, tested and implemented to achieve the third objective (iii).

3.2 Baseline Study

A baseline study involves data collection and analysis in order to identify basic conditions before or at the beginning of an intervention (project or program). The baseline provides a benchmark against which to measure the progress and achievements of the project or programs. As baseline data shows the pre-intervention conditions of the target area, it represents the starting point for each performance indicator of intervention at every level of the results chain [167].

The purpose of baseline study helps to review, adjust and improve the direction, strategy and activities of an intervention, thereby enhance and support the effectiveness of the intervention. As an essential component of the monitoring and evaluation functions, baseline is at the heart of the performance management system, that is; based on the data collected from pre-intervention conditions, change and impact resulting from the intervention can be measured regularly and systematically, allowing one to monitor progress versus the target for the intervention; and baseline data also provides important reference points necessary for setting realistic goals and enhancing transparency. Also as baseline data enables the accurate tracking of changes that have occurred, it can raise the level of motivation and accountability for the stakeholders (e.g. project managers and implementers) concerning the results of the intervention. By sharing baseline data as well as the goals and targets of a planned project with partner organizations and other local stakeholders, their ownership of and mutual accountability for the project can be fostered [168].

The purpose of this baseline study was twofold namely, to establish the challenges of overloading on public buses in Zambia, and to establish ways of mitigating the challenges.

3.2.1 Research Design and Method

A research design is defined as a blueprint for conducting a study with maximum control over factors that may interfere with the validity of the findings [169]. Also research design is defined as "the researcher's overall process for answering the research question or testing the research hypothesis" [170]. In other words, the research design articulates what data is required, what methods are going to be used to collect and analyze the data, and how all of this is going to answer the research question.

In this research design, the pragmatic (mixed-method) approach was employed in the baseline study whose data output (system requirements) were used to come up with a design of an automated system model (LWMS) to monitor load weight of passengers and luggage on public buses. This in turn assisted in the development, implementation and testing of the prototype model which was based on Sensor Technologies (motion and weight) and Emerging Technologies (cloud computing, IoT, digital communication).

Descriptive statistics analysis techniques (SPSS) were used to analyze the data obtained from the questionnaire. Qualitative data was analyzed by bringing out emerging themes that were categorized and interpreted to form part of the input in the design of proposed system.

The system development method employed was the Water Fall Model approach because of its need to define all the system requirements at first which provides the basis of testing and its flexibility in implementation (modules). The Water Fall Model approach is very simple to understand and use. Each phase must be fully completed fully before the next phase can begin. At the end of each phase a review takes place to determine if the system development is on the right path or not. [171] – [173].

3.2.2 Population and Sample Size

Population is defined as the total number of units from which data can be collected, such as individuals, events or organizations [174]. Population is described as all the elements that meet the criteria for inclusion in a study.

The sample size is defined by the Eligibility Criteria which is defined as a list of characteristics that are required for participation in the target population [169]. In this study, the criteria for inclusion was all key stakeholders in public transport industry who included: Senior Management, Engineers and Weighbridge operators from the road sector agencies responsible for the planning, design, construction and maintenance of public roads (RDA); Senior Management, Regulator and Enforcement Officers in the road safety sector (RTSA); Bus Station Authorities: Bus Owners/Operators; and Bus Crew (Drivers, Conductors, Inspectors and Loaders).

This research study was confined to Lusaka because it is the main hub of the public transport system in Zambia with modern facilities and has the highest number of routes, both national and international. All the relevant stakeholders can be found in Lusaka. During this reseach study, the following targeted stakeholders participated in the study: eleven (11) various institutions/agencies with thirty-six (36) participants; fourteen (14) bus owners/operators; and forty-two (42) bus crew; giving a total population sample size of ninety two (92) participants.

3.2.3 Sampling Methods

Sampling refer to a process of selecting a group of people, events or behaviour with which to conduct a study [169]. In sampling, it is confirmed that a portion that represents the whole population is selected [170]. Sampling is closely related to generalizability of the findings.

There are two categories of sampling: (i) Random Sampling; and (ii) Non-Random Sampling; with a number of sampling selection techniques contained within the two categories.
Non-random sampling was adopted in this study which deliberately targets individuals within a population and it indicates that there are three main techniques, namely:

(i) Purposive Sampling: where a specific population is identified and only its members are included in the survey;

(ii) Convenience Sampling: where the sample is made up of the individuals who are the easiest to recruit;

(iii) Snowballing: where the sample is identified as the survey progresses, that is, as one individual is surveyed or interviewed, he or she is invited to recommend others to be surveyed or interviewed [175] – [177].

In this study the sampling method was non-random or non-probability and purposive going by the eligibility criteria stated above.

In non-probability sampling, researchers use their judgment to select the subjects to be included in the study based on their knowledge of the phenomenon [174]. Purposive sampling is further described as a method of sampling where the researcher deliberately chooses who to include in the study based on their ability to provide necessary data.

The rationale for choosing this approach was that the researcher was seeking knowledge about the challenge of overloading on public buses which the participants provided by virtue of their experience. Purposive sampling leads to greater depth of information from a smaller number of carefully selected cases, whereas probability sampling leads to greater breadth of information from a larger number of units selected to be representative of the population.

Non-probability sampling technique was used in this study because of the different specialized knowledge and work experience possessed in the subject area. This approach was preferred as the research required information from different stakeholders; those who were responsible for policy, regulation, enforcement, bus owners/operators, and the bus crew, who include drivers, conductors, inspectors, ticket sellers, and bus loaders.

3.2.4 Data Collection

The period for data collection was between November 2017 and July 2018, lasting about eight (8) months in total. The period taken was longer than anticipated due to various reasons which are highlighted in the subsequent subheading *limitation of baseline study* in *subsection 3.2.7*. The questionnaire were distributed to the respondents in the various institutions, agencies, bus stations, bus owners/operators, and bus crew (drivers, conductors, inspectors, and bus loaders). Both Primary and Secondary data was used in this study.

3.2.4.1 Primary Data

Primary data was collected through structured questionnaires consisting of a mixture of Closed-Ended and Open-Ended Questions.

The relative advantages and disadvantages of each are elaborated, as follows:

(a) Closed-Ended or Structured Questionnaires

Closed-Ended Questionnaires provide the inquirer with quantitative or numerical data and open ended questionnaires with qualitative or text information. This offers a list of options from which respondents must make a choice of what is most suitable. The options must be exhaustive and stiff [179].

Advantage of Closed-Ended Questions is that it is very easy to analyze the answers while the disadvantages are:

(i) They are not suitable for face to face interviews;
(ii) Respondents may choose options that they might otherwise not have thought of especially if the options are not exhaustive;
(iii) Information may be missed out through lapses; and
(iv) The respondents may lose interest and suffer from boredom and fatigue.

(b) Open–Ended Questionnaires

These have questions which permit free responses that should be reported in the respondents' own way, that is, the respondent is not given possible answers to choose from. This is important when the researcher wants to get information on opinions, attitude and reactions to sensitive questions [179].

Advantages of Open-Ended Questions include:

(i) Issues that may not have been asked may be explored, thereby allowing the researcher to gain more information;
(ii) Information is given spontaneously and it is more likely to be true than answers which are limited to choice; and
(iii) The information in the respondents' own way may be very useful as examples or illustrations that add interest to the final report.

Disadvantages of Open-Ended Questions include:

(i) Analysis of information can be time consuming, and
(ii) Requires responses which are not numeric, meaning going through all the questions and summarizing the relevant information.

In terms of administration of questionnaires, two types of questionnaire surveys are available, namely [179]:

(i) Self-Administered Questionnaires: posted to the respondent and returned completed; and

(ii) Administered Questionnaires: delivered by the interviewer to the respondent, guided to be completed and then collected.

For this study in particular, the questionnaires had the following advantages:

(i) They were simultaneously issued to different of key stakeholders;

(ii) Respondents' anonymity made them to share information more easily; and

(iii) They were efficient in term of time to collect mass data from many respondents.

Some of the limitation encountered with the use of questionnaires included following:

(i) They were relatively costly as there was need to physically deliver them to each respondents;

(ii) Sometimes the answers given were inaccurate and questionable;

(iii) Some questions could have been misunderstood going by the responses obtained;

(iv) Negative attitude from some respondents; and

(v) No law in place to compel firms to provide information for academic purposes.

In this study, both the open-ended and closed-ended questions were used in the questionnaires. Also the use of filter questions was applied because not all and same questions were asked to all the stakeholders: institutions/agencies, bus owners/operators and the bus crew. The use of filter questions is a common method in standardized questionnaire surveys to make the interview more effective and efficient.

3.2.4.2 Secondary Data

Secondary information was sourced from literature such as books, journal articles, newspaper, and reports. This technique has some advantages and disadvantages [180].

Advantages of Secondary Data includes:

(i) It is inexpensive in that the data is already in existence and one just has to pick it; and

(ii) It permits the analysis of trends such as traffic or population growth trends.

Disadvantages of Secondary Data includes:

(i) Ethical issues of confidentiality for instance in the case of on-going government projects might make the information not to be availed to the researcher; and

(ii) Information may be not up to date, incomplete and imprecise, depending on the methods employed.

The source of information can be considered to be an important factor when checking the validity of the information obtained. Below is a brief review of the various sources of information [179].

(i) *Journal Articles*: are good especially for up-to-date research in subjects of particular interest. They are usually short papers on specific topics. Journals are produced on a continuous basis and are also known as periodicals or serials.

(ii) *Books*: tend to be less up-to-date as it takes longer for a book to be published than for a journal article. Text books are unlikely to be useful for literature review as they are intended for teaching, not for research, but they do offer a good starting point from which to find more detailed sources. Books are excellent sources for information such as: (a) In-depth coverage of a subject; (b) History and Chronology; (c) Overview of a big topic; (d) Background information; and (e) Bibliographies of additional sources.

(iii) *Conference Proceedings*: are a major source of cutting edge research, particularly in science and engineering. They can be useful in providing information on the latest research, or research that has not yet been published. They are also helpful in providing information on current research areas, and as such can be helpful in tracking down the work done by others.

(iv) *Government and Corporate Reports*: many government departments and corporations commission research projects. Their published findings can provide a useful source of information, depending on the field of study.

(v) *Newspapers*: are a serial publication containing news, other informative articles. They are generally intended for a general public audience, the information they provide will be of very limited use for literature review. Often newspapers are more helpful as providers of information about recent trends, discoveries or changes, for example announcing changes in government policy, but one needs to then search for more detailed information in other sources.

(vi) *Theses and Dissertations:* can be useful sources of information. However, their major disadvantage is that they can be difficult to obtain since they are not published, but are generally only available from university library shelf or through inter-library loan. The student who carried out the research may not be an experienced researcher and therefore the subsequent researcher might have to treat their findings with more caution than published research. The Internet is the fastest-growing source of information. It is impossible to characterize the information available but there are some hints about using electronic sources: it should be borne in mind that anyone can post information on the internet so the quality may not be reliable; the information found may be intended for a general audience and may not be suitable for inclusion in literature review as information for a general audience is usually less detailed; and more and more refereed electronic journals are appearing on the internet. If they are refereed, it means that there is an editorial board that evaluates the work before publishing it in their e-journal, so the quality should be more reliable depending on the reputation of the journal.

(vii) *Magazines*: intended for a general audience are unlikely to be useful in providing the sort of information one needs. Specialized magazines may be of use, but usually magazines are not dependable sources for research except as a starting point by providing news or general information about new discoveries, policies, etc. that one can further research on in more specialized sources.

3.2.5 Data Processing and Presentation

Descriptive statistical analysis technique was used to analyze the data obtained from the questionnaire. Qualitative data were analyzed by bringing out emerging themes that were categorized and interpreted. These responses were grouped according to themes of the questions.

Furthermore, quantitative data were analyzed using IBM SPSS Statistics software. Descriptive statistics were applied to the processed data by showing variable frequency distributions from the responses obtained. Data were presented using graphs, charts, tables and percentages.

