USE OF LIFE CYCLE ASSESSMENT REFERENCE METHOD TO IMPROVE LIFE SPAN OF ROADS IN MASERU

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Declaration and Copyright

I MOLIEHI MONTS'I, identity number and student number , acknowledge that the dissertation I submitted to the Central University of Technology is my own work and has not been submitted to this University or elsewhere. All the sourced work cited and quoted is acknowledged through a list of references.

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SIGNATURE OF STUDENT DATE

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This research would not have been a success without GOD Almighty, so I thank HIM for being part of it.

Abstract

Poor road infrastructure in Lesotho has led to investigating the failure reasons and solutions to improving the transportation sector using life cycle assessment reference method. Life Cycle Assessment is an evaluation of pavement products from manufacturing to demolition.

A critical review of Lesotho laws and policies was done. These laws and policies governing the construction of roads sector were studied to review how the road construction is to be carried out in Lesotho. The expectations from the government concerning the transportation sector were reviewed. There has been a gap in that the government being the main client, as the construction does not fulfill the long term needs of communities. The literature reviews, questionnaires, interviews, observations and case studies were carried out to develop a framework to eliminate the early failure of roads. It concentrated mainly on the environmental impacts on the pavement product. For both economic prosperity and personal mobility, roads are a basic need in infrastructure systems. Life Cycle Assessment is being integrated daily in different disciplines to achieve sustainable practices that include the road construction sector. It studies the environmental impacts and helps predict future circumstances. This study elaborates on ways to improve current situations to meet future economic needs. This study quantifies the environmental impacts of a product, in this case, road construction. It is used to assess the environmental issues to enhance prolonged pavement life in the Lesotho roads.

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Acronyms and Abbreviations

CBD	Central Business District
CO	Carbon Monoxide
CRC	Continuously Reinforced Concrete
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
HC	Hydrocarbons
ISO	International Standards Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LoS	Level of Service
LRMS	Lesotho Road Management System
NOx	Nitrogen Oxide
PaLATE	Pavement Life-cycle Assessment Tool for Economic and environmental effects
SA	South Africa
SAICE	South African Institute of Civil Engineers
SD	Sustainable Development
SETAC	Society of Environmental Toxicology and Chemistry
SOx	Sulfur Oxide

VCI Visual Condition Index

VGI Visual Gravel Index

VOC Volatile Organic Compound

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Introduction

Life Cycle Assessment (LCA) is an evaluation of pavement products from their birth to end of life (Santero, 2010). It concentrates on the pavement materials from the design stage to being recycled or even disposed of as waste. The raw materials extracted, processed and used, energy inputted, products from waste flows are studied with their mobility between stages until they can no longer be re-used or re-cycled (Stripple, 2001; Mroueh et al., 2001). All these are assessed and their impacts on the environment monitored.

1.2 Background

Lesotho roads do not meet the expected life span due to evident factors that include the ever-increasing and congested traffic, narrow road widths, private properties protruding into the road corridors, small spaces between the roads and the roadside properties to allow for road width widening, poorly planned townships, type of designs, and roadside distractions that include private properties. Most roads are not constructed with water drainages, which are a major concern to negative environmental impacts since the water soaks into the pavement structures (Vieira et al., 2015; Dawson, 2008). The road corridors are designed not to accommodate roadside bays, which lead to most vehicles being packed in the carriageways leading to even further congested traffic. These mainly lead to failure in reaching roads' life span, an increasing number of accidents and an increase in maintenance costs (Douglas, 2016).

1.3 Problem Statement

The average Visual Condition Index (VCI) (Figures 1.1 and 1.2 below) show the results for the detail of the VCI calculation as calculated by the Roads Directorate, (2015). In 2014, the paved road network had deteriorated by approximately 5% from 2010 to 2011. Though the average condition still falls in the 'fair' category, the roads need to be upgraded to enhance consistency in improved roads conditions, maintained and rehabilitated to address future major deteriorations. The conditions were even worse for the unpaved roads in the same years as the average Visual Gravel Index (VGI) was in the "very poor" region as indicated by figure 1.3. Many of the roads, both paved and unpaved are in great danger of experiencing further deteriorations and if abandoned would lead them to being completely rebuilt which would be at high costs (Mokhehle and Diab., 2001).

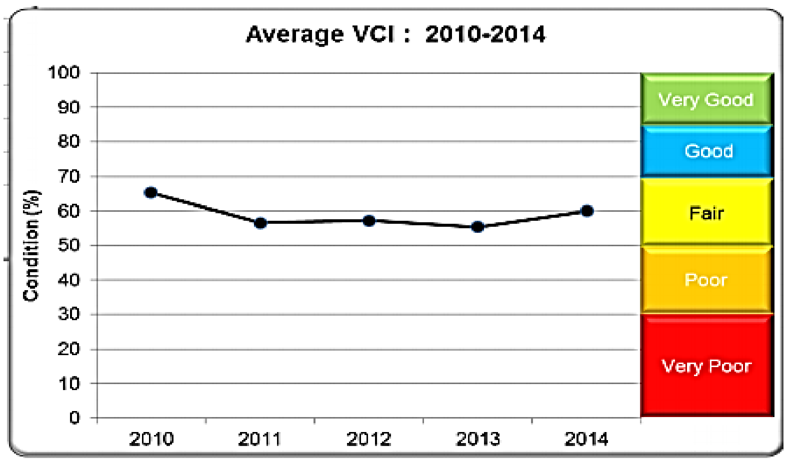
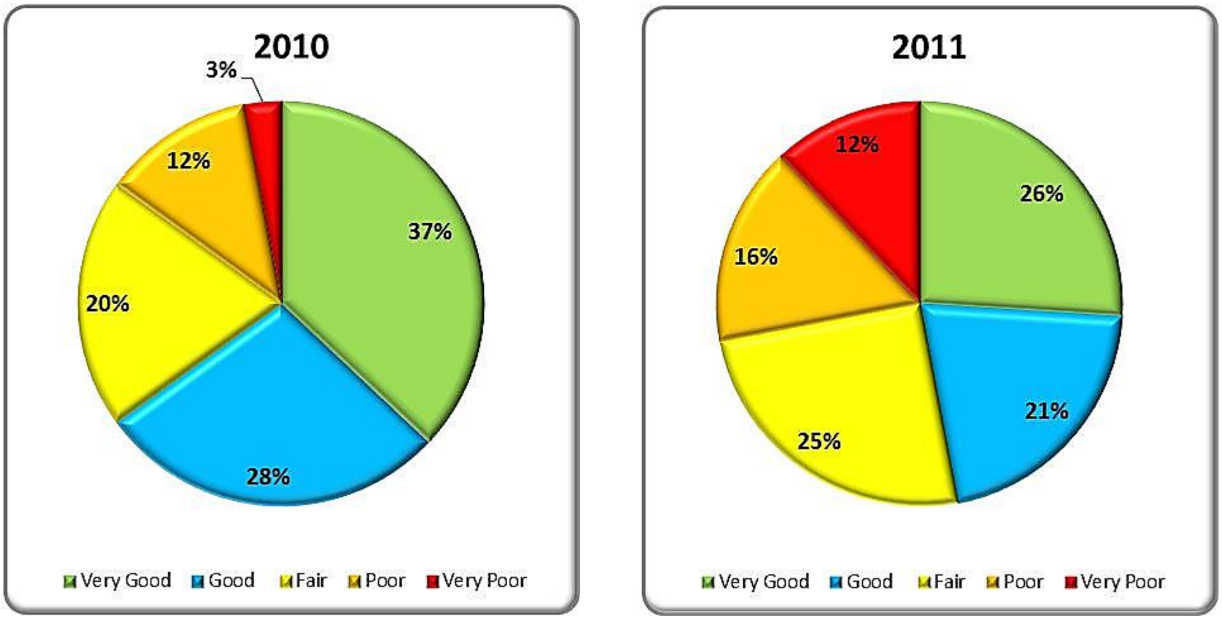


Figure 1.1 Paved Average VCI trend for 2010 to 2014 (Roads Directorate, 2015)

From Figures 1.1 to 1.3, it can be seen that the Lesotho road infrastructure is deteriorating yearly. The 70% of the respondents argued that it is evident that in Lesotho, the sewer pipelines and water pipelines passing and those adjacent the roadways are not designed initially while to allow their easy passage through and lack of inconsistency in the construction. This leads to everyday cut-offs in the road corridor. The consent departments do not communicate, thus, in the construction stage of placing layers; these pipelines are not considered unless they existed prior to construction taking place. This leads to inconsistency in the strength of the roads as the everyday cuts to allow for these pipelines' construction, are not implemented in accordance with the initial intended road specifications. Inconsistent fills to road cuts are prone to early damage before the road reaches its expected life (Mao, 2012).



A B

Figure 1.2 A. 2010 VCI distribution for paved roads (Roads Directorate, 2015) B. 2015 VCI distribution for paved roads (Roads Directorate, 2015).

Most of the Maseru roads are narrow and with no or not up to standard pedestrian-walkways and no bicycle lanes. Maseru experiences the traffic signals toward the central areas ever being damaged and wrongly timed. In most cases, it is due to everyday accidents happening because of drivers' negligence and the residents stealing roadside furniture made of steel to sell in scrapyards, and the timber ones being used as firewood as argued by 58% of the respondents. These pose major problems as they form part of the growing traffic and the speeding vehicles do not take note of the cyclists, leading to injuries and accidents.

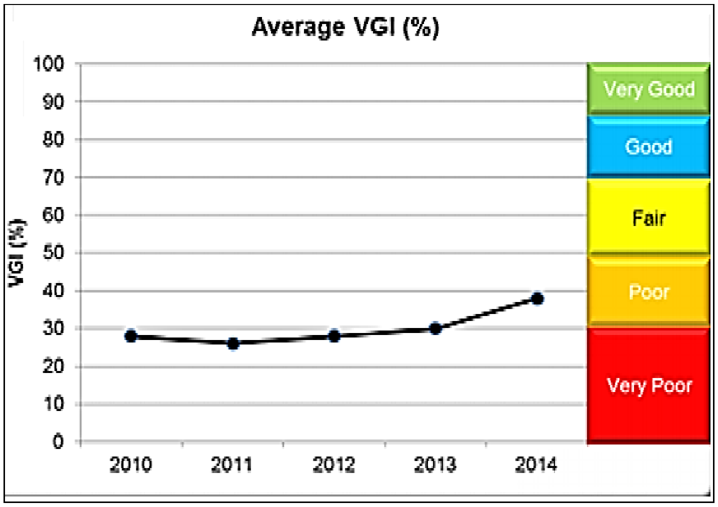


Figure 1.3 Unpaved average Visual Gravel Index (VGI) trend for 2010 to 2014 (Roads Directorate, 2015).

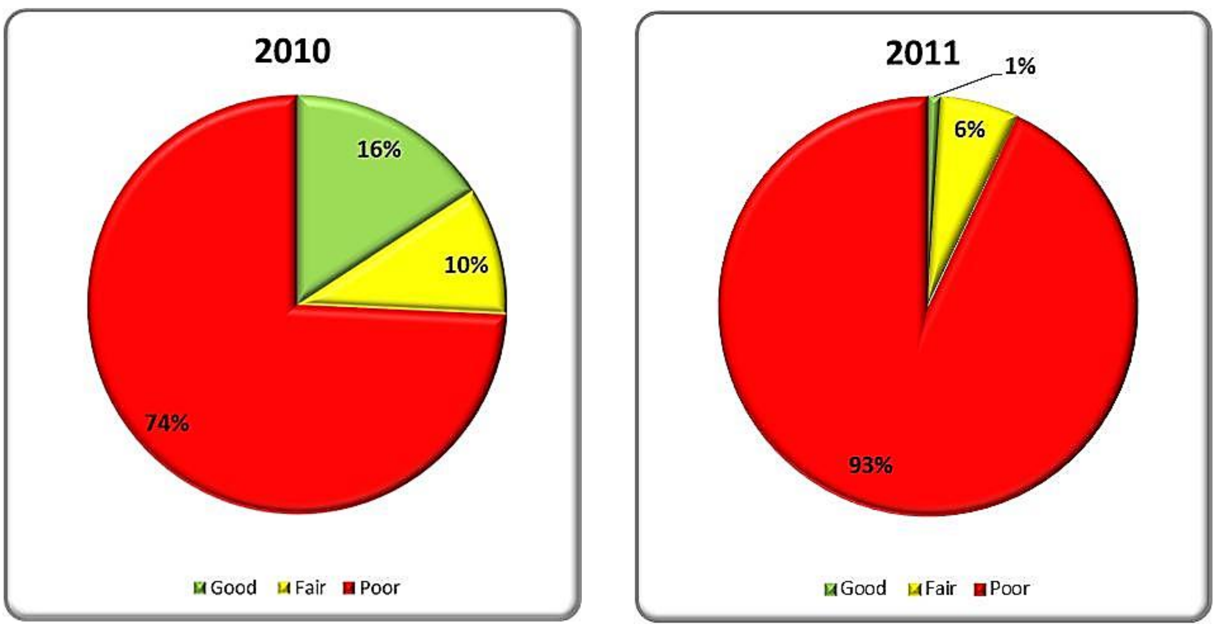


Figure 1.4 A. 2010 VGI distribution for unpaved roads (Roads Directorate, 2015) B. 2015 VGI distribution for unpaved roads (Roads Directorate, 2015).

The ever-growing traffic on roads brings about a fear of less environmentally friendly emissions to the environment (Lewis et al., 2007). This means the government subsidies in fuel consumptions are expected to grow greatly in the next few years as high traffic leads to traveling at speeds lower than optimal. Roads are designed for long periods and they reach the expected life already congested with traffic. This leads to a less friendly environment as emissions from the fuel in cars cloud the environment. Being aware of this idea, this study is to help find solutions to the prevailing conditions. The amount of gases produced and their expected impacts are to be lowered, leading to more sustainable road construction. It should also encourage recycling of materials for maintenance, reconstruction or upgrading.

Figures 1.5 A and B elaborate on the negative encounters in the road networks. Maintenance procedures not considered in time lead to early damages in the road corridors. To overcome these problems, usage of LCA methods to improve life expectancy will be utilized in the roads. The severity and the extended ratings of distresses provide a basis for eventual maintenance computations. The ever-increasing traffic requires new pavement constructions amounting to considerable expenditure which pose a threat to the country‘s economy (Dawson, 2008). LCA techniques are used to improve the life-span of roads.

A. Mainly trafficked gravel road leading to Leqele village showing private property projecting into the road and a pool of water in the corridor due to lack of water channels

B. Main asphaltic road leading into Qoaling Village showing wearing off pavement layers within 5 years after its construction

Figure 1.5 Typical road pictures taken in Qoaling and Leqele areas showing some of the problems encountered in most of Maseru roads.

1.4 The Study Area

Lesotho is a mainly mountainous country fully enclosed by the Republic of South Africa in the southern part of the African continent, as shown in Figure 1.6. The Lesotho Bureau of Statistics (2006) shows Basotho population of 1,872,721. Maseru is the capital city and in the lowlands of Lesotho, has a population approximated at 23.1% of the country's whole population (Lesotho Bureau of Statistics, 2006). Most Basotho leave their native lands to cluster in the heart of the city for emigrational purposes that include seeking jobs, academic endeavors and even starting a home. This country falls among the poorest in the southern part of Africa and largely depends on South Africa (SA) for its economy (Cobbe, 1983; Abaza, 2000). Due to lack of funds, the existing ones need to be utilized wisely compromising the future; hence the importance of this research.

Figure 1.6 Lesotho fully enclosed by South Africa (Fogelman and Bassett, 2017).

1.4.1 Pavement Layers and Materials

Materials used in pavements depend largely on their availability, social considerations, economic considerations, environmental considerations, design specifications and previous experience (Adedeji, 2015). Firstly, an assessment of the barrow pits is done and then extraction of the natural materials can be done in case the materials meet specific requirements (Rowntree et al., 1991). The Lesotho road network, as illustrated in Table 1.1, comprises 1515km of paved roads, 3078km unpaved roads, 1149 km earth roads and 117km tracks (Roads Directorate, 2015). The focus is on the flexible asphalt or paved roads and the gravel or unpaved roads as they are dominant in the study.

The Lesotho Road Management System (LRMS) (Roads Directorate, 2015) gives the following scenario of roads in Lesotho as in Figure 1.7. In this study, mainly the gravel and the surfaced roads have been considered.

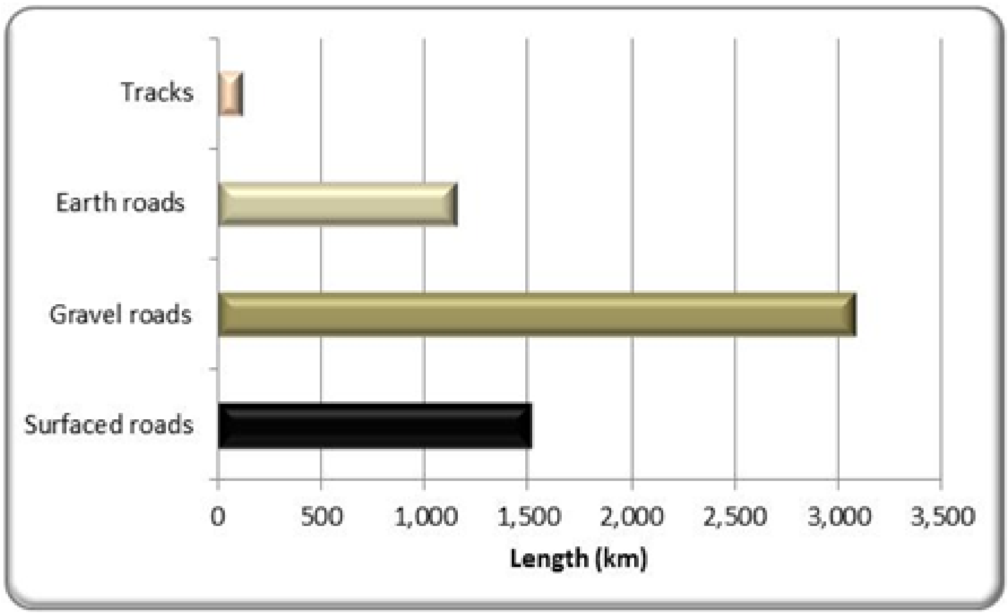


Figure 1.7 LRMS length of the Lesotho road network (Roads Directorate, 2015)

1.4.2 Road Network

From Table 1.1, Lesotho comprises mainly low-volume roads throughout the country (Rogerson, 2009). As such, it can be expected that time for these roads to reach deterioration is prolonged and with minimal maintenance costs, if properly maintained and if standard methods are followed accordingly they should last much longer (Schadt et al., 2010).

Table 1.1 Unpaved Road Length (Roads Directorate, 2011)

	Gravel	Earth	Track	Total
Central Region	692	296	28	1,016
North Region	713	564	44	1,321
South Region	711	296	46	1,052
Total	2,117	1,155	117	3,389

1.4.3 Geology and Material Compositions

Figure 1.8 illustrates Lesotho has a geological record extending from 250 million years ago: terrestrial sedimentary successions underlain by rocks of the Karoo Super-group (Milani and De Wit, 2008). It has an overlaying crystalline metamorphic basement that comprises unconsolidated sediments of the Drakensberg Group mainly found in the lowlands (Appleton and Stiles, 1976; Arena et al., 2003). This gives Lesotho the best basis for the required and strong foundation for any form of construction, as unstable soils are prone to damage the environment to the foundation of any structure (Smyth and Dumanski, 1993).

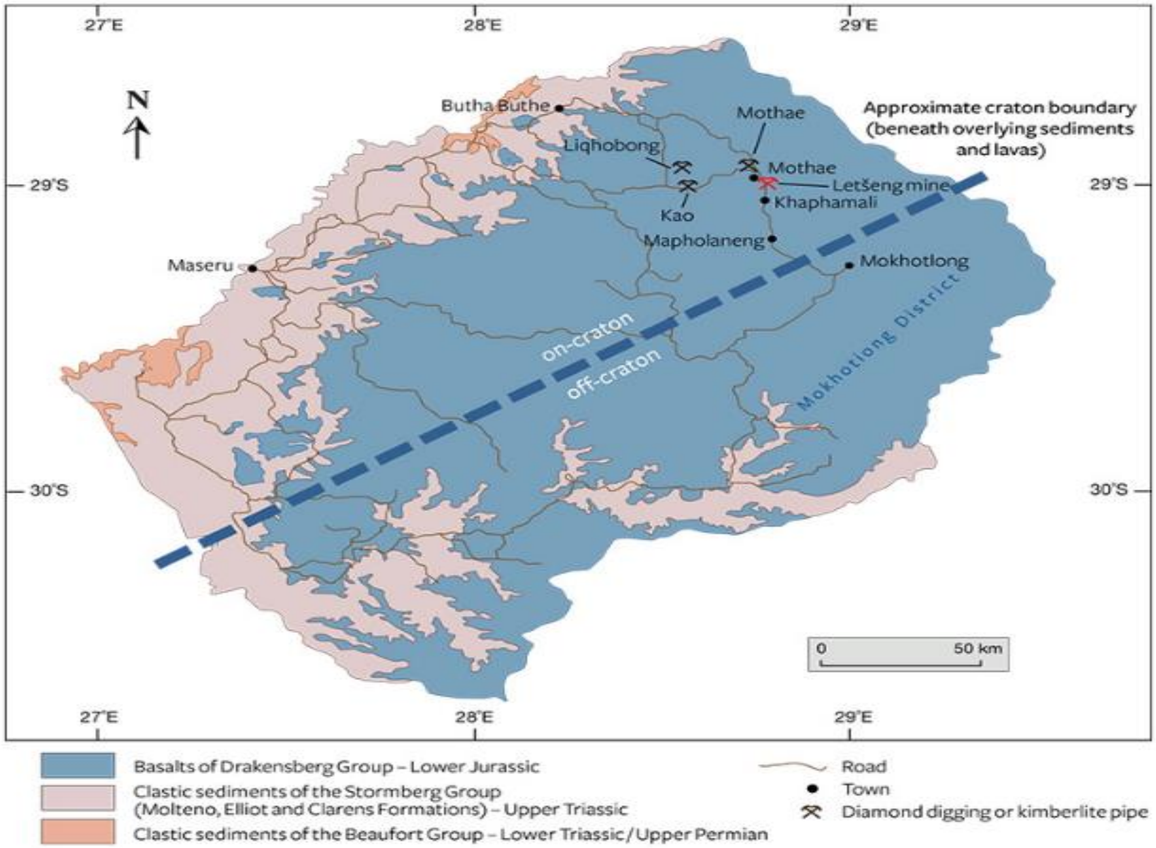


Figure 1.8 Lesotho geological map (Marsh et al., 1997).

1.5 Research Aim

The aim of this research is to utilize the LCA Reference Method to improve life span for roads in Maseru.

1.6 Research Objectives

To achieve the aim of this research, the following objectives need to be considered:

- To investigate causes of roads failure in Maseru
- To use the Life Cycle Reference method to improve life span in Maseru roads
- To develop guidelines for improving the life cycle of pavements in Maseru roads networks

1.7 Limitations of the study

The study concentrates on the gravel and paved roads in Lesotho and does not concentrate on the tracks and earth roads in the country though they form part of the road network. The method under study is mainly the Reference method. The other methods have not been dealt with as they have some lacking aspects that the research wanted to cover. These methods include Greet method that concentrates on the use and end of the project, the NonRoad method does not take into account the use phase of the project while all the other phases are essential in it. Quickzone method concentrates on the construction, maintenance, rehabilitation, and end phases of the project. The miscellaneous method concentrates on the use and end phases of the project while the mobile method concentrates on construction, maintenance, rehabilitation and end of the project.

A difficult issue is the translation of emissions into environmental impacts (Kolk et al., 2008). The main problems faced during life cycle impact assessment (LCIA) result from the need to connect the right burdens with the right impact index at the correct location and time (Frischknecht et al., 2007; Pfister et al., 2009). For instance, impacts dependent upon local conditions that include ecological toxicity, smog and human health that may result in an over simplification of the actual impacts, if the chosen impact indices are not tailored to localities (Pickett et al., 2001; Reap et al., 2008).

1.8 Structure of the Dissertation

This section shows the contents of this dissertation.

Chapter 2 focuses on the phases of the LCA and the different methods it entails. This chapter gives an overview of the methods though no well detailed.

Chapter 3 focuses on the main LCA method for this dissertation, being the reference method.

Chapter 4 focuses on the methodological tools used in data gathering of the dissertation and how they were utilized. These methodologies are interviews conducted and the questionnaires issued to consent stakeholders.

Chapter 5 focuses on the research findings and analysis of the dissertation. The statistical information is interpreted to give the view and feel of the current situation in Maseru so the information can be utilized to come up with recommendations that will lead to sustainable and maintained roads to meet future needs.

Chapter 6 focuses on the development of guidelines in the dissertation.

Chapter 7 focuses on the conclusions and recommendations of the dissertation.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Natural minerals are used continuously as aggregates for constructions and earthworks and this leads to depletion of best materials (Reeves et al., 2006; Langer, 2009). Therefore, there arises a need for resource conservation and lengthy transport distances have increased, hence the need for secondary materials to substitute the natural ones where necessary. This leads to a serious consideration: a need for inspection and LCA methods in any form of construction. This is so as there some uncertainty in the utilization of secondary products in construction (Mroueh and Wahlström, 2002).

2.2 Life Cycle Assessment

LCA as defined by the Society of Environmental Toxicology and Chemistry (SETAC) as "an objective process to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and waste released to the environment, and to evaluate and implement opportunities to effect environmental improvements" (Rogerson, 2009; Barth,1998). Therefore, the LCA network assesses the environmental impacts on a product that include depletion of resources, water, and land use, as illustrated by Figure 2.1 (Santero et al., 2011c; Huang, 2007). This product starts from the design of the pavement until it reaches its end of life, then redesigning. LCA focuses on each step independently and then on what happens with the emissions and wastes afterward. These result in environmental impacts that are either positive or negative to the natural environment, human health and resources perspective (Carlson, 2011; Laszlo, 2003).

The following is a system of boundaries under LCA:

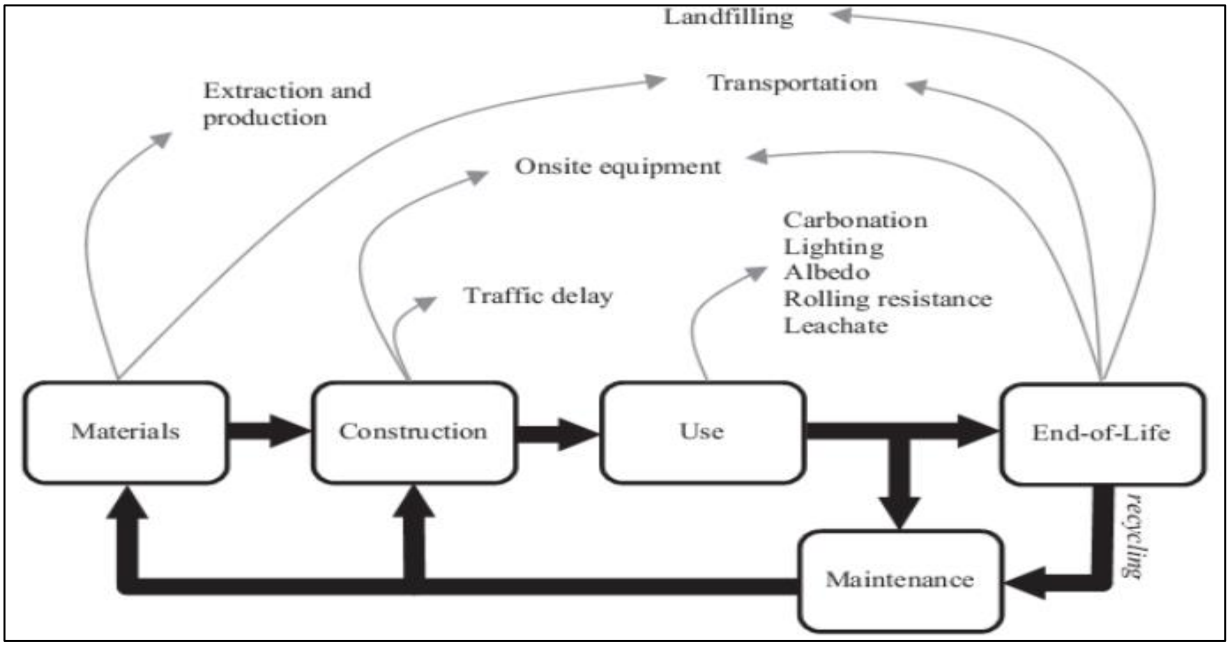


Figure 2.1 Pavement life cycles' phases and components (Santero et al., 2011c)

The need for a product is seen and all the processes to be taken out are laid down and tabled and procedures to be followed are drawn in a systematic way. This leads to LCA's main focus being from the design, construction, usage, till the recycle stage and the disposal of pavements as well as methods involved in implementing each process (Huang et al., 2006). It also concentrates on the transportation of materials to be used and the energy produced from fuel used in plants used for construction (Thakkar, 2016). All these give the LCA of a pavement. It explores how materials may be used while compromising the future (Santero et al., 2011b; Loijos et al., 2013). It deals with the recycling of already used materials as well as their influence on the environment.