3.3 Ethical Considerations

This research study was guided by the University of Zambia (UNZA) research ethics. An introductory letter was obtained from UNZA which the researcher sent to all prospective stakeholders and after getting a positive feedback, arrangements for administering the questionnaires were made. Both methods of self-administered and administered were used, going by the preference of the respondent. A formal consent was obtained from each respondent to participate. Assurance on confidentiality and anonymity was guaranteed to all participants. Above all, the researcher was respectful and courteous towards all participants in order to gain their confidence and respect.

The study was clearly explained to would be participants. The participants were asked individually on their willingness to take part in the research and given the liberty to discontinue at any time if felt uncomfortable.

3.4 Limitations and Challenges of Study

The major limitation of the proposed system was the slow speed of data transmission between the Arduino Module and the GSM Module, which adversely affected the update of the Database. This makes the use of the Arduino and GSM modules inappropriate for commercial deployment of the proposed system but just adequate for study and demonstration purposes.

Another limitation of the study was the difficult to get back all the questionnaires distributed and on time. The respondents usually give priority to their respective core work rather than the academic survey exercise normally considered as none productive as currently there is no piece of legislation to compel them to participate in these academic survey.

Despite getting administrative approval from Management, no authority was granted to take a site visit one of the key study areas, the Weighbridges. All efforts to undertake site visits proved futile. A comparative study could not also take off with the Airline industry as they just kept on promising but nothing fruitful came out. Bus Stations are also another highly politicized area where researcher was viewed with suspicion until detailed explanation of academic authenticity, integrity and confidentiality then that is when they opened up and offered to cooperate.

The main challenge encountered by the researcher was finances. There was no sponsorship or monetary assistance to carry out the research study work. This work was accomplished from own personal resources which could not be available at once, but came in slowly hence the reason for taking longer to complete the study. Besides, the researcher had to be engaged in other duties to raise funds, hence taking away the potential time for research work.

3.5 System Automation

The results of the baseline study were used to come up with a conceptual model for the Load Weight Monitoring System (LWMS).

The proposed model developed was based on Sensing Technologies (weight and motion) to measure, detect, capture and monitor the *load weight* on or off the bus and determine whether the maximum load weight limit has been exceeded or not. Other existence and emerging technologies like Web-based Mobile Communication, Cloud Computing and Internet of Things (IoT) could be used to facilitate efficient and economical way of data transmission and storage.

Qualitative data obtained from the questionnaires was used to come up with the system requirements and model design of the system in this study. In addition, the current load weight management was appreciated from the baseline study undertaken. The main technique used in the design was Process Modelling and used flowcharts for clarity easy of description of the logic to the entire system.

The implementation of the LWMS model was split into two (2) main separate modules, namely; *Loading Bay Module* and *Step Sensor Module*. The data readings from both the loading bay module and the step sensor module are then computed using the Ardiono UNO microcontroller.

3.5.1 Current Load Weight Management

At bus stations, the loading points, the current system of loading passengers and luggage on public buses is chaotic and not well defined. Refer to images in Figure 3.1. The bus crews have no system or means to establish how much *load weight* is to be loaded on the bus within the prescribed maximum *load weight* limits.

The only point where the bus weight is measured is at designated weighbridges on few selected roads way off from the loading point. This challenge leads to overloading which in turn leads to compromised road safety, damage to road pavements, damage to vehicle and higher fuel consumption among other several adverse effects of overloading. Since the *load weight* loaded on the buses is not measured, the bus owners or operators also do not have any means to obtain detailed accurate data on how much *load weight* is carried on their buses, apart from relying on number of passenger tickets to calculate expected income and apparently very little or no income from luggage.

The images in Figure 3.1 shows the chaotic situation at Lusaka Intercity Bus Terminus.

Figure 3.1: Images of Current Load Management at LIBT [Source: Field Capture, 2018]

The current mode of load weight management on public buses in Zambia can be expressed diagrammatically as shown in Figure 3.2.

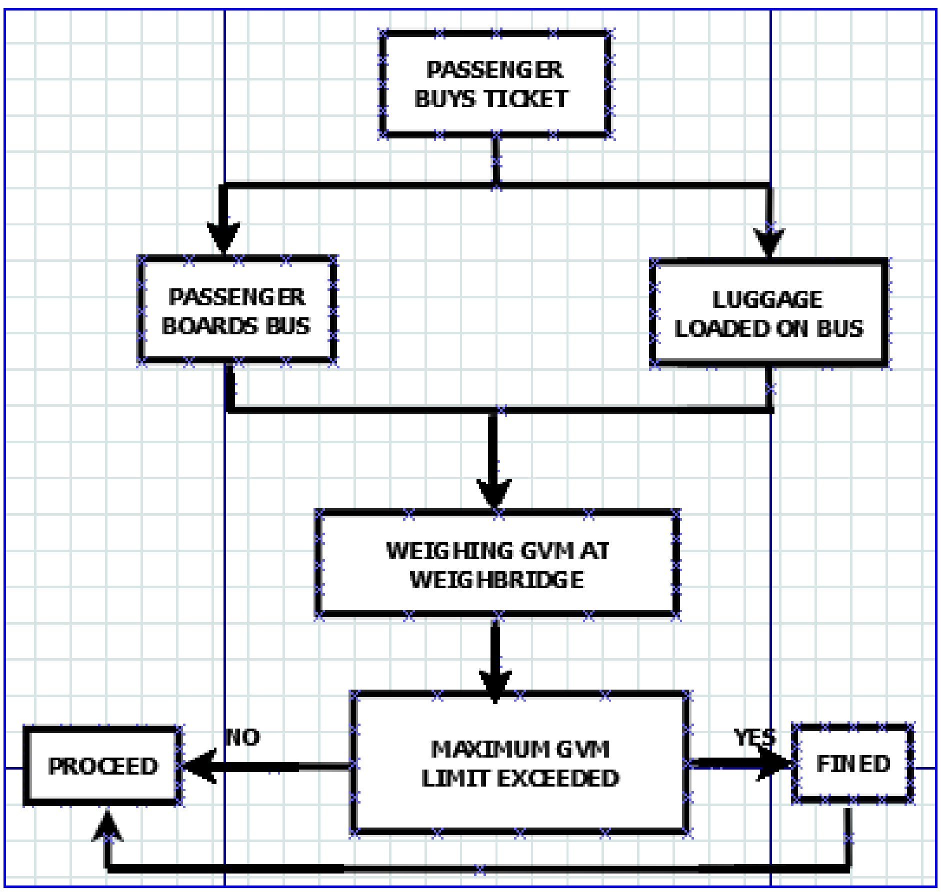

Figure 3.2: Current Load Weight Management on Public Buses in Zambia

3.5.2 Bus Terminus – The LIBT

Figure 3.3: Lusaka Intercity Bus Terminus [Source: Field Capture, 2018]

The Lusaka Intercity Bus Terminus (LIBT), Figure 3.3, is the largest bus station in Zambia and was officially opened on 23rd October, 1980 by the first President of Zambia Dr K.D. Kaunda. It caters for all major routes; International and National, Long and Short Distances. Approximately, 150 to 180 buses per day are loaded and dispatched from LIBT, handling about 12,000 passengers. The LIBT was chosen for the study because it has the best infrastructure and facilities, with all major routes and operators therein. LIBT is the legal establishment under the local authority, the Lusaka City Council with the full mandate to manage and superintend the affairs at the terminus. However, due to large number of buses and old age of the infrastructure, the LIBT cannot cope with the huge demand to offer best service to operators and travelling public in general.

Facilities like weighing scales have broken down and now none existence. It is a place characterized by disorder of commotion, hustlers, call boys, vendors, insecurity, and so on, such that the LIBT Staff are overwhelmed to maintain order and sanity, perhaps that is what gives credence that the cadres are in control of the terminus. The LIBT officially charges three hundred kwacha (ZMK 300.00) per bus load per day while cadre charge extra seven hundred kwacha (ZMK 700.00) per bus load per day. This came out as a salient point contributing to bus owners/crew to overload to compensate for the lost income.

Other main bus stations are Kitwe Main Bus (KMB) station, Ndola Main Masala Bus station, and other minor ones in each provincial and districts. The situation is much more like the one at LIBT but may just vary in dimension and magnitude considering that they are smaller stations compared to LIBT.

3.5.3 Proposed System - LWMS

3.5.3.1 Load Weight Monitoring System (LWMS)

Due to none existence of means to measure *load weight* at bus stations, the need to have an automatic load weight detection and monitoring on public buses motivated this study. Therefore, a *Load Weight Monitoring System (LWMS)* is proposed. The results of the baseline study were used to come up with a conceptual model and design for the LWMS on public buses as shown in the flowchart of Figure 3.4.

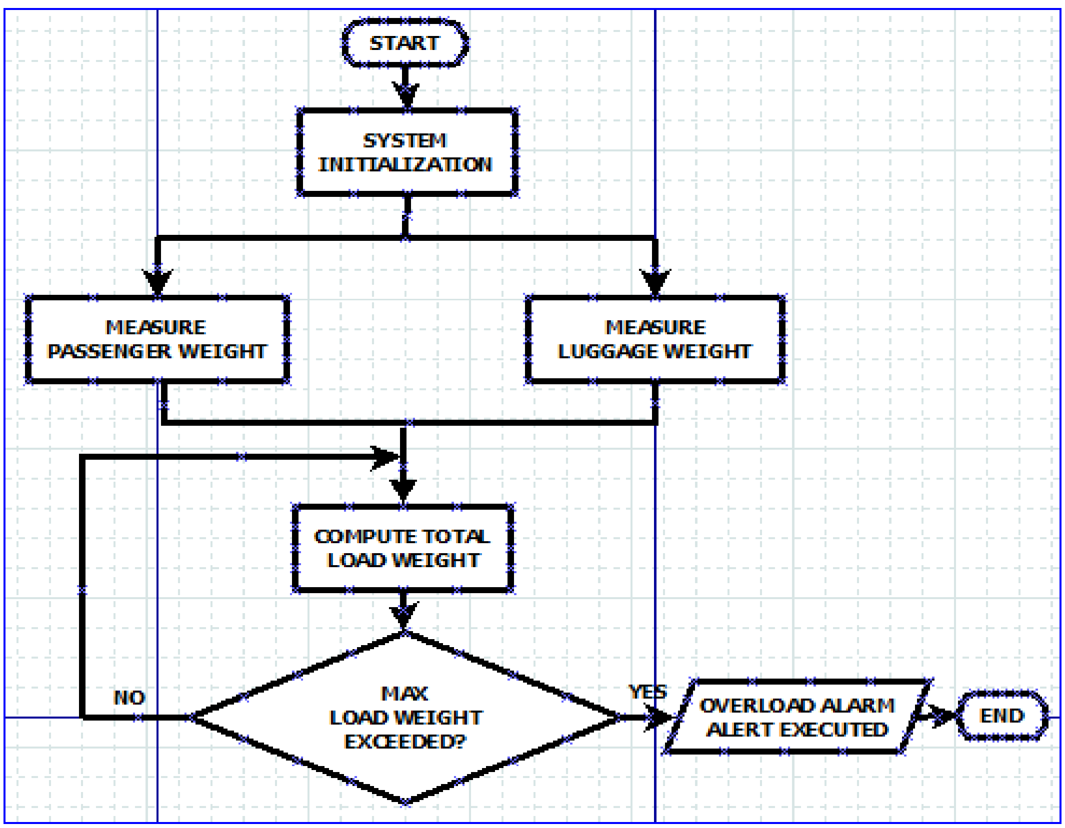

Figure 3.4: Flowchart of Proposed LWMS Model

3.5.3.2 System Design Approach

The system development method used was the Water Fall Model approach and the qualitative data obtained from both the questionnaires and the interviews were used to come up with the system requirements. Currently, the bus seating capacity determines the limit and hence the number of tickets/passengers to loaded on the bus while there is no means to measure the weight of the luggage which is left to the discretion of the bus loaders and crew.

3.5.3.3 System Design Methods and Materials

The LWMS model was designed and developed using of selected hardware and software materials suitable, to achieve the task at hand. Load Cells, Microcontrollers and Sensors were used to measure, monitor and control the weight of the load weight on the bus. A SIM900A GPRS/GSM Shield was used to provide General Packet Radio Services (GPRS) and connect to internet. This was essential to enable load weight data to be captured and logged in to the central database server for stored. This information which mainly consisted of the status of the load weight from the model, was displayed using web pages created using HyperText Makeup Language (HTML), Cascading Style Sheets (CSS) and HyperText Preprocessor (PHP). Through the use of the GPRS/GSM service, the same information in form of Short Messaging System (SMS) was able to be sent to relevant agencies and/or owners/operators.

The following hardware and software materials were used:

(i) Load Cell

A load cell is a hardware weight sensing component. It is a transducer which converts force into a measurable electrical output. Load cell designs can be distinguished according to the type of output signal generated and the way the detect weight. The various types of load cells include: Hydraulic; Pneumatic; and Strain Gauge Load Cells. For details on load cell, refer to *Literature Review* in the previous Chapter Two under Subsection 2.4.

(ii) Arduino UNO R3 Microcontroller

Arduino is an open-source electronics platform based on easy to use hardware and software. In its simplest form, an Arduino is a tiny computer that can be programmed to process inputs and outputs going to and from the chip. The Arduino is what is known as a Physical or Embedded Computing platform, which is an interactive system and through the use of hardware and software, it can interact with its environment. The main advantages of using an Arduino include following: Inexpensive; Cross-platform; Simple, Clear Programming Environment; Open Source and Extensible Software and Hardware.

(iii) SIM900A GPRS Shield

The GPRS module is a breakout board and minimum system of SIM900A Quad-band/SIM900A and Dual-band GSM/GPRS module. It is capable of communicating with controllers via ATtention (AT) commands which are instructions used to control a modem. These instructions help: Get information about the mobile phone; Get basic information about the subscriber; Get the current status of the mobile phone or GPRS/GSM module; Establish a data connection or voice connection to a remote modem; Send or delete an SMS message and obtain notifications of newly received SMS messages; Perform security related tasks such as changing a password; Control the presentation of error messages of AT commands; Get or changes the Configurations of a mobile phone or GPRS/GSM module; and Save the Configurations of a mobile phone or GPRS/GSM module. The module also furthermore supports software power on and reset functions.

(iv) Programming Environment

Because the project include a web application to be developed, the use of HTML was essential. HTML which stands for Hypertext Makeup Language is a standard markup language for creating web pages and web applications. Through the use of HTML, CSS (Cascading Style Sheet) and JavaScript was included to make the web application more dynamic and responsive.

PHP is a widely-used open source general-purpose scripting language that is especially suited for web development and can be embedded into HTML. What distinguishes PHP from other server-side scripting languages is that it is simple to use and code written can be executed on the server which then generates the required HTML pages. Further, more configuration of a webserver to process all HTML files using PHP is possible. For the purpose of this project, the latest version of PHP which was PHP 7.0 was used to create the web application necessary for the project.

Firebase is a mobile and web application development platform. It primarily consists of services such as: Firebase Clouding; Firebase Authentication; Real-time Database; and Firebase Hosting. An Arduino IDE platform was used to programme the microcontroller, sensors and shields used to develop the module. The Arduino IDE provided an easy interface to programme the different software programs required run the hardware devices of the model.

3.5.3.4 System Prototype Model Implementation

The implementation of the LWMS prototype model was split into two main separate modules, namely; the *Loading Bay Module* which represents the loading bay of luggage and is also responsible for measuring and capturing luggage load weight in or out of the luggage compartment; and *Step Sensor Module* which represents a door step on the bus and is also responsible for measuring and capturing the passenger and hand luggage load weight in or out of the bus.

(i) Loading Bay

Figure 3.5 below shows the flow of the proposed Loading Bay module for the LWMS model. The Loading Bay module was used to measure, monitor and calculate the weight of luggage either in or out of the luggage compartment of the bus. A threshold was set to indicate the maximum allowed luggage weight loaded on the bus. Main components of the Loading Bay module were: Arduino Uno R3 Microcontroller; Load Cell; Liquid Crystal Display (LCD); and Piezo Buzzer.

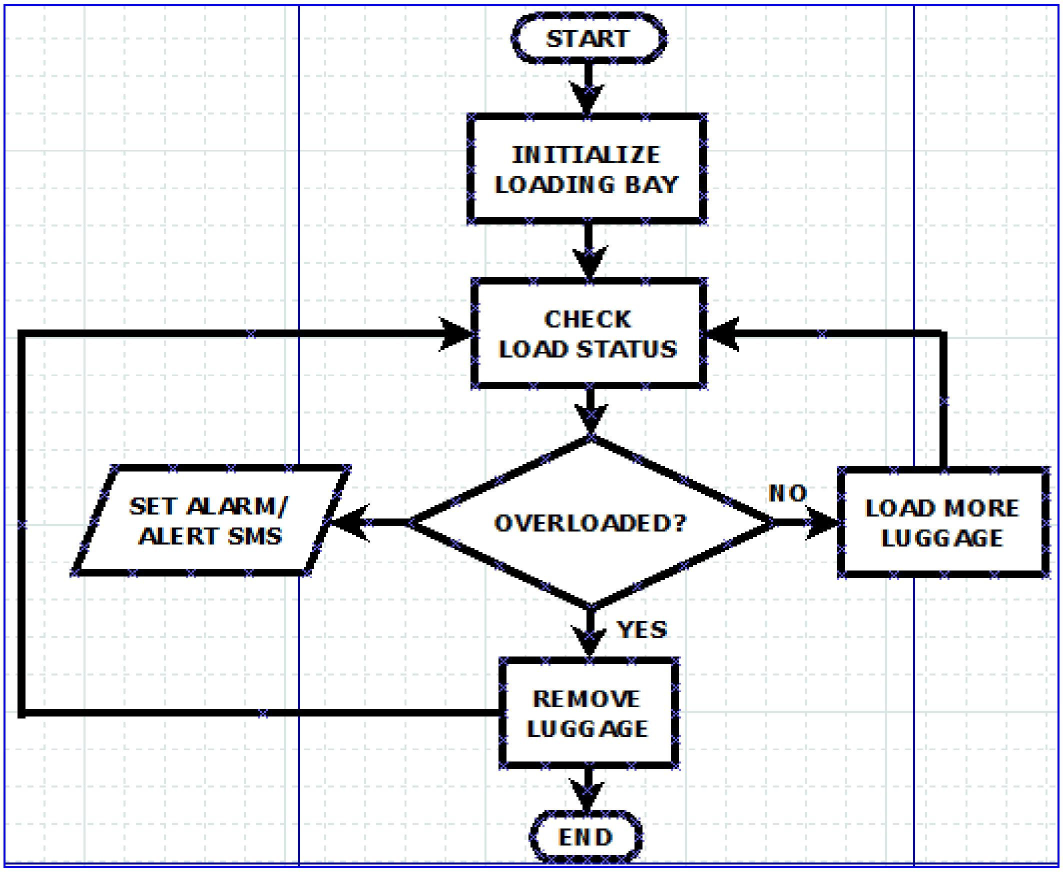

Figure 3.5: Flowchart of Proposed Loading Bay

(ii) Step and Motion Sensors

Figure 3.6 shows the flow chart for the proposed Step Sensor module for LWMS model. The Step Sensor initialization occurs when the system boots, thereafter it remains idle and waits for any motion to be detected. Once motion is detected, code in the Step Sensor determines whether it was a forward motion, that is, a passenger steps into the bus or backward motion, that is, a passenger steps out of the bus. Depending on the type of motion, the load value on the local storage of the Step Sensor, the Arduino storage is updated with a new value for the load weight of the vehicle, this value is then transferred to the online database. It is the value in the database that the system checks to ensure the vehicle is not exceeding the allowed maximum load weight.

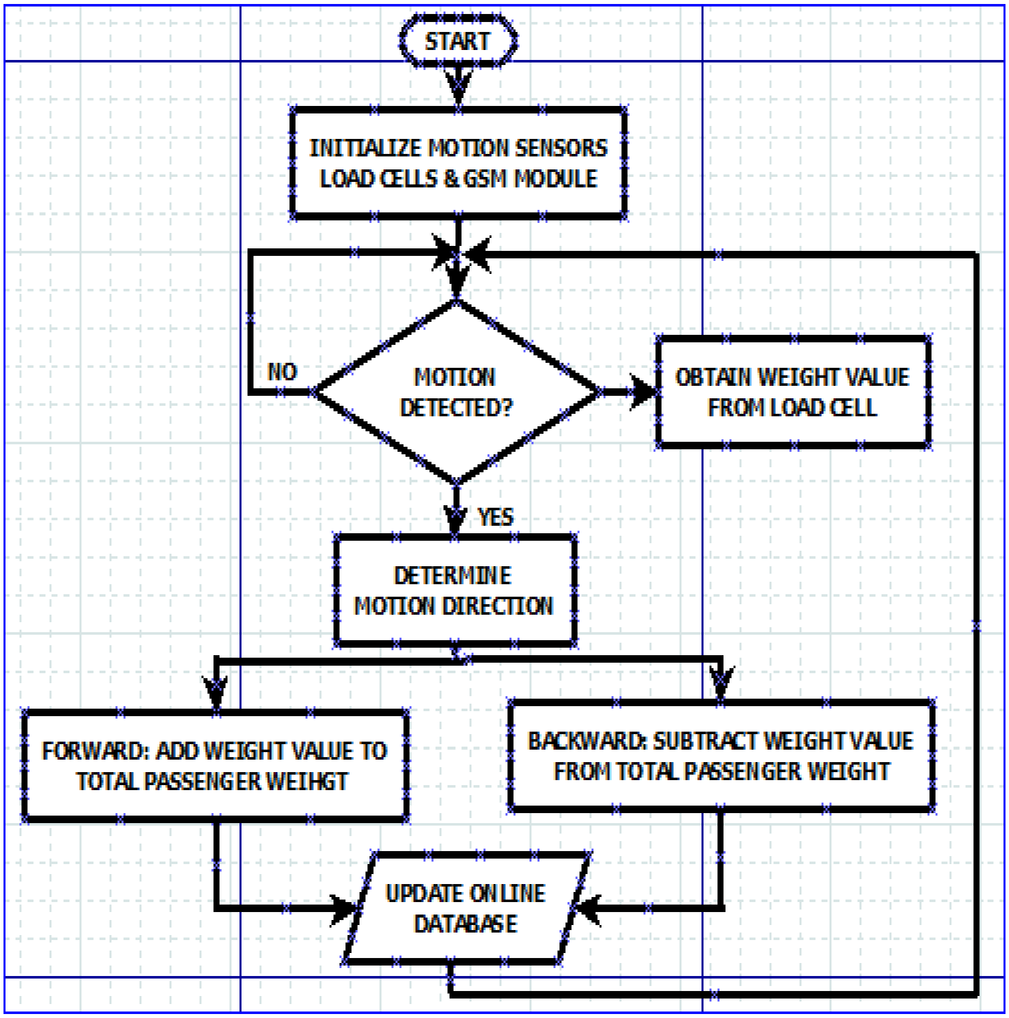

Figure 3.6 Flowchart of Proposed Step/Motion Sensor

The Step Sensor is crucial in detecting passenger weight and it consists of the following components: Motion Sensors, a GSM module and Load Cells, all of which are linked through an Arduino Uno R3 Microcontroller development board. Figure 3.7 illustrates an image of the diagrammatic design of the Step and Motion Sensors. The Side view shows how the sensors are positioned one after the other, in relation to the position of the load cell while the Top view shows the sideward position of the Sensors in order to detect the forward or backward motion direction. The bus entrance has one of the steps embedded with a load cell under it.