2.2.1 Brief History of Life Cycle Assessment

The study of environmental impacts of consumer products dates back to the 1960s and 1970s (Porter, 1981; Rothwell, 1992). The cost-effective use of raw materials is of great importance for the benefit of the present and future generations (Talawar, 2009; Page, 2013). The materials used in construction are extracted from the natural earth and if not used wisely may deplete with time(Wackernagel and Rees, 1998). In the late 20th century decades, it became acceptable that non-renewables are scarce and even the renewable ones need to be inteligentely used since they appear to be (Poizot and Dolhem, 2011). The waste emissions into the air, water and the ground have impacts to the immediate environment and the organisims living there. It is by this point important to engage the LCA methods to minimize the negative global effects (De Silva, 2009; Misra and Pandey, 2005). These effects include soil degradation, deforestation and climate change.

The environmentalists have broadened their focus on the assessment of costs, economic, environmental and social aspects that have led to the development of life cycle (Peattie and Charter, 2003; Heijungs et al, 2010). This development has led to sustainability assessment, life cycle costing, green chemistry, and life cycle assessment to mention a few. LCA has been useful as an environmental tool since the 1960s (Kendall et al., 2009; Swan, 1998). This term has been used in consideration of the operational and maintenance costs in systems. In its first appearance, the study was supported by the Coca-Cola organization, quantifying the environmental effects from the beginning to the end of packaging (Huang et al., 2007). The emphasis concentrated mainly on reducing solid wastes. To standardize the LCA methodologies, many initiatives were introduced of which the International Standards Organization (ISO) stood out and were published from 1997.

Sustainable Development (SD) links many issues of concern: environmental quality, equity, population control, safety and so on. SD general field is subdivided into three areas: economic, social and environmental (Bansal, 2005; Eriksson et al., 1996).

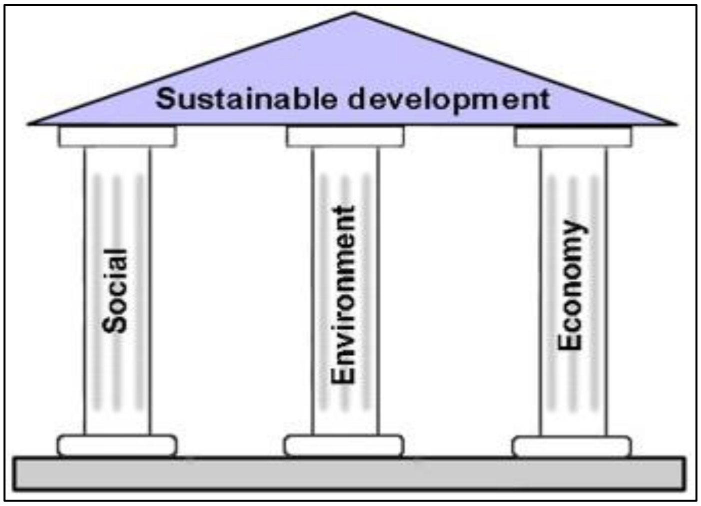


Figure 2. 2 Pavement life cycles' phases and components (Heijungs, 2010).

Figure 2.2 gives the social pillar representing people, the environmental representing planet while the economy is representing profit. At the World Summit on Sustainable Development in Johannesburg, 2002, this was modified into People, Planet, Prosperity, where the change of Profit into Prosperity is supposed to reflect the fact that the economic dimension covers more than company profit (Heijungs, 2010). LCA) can develop into life cycle sustainability assessment (LCSA), rather than a model in itself (Hall and Sharples, 2004; McKinnon, 2010). It is clear that LCA is growing in all angles (Frankl and Rubik, 1999).

2.2.2 Developments of LCA asphalt pavement methods

To achieve a long-term product or service, the requirements are studied in detail with all the involved processes studied as shown in Figure 2.2. These studies lead to the sustainable development of a pavement product. Every product has a life, hence the need to study its impacts on the environment and ways to prolong its life period (Murphy, 2000).

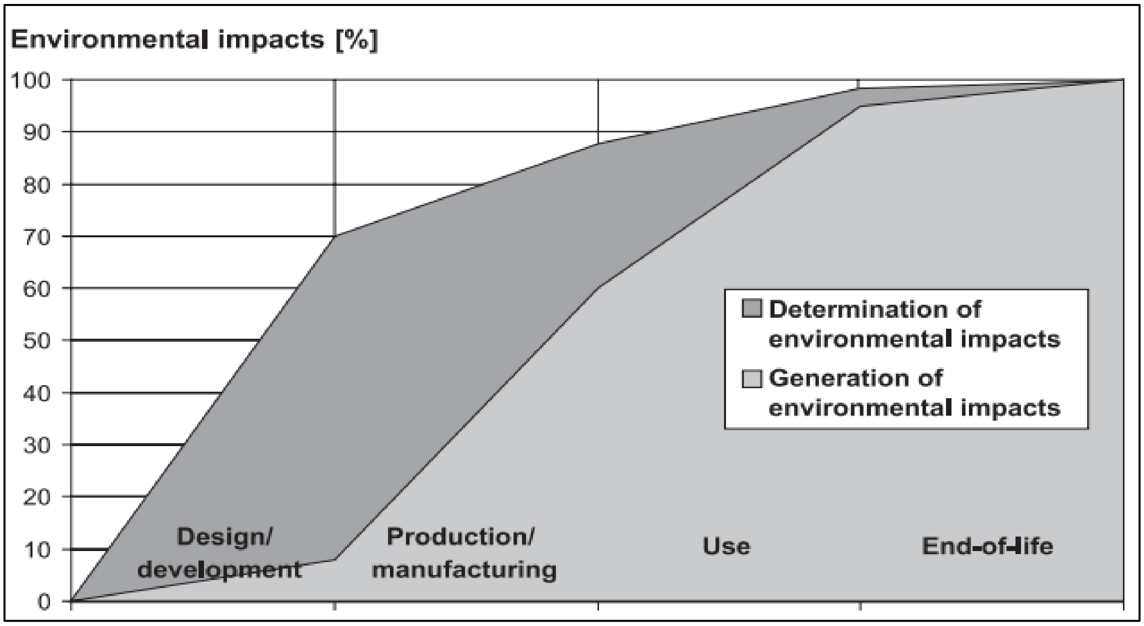


Figure 2. 3 Generalized representation of the (pre)determination and the generation of environmental impacts in a product’s life cycle (Rebitzer et al., 2004)

The environmental impacts are studied and further tabled against all expected stages in the development of a product, and each stage is affected in a different manner to another stage (Tiruta-Barna et al., 2007; Harvey et al., 2014). The studies are carried out at the development of the product. The study concentrates on the asphaltic and gravel roads as highlighted in the flow chart diagram in Figure 2.3 (Burroughs and King, 1989). The depth of this research is from the LCA of pavement as the main topic, down to Impacts Assessment, then to the Environmental Effects (Mroueh and Wahlström, 2002). In the Environmental Effects, this research looks at the asphaltic and the gravel roads in Lesotho. This study is to bring a positive influence to the country’s economy as funding will be focused on the country’s other basic needs and even less on pavement infrastructure (Mokhehle and Diab, 2001; Baumann and Rydberg, 1994).

2.3 Phases of Life Cycle Assessment

The environmental effects assessment is concerning the materials used and the wastes produced. LCA follows mainly the following phases in which each comprises different components, as elaborated in Figure 2.4:

Table 2.1 gives the phases in their order, beginning with the design and re-design phases down to reaching the end-of-life phase of a pavement (Loijos, 2011; Huang et al., 2009). Components involved in each phase are also laid out with explanations for each.

Table 2.1 Descriptions of pavement life-cycle components

<table>
<tr><th>PHASES</th><th>COMPONENTS</th><th colspan="2">DESCRIPTIONS</th></tr>
<tr><td>Design and Re-design</td><td>Engineering and administration</td><td colspan="2">Activities that support the conceptual development of pavement are drawn. Conducting the feasibility studies leads to ideas to make the project work. Each product after reaching its end-of-life may need to be re-designed. Then the cycle starts over (Colledani, 2014).</td></tr>
<tr><td rowspan="2">Materials Acquisition, Processing, and Production</td><td>Extraction and production</td><td>Produces pavement materials including recycling processes needed to manufacture new materials (Huang, 2007).</td><td rowspan="2">This phase deals with the extraction of raw materials and their conversion to being a finished product that is ready for use on site. For instance, limestone is extracted as raw material and then later transformed into cement as a by-product ready for use. In this stage, all the necessary processes are considered like transportation of raw materials from borrow pits. For the one project, long life of the pavement is required to eliminate problems in the future that may be associated with exhausted materials like quarries, or inaccessible quarry sites due to encroachments of housing. 20, 40 and 100-year designs demand 17000, 7000-9000 and 7500-10000t respectively of aggregates in maintenance (Tennis, 2004), hence economical to design pavements for long spans.</td></tr>
<tr><td>Transportation</td><td>Transportation is needed to bring pavement materials on to construction site (Taylor and Khosla, 1983).</td></tr>
<tr><td rowspan="2">Assembly and Construction</td><td>Onsite Equipment</td><td>This equipment assists in placing of pavement materials onsite. This equipment is based on the production estimates that can be from the stated tabled product designs.</td><td rowspan="2">This phase focuses on all the processes that include placing of pavement materials on required layers. It includes all the delays in traffic and the equipment used.</td></tr>
<tr><td>Traffic delay</td><td>Traffic delays (and detours) induced by pavement construction. This is a sensitive parameter in construction that cannot be modeled easily as it may require over 40 years' future prediction delays that are just</td></tr>
</table>

		impractical (Santero et al, 2011a).	
Use and Service	Carbonation	Sequestering of CO_2 in concrete pavements.	All the activities that happen after the pavement layers are done and complete. Although not quantitatively understood, they have a negligible effect on the overall results (Santero et al., 2011a).
	Lighting	Lighting requirements associated with the properties of pavement materials.	
	Albedo	The solar reflectance of pavement as it contributes to the urban heat island effect and direct radioactive forcing.	
	Rolling Resistance	Effect of pavement characteristics (e.g. structure and roughness) on vehicle rolling resistance.	
	Run-off	Water pollution associated with pavement materials (e.g. leachate) (Kayhanian et al., 2009).	
Maintenance	Materials phase	Associated with new materials used for maintenance activities.	Maintenance, rehabilitation, and reconstruction are activities that fall under this phase. These activities retain the structure and ensure maximum functionality of the pavement for the required life span. The shorter the design life of a pavement, the more the maintenance activities required to maintain serviceability of the pavement.
	Construction phase	Associated with construction processes used for maintenance activities.	
End-of-life or Retirement	On-site equipment	Equipment used on construction site to demolish pavement at the end of its life.	Demolishing, disposal into a landfill and recycling processes in this phase. At the end of life, the studies look at economical ways to handle an out of order product (Hamdar et al., 2015). The easy way could be recycling before any other process. It is cheaper and quite economical. Other processes can be considered if the product has reached a point of no return or rather cannot be transformed into a more useful product (McDonough and Braungart, 2010). The end of life of buildings is reached when all components and materials that have to be removed from
	Transportation	Transportation of demolished materials to a landfill or recycling facility.	
	Land-filling	The process needed to landfill pavement debris.	
	Re-use	The process needed to directly reuse the materials.	
	Recycle	The process needed to recycle pavement materials into new products (Soutsos, 2011).	

			the site have been removed (Achenbach et al., 2018). The big difference between buildings and torrent control structures is that the torrent control structures have reached their end of life after loss of functionality and then go directly into nature as a landfill (Goudie, 2018). Thus, the material inert CO_2 is returned to the natural cycle and the energy contained in the material is not used any further (Worrell et al., 2001).

2.4 LCA Methods for Pavement

Sustainability requires special methods and tools to measure the environmental impacts most especially for human activities (Rosen and Kishawy, 2012). These impacts could either be from emissions into the environment or through resource consumptions and other interventions that include land usage (Chowdhury et al., 2010). These interventions are associated with material productions, products from manufacturing, and these products' end of life. These emissions and consumptions lead to a wide range of impacts that include climate change, toxicological on human health and ecosystems, resources depletion noise, depletion or even smog formation in the ozone, water and land use. Reduction of these impacts requires proactive and complementary insights apart from regulatory practices (Allen, 2014; Christmann, 2000). These considerations shall help to prevent or even minimize the pollution opportunities through the entire product life cycle.