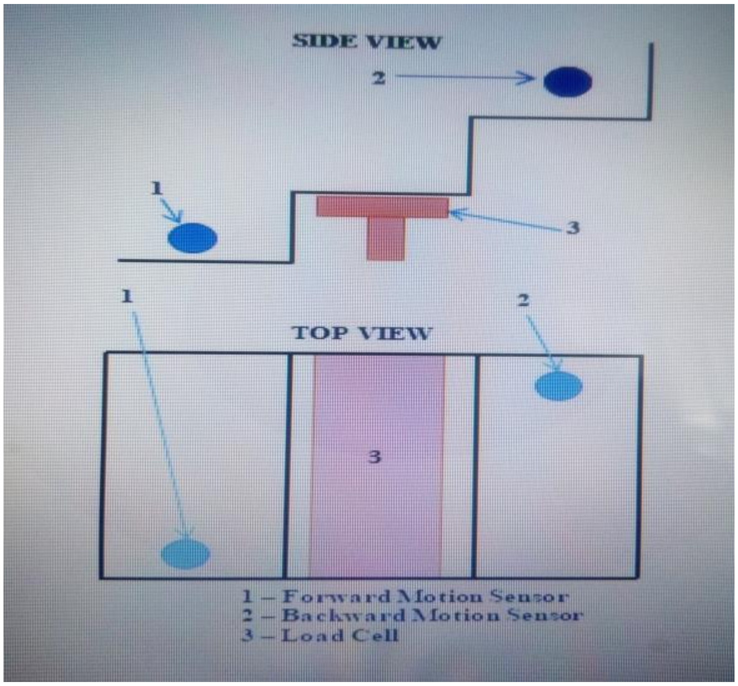

Figure 3.7: Step - Motion Sensors Design

The HC-SR501 Passive Infra-Red (PIR) Motion Sensors is compatible with an Arduino Uno R3 Microcontroller. It possess a 110 degrees viewing area, range of 3 to 7 meters, a LHI778 Infrared Sensor that detects light, and a BISS0001 Integrated Circuit which controls how motion is detected.

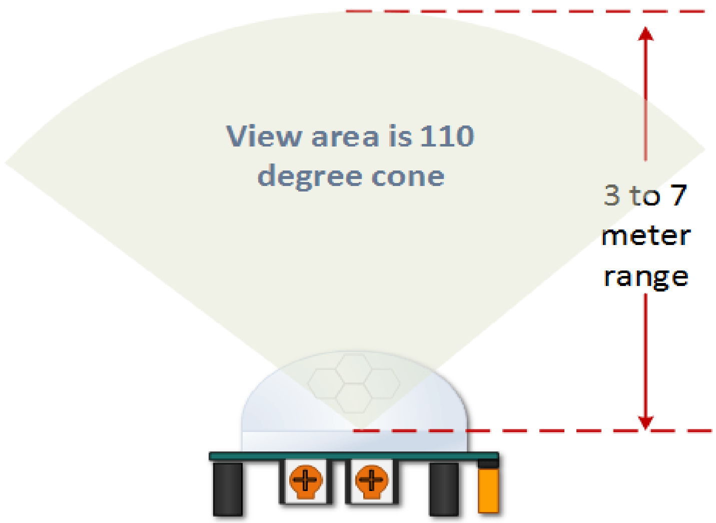

Figure 3.8: HC-SR5O1 Field of View and Range

The HC-SR501's field of view is enhanced by the presence of a spherical Fresnel cap which reflects light inwards towards the infrared sensor as shown in Figure 3.8. The positioning of the motion sensors is very important; one sensor is placed in front of the other in the step sensor. This is designed in this way so that the order in which the motion sensors are triggered determines the direction of motion of the step and subsequently whether to add or subtract the value of the weight that is detected by the load cell placed underneath the step. Figure 3.9 is the layout of the HC-SR501 motion sensor.

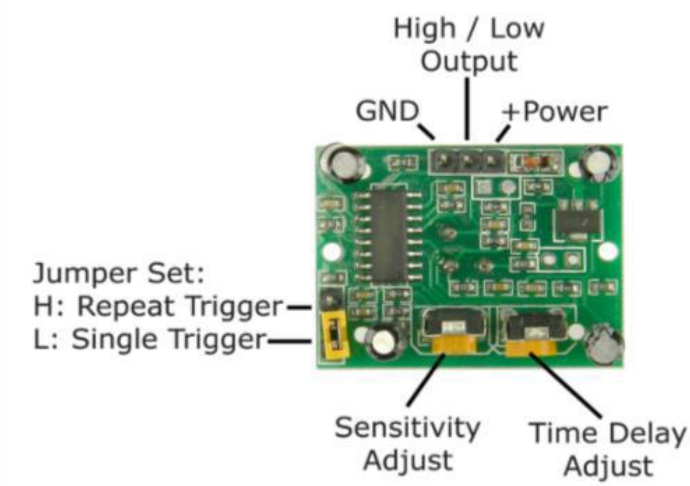

Figure 3.9: Layout of HC-SR501 PIR Motion Sensor

When motion is detected by the sensor, it sends out a HIGH signal through its output pin. The *time delay* is the amount of time the signal will be set HIGH and this is adjustable through the potentiometer on the front of the sensor. The *time delay* is a very important parameter, it must be long enough for both sensors to be HIGH at the same time but not too long so as to block the potential detection of more movement on the sensor that is currently HIGH. The *time delay* of the HC-SR501 ranges from 3 seconds to 5 minutes. For the demonstration, it was set to the minimum of 3 seconds after taking into consideration the average speed at which people walk. The HC-SR501 has a Jumper set, this differentiates between two trigger modes, namely,

(i) *H – Repeat Trigger*: Each detected motion resets the time delay. Thus the time delay begins with the last motion detected.

(ii) *L – Single Trigger*: The time delay begins immediately when motion is first detected.

For the Purposes of the demonstration the sensor was set to H – Repeat mode. The HC-SR501 has limitations of its own, for starters, it requires a minute to initialize after it is first turned on, during this time it gives false readings, secondly and the biggest disadvantage the device possesses is the off time after a detection. What this means is that every time the sensor detects motion and goes HIGH, it becomes inactive after it goes LOW for a period of 3 seconds. During this period the device detects no motion whatsoever and is as good as absent. This implies that continuous sequential movement of passengers in to and out of the bus will result in erroneous readings for weight as the motion sensor would detect some movement and become inactive, during this period of inactive the demonstration sensor does not detect any movement and therefore provides a window for passengers to enter or exit the vehicle without the weight being logged by the system.

(iii)GSM Module

The LWMS model updates the online centralized database through the use of wireless digital communication link, the GSM module. The specification of module used in the model is the TinySine GSM shield, shown in Figure 3.10, which uses the SIM900 module. It can be used to send and receive data, voice calls and SMS messages, hence its suitability for the model. However the speed of the device is slow, which is a great hindrance to updating the database. This makes the use of the Arduino and GSM module inappropriate for commercial deployment of the proposed system but is adequate for demonstration purposes. When the maximum load weight of the bus is exceeded the GSM module sends an SMS to the bus owner/operator and relevant agencies.

Figure 3.10: TinySine GSM Shield for Arduino Uno

3.6 Summary

This chapter discussed the research design, methods and strategy used in accomplishing the aim and objectives of the study. A comprehensive literature review was conducted and a mixed method, which integrates qualitative and quantitative data collection and analysis, was employed. Non-random sampling was adopted in this study to deliberately target individuals within a population. Structured questionnaires were used as data collection tools.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents the detailed results of the baseline study whose objective was to establish the challenge of passengers and luggage overloading on public buses and then propose a solution, the LWMS, to mitigating the challenge of overloading. The results of the system development, implementation, testing and evaluation are also highlighted in this chapter.

4.2 Baseline Study

In this section, the results of the baseline study are presented as derived from the analysis of the responses from the questionnaires. The challenges of overloading on public buses as expressed by all stakeholders and the possible solutions to the challenges are presented. All stakeholders confirmed that there was rampant overloading on public buses because of none availability of means to measure passengers and luggage at bus stations. The findings from both key informants and respondents were grouped together according to the themes on the qualitative data.

4.2.1 Profile of Respondents

A sample size of 120 participants were targeted and 106 questionnaires were distributed out of which 92 were successfully completed and returned. A study [181] found that where the target respondents are homogeneous [181], a sample size of 120 participants would be considered sufficient and adequate. Further, a response rate of above 65 percent for self-completion questionnaires is considered acceptable [182]. Therefore, with the response rate of 86.79 percent for this study shows that the achievement was well above acceptable level [182]. Table 4.1 below summarizes this data.

Table 4.1: Number of Targeted Sample Size verses Number of Respondents

	Targeted Sample Size	**Number of Respondents**	**Response Rate**
TOTAL	**120**	**106**	**86.79%**

The total number of respondents from all participants was 92, broken down as shown in Table 4.2.

Table 4.2: Overall Respondents

Category	**Number**	**Percent**
Institution	36	39%
Operator	14	15%
Crew	42	46%
TOTALS	**92**	**100%**

4.2.2 Demographic Information

This section presents data on the study participants' demographic information. These include gender, age, levels of education, responsibility and category of organization the respondents were coming from.

4.2.2.1 Gender Distribution of Respondents

The data collected from the respondents as shown in Table 4.3, shows that there were eighteen (18) females representing 20 percent and seventy-four (74) males representing 80 percent of the respondents. This shows that there were more males who participated in the study than females.

Table 4.3: Gender Representation

Category	Male	Female
Institution	23	13
Operator	13	1
Crew	38	4
TOTALS	**74**	**18**

4.2.2.2 Age Distribution of Respondents

The overall age distribution was found that, eight (n=8) were between 17 and 27 years of age representing 8.7 percent of the respondents. Thirty-six (n=36) came from 28-38 age group range representing 39.13 percent of the respondents, forty-four (n=44) were from 40-49 age group range representing 47.83 percent of the respondents, and four (4) were above of 50 years of age representing 4.35 percent. The information on age was important because it helped the researcher to know the active age group in the public transport industry as shown in Figure 4.1.

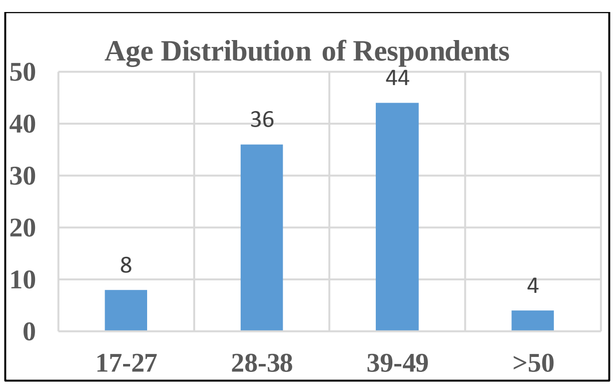

Figure 4.1: Age Distribution of Respondents

4.2.2.3 Level of Education of Respondents

The bar chart represented in Figure 4.2 shows the numbers of highest level of education of the respondents. Thirty-four (34) respondents representing 37 percent went up to Grade 12, Five (5) respondents representing 5 percent had Professional Certificates, sixteen (16) respondents representing 17 percent were Diploma holders, thirty (30) respondents representing 33 percent were Degree holders, and seven (7) representing 8 percent were Masters' Degree holders.