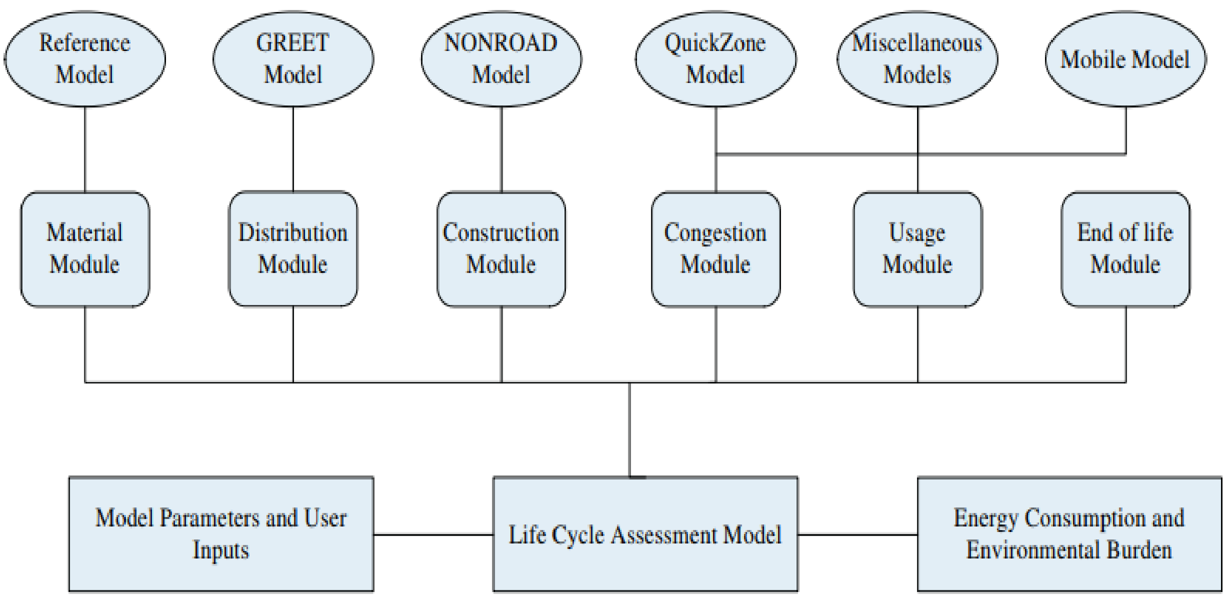


Figure 2. 4 Relationship between methods (Yu and Lu, 2012)

Figure 2.4 is a framework of methods that can be used to meet the required life of a product. These methods can be used depending on what the product needs to achieve as they do not work in the same manner (Yu and Lu, 2012).

2.4.1 LCA GREET Method

The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) method deals with the greenhouse gases, regulated emissions, and energy used and gases burned that may be used during pavement lifetime (Huo et al., 2008). The ever-increasing number of vehicles poses a threat to air pollution as emissions are of a dominant type (Huo et al., 2008). Soon global warming issues are to be experienced and greenhouse gases, hence a need to review the type of oils used in the vehicles (Chapman, (2007). Use of biodiesel oils is recommended as they are clean and renewable (Hossain et al., 2008). Biodiesels are derived from plants, animal fats, and wasted oils. It has been proven that they are degradable and produce low contents of hydrocarbons (HC), Carbon Monoxide (CO) and other oxides that include sulphur and carbon emissions (Labeckas, and Slavinskas, 2006; Zamel and Li, 2006). This may require the Agricultural Department to review plantation of these biodiesel plants to lessen the great chances of experiencing global warming issues and leading to sustainable environments (Abbasi and Abbasi, 2010; Hamdar et al., 2015).

2.4.2 LCA NonRoad Method

This method is used for construction and maintenance activities (Birgisdóttir and Christensen, 2005). It looks into ways the pollutants from construction and maintenance sites can be eliminated. The inputs in construction and the outputs during and after construction are monitored closely. This industry is primarily responsible for air emissions, waste generation, energy use and land use amongst others (Scaltriti et al., 2004; Loijos et al., 2011).

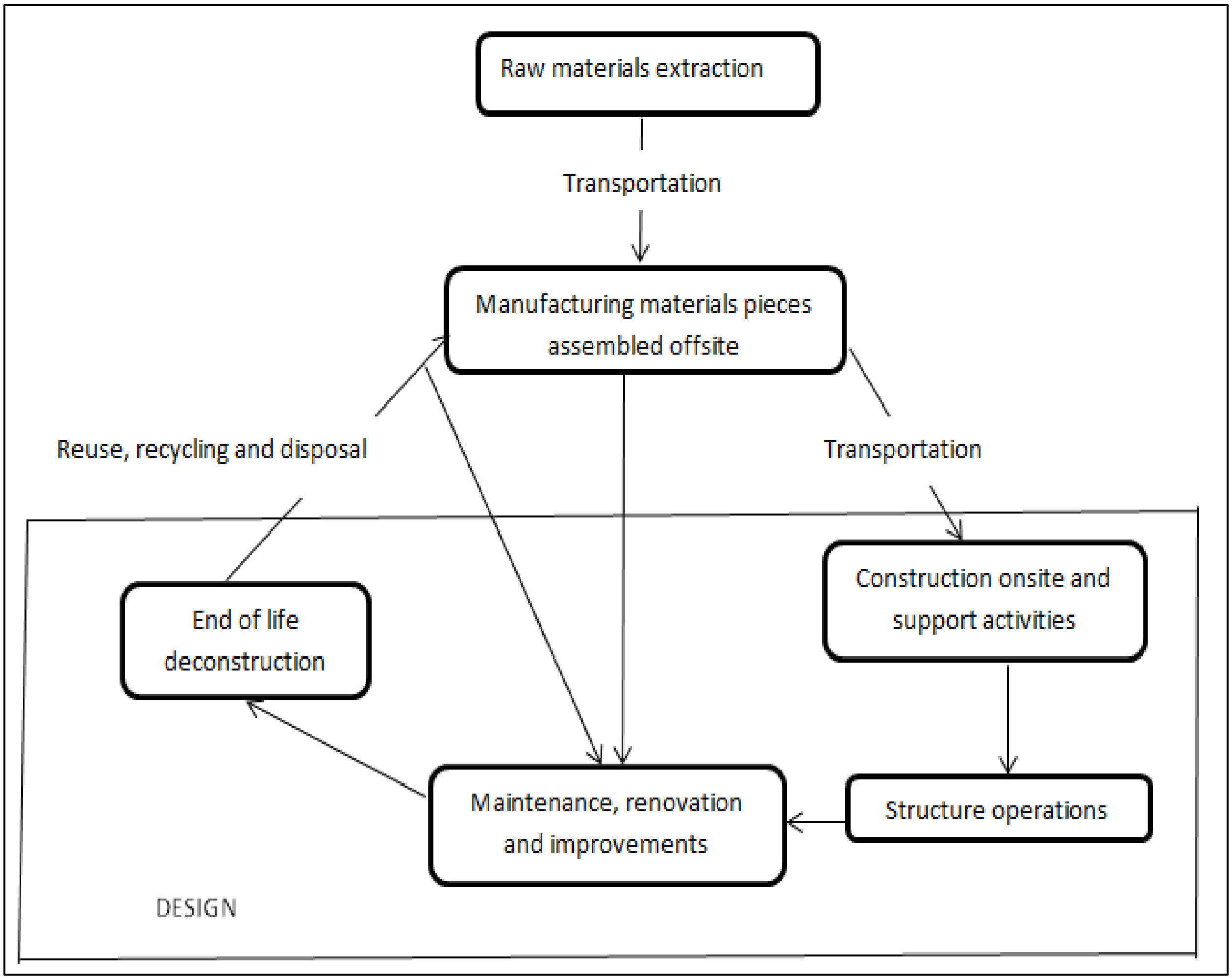


Figure 2. 5 LCA of a construction project (Scaltriti et al, 2004)

Figure 2.5 shows the raw materials extracted and then transported to manufacturing sites then later transported as by-products to construction sites for operations to take place (Scaltriti et al, 2004). Some materials from the manufacturing sites and operational works are to be disposed of as wastes into the disposal sites directly since they may not be useful to construction works (Latham et al., 2000). With time the product, which is the road, is maintained, renovated or improved for longer life, then later it deteriorates beyond repair, which leads to material recycling and disposal (Gupta, 1995).

2.4.3 LCA QuickZone Method

Traffic delay induced by construction and rehabilitation activities has significant influences on energy consumption and pollutant emissions compared with those under normal vehicular operations (Nagarajan, 2016; Yu and Lu, 2012). The changes in traffic flow, traffic delay, and queue length are estimated using the QuickZone method (Zhu et al., 2009). This method defines delayed traffic quantity and queue length (Sharma et al., 2007). These are from the work zones on the highway. The open cuts in construction sites lead to traffic disruptions and escalations in cost values associated with the commercial and industrial activities (Celik, 2014; Matthews et al., 2015).

2.4.4 LCA Miscellaneous Method

The Miscellaneous method focuses on the fuel consumption and pollutant emissions due to vehicle operations within the analysis period; roughness effect, pavement structure effect, albedo, and carbonation are investigated (Yang, 2014; Chevalier et al., 2003). Three major factors pose great influences on the LCA inventory, including traffic volume, fuel economy, and pavement roughness (Wang et al 2018; Suh et al., 2004).

2.4.5 LCA Mobile Method

This method concentrates on detour rate, queue length and speed reduction within construction zones. Once vehicle delays due to construction and maintenance events are determined, they are coupled with fuel consumption and vehicle emissions to measure their environmental impacts (Bazzan, and Klügl, 2013; Guinee and Heijungs, 1993).

2.4.6 LCA Reference Method

This method deals with data from various sources including the energy consumption and discharged environmental pollutants, including carbon dioxide (CO2), carbon monoxide (CO), methane (CH), nitrogen oxide (NOx), Sulphur oxide (Sox), volatile organic compound (VOC), etc. (Yu and Lu, 2012). It estimates the amounts and quantities of resources consumptions, emissions, and the waste flows caused by the product's life cycle (Esin and Cosgun, 2007; Tunnell and Brewster, 2005). All stages are monitored independently as wastes or emissions are generated as the resources are consumed.

After collection of data, the web-based models are used to obtain basic calculations that afterward can be used by the consent bodies to weigh their impacts on the ecosystem and environment at large (Schadt et al., 2010; Santero, 2009). The input parameters include pavement thickness, length of the road and the width of the road in a consent area of study materials used, distances of travel and the mode of transport used (Ekvall and Finnnveden, 2000). These input parameters are to give impact categories that include energy, cost and the toxicity categories to be expected (Ekvall and Weidema, 2004). Then, from these, analysis is done and tabulations are drawn up to assist in the development of guidelines for improving the life cycle of pavements in road networks (Zhangand Ma, 2008; Chan, 2007). Future projections are made and the alternative ways that are environmentally friendly then followed (Sarewitz, 2004; Porter and Van der Linde, 1995).

2.5 Justification for using the LCA Reference Method

This research supports strategies that reduce the negative direct and indirect long-term environmental impacts related to the construction of both gravel and asphalt roads as well as the major processes in the LCA (Yu and Lu, 2012; Yoder and Witczak, 1975). The impacts on the sustainability include, but are not only confined to, energy use, land use, and toxic releases into the environment. Different defects are to be looked at and assessed to see the present situation and work towards a better future in the road network (Kemp et al.,2007; Giani et al., 2015; Horvath, 1998). The defects include the structural, functional and surfacing defects (Roads Directorate, 2011).

The method under study is mainly the Reference method that is present in all the phases of the project. The methods that have not been of major concern to the research include Greet method that concentrates on the use and end of the project, the NonRoad method does not take into account the use phase of the project while all the other phases are essential in it. Quickzone method concentrates on the construction, maintenance, rehabilitation, and end phases of the project. The miscellaneous method concentrates on the use and end phases of the project while the mobile method concentrates on construction, maintenance, rehabilitation and end of the project. Table 2.2 elaborates the differences between methods in the five phases of the project.

Table 2.2 Difference between LCA methods

		PHASES				
		Material Extract	***Construction***	***Use***	***Maintenance and Rehabilitation***	***End***
METHODS	***Reference***	X	X	X	X	X
	Greet			X		X
	NonRoad	X	X		X	X
	Quickzone		X		X	X
	Miscellaneous			X		X
	Mobile		X		X	X

Table 2.2 gives a clear distinction between the methods and the reference method concentrates on all the phases. This says a complete product needs to be assessed at all stages to easily monitor which needs modification to improve its expected life. Concentrating on one or not into all the phases could mean some phases are compromised and thereby could be problematic to the product in a long run.

2.6 Summary

The reference method defines all phases in LCA processes, and so may not need to be modified with a different method. Other methods may require to be complemented with additional information from other methods for all phases to be met. For instance, the NonRoad method may require to be complemented by the Miscellaneous method to have all phases considered. The phases in the project are material extraction, construction, use, maintenance and rehabilitation, and end phases. The road project in any of the phases needs to meet the needs for sustainability.

CHAPTER THREE: LCA REFERENCE METHOD

3.1 Introduction

LCA starts with the aim definition and scope of the study. Then the Life Cycle Inventory (LCI) is developed whereby processes are quantified. This is then followed by the Life Cycle Impact Assessment (LCIA) whereby calculations of results are defined and further analysis predefined. Interpretations are done at all stages as the processes proceed.

3.2 Performance Concept

The product in this study is the road construction itself. The level of performance is essential as it is brought by the type of materials used in construction and the combinations of the components (Leong 1990; Ackoff, 1970). All these are brought by different aspects that include costs involved, environmental endeavors, technical skills, and the legal requirements as per figure 3.1 (Mao, 2012).