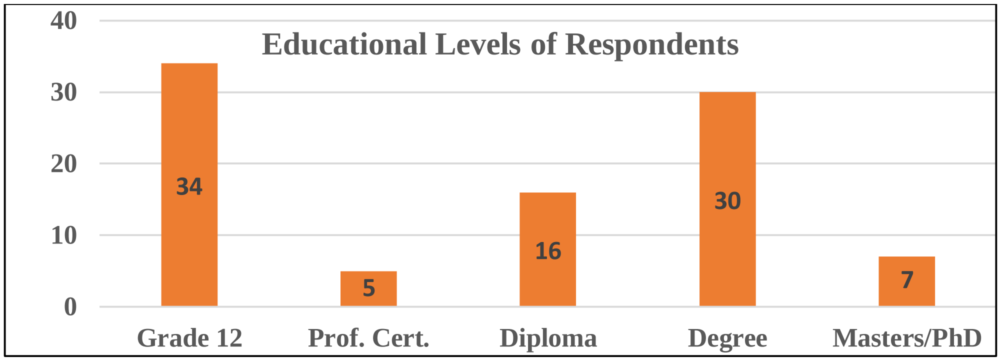

Figure 4.2: Highest Educational Level Attained

Educational levels were important to the study because they influenced the respondents' way of assimilation, analyzing, and responding to the questions. The higher the educational level the more the level of critical thinking, addressing issues at hand and quality of responses offered.

4.2.2.4 Level of Responsibility of Respondents

The level of responsibility from all respondents was at 5 percent (n=5) for CEO/Directors, 25 percent (n=23) each for Managers/Administrative and Support Staff, and 45 percent (n=41) for Others/Bus Crew, as shown in Figure 4.3.

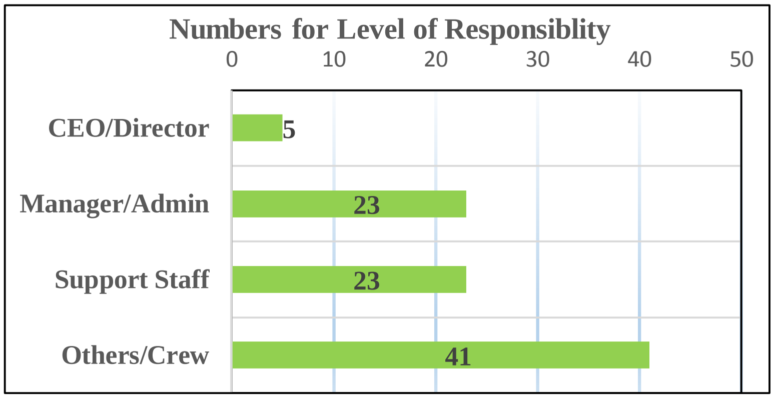

Figure 4.3: Level of Responsibility

4.3 System Automation

4.3.1 Baseline Study

The research study also showed that 94 percent of the respondents were in fovour and 6 percent were not in fovour of an automatic load weight monitoring system on public buses as shown in Figure 4.4.

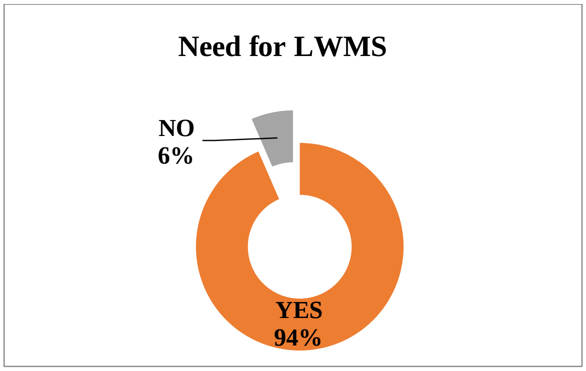

Figure 4.4: Responses for Need of LWMS

Only 6 percent gave dissenting views expressing skepticism that negative human attitude will always prevail despite measures put in place to mitigate any challenge. Figure 4.4 shows respondents response as to whether there is need for an automated system or not.

The research findings also confirm that the challenge of overloading, as indicated in Table 4.4, was attributed mainly to luggage at 93 percent while that of passengers was only about 7 percent.

Table 4.4: Level of Overloading Challenge on Buses

No.	Cause	Number	Percent
1	Luggage	86	**93.4**
2	Passengers	06	**6.6**
	TOTAL	**92**	**100**

Another interesting revelation from the research study was the varying perception from various stakeholders on the most risk factors contributing to road traffic accidents (RTAs) as shown in Table 4.5.

Table 4.5: Most Risk Factor Contributing to RTAs

No.	Factors	Institutions	Owners	Crew	Overall
1	Human	75%	29%	35%	**54%**
2	Road/Environ.	19%	64%	55%	**39%**
3	Vehicle	03%	07%	10%	**06%**
4	Others	03%	00%	00%	**01%**
	TOTAL	**100%**	**100%**	**100%**	**100%**

Worth noting is also the overall responses from all stakeholders on the most risk factor that contributes to RTAs as being the human factor at 54 percent compared to the next road/environmental factors at 39 percent as shown in Figure 4.5.

Further analysis of human factors revealed issues of over-speeding, driver fatigue, substance use or drunk driving and use of cell phone while driving. However, there was no direct mention of overloading as a cause of RTA, though acknowledged to be rampant and a road safety hazard. Indirect mention of tyre burst as a cause of RTA due to overloading was mentioned. This actually underscores the point that there is currently no mechanism or means to measure the load weight on vehicles in Zambia apart from few weighbridges located on few selected roads.

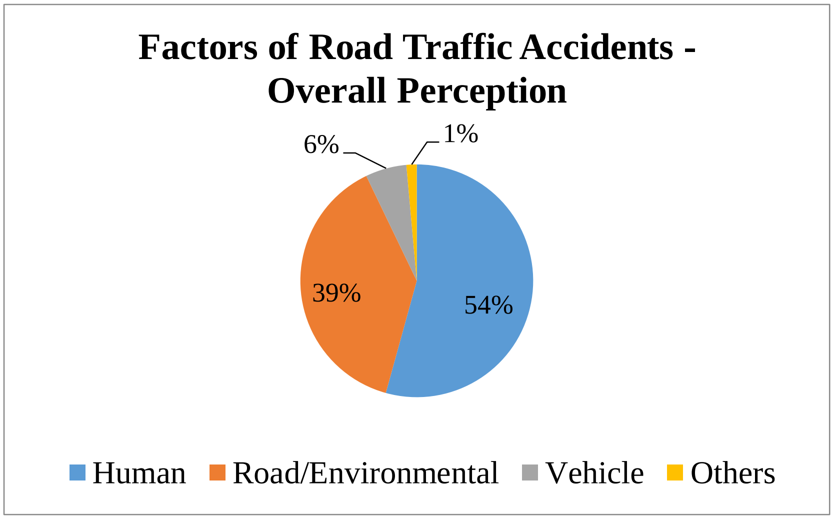

Figure 4.5: Factors of RTA – Overall Perception

This research also brought out important points on the fact that the challenge of overloading on public buses in Zambia is related to one of the factors that contribute to road traffic accidents, that is, the human factor. Further analysis of human factors revealed that a number of issues ranging from social-economic factors to survival requirements contribute to the crew overload the buses to make extra income without the knowledge of the bus owners/operators and contravening road traffic regulations. The specific responses from the baseline study also highlighted the following as factors contributing to overloading:

(i) Selfishness by culprits;
(ii) Greediness of the transporters wanting to maximize their profits at the expense of damage to the roads;
(iii) Haste to deliver essential goods due to market forces;
(iv) Corruption by weighbridge officers;
(v) Lack of proper load adjusting facilities at weighbridges;
(vi) Abrupt braking by HGVs due to unforeseen conditions especially on bad road sections causes shifts in loads hence disturbing the load distribution over axles;
(vii) Lack of weighbridges at loading points;
(viii) Ignorance of the regulation;
(ix) Lack of effective controls;
(x) Lack of highway patrols;
(xi) Modifications of trailers making them carry more than recommended load weights.

4.3.2 System Prototype Model Implementation

The results of the baseline study provided the necessary system requirements for the design and implementation of the LWMS prototype model. It was implemented successfully and was capable of performing the required tasks as specified. The separation of the Loading Bay and Step Sensor modules was done to facilitate easy in design and implementation, and clarity in explanation.

Other modules in the prototype model included: GSM Module; Mobile Phone and Web Application Modules

4.3.3 Loading Bay Module

The image in Figure 4.7 below shows the developed prototype of the Loading Bay for the LWMS. The main components of the Loading Bay Module were:

No.1: Weighing Platform: surface upon which the luggage is placed for measurement;

No.2: Load Cell: active component transducer that converts physical weight into electric signals; No.3 Base Mounting: firm base that holds and supports the entire device.

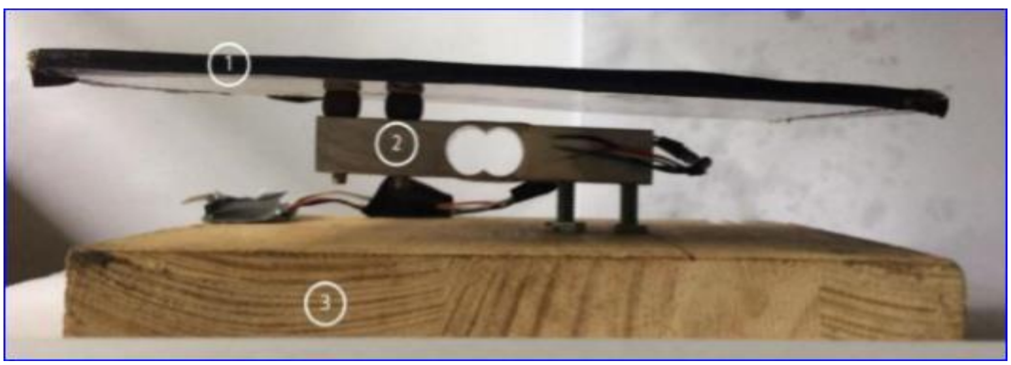

Figure 4.6: Prototype Loading Bay for the LWMS Model

4.3.4 Step Sensor Module

The image in Figure 4.8 shows the fully implemented Step Sensor module for the LWMS. The main components of the Step Sensor Module were:

No.1: Motion Sensors: shielded to avoid wrong motion detection;

No.2: Step Sensor: imbedded with a Load Cell;

No.3: Arduino/GSM: module for control and communication; and

No.4: Breadboard: used to inter connections.

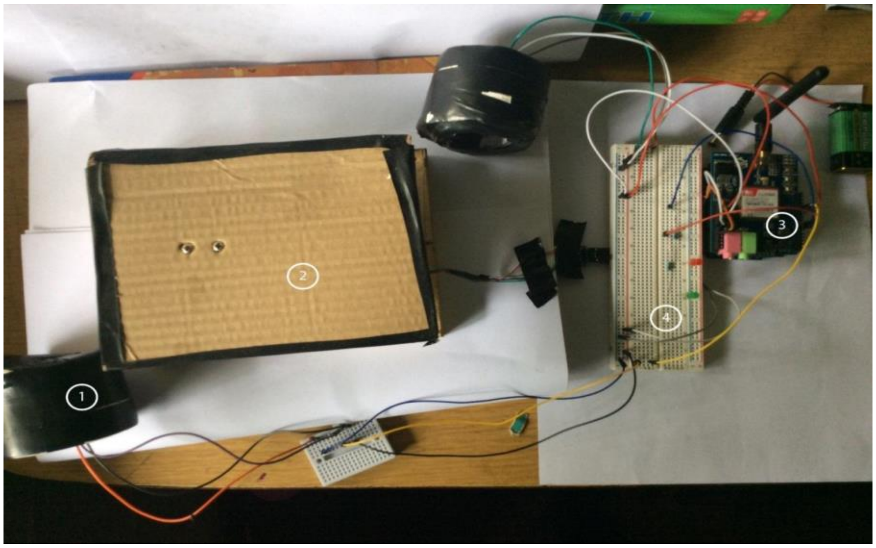

Figure 4.7: Step Sensor component for the LWMS Model

4.3.5 GSM Module

The LWMS model updates the online centralized database through the use of wireless digital communication link, the GSM module. The specification of module used in the model is the TinySine GSM shield which uses the SIM900 module. It can be used to send and receive data, voice calls and SMS messages, hence its suitability for the model. However the speed of the device is slow, which is a great hindrance to updating the database. This makes the use of the Arduino and GSM module inappropriate for commercial deployment of the proposed system but is adequate for demonstration purposes. When the maximum load weight of the bus is exceeded the GSM module sends an SMS to the bus owner/operator and relevant agencies.

4.3.6 Mobile Phone and Web Applications

This module provides the user interface to enable the user to monitor the current load weight of the bus as the passengers and luggage are loaded, using the Software Component of the system. It was essential for users of the system to have real time information displaying the current status of load weight of the bus at any given time. This is achieved through use of a thin client model in a browser. A user of the system is able to login to the system, using his/her credentials and check the status of the bus through a browser. Use of a browser is not very efficient as it is not real time, so the client is able to access his/her bus status through a mobile application.

Figure 4.8 shows the screenshot of the user's view of the current weight calculated from the prototype model while Figure 4.9 shows the screenshot the alert message.

Figure 4.8: User View of the Current weight

Figure 4.9: Screenshot 2019/01/15 12:43:27

The client can view the current weight of the bus through the browser as shown above. Upon reading the Loading Bay and Step values, they are added and then data was sent to online database through the GSM module already described above. The process of transmitting data was successful with the only drawback of the slow speed at which the Arduino uploaded the data. When the maximum load weight is exceed, an overload alert alarm is executed and an SMS message is sent to the bus owner/operator and relevant agencies using the GSM module which is equipped with a SIM card to connect to Mobile Network Service Provider to report overloading. Figure

4.4 Testing and Evaluation

The system was tested by testing the quality and integrity of both the physical and software model developed. The testing of the physical model was done by setting a threshold that represented the maximum allowed weight. A series of known and unknown weights were used to test the threshold and the response of the system. Using the Web and Mobile Apps, it was demonstrated by capturing the status of current load weight, then the data sent to the User View, who can be the owner/operator or regulating agency. The data results of the tests were also sent to a web server which stored the information in a Firebase database.

4.5 Summary

In this chapter, results of the baseline study with respect to the profile and demographic data were highlighted; the system development, design and implementation was also highlighted in details showing how the module components of the loading bay and step sensor were implemented.

The baseline study established that the challenge of overloading was real on public buses deducing from the overwhelming responses from stakeholders. In the same spirit, the respondents overwhelmingly supported and recommended the need for an automated load weight monitoring system on public buses. The LWMS model was tested satisfactorily, integrating the physical hardware model and the software program developed and results obtained show-cased the point that it can be concluded that the LWMS was feasible to be implemented on a large scale in real life situation though need some improvement to tap into already existing technologies. The testing and evaluation of the LWMS gave positive results hence proving that given the necessary resource, this can be implemented on a large scale in real life environment.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

5.1 Introduction

This chapter presents the discussion of the research findings as presented in chapter four. A discussion of the results of the baseline study, system design and implementation, conclusion of the research, recommendations and future works are presented.

5.2 Baseline Study

A baseline study was conducted in order to establish the challenge of overloading on public buses in Zambia and help find a solution to mitigate the challenge of overloading. The findings helped to come up with a solution that could mitigate the challenge of overloading and improve the orderliness and accountability in the management of load weight on public buses.

The loading of passengers and luggage on public buses in Zambia is currently chaotic and disorderly, posing several challenges to the nation at large and to society, families and public transport business operators in particular. The first challenge identified and confirmed from the baseline study was that of overloading on public buses.

Overloading on public buses is very rampant, more especially on luggage at 93.6 percent than on passengers at 6.6 percent, as results indicate. The main reason attributed to this vice of overloading was the absence of a mechanism to establish the load weight limit at bus stations as the passengers and the luggage was loaded on the bus. At least for passengers, the sitting capacity of the bus was at times used as the maximum number of passengers to be carried. But as for luggage, it was only limited by how much the luggage compartment could possibly allow with no regard to the actual weight it was. In fact the conductors and loader even take advantage of this current situation because the luggage price is not determined by any standard unit of measurement, but rather on how big or small, or how the passenger is looking, and the price is charged of course sometimes with recourse of negotiation. Alas, this luggage income is rare accounted for and reaches the bus owners/operators.

The results from the study also reveals interesting responses from the question as to the most risk factors contributing to road traffic accidents. From the regulator institutions and agencies they attributed it to the human factor at 75 percent; while the bus owners/operators attributed it to the road and environmental conditions at 64 percent; and the bus crew also attributed it to the road and environmental conditions at 55 percent. These different views and responses could be attributed to the human aspect or professional inclination where any vice would usually be blamed on others than what is in my domain. But on the overall, the study confirmed that the two most risk factors contributing to road traffic accidents are the human factors followed by the road and environmental factors.

Therefore, it is important to raise road safety educational awareness programs to the bus crew, who seems have low levels of education, and bus owners/operators. Also the introduction of an automated system to monitor load weight on public buses as proposed in the LWMS is one positive way in this direction. At the same time, the road and environmental conditions must also be in acceptable condition, and with proposed LWMS being rolled out, it can lessen road pavement damage and reduced expenses on road maintenance.

5.2.1 Demographic Information

The demographic information for the respondents was captured such as sex, age, educational level, and responsibility. The results showed that there were more men than women who participated in the research study. The age of the respondents who participated in this study ranged from 17 to 54 years old with 20 percent female and 80 percent male. The levels of education for the participants ranged from Grade 12 to Master’s degree.

It was clear from the demographic result that transport industry on public buses was a more male dominant field especially on the bus owners and crew in the middle age group between 28 and 49 years old. Their levels of education were rather on the lower side especially the crew but remarkably acceptable and reasonable from the bus owners/operators and agencies/institutions. Actually, from the results it clearly showed that the level of highest qualification attained was directly proportional to the level of the responsibility.

5.3 System Prototype Model

5.3.1 System Design and Development

The results of the baseline study presented in Chapter Four, as derived from the analysis of the questionnaire, provided the basis for the system prototype model design, development and implementation as they gave a full appreciation of the current load weight management with its associated challenges. It also brought out the necessary system design requirements for an enhanced proposed system to mitigate the challenges of the current method of load weight management.

The results of the baseline study also gave a clear confirmation that there was rampant overloading from all respondents and that there is need to come up with an automated system to mitigate the challenge of overloading, improve road safety, lessen road traffic accidents, and above all bring that conscious awareness to the bus crew as how much load weight they were carrying and avoid being surcharged on weighbridges while preventing road pavement damage. As stakeholders directly involved on the ground, the bus crew also pledged to embrace the new system if introduced and make full benefit of it

5.3.2 System Prototype Model Implementation and Testing

The main technique that was used in the system design was Process Modelling and employed flowcharts because of the easy and clarity of description of the logical processes needed in the model. To easy the implementation, two main modules had to be done separately and these are the Loading Bay Module and Step Sensor Module. The Motion Sensor Modules were also important in this model and they were incorporated to sense passengers/luggage either in or out of the bus so as to effectively calculate the current load weight. The GSM Module was also used to update the online centralized database through the use of Wireless Digital Communication link. All these modules were linked through the Arduino Uno Microcontroller development board which provided the control and interface.

From the positive and successful testing and evaluation results, it was evident that technically an automatic load weight monitoring system can be implemented on public buses to mitigate the challenge of overloading using modern technologies to improve efficiency in operation, road safety, reduce road infrastructure and vehicle degradation.

5.4 Conclusion

This study brought out a lot of important points concerning the challenges faced in the public transport sector particularly on public buses. The literature reviewed gave a clear understanding of the challenges of public transport in general and public buses in particular. One of the many challenges on public buses was identified to be overloading of passengers and luggage, hence exceeding the maximum permissible load weight. It also gave a wide knowledge and insight on the various existing and emerging technologies like Sensor Technologies for weight and for motion, Mobile Web Applications, Wireless Sensor Network (WSN), Cloud Computing and Internet of Things (IoT); all in one way or another could be exploited to provide viable solutions to our human challenges. The three (3) objectives of the research study were realized, that is, to conduct baseline study, propose and design new system, and develop prototype model of new system.

In meeting the first objective, a baseline study was conducted in order to establish the challenge of overloading on public buses in Zambia to which all stakeholders positively affirmed its existence and also affirmed need to have an automatic load weight monitoring system to prevent overloading. From results of analysis of the respondents' feedback, it was overwhelming that overloading was real, attributed to over loading of luggage and passengers. While there was currently no mean to measure the weights of both luggage and passengers, the latter was relatively easy to handle because it is limited by the seating capacity of the bus. Accordingly, the number of tickets sold corresponds to the bus seating capacity thereby limiting number of passengers boarding the bus, hence rarely contribute to overloading. On the other hand, the former in current situation is very difficult to manage in establishing the weight of luggage loaded on each bus because apart from passenger luggage, there is also additional unaccompanied luggage carried on the bus for extra income for the crew without the knowledge of the owners/operators.

To achieve the second objective, the baseline findings were also used to propose and design a new system, the LWMS, as a solution that was demonstrated to be much better to solve the challenge of overloading on public buses using modern technology thus improving the efficiency in operation, road safety, reduce infrastructure and vehicle degradation, and many more.

Lastly, the third objective was realized by actually developing and implementing the prototype model of a new system, the LWMS which was tested and evaluated successfully indicating that it is technically possible and viable to introduce the automated load weight management system on public buses to mitigate the challenge of overloading on public buses.

In conclusion, the introduction of the proposed LWMS would introduce an orderly, logical and accountable system with up-to-date accurate data on the load weight of each bus at any given time using the state-of-art technology. One of the major contribution of this research study was explaining the challenge of overloading on public buses which helped to come up with a solution that uses the current technologies to ensure efficiency and road safety in the public road transport system. The results obtained show that in Zambia, there is already a wide use of these ICTs like digital communication system of Public Mobile Network which was easily integrated to be used for data transmission to all other relevant parties. Other ICT infrastructure already in use like the Transport Intelligent System (TIS) and Vehicle Identification (VID) can easily be integrated with the LWMS. All in all, the anticipated benefits and associated cost savings of LWMS to reduced overloading relates to operational enhancements, road infrastructure preservation, increased road safety, reduced vehicle damage, congestion, fuel consumption and reduced harmful emissions.

5.5 Recommendations

This research study has revealed that the automated load weight monitoring system in Zambia is desirable and therefore it is recommended that the system be supported and be fully implemented on all public buses together with the speed limit monitoring system which is already in operation on some buses.

As technology keeps on changing and advancing, it is important that the management and operation of public transport system in Zambia is kept abreast with the world trends like tighter coordination and collaboration between all relevant agencies in the transport sector by sharing computer infrastructure resources like cloud computing, centralized databases, and so on. The phenomenon of overloading on public buses is multi-sectorial in nature and hence requires consented effort from all stakeholders to combat. These efforts may require policy, legal, social, institutional and infrastructural reforms. As a way forward, employing technology in the management of load weight on buses could be well integrated with other initiatives like the intelligent road management systems.

The introduction of Global Positioning System (GPS) on some public buses to monitor speed in dealing with the challenge of over-speeding can also in a similar way be made to incorporate overloading and regulation passed to make it mandatory.

The use of Weight-In-Motion (WIM) technology in the management load weight of commercial vehicles on the roads as done in developed countries need to be thoroughly studied so that it can be customized and incorporated in our systems too.

Other sectors in the public road transport industry like heavy commercial vehicles (HCV) and trucks can also take advantage and incorporate the emerging technologies to ensure compliance of maximum load weight limit by having them fitted with automated weight monitoring system to prevent overloading. Therefore, it is also recommended that this proposal with modification to measure and monitor the load weight from the source and throughout the trip be extended to all HCV and trucks, for example, construction trucks from the quarry sites, HCV and trucks from industrial loading bays, and so on.

5.6 Future Works

The future works for this prototype model would be to develop it as a full-fledged bus system, one to be used for ticketing of passengers and luggage as well. The addition of a full-fledged user Mobile application would lend to this idea, passengers would be able to book a ticket and also make payments through it. Adding RFID for use with the luggage tracking would improve the security of the system too.