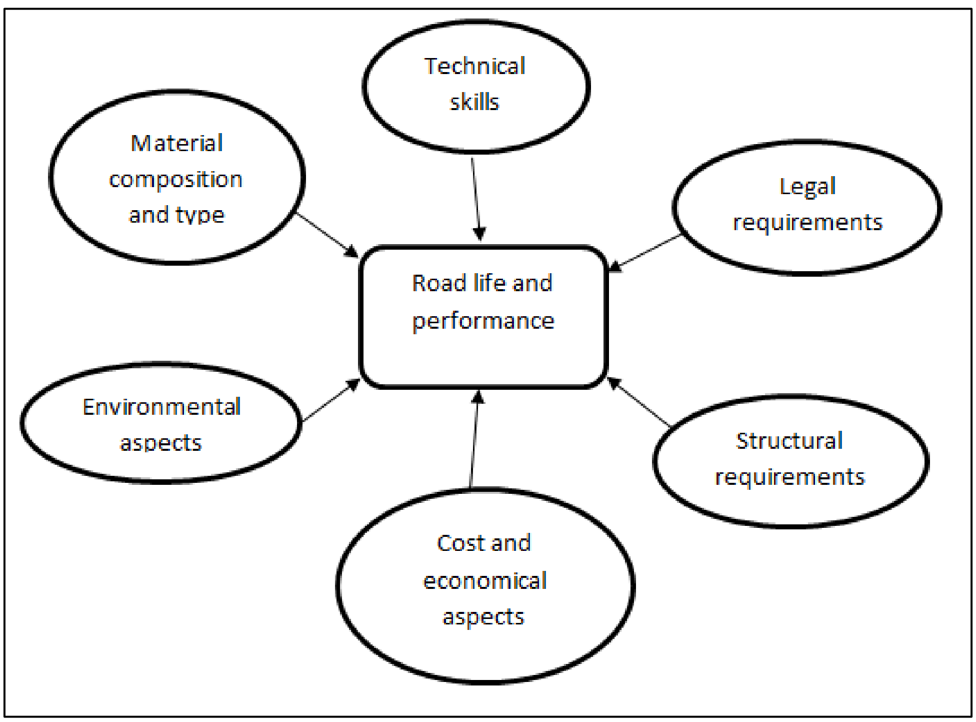


Figure 3.1 Performance concept framework (Mao, 2012).

For different road types, different material compositions are required as the different roads serve different functions. Roads connecting towns and districts may differ from those connecting villages (Baum-Snow et al., 2017; Barth, 1998). Their levels of performance normally differ as they are to carry differing loads (Ellingwood, 1980).

3.3 Life Cycle Assessment method Framework

In the construction of roads, different standards of practice are considered. Quantifying potential environmental impacts that include air emissions, wastes into the water and soil, raw materials and exploitation of natural vegetation are essential and come in four different phases (International Organization for Standardization, 2006) as in figure 3.2 below. LCA approaches are generally guided by standards but a professional code of practice has also been developed.

LCA generally has four components:

(i) goal and scope definition;
(ii) inventory analysis;
(iii) impact assessment; and
(iv) interpretation assessment.

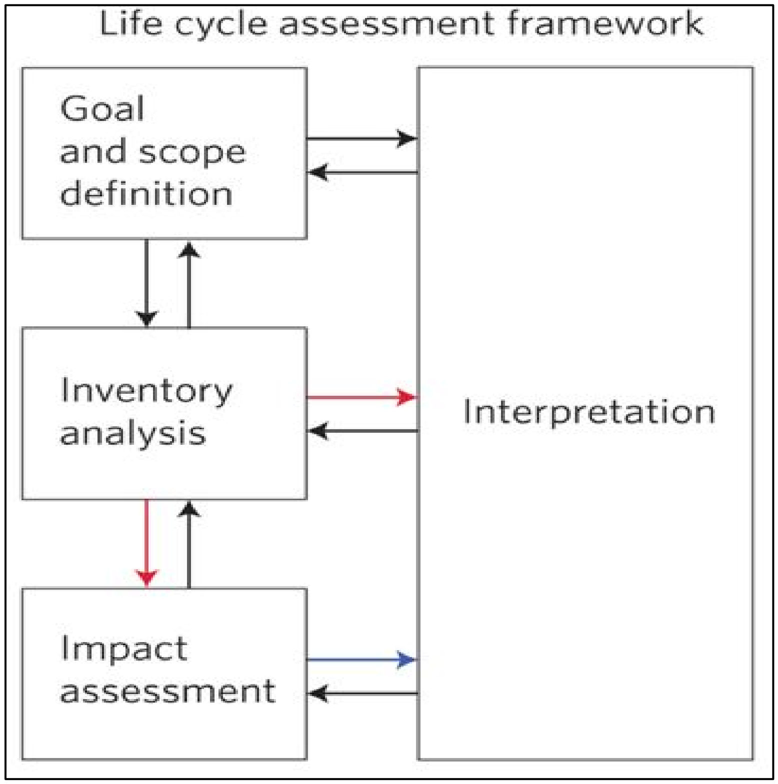


Figure 3. 2 Life cycle assessment framework (International Organization for Standardization, 2006)

3.3.1 Goals and Scope

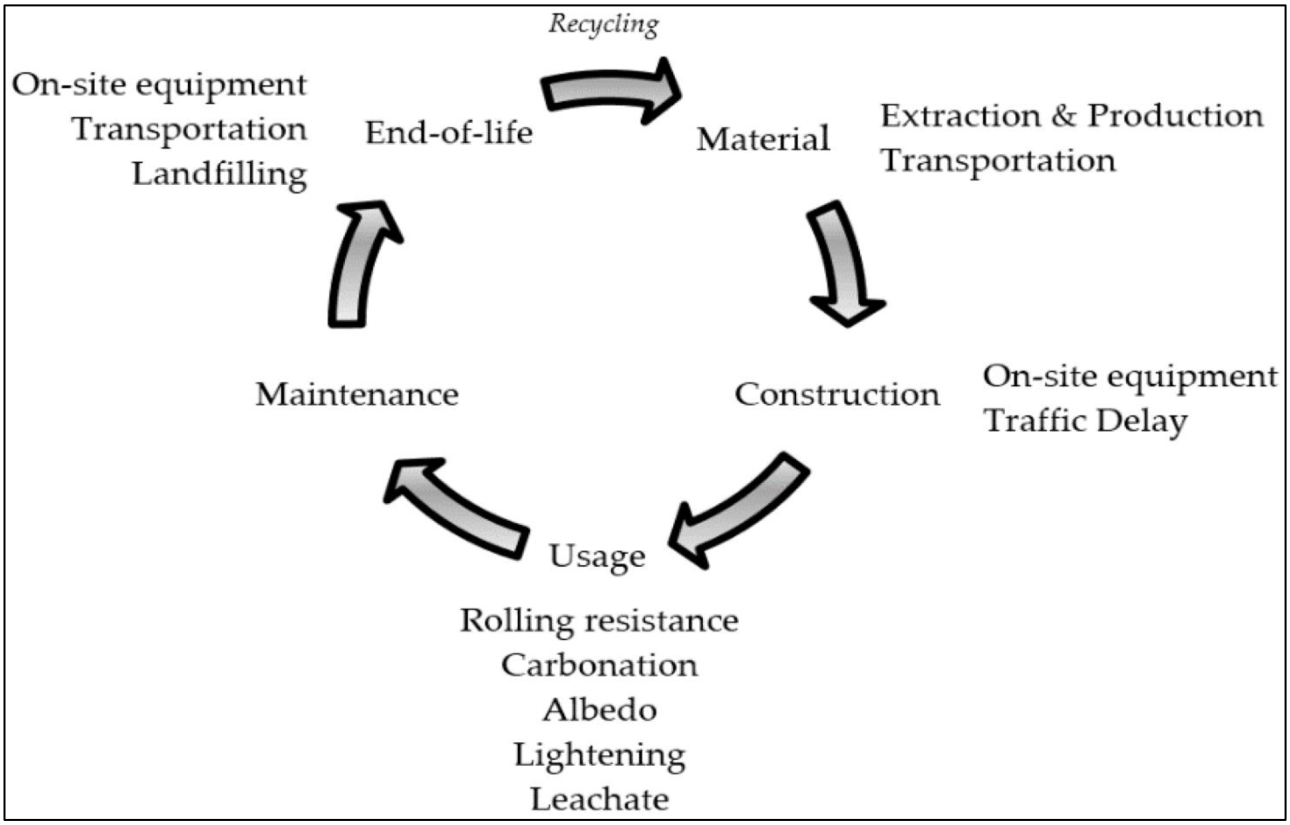


Figure 3.3 Diagrammatic representation of processes in LCA (Santero et al., 2011a)

The goals are focused on the subjects of examination and the scope describes the system boundaries. Sustainability objectives are established as required. The functional unit and descriptions are laid out from the construction performance aspect. In figure 3.3 above, a need is seen and design preparations are taken into consideration, and when completed, production takes over (Vernon, 2017; Wenzel et al., 2000). In the production phase, primary resources are collected and waste emitted while useful resources are recycled and reused in construction in the road production phase (Li et al., 2010; Chowdhury et al., 2010; Herold, 2003). Afterward, the road comes as a product to fulfill the needs of communities (Wenger et al., 2002; Braungart et al., 2007). The roads are sorted for differing uses as some are those that connect cities and some connect villages.

The post-consumer products, being the roads, are reused or recycled after a period of time, then with time the redesigns are implemented (Rebitzer, 2004). When the cycle begins again, the secondary resources may be useful and the processes in the initial cycle followed again while still considering their usefulness to construction (Fowler and Foemmel, 2006). The waste materials are treated carefully (Mittal et al, 2005) and are to be used as landfills in final disposal (Huang et al 2006; Ekvall and Weidema, 2004).

3.3.2 Inventory Assessment

In this phase, necessary materials, inputs, and outputs of energy are considered. In this, the system boundaries are described that include the service life and construction's physical performance of the road (Santero et al., 2010). Utilization of collected information on physical materials and their impacts on the environment in different stages are monitored.

3.3.3 Impact Assessment

Impact categories are monitored for environmental effects in this phase. This deals with land use and the impacts of the eco-system (Yu and Lu, 2012). Impact categories that include global warming and human health, water consumption and pollution, waste generation and land use are considered here (Jacobson, 2009).

3.3.4 Interpretation of Results

The results are from the goal and scope definition implementations. Recommendations and conclusions are drawn from their analysis and evaluation of impacts (Carlson, 2011). This part states the limitations, uncertainties, and assumptions incorporated.

3.4 LCA Case Studies

Case studies have been used to get an in-depth study in the case of LCA methods in pavements. They have been used to investigate the already existing scenarios that can be incorporated in the area of study to overcome the present situation.

3.4.1 Railway sleepers

This case study demonstrates a selection between competing and alternative materials. It highlights the importance of appropriate functional unit and considers durability and service life of competing materials.

Scope: The study quantifies the water and energy inputs and the greenhouse gas emissions associated with reinforced concrete and hardwood timber materials using table 3.1.

Functional unit: In this study, a 1km length of track was assessed. The reinforced concrete sleepers are expected to last longer than the hardwood timber sleepers over a 100 year time period (Kaewunruen, 2007).

Table 3. 1 Railway sleeper properties (Kaewunruen, 2007).

Reinforced concrete sleeper:	
Concrete weight	285 kg per sleeper
Concrete strength	50 MPa, based on Australian Standard 1085.14 (2003)
Steel reinforcement	2,700 x 8 dia x 4 per sleeper
Fastening details	10 kg per sleeper
No. of sleepers per km track	1,400 (714 mm spacing)
Timber sleeper:	
Species	River red gum, Eucalyptus camaldulensis
Air dry density	900 kg/m^3
Dimensions	2,850 x 125 x 250
Weight	80.2 kg per sleeper
No. of sleepers per km track	1,460 (685 mm spacing)

System boundary**:** The energy and water inputs and greenhouse gas emissions associated were assessed as per figure 3.4 and 3.5. The inputs and outputs associated with maintenance, end of life disposal and reuse and recycling of the materials were also assessed as presented (Kennedy et al., 2013).

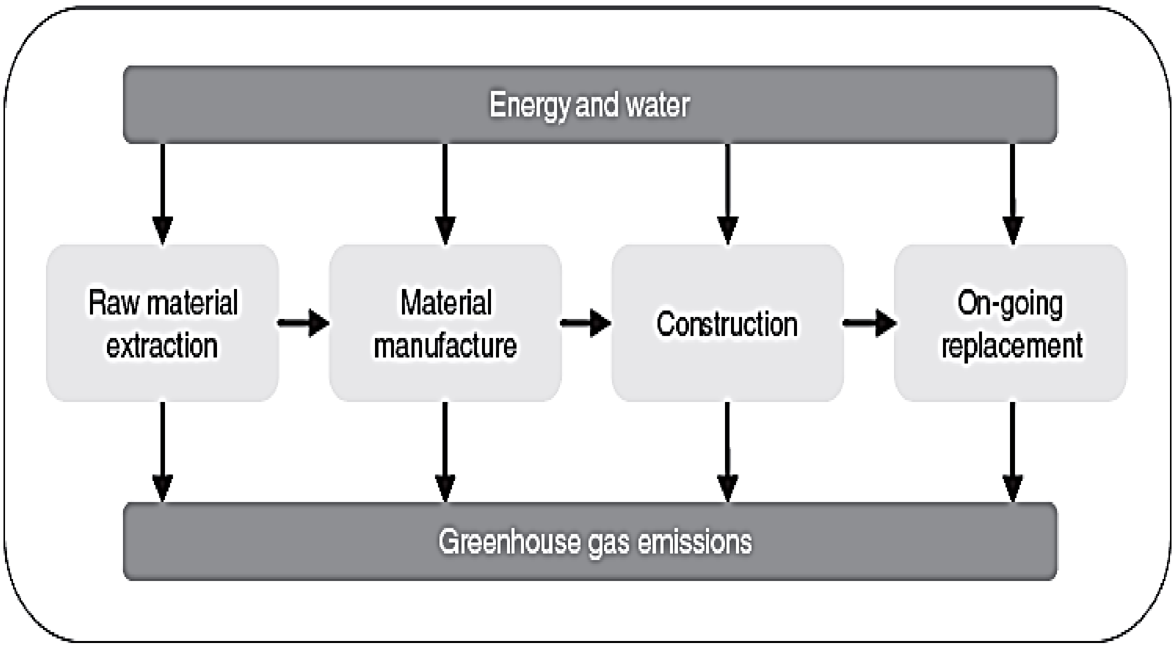


Figure 3. 4 Life cycle stages, inputs, and outputs considered for railway sleeper cycle assessment (Kennedy et al, 2013).

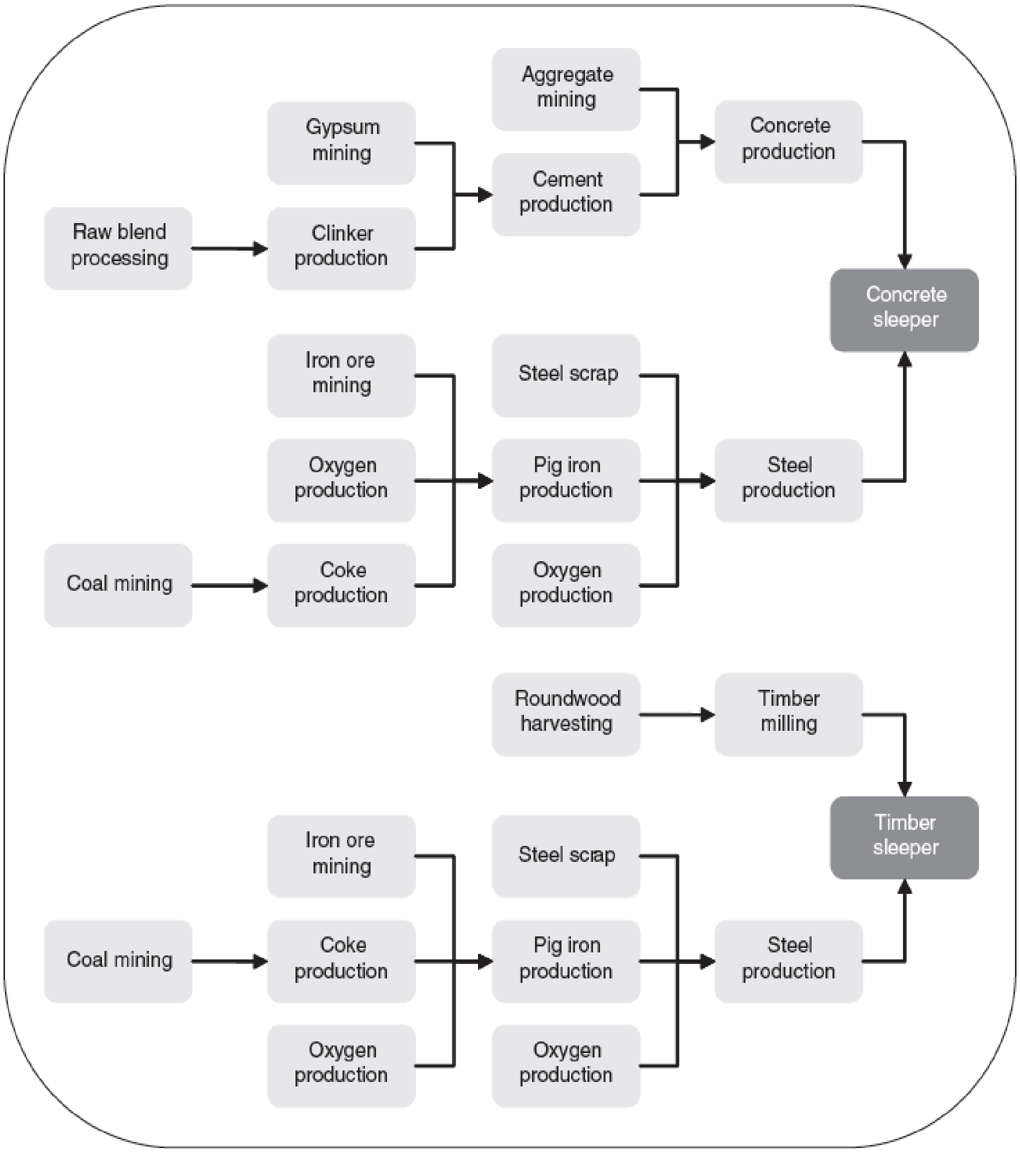


Figure 3. 5 LCA processes in process-based system boundary for reinforced concrete and timber sleeper (Richter, 1998).

Table 3. 2 Impact categories and indicators for railway sleeper LCA (Richter, 1998).

Impact category	*Category indicator*
Energy use	Gigajoules of energy (GJ)
Water use	Kilolitres of water (kL)
Global warming	GWP (t CO_2-e)

Life cycle inventory of reinforced concrete and timber sleeper production

The energy and water requirements associated with the production of the two sleeper types were calculated. The quantities of the constituent sleeper materials were multiplied with the coefficient of the hybrid material as per table 3.2 and 3.3. The service life of the two sleeper types can vary depending on usage frequency, loads and environmental conditions (Remennikov and Kaewunruen, 2008).

Table 3. 3 Life cycle energy, water and emissions of concrete and timber sleepers (Remennikov and Kaewunruen, 2008).

Parameter	*Sleeper type*	*Initial input/ output*	*Recurrent input/output*	*Life cycle input/output*
Energy (GJ/km)	Reinforced concrete	4,335	4,335	8,670
	Timber	6,658	18,388	25,046
Water (kL/km)	Reinforced concrete	8,814	8,814	17,627
	Timber	9,589	26,482	36,071
Emissions (t CO_2-e/km)	Reinforced concrete	328	328	656
	Timber	812	2,244	3,481*

Impact assessment:

Each impact category is weighted based on the perceived impact relative to the magnitude of the impacts caused by the other two impact categories as per table 3.4 (Crawford, 2011).

Table 3. 4 Weighting of impact categories and life cycle inventory results for railway sleeper LCA (Crawford, 2011)

Impact category	*Life cycle input/output per km of sleepers*		*Weighting factor*	*Weighting result*	
	Concrete	*Timber*		*Concrete*	*Timber*
Energy use (GJ)	8,670	25,046	0.3	2,601	7,514
Water use (kL)	17,627	36,071	0.2	3,525	7,214
Global warming (t CO_2-e)	656	3,481	0.5	328	1,740
			Total	6,454	16,468

Interpretation – evaluation of results

The reinforced concrete sleepers' result in the sensitivity of the weighted findings to variations in this data can be ascertained. Based on an error range of ±40 percent for the energy, water and emissions data used, Table 3.5 shows the possible effect of this data on the weighted environmental impacts associated with the sleeper production. This sensitivity analysis shows lower environmental impacts than timber sleepers do (Crawford, 2011).

Table 3. 5 Sensitivity analysis on weighting result for embodied energy, water, and emissions data uncertainty, by railway sleeper type (Crawford, 2011).

Impact category	*Weighting result*	
	Reinforced concrete	*Timber*
Energy use (GJ)	2,601	7,514
Water use (kL)	3,525	7,214
Global warming (t CO_2-e)	328	1,740
Deviation (%)	±40	±40
Energy use range (GJ)	1,561 – 3,641	4,508 – 10,520
Water use range (kL)	2,115 – 4,935	4,328 – 10,100
Global warming range (t CO_2-e)	197 – 459	1,044 – 2,436
Sensitivity (%)	40	40

3.4.2 Road construction

A streamlined LCA approach has been taken, quantifying only energy consumption, in order to highlight the process used for selecting an environmentally preferred type of road construction (Cabeza et al., 2014).

Scope: The study quantifies the energy inputs associated with the construction and maintenance of four alternative road constructions, these road types are detailed in Table 3.6 (Jullien et al., 2014).

Functional unit: The assessment was a 1m length of the road over a period of 40 years. The traffic cable width of the road was assumed 7m with 2m-wide shoulders on either side (Heijungs et al., 1992).

System boundary: The energy inputs associated with the initial construction and on-going maintenance of each road type were assessed. All energy requirements associated with the actual road construction process and all supporting processes and services upstream of this were included, as per figure 3.6 and 3.7. Energy requirements associated with the installation of sub-surface drainage were assumed to be the same for all road types and thus not included in the analysis (Heijungs et al., 1992). The demolition stage was not included as very rarely are existing roads demolished; rather they are often maintained indefinitely into the future.

Table 3. 6 Road type characteristics for 1 m length of road (Heijungs et al., 1992).

Road type	*Base*	*Sub-base*
Continuously reinforced concrete (CRC)	2.09 m^3 of 32 MPa concrete; 133 kg steel reinforcement	1.38 m^3 of 5 MPa concrete
Full-depth asphalt (FDA)	2.97 m^3 of asphaltic concrete	1.65 m^3 of stabilized earth*
Deep-strength asphalt (DSA)	2.22 m^3 of asphaltic concrete	Compacted graded earth
Deep-strength asphalt on bound sub-base (DSAB)	1.65 m^3 of asphaltic concrete	2.2 m^3 of stabilized earth*

*For road types FDA and DSAB, the sub-base of stabilized earth is assumed to be modelled adequately by 5 MPa concrete. No embodied energy is attributed to compacted graded earth, other than the amount of direct energy implied in the input-output model for the road construction process.

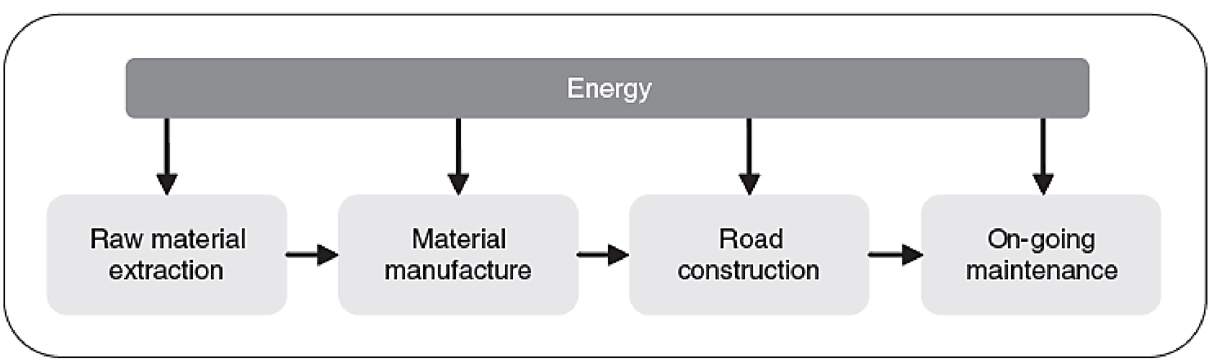


Figure 3. 6 Life cycle stages, inputs, and outputs considered for road construction LCA(Kennedy et al, 2013).

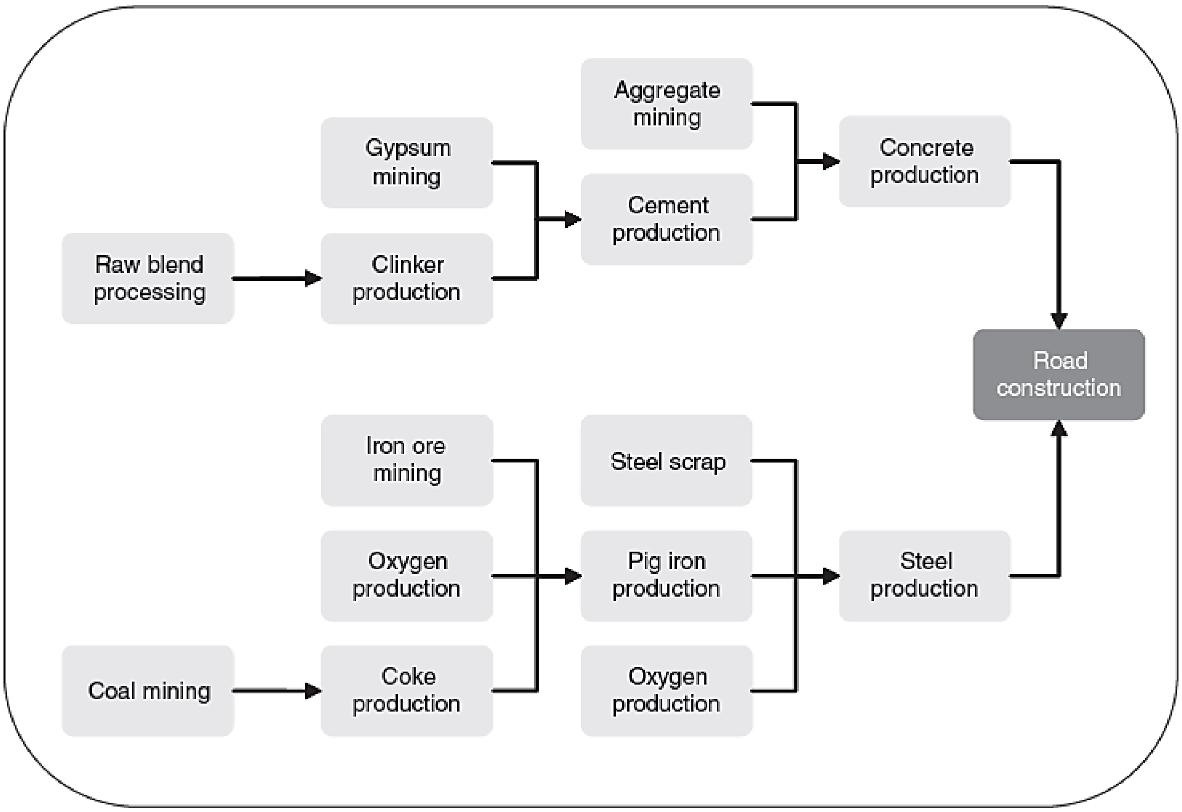


Figure 3. 7 Processes included in process-based system boundary for continuously reinforced concrete (CRC) road construction LCA (Zapata and Gambates, 2005).