Future editions of the system would seek to use better communication technology, possibly through the use of a Wi-Fi module to improve on the speed at which the transmission of load weight data values are uploaded to the centralized database server.

Furthermore, clients of the system, i.e. bus owners/operators and relevant agencies/institutions should be given more functionality through a Client App. The option to intervene when the bus is overloaded would be of great benefit, for instance, to disable the bus through the Client App would go a long ways to preventing road infrastructure damage and all other associated risks.

Additionally, power to the client would be in form of GPS functionality to the Client App., the ability to monitor the position, speed, and so on of the bus would be an added benefit for the system versatility.

Further studies could be the direct coupling to the ignition system of the bus, to inhibit the ignition system if the bus is overloaded and only start if the load weight is within acceptable limits.

5.7 Summary

The study brought out important points on the fact that there are challenges in the public transport sector in general and on public buses in particular in term of load weight management. The main challenge highlighted in this study was that of passengers and luggage overloading on public buses. All the stakeholders from the three sectors institutions/agencies, bus owners/operators, and bus crew, overwhelmingly agreed that currently there was rampant overloading on public buses. They also agreed that introduction of an automated load weigh monitoring system would go a long way to curb the vice of overloading and help foster sanity and order in the management of load weight on public buses.

The proposed LWMS would enhance business in because of its inherent accountability attributes and it would cut down on some unnecessary processes thereby the reducing cycle time. According to some scholars, cycle time is defined as the time it takes to complete a process from the beginning to the end [183]. Time is recognized as a major resource that provides competitive advantage, and therefore cycle time reduction is a major objective in any business enterprise.

A major contribution of this research study was highlighting the challenge of load weight management on public buses and to come up with a solution that uses the modern technologies to ensure efficiency, effective and improved load weight management on public buses. Similarly, other sectors in the public transport industry can also take advantage of these emerging technologies to ensure improved compliance on maximum load weight limit adherence. The results obtained show that in Zambia the deployment and utilization of Information and Communication Technologies (ICTs) is on the upswing, hence it makes business sense to come up with systems that leverage on these technologies.

As technology takes up a positive trajectory on advancement, it is important that systems also are regularly updated to match the pace. In this study, use of sensing technologies and ICTs have been proposed to measure, capture and transmit load weight data to centralized database server to provide effective information distribution to all relevant parties.

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APPENDICES

Appendix A: List of Key Stakeholders

National Road Fund Agency (NRFA)

Road Development Agency (RDA)

Road Transport and Safety Agency (RTSA)

Zambia Airport Corporation Limited (ZACL)

Zambia Metrology Agency (ZMA)

Zambia Bureau of Standards (ZABS)

Lusaka Intercity Bus Terminus (LIBT)

Bus and Taxis Owners Association of Zambia (BTOAZ)

Private and Public Drivers Association of Zambia (PPDAZ)

C.R. Holdings Limited

C.V. Transporters

Chibeka Express

Euro-Africa Bus Services

Jordan Bus Services

Kays Bus Services

Khondwani Bus Services

Kobs Coach Services

Mazhandu Family Bus Services

Miracle Express

Power Tools Bus Services

R.K. Travellers

Shalom Bus Services

Trans-Africa Bus Services

Wada Chovu

Zampost Post Bus Services

Appendix B: Questionnaires [*Three Sets: Institutions, Bus Owners and Bus Crew*]

The University of Zambia

School of Natural Sciences

Department of Computer Science

QUESTIONNAIRE

PASSENGER AND LUGGAGE WEIGHT MONITORING SYSTEM ON PUBLIC BUSES BASED ON SENSOR TECHNOLOGY IN ZAMBIA

Contact Details:

Name : **Apolinalious Bwalya**

Email : **apolinalious@cs.unza.zm**

Mobile: **+260 966 362 494**

The University of Zambia

School of Natural Sciences

Department of Computer Science

Semi-Structured Questionnaire for Institutions/Agencies

TOPIC:

PASSENGER AND LUGGAGE WEIGHT MONITORING SYSTEM ON PUBLIC BUSES BASED ON SENSOR TECHNOLOGY IN ZAMBIA

Dear Respondent

I am a student at the University of Zambia pursuing a Master of Science in Computer Science and I am in second year (research) of my study program. As partial fulfillment for the award of a Master of Science degree, I am conducting a baseline study on: "***Passenger and Luggage Weight Monitoring System on Public Buses in Zambia***"**.**

You have been randomly sampled to provide information for the topic indicated above. The information being collected is purely for academic purposes as such, it will be treated with maximum confidentiality. Subsequently, you are not supposed to indicate your name or any personal information that can lead to revealing of your identity.

Your co-operation will be greatly appreciated.

For more information or any queries, kindly get in touch with the following:

Project Supervisor: **Dr. Jackson Phiri**

Contact Details: **jackson.phiri@cs.unza.zm** or **0966 693 731**

Head of Department – Computer Science: **Mrs. Monica K. Kabemba**

Contact Details: **monica.kabemba@cs.unza.zm** or **0971 577 705**

QUESTIONNAIRE FOR INSTITUTIONS/AGENCIES

Instructions

1. Answer all questions.
2. Mark ☒ in the appropriate checkbox.
3. Circle on the response that characterizes how you feel.
4. Write answers for the other questions in the spaces provided.

Section A: Basic Background Information

1. What is your gender?
   - ☐ Male
   - ☐ Female

2. What is your age group?
   - ☐ 17 – 27
   - ☐ 28 – 38
   - ☐ 39 – 49
   - ☐ 50 years and above

3. What is your current highest educational level of qualification attained?
   - ☐ Grade 12 Certificate
   - ☐ Professional Certificate
   - ☐ Diploma
   - ☐ Degree

☐ Master's degree
☐ PhD

4. What is the level of responsibility in your institution/agency?
   ☐ CEO
   ☐ Administrator
   ☐ Planner
   ☐ Manager
   ☐ Support Staff
   ☐ Other(Specify)

   ____

Section B: General Information

5. What is the name of your institution/agency____

6. How many years has your institution/agency been in existence?
   ☐ Below 10 years
   ☐ 11 – 20 years
   ☐ 21 – 30 years
   ☐ Above 30 years

7. What is/are your key role/roles do you play in the field of public transportation?
   ☐ Policy Maker/Regulator
   ☐ Planner/Financing
   ☐ Road Construction/Maintenance
   ☐ Traffic Control/Management
   ☐ Support Services/Bus Services Owner/Operator
   ☐ Other(Specify)

   ____

8. Are your institute/agency operations involved with public transport bus services?
   ☐ YES
   ☐ NO

9. If YES to Question 8, what is the average number of public buses you deal with in a day?
   ☐ Less than 10

☐ 11 - 50
☐ 51 - 100
☐ Above 100

10. What do you think is the most risk factor contributing to road traffic accidents? (Choose one)
☐ Road Environmental Factors
☐ Vehicle Factors
☐ Human Factors
☐ Others (Specify)

____

11. For each of the statements below, circle on the response that best characterizes how you rate the risk factors contribution to road traffic accident, where:
1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree Nor Disagree; 4 = Agree; and 5 = Strongly Agree.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1. Road Environmental Factors include Poor Road Construction, Signage, Markings, Lighting, Potholes, Obstructions, etc.	1	2	3	4	5
2. Vehicle Factors include Manufacturer Defects, Tyre Burst, Excessive Loading, Unroadworthy Vehicles, etc.	1	2	3	4	5
3. Human Factors include Human Errors, Negligence, Over-loading/-speeding, Traffic Rules Violation, etc.	1	2	3	4	5
4. Other Factors include various Unknown factors	1	2	3	4	5

12. What measures can be put in place to mitigate Road Environmental Factors?

____

____

13. What measures can be put in place to mitigate Vehicle Factors?

14. What measures can be put in place to mitigate Human Factors?

15. State any other mitigation measures in general.

Section C: Specific Information

16. Which is the most common form of overloading which exceeds prescribed limit on public buses?

- ☐ Passengers Overloading
- ☐ Luggage Overloading
- ☐ Both Passenger and Luggage Overloading

17. What mechanisms are currently in place to establish the weight of passengers to avoid overloading? (Tick **all** which you know)

- ☐ Passengers Mechanical Scales
- ☐ Passengers Electronic Scales
- ☐……....Others(Specify)

18. What mechanisms are currently in place to establish the weight of luggage to avoid overloading? (Tick **all** which you know)

☐ Luggage Mechanical Scales
☐ Luggage Electronic Scales
☐ Others (Specify)

____

19. Apart from accidents, state any other challenges experienced by overloading.

____

____

____

Section D: Recommendations

20. For this question, circle on the response that best characterizes how you feel about the statement, where: 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Disagree nor Agree; 4 = Agree; 5 = Strongly Agree.
So, on the scale of 1 to 5, what is your view on having an automated mechanism of load weight monitoring system on public buses?
☐ 1. Strongly Disagree
☐ 2. Disagree
☐ 3. Neither Agree nor Disagree
☐ 4. Agree
☐ 5. Strongly Agree

21. Do you think the use of a load weight monitoring system can be a means to help mitigate the compliance of maximum load weight limit on buses?

☐ YES
☐ NO

22. Give any other suggestions to ensure compliance of load weight limit on public buses.

____

____

____

____

THANK YOU FOR YOUR PARTICIPATION

The University of Zambia

School of Natural Sciences

Department of Computer Science

Semi-Structured Questionnaire for Bus Owners/Operators

TOPIC:

PASSENGER AND LUGGAGE WEIGHT MONITORING SYSTEM ON PUBLIC BUSES BASED ON SENSOR TECHNOLOGY IN ZAMBIA

Dear Respondent

I am a student at the University of Zambia pursuing a Master of Science in Computer Science and I am in second year (research) of my study program. As partial fulfillment for the award of a Master of Science degree, I am conducting a baseline study on: "***Passenger and Luggage Weight Monitoring System on Public Buses in Zambia***"**.**

You have been randomly sampled to provide information for the topic indicated above. The information being collected is purely for academic purposes as such, it will be treated with maximum confidentiality. Subsequently, you are not supposed to indicate your name or any personal information that can lead to revealing of your identity.

Your co-operation will be greatly appreciated.

For more information or any queries, kindly get in touch with the following:

Project Supervisor: **Dr. Jackson Phiri**

Contact Details: **jackson.phiri@cs.unza.zm** or **0966 693 731**

Head of Department – Computer Science: **Mrs. Monica K. Kabemba**

Contact Details: **monica.kabemba@cs.unza.zm** or **0971 577 705**

QUESTIONNAIRE FOR BUS OWNERS/OPERATORS

Instructions

5. Answer all questions.
6. Mark ☒ in the appropriate checkbox.
7. Circle on the response that characterizes how you feel.
8. Write answers for the other questions in the spaces provided.

Section A: Basic Background Information

23. What is your gender?
    - ☐ Male
    - ☐ Female

24. What is your age group?
    - ☐ 17 – 27
    - ☐ 28 – 38
    - ☐ 39 – 49
    - ☐ 50 years and above

25. What is your current highest educational level of qualification attained?
    - ☐ Grade 12 Certificate
    - ☐ Professional Certificate
    - ☐ Diploma

☐ Degree
☐ Master’s degree
☐ PhD

Section B: General Information

26. What is the name of your company?

____

27. How many buses do you have for your business of public bus services?
☐ Less than 10
☐ 11 - 50
☐ 51 - 100
☐ Above 100

28. For how long have you been in this business of public bus services?
☐ Below 10 years
☐ 11 – 20 years
☐ 21 – 30 years
☐ Above 30 years

29. In terms of operation, which route(s) do your buses cover?
☐ Local
☐ Intercity
☐ National
☐ International

30. What do you think is the most risk factor contributing to road traffic accidents? (Choose one)
☐ Road Environmental Factors
☐ Vehicle Factors
☐ Human Factors
☐ Other Factors (State)

____

31. For each of the statements below, circle on the response that best characterizes how you rate the risk factors contribution to road traffic accident, where:
1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree Nor Disagree; 4 = Agree; and 5 = Strongly Agree.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree

1. Road Environmental Factors include Poor Road Construction, Signage, Markings, Lighting, Potholes, Obstructions, etc.	1	2	3	4	5
2. Vehicle Factors include Manufacturer Defects, Tyre Burst, Excessive Loading, Unroadworthy Vehicles, etc.	1	2	3	4	5
3. Human Factors include Human Errors, Negligence, Over-loading/-speeding, Traffic Rules Violation, etc.	1	2	3	4	5
4. Other Factors include various Unknown factors	1	2	3	4	5

32. What measures can be put in place to mitigate Road Environmental Factors?

____

____

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33. What measures can be put in place to mitigate Vehicle Factors?