Life cycle inventory of road construction and maintenance

The quantity of materials contained within a 1 m length of road (for all four road types) was determined based on an analysis of the individual road types (Table 3.7). The energy requirements associated with the production of the road materials were calculated by multiplying the quantity of these materials by the hybrid material energy coefficients for the respective materials as per Table 3.8. (Zapata and Gambates, 2005). The pathways representing the individual materials quantified for the four road types were identified within the relevant economic sector and the sum of their total energy requirements (as per Table 3.9) subtracted from the total energy requirement of the sector.

Table 3. 7 Calculation of remainder to fill sideways and downstream embodied energy data gaps for road construction (Horvath, 2004).

Road type	*Sector*	*Sector TER (GJ/A$1000)*[a]	*Cost (A$)*[b]	*Sum TER of related paths (GJ/A$1000)*[c]*	*Remainder (GJ/m road)* ((a–c) x b/1000)
CRC	*Other construction*	9.9798	596	5.074	2.924
FDA	"	"	858	4.695	4.534
DSA	"	"	630	3.904	3.828
DSAB	"	"	643	4.695	3.398

*This figure also includes inputs considered to not be used in road construction (e.g. glass products).

Table 3. 8 Calculation of initial embodied energy of CRC road construction (Horvath, 2004)

	Embodied energy (GJ/m road)
Process data for quantified road materials[a]	14.76
Input-output data used to fill *upstream* gaps for road materials[b]	12.58
Initial embodied energy (a+b)	27.34[c]
Input-output remainder (to fill *sideways* and *downstream* gaps) (Table 5.26)	2.924[d]
Total (c+d)	30.26[e]
Proportion of process data (a/e)	48.8%

Table 3. 9 Life cycle energy requirements of four road types, per meter of the road (Horvath, 2004).

Road type	*Initial embodied energy (GJ)*[a]	*Annual maintenance energy (GJ)*[b]	*Life cycle energy (GJ)*[(a+(b x 40))]
Continuously reinforced concrete (CRC)	30.26	1.21	78.68
Full-depth asphalt (FDA)	18.28	0.73	47.53
Deep-strength asphalt (DSA)	10.66	0.43	27.72
Deep-strength asphalt on bound sub-base (DSAB)	14.62	0.58	38.01

Note: Figures may not sum due to rounding.

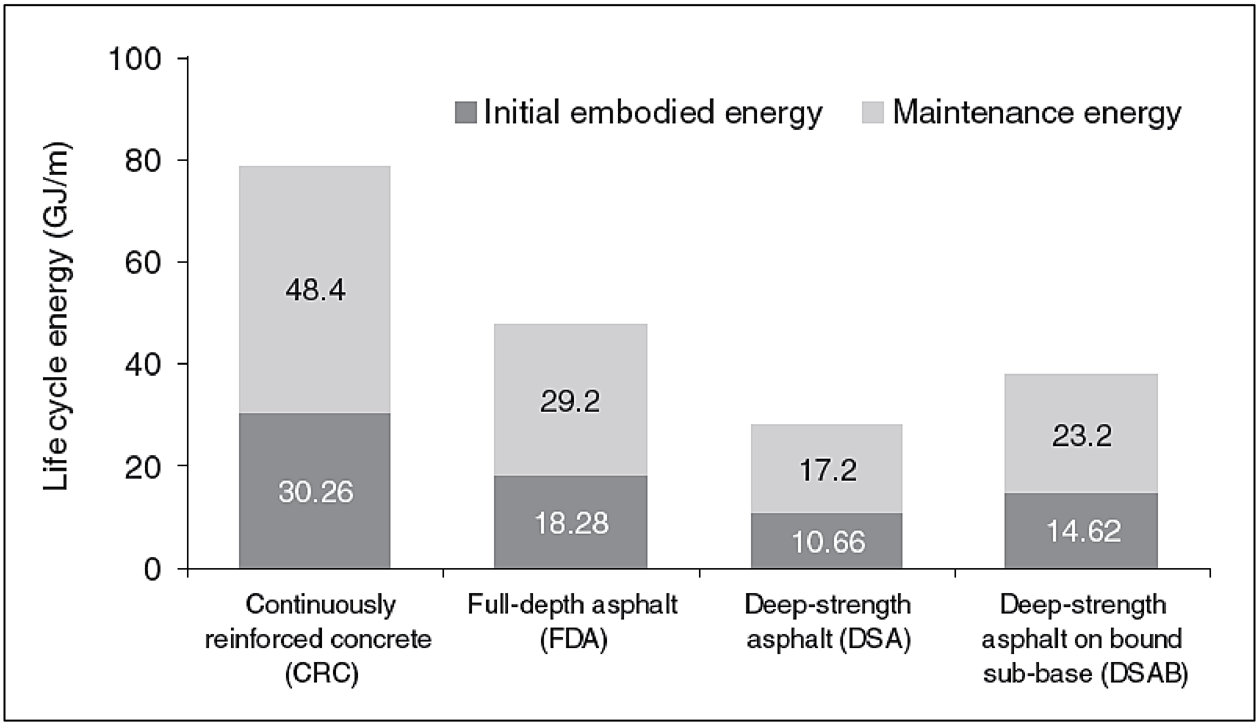


Figure 3. 8 Life cycle energy requirements of alternative road types (Horvath, 2004).

Interpretation – evaluation of results

By assessing the environmental performance of a range of possible solutions, in this case, road construction, it is possible to identify a solution that may potentially result in the lowest environmental impact of all options considered so this is the preferred option (Vachon and Klassen, 2006). Simple improvements to other options as the type and source of raw materials used that may initially appear to have a greater environmental impact may, in fact, prove to be a better option (Horvath, 2004). For example, the replacement of some or all of the cement used to manufacture the Continuously Reinforced Concrete (CRC) road type with waste or lower impact cementitious material may significantly reduce the energy requirements for concrete production as per figure 3.8 (Delatte, 2018).

3.4.3 Building Structural System

The decisions on the design, construction, operation, maintenance, and eventual demolition come from the complexity of the structure (Lemer, 1996). There is a broad range of possible design solutions, ranging from the selection of materials to the building components and other systems that might be used within a building. The growing demand for buildings with improved environmental performance means that possible environmental design solutions must be assessed to ensure that they provide improved environmental outcomes (Ding, 2008). LCA is an important tool for conducting such an assessment.

Selecting a building structural system – steel or reinforced concrete

This case study demonstrates how LCA can be used to select between competing or alternative construction materials or systems at the whole building level (Bribián, et al., 2011). It also highlights some of the decisions that may need to be made in this type of comparison and why a life-cycle approach to this decision is essential (Smith et al., 2004).

Scope: The study quantifies the energy inputs associated with two variations to the construction of a commercial office building in order to determine the alternative with the lowest embodied energy and thus associated environmental impacts (Ramesh et al., 2010). These variations relate to the structural elements of the building and include a steel-framed construction and concrete-framed construction approach. All building elements – other than the beams, columns, and slabs – were considered identical for both alternatives (Robertson et al., 2012).

Functional unit: The functional unit for the assessment was the construction of a 75,570 m^2, 50-story commercial building with external dimensions of approximately 42 × 42 m^2 (Figure 3.9). The energy required to construct the building (in gigajoules) was assessed based on both the steel and concrete framed construction methods using an identical floor plan. For the concrete-framed alternative, 40 MPa steel-reinforced concrete was used for the footings and columns, with 30 MPa steel-reinforced concrete used for the beams, slabs, and staircases. The steel-framed building consisted of steel columns and beams, 40 MPa steel-reinforced concrete for the footings and 30 MPa steel reinforced concrete slabs. The external façade for both construction types consisted of aluminium-framed double-glazed panels (Kennedy, 2013).

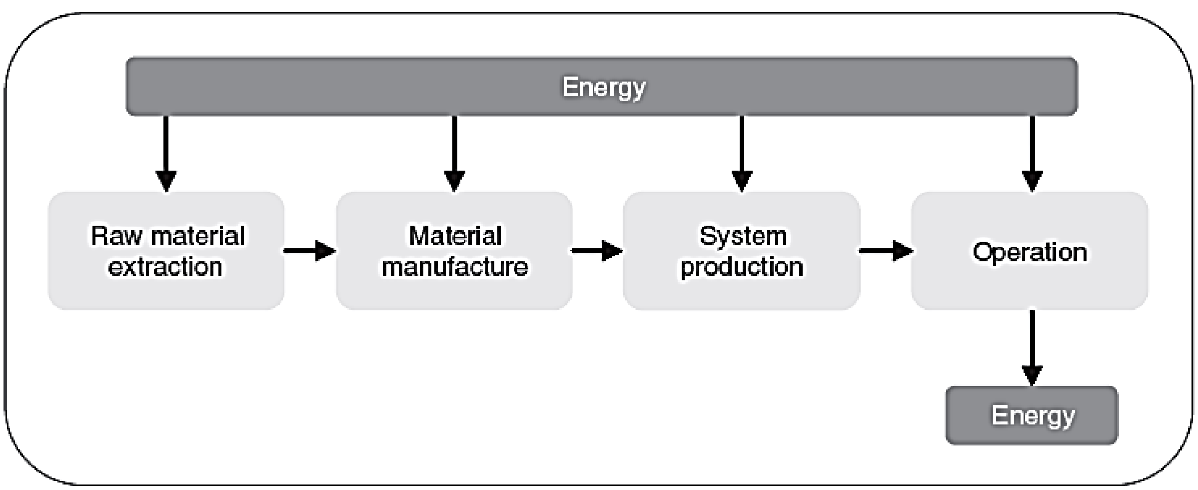


Figure 3. 9 Life cycle stages considered for steel and concrete building LCA (Kennedy, 2013).

***System boundary*:** Only the energy inputs associated with the initial building construction were assessed, excluding energy required for on-going component replacement, end-of-life refurbishment, disposal, and possible reuse and recycling of materials. All energy requirements associated with the actual construction process and all supporting processes and services upstream of this were included as per Figure 3.10 (such as but not limited to, raw material extraction, transportation, and manufacturing of materials). Where process data was not available, input-output data was used to fill any gaps in the construction system boundary.

The choice of the structural system is unlikely to have any significant impact on the thermal performance and thus the operational energy requirements and associated environmental impact of a building and so this stage was not included in the analysis (Kennedy, 2013). Figure 3.10 shows the individual material production and building construction processes for which process data was obtained. All remaining material and minor goods and services requirements were quantified using input-output data (Cliff et al., 2000).

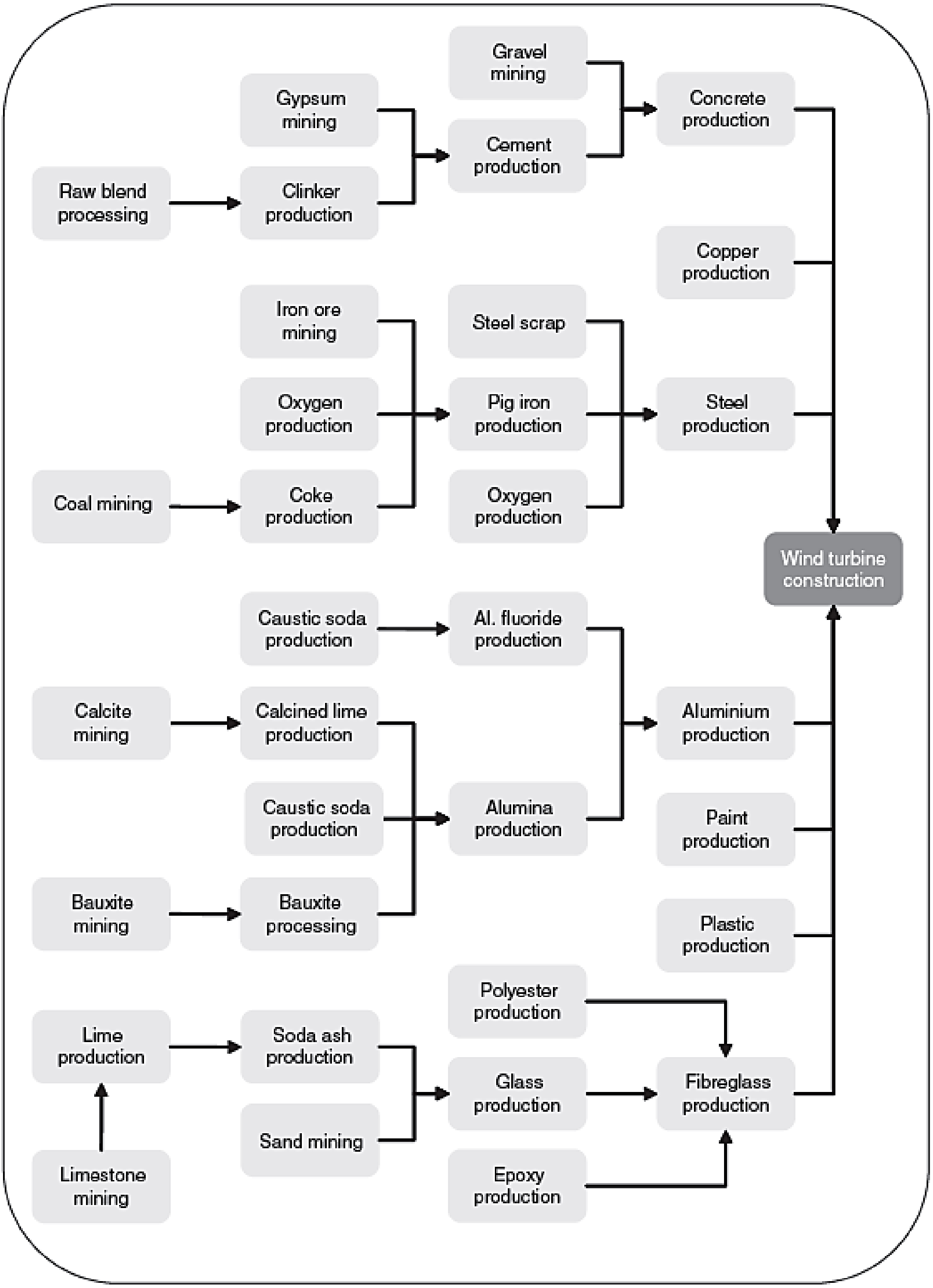


Figure 3. 10 Processes included in process-based system boundary for steel and concrete building LCA (Optis and Wild, 2010)

3.5 Summary

Case studies have been provided across some various elements of the built environment to demonstrate the application of LCA in the built environment context. The findings from these studies provide useful information to help decision makers make more informed environmental choices to improve the environmental performance of the built environment. The impact that some of the limitations of the LCA approach can have on assessing environmental performance has been demonstrated.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

In this chapter, the qualitative research methods adopted in this study are described in detail. The questionnaire survey designs are discussed as well as their sample respondents' selection. The individual responses were put together in a statistical sheet designed for their collection so easy analysis could be drawn. The interviews were also conducted from a random selected respondants. The respondents to the questionnares and the interviews were asked their age and the minimum age was 18. The consent letter stating the respondents were of the required age is attatched in appendix D. The observation data collection method was also carried out to get the trustworthiness of the gathered information from both the questionnaires and interviews.