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____

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34. What measures can be put in place to mitigate Human Factors?

____

____

____

Section C: Specific Information

35. Which is the most common form of overloading which exceeds prescribed limit on public buses?

☐ Passengers Overloading
☐ Luggage Overloading
☐ Both Passenger and Luggage Overloading

36. What mechanisms are currently in place to establish the weight of passengers to avoid overloading? (Tick **all** which you know)

☐ Passengers Mechanical Scales
☐ Passengers Electronic Scales
☐ Others (Specify)

____

37. What mechanisms are currently in place to establish the weight of luggage to avoid overloading? (Tick **all** which you know)

☐ Luggage Mechanical Scales
☐ Luggage Electronic Scales
☐ Others (Specify)

____

38. Apart from accidents, state any other challenges experienced by overloading.

____

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____

Section D: Recommendations

39. For this question, circle on the response that best characterizes how you feel about the statement, where: 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Disagree nor Agree; 4 = Agree; 5 = Strongly Agree.
So, on the scale of 1 to 5, what is your view on having an automated mechanism of load weight monitoring system on public buses?

☐ 1. Strongly Disagree
☐ 2. Disagree
☐ 3. Neither Agree or Disagree
☐ 4. Agree
☐ 5. Strongly Agree

40. Do you think use of a load weight monitoring system can be a means to help mitigate the compliance of maximum load weight on buses?

☐ YES
☐ NO

41. Give any other suggestions to ensure compliance of load weight limit on public buses.

____

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____

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THANK YOU FOR YOUR PARTICIPATION

The University of Zambia

School of Natural Sciences

Department of Computer Science

Semi-Structured Questionnaire for Bus Crews (Managers/Drivers/Conductors/Loaders)

TOPIC:

PASSENGER AND LUGGAGE WEIGHT MONITORING SYSTEM ON PUBLIC BUSES BASED ON SENSOR TECHNOLOGY IN ZAMBIA

Dear Respondent

I am a student at the University of Zambia pursuing a Master of Science in Computer Science and I am in second year (research) of my study program. As partial fulfillment for the award of a Master of Science degree, I am conducting a baseline study on: "***Passenger and Luggage Weight Monitoring System on Public Buses in Zambia***"**.**

You have been randomly sampled to provide information for the topic indicated above. The information being collected is purely for academic purposes as such, it will be treated with maximum confidentiality. Subsequently, you are not supposed to indicate your name or any personal information that can lead to revealing of your identity.

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Contact Details: **jackson.phiri@cs.unza.zm** or **0966 693 731**

Head of Department – Computer Science: Mrs. Monica K. Kabemba

Contact Details: **monica.kabemba@cs.unza.zm** or **0971 577 705**

QUESTIONNAIRE FOR BUS CREWS (MANAGERS/INSPECTORS/DRIVERS/CONDUCTORS/LOADERS)

Instructions

9. Answer all questions.
10. Mark ☒ in the appropriate checkbox.
11. Circle on the response that characterizes how you feel.
12. Write answers for the other questions in the spaces provided.

Section A: Basic Background Information

1. What is your gender?
   - ☐ Male
   - ☐ Female

2. How old are you?
   - ☐ Below 20
   - ☐ 21 – 30 years
   - ☐ 31 – 40 years
   - ☐ 41 – 50 years
   - ☐ Above 51

3. What is your current level of education attained?
   - ☐ Primary School
   - ☐ Secondary School

- ☐ College
- ☐ University
- ☐ Others (Specify)

____

4. What is your role in the public transport bus services?
   - ☐ Driver
   - ☐ Conductor
   - ☐ Loader
   - ☐ Inspector
   - ☐ Manager
   - ☐ Other (Specify) ____

Section B: General Information

5. What is the name of the public bus service company where you are working?

   ____

6. What is the number of buses in the company where you are working do they have?
   - ☐ Less than 10
   - ☐ 11 - 50
   - ☐ 51 - 100
   - ☐ Above 100

7. For how long have you been working in this business of public bus services?
   - ☐ Below 10 years
   - ☐ 11 – 20 years
   - ☐ 21 – 30 years
   - ☐ Above 30 years

8. In terms of operation, how do your buses operate?
   - ☐ Local
   - ☐ Intercity
   - ☐ National
   - ☐ International

9. What do you think is the most risk factor contributing to road traffic accidents?
   - ☐ Road Environmental Factors
   - ☐ Vehicle Factors
   - ☐ Human Factors
   - ☐ Others (Specify)

   ____

10. For each of the statements below, circle on the response that best characterizes how you rate the risk factors contribution to road traffic accident, where:
1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree Nor Disagree; 4 = Agree; and 5 = Strongly Agree.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
5. Road Environmental Factors include Poor Road Construction, Signage, Markings, Lighting, Potholes, Obstructions, etc.	1	2	3	4	5
6. Vehicle Factors include Manufacturer Defects, Tyre Burst, Excessive Loading, Unroadworthy Vehicles, etc.	1	2	3	4	5
7. Human Factors include Human Errors, Negligence, Over-loading/-speeding, Traffic Rules Violation, etc.	1	2	3	4	5
8. Other Factors include various Unknown factors	1	2	3	4	5

11. What measures can be put in place to mitigate Road Environmental Factors?

____

____

12. What measures can be put in place to mitigate Vehicle Factors?

____

____

13. What measures can be put in place to mitigate Human Factors?

____

____

Section C: Specific Information

14. Which is the most common form of overloading which exceeds prescribed limit on public buses?
    - ☐ Passengers Overloading
    - ☐ Luggage Overloading
    - ☐ Both Passenger and Luggage Overloading

15. What mechanisms are currently in place to establish the weight of passengers to avoid overloading? (Tick **all** which you know)
    - ☐ Passengers Mechanical Scales
    - ☐ Passengers Electronic Scales
    - ☐ Others (Specify)

    ____

16. What mechanisms are currently in place to establish the weight of luggage to avoid overloading? (Tick **all** which you know)
    - ☐ Luggage Mechanical Scales
    - ☐ Luggage Electronic Scales
    - ☐ Others(Specify)

    ____

17. Apart from accidents, state any other challenges experienced by overloading.

    ____

    ____

Section D: Recommendations

18. For this question, circle on the response that best characterizes how you feel about the statement, where: 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Disagree nor Agree; 4 = Agree; 5 = Strongly Agree.
    So, on the scale of 1 to 5, what is your view on having an automated mechanism of load weight monitoring system on public buses?
    - ☐ 1. Strongly Disagree
    - ☐ 2. Disagree
    - ☐ 3. Neither Agree nor Disagree
    - ☐ 4. Agree
    - ☐ 5. Strongly Agree

19. Do you think the use of a load weight monitoring system can be a means to help mitigate the compliance of maximum load weight limit on buses?
    - ☐ YES
    - ☐ NO

20. Give any other suggestions to ensure compliance of load weight limit on public buses.

____

____

____

____

THANK YOU FOR YOUR PARTICIPATION

Appendix C: Program Code Listing: LWMS_TEST

```
#include <KeyDetector.h>      //This Library is for Detecting Triggers (PIR triggers)
#include <HX711.h>
#include "SIM900.h"
#include "inetGSM.h"
#include "sms.h"
#define DOUT A1
#define SCLK A0
#define KEY_A 1
#define KEY_B 2

//Create and Initialize necessary variables

//GSM VARIABLES
bool started = false;

//Error Rate = +=3
//SCALE VARIABLES
float calibration_factor = 840;
float scale_value = 0.00;

//PASSENGER WEIGHT VARIABLES
float totalWeight = 0;
float weightThreshold = 40.00;

//PIR SENSOR VARIABLES
const byte pinA = 10;
const byte pinB = 11;
long waitTime = 1000;
long triggerTime = 0;
long timeLimit;
String str1 = "temp=";
//RGB VARIABLES
const int RED_PIN = 4;
const int GREEN_PIN = 5;
const int BLUE_PIN = 6;

//Create necessary Objects
HX711 scale;
SMSGSM sms;
InetGSM inet;
Key keys[] = {{KEY_A,pinA},{KEY_B,pinB}};
KeyDetector myKeyDetector(keys, sizeof(keys)/sizeof(Key));

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  Serial.println("...SETTING UP...");
  initGSM();
  //initScale();
  delay(3000);
  pinMode(pinA, INPUT);
  pinMode(pinB, INPUT);
  pinMode(RED_PIN,OUTPUT);
  pinMode(GREEN_PIN,OUTPUT);
  pinMode(BLUE_PIN,OUTPUT);
  Serial.println("READY");
}
```

```
void loop() {
  // put your main code here, to run repeatedly:
  myKeyDetector.detect();
  switch(myKeyDetector.current){
    triggerTime = millis();
    timeLimit = triggerTime + waitTime;
    case KEY_A:
      Serial.println("PIN 10 HIGH");
      do{
          if(digitalRead(pinB) == HIGH){
            Serial.println("FORWARD");
            setColor(0,255,0);
            inet.attachGPRS("airtel","","");
            sendData(3);
            break;
          }
        }while(millis() <= timeLimit);
      break;
      case KEY_B:
        Serial.println("PIN 11 HIGH");
        do{
          if(digitalRead(pinA) == HIGH){
            Serial.println("BACKWARD");
            setColor(255,0,0);
            //Have to Attach GPRS everytime you send data :|
            inet.attachGPRS("airtel","","");
            sendData(-22);      //Dummy data.
            break;
          }
        }while(millis() <= timeLimit);
        break;
  }
  if(totalWeight >= weightThreshold){
    sms.SendSMS("0978266148", "ALERT! \n VEHICLE PAST WEIGHT LIMIT");
    setColor(0,255,0);    //Set Color to RED?
    /*
     * DO SOMETHING.
     */
  }
  setColor(0,0,0);
}
/*
 * Initialise the GSM Module
 *
*/
void initGSM(){
  Serial.println("INITIALISING GSM MODULE");
  if (gsm.begin(4800)){
    Serial.println("\nSTATUS = READY");
    started = true;
  }else Serial.println("\nSTATUS = IDLE");
   delay(1000);
}
```

```
/*
 * This Method Sends the Data to the Server
 * It works by first creating a character array from the float value and combining
 * it with the string "temp=" and passing it as an argument to the httpPOST() method.
 *
 * httpPOST()(const char* server, int port, const char* path,const char* arg,
 * char* result, int resultlength);
 *
 */
void sendData(float s){
  int resLength = 150;
  char result[resLength];
  String str2 = String(s);
  String str3 = str1 + str2;
  char str4[20];              //Array size is 20 just to make sure all the data is sent
  str3.toCharArray(str4,10);
  inet.httpPOST("tempsensor.azurewebsites.net",80,"/getTemp.php",str4,result,resLength);
}

void setColor(int red,int green, int blue){
  analogWrite(RED_PIN,red);
  analogWrite(GREEN_PIN,green);
  analogWrite(BLUE_PIN,blue);
}
/*
 * Initialise the Scale
 *
*/
void initScale(){
  Serial.println("INTIALISING SCALE");
  scale.begin(DOUT,SCLK);
  scale.set_scale(calibration_factor);
  delay(1000);
  scale.tare();
  Serial.println("SCALE SETUP COMPLETE");
  delay(1000);
}
```