4.2 Data Gathering Methods and Instruments

This study concentrated on three different units of analysis: Questionnaires, interviews, and observations as follows:

4.2.1 Questionnaire Design Theory

The questionnaires were designed to address the following areas:

a) Assessing the prevailing state of roads in Maseru

The current state of roads needed to be assessed to take note of the conditions so as to note the major areas that need to be addressed.

b) Assessing reasons that lead to the high accident rate

The high accidents lead to damaged road properties and the public well-being is threatened.

c) Assessing reasons for the short lifespan of roads in Maseru

The shortened life-span leads to the need for maintenance in a short period, this requires regular funding, and being a poor country, it takes longer for proper maintenance to be done due to insufficiency in budgets.

d) Assessing the working conditions during the road construction phase

The proper working conditions lead to the product being of the required standards.

e) Assessing the wellness of stakeholders during construction

The stakeholder's good health conditions lead them to proper decision making in assessing what methods need to be followed to maintain the required standards of a product.

f) Assessing if stakeholders are aware of their different tasks to achieve the required product

The stakeholders need to know their individual responsibilities to meet the required standards.

4.2.2 Questionnaire

The goal of the questionnaires was to come up with the state of the Maseru roads that could lead to early deterioration of the consent roads. They also capture the overview of the current state provided to the end users. This is an efficient means to gather information as the respondents give their opinions concerning the roads in the country. The consent letters attatched in appendix D were also issued so the respondents confirmed to have participated in the questionnaire answering and they were of the ages above 18 years.

Two different sets of questionnaires were issued by random sampling to participants to complete, to help present the best methods of this study. For this to be a success, and to ensure that the respondents came from different geographical parts of the district, ten different people from dispersed regions were mentored individually through the questionnaires and required to post and deliver them to the required sets of stakeholders. They were expected to give guidance to respondents as they filled them in. This was quite helpful as it gave a wide range of responses from different parts and the information received was not restricted to a small set of individuals living in a confined area. This was done to reach a fair overview of respondents, as people of different regions have different views towards this study.

The first set of 50 questionnaires was filled in by environmentalists, civil engineering consultants, local contractors, municipality and the roads directorate, while the second set of 150 was filled in by the residents, taxi associations, business people, and health practitioners and the samples are in appendixes B attached. The questionnaires had to differ as the public is mainly the unskilled personnel and have just the basic knowledge when it comes to road construction. These respondents came out helpful as they also form part of the end users of the roads. Their opinions to how they perceive the road infrastructure is of help to improve in the recommendations to meet the communities needs. This questionnaire became shallow in technicality to accommodate the participants. The questionnaire to the skilled personell when it comes to construction became more detailed as the respondents had the technical knowledge to answer the questions.

The information given was helpful, as most aspects involved in this research have been addressed. The only drawback was that some firms and individuals do not easily give out detailed information as they claim it to be confidential while others gave out limited information; most of the engineers in different firms that were conducted with questionnaires are from foreign countries having tight schedules and did not respond to questionnaires.

4.2.3 Interviews

The face-to-face type of interviews were conducted between the researcher and the randomly selected stakeholders to reach the research objectives. The questions were asked and the interviewees were given a chance to respond. The sample of questions conducted is in Appendix C attached. The interviews were conducted face-to-face and the interviewer was at liberty to request further clarity in case there was a need. The interviews were unstructured to give flexibility to the respondents to air their views. The limiting factor was mainly the respondents not having enough or much of the designated time to be interviewed though, the information given became mostly useful to this study. The questions were structured as in the attached interview sample in Appendix C attached.

The respondents included civil engineers, technologists and technicians were individually interviewed to get a broader view in the study. Considering the brief of the study, introduction to respondents was given and the objectives expressed. Anonymity and confidentiality were assured and the respondents were not required to give their personal information. This was helpful since the researcher could direct the questions to collect data that is beneficial to this study. Issues not clear to respondents were clarified further to meet their understanding of the process.

4.2.4 Observation Data Collection

An observation is a data collection method, by which you gather knowledge of the researched phenomenon through making observations of the phenomena (Kothari, 2004). This research was conducted by going to the field to gather information. The nature of the different roads was observed and pictures were taken for the report to be compiled. To provide contextual information needed to frame the evaluation and make sense of data collected using other methods observation data collection was done (Corbin and Strauss, 1990).

4.3 Summary

Questionnaires were drawn; 200 were distributed to different stakeholders. The stakeholders were selected in a way, whereby 150 were mainly the road users and not engaged in the road development sector, coming from different disciplines and not necessarily the construction sector. In this category, the public and the general road users became the respondents. For a set of 50, the stakeholders included the local contractors, transport and road planners and the civil engineers. Interviews were conducted with 12 interviewees; the structure of the questions is as in Appendix C attached. Observations were done to the roads to give an overview of the prevailing situation.

CHAPTER FIVE: RESULTS AND ANALYSIS

5.1 Introduction

In this chapter, the causes that lead to pavement failure are addressed and analysis drawn to come up with ways to rectify them. The findings from both the questionnaires and interviews results are analyzed. On rainy days, the behavior of the storm was monitored. There were found places where the water could not flow freely.

5.2 Causes of Pavements Failures in Maseru

5.2.1 Failure to reach optimum compaction

Respondents 1 and 3 indicated that the machinery used in most cases was not calibrated, leading to inconsistency in compaction and not reaching the required standards.

Figure 5.1 Poorly compacted culvert crossing main Sehlabeng road in Maseru.

Respondents, 1, 3, 5, 8 and 10 indicated that the required standards of compaction were not adhered to. These roads are prone to easy weathering and early settlements. Figure 5.1 shows poorly compacted layers after placing of the culvert across the road in the road passing Sehlabeng in the Maseru district. With time and heavy rains, it can be expected that in this section the roads will dilapidate in a short time.

5.2.2 Designs and Construction failures

Respondents 2, 3 and 6 indicated that the gravel roads in Lesotho are given to contractors to design and build with minimal supervision from the client. The contractors are always working to gain maximum profits with minimal effort. For paved roads, the client appoints contractors that are felt to be worthy for the job and can deliver the required services and up to the required standards. Respondents 4, 5 and 11 indicated that the contractors normally present to the client the personnel they believe are skilled and can deliver, only to pass the tendering phase of the project, and then later unskilled labor is used to take over the construction phase. Figure 5.2 shows a water pond in the road carriageway. This is because of poor and inadequate cross-fall in the road.

Figure 5.2 Road showing water pond in the carriageway in Sehlabeng Road in Maseru.

5.2.3 Highway facilities

Respondents 7 and 12 indicated that the roads do not have adequate facilities such as drainage, adequate cross-falls, roadside furniture, road markings, and fail at an early stage before reaching the required lifespan. During the rainy seasons, it is always evident that there is a clear requirement in the upgrading of the roads. In most cases, along the road carriageways, the water does not flow smoothly on the surfaces, instead, it forms ponds and at a later stage, the roads easily way-off as shown in Figure 5.3. Following the terrain of Lesotho, there are a number of roads built along the hills and mountainsides. These roads are to be constructed with protection walls along the hilly sides. In most cases, this is not incorporated, which leads to roadside structures drifting into the carriageway. In a short period of time, these structures that include large stones fall onto the carriageway, leading to deterioration of pavements as they hit it.

Figure 5.3 A meandering curve with stones protruding into the road carriageway.

5.2.4 Poor Workmanship, Monitoring, and Supervision

Figure 5.4 shows an inadequate thickness of the asphalt layer and poor maintenance in the structure. The road has clearly been constructed on poorly compacted layers and on rainy days, the water seeps from the layers below. Respondents 6 and 9 indicated that poor quality workmanship leads to poor results in the product. This is brought by inappropriate use of inferior materials and unskilled personnel. Issues that relate to this, include over/under-consolidated aggregates that eventually lead to structural failure.

Figure 5.4 shows an inadequate thickness of asphalt layer

5.2.5 Maintenance Budget and Culture

Over the years, there has been a poor maintenance culture in Lesotho constructions that leads to conditions as shown in Figure 5.5. Respondent 11 indicated that pavements are left to wear off fully before they can be maintained, which leads to a need for reconstruction of pavements which is costly, rather than having to maintain it accordingly. The consent departments in the government need to revise ways to monitor good maintenance culture. In Lesotho, pavements are constructed and left for use with minimal or absolutely no maintenance, then ultimately deteriorate beyond repair, so leading to a need for reconstruction.

Figure 5.5 shows pavements not undergoing proper maintenance. Respondents 1, 2 and 12 indicated that potholes are left to degrade the pavements and this encourages unwanted accidents. Drainage systems not attended to in the long run lead to water soaking into the road layers and deteriorating them, then at a later stage the pavement weakens. The need for a maintenance budget is essential to prolong the pavements life.

Figure 5.5 Potholes in the traffic control circle Ha Pita.

Figure 5.6 was captured after a heavy storm. It shows drainage culverts blocked with plastics and unwanted materials. Respondent 9 indicated that culverts blockage has led to water not flowing in the required channels but rather ponding on the road surface. In the case of frequent maintenance and cleaning, the blockage would have been monitored and the water let to flow in the required constructed channels. The figure also shows cars being driven on unaffected lanes.

Figure 5.6 Illustrating silted drainages at haThetsane.

Figure 5.7 shows a section of a road with heavily silted drains. Respondent 2 indicated that the drains are left for grass and plants. In the meantime, the roots to these plants are buried in the road layers leading to early deterioration of the pavement layers.

Figure 5. 7 Illustrating silt composition after a heavy storm.

Point A in Figure 5.8 gives a point whereby it would be required that pavements reach that span in case there are no rehabilitation and resurfacings done during the structural design period (Huang, 2009; Ochsendorf et al., 2011). Respondents 3 and 5 indicated that at this point, the terminal riding quality is reached and this leads to more finance having to be invested in the project as re-construction may be an option. In the case, whereby maintenance is being done accordingly, for instance in the case where at least one resurfacing operation is done, then the required structural design period can be reached. In Lesotho, pavements way long before their design life.

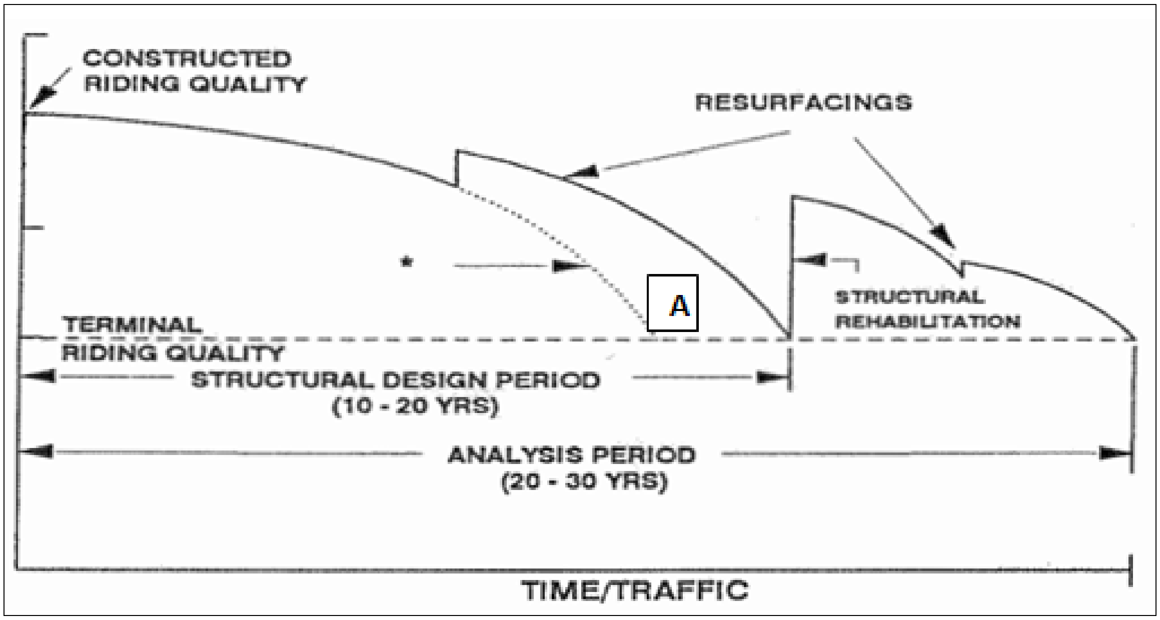


Figure 5.8 Design requiring two resurfacings and one structural rehabilitation during the analysis period (TRH 4).

Figure 5.9 is an elaboration of the Lesotho state in the LCA of Maseru roads. Respondent 9 indicated that there is minimal or no maintenance of roads, leading to early deterioration as can be described by Figure 5.11 below. Preventive maintenance is a systematic approach that prolongs road conditions and delays early damage and is elaborated on in Figure 5.13. Minor problems are corrected before they become major, thereby, improving safety and reducing maintenance costs.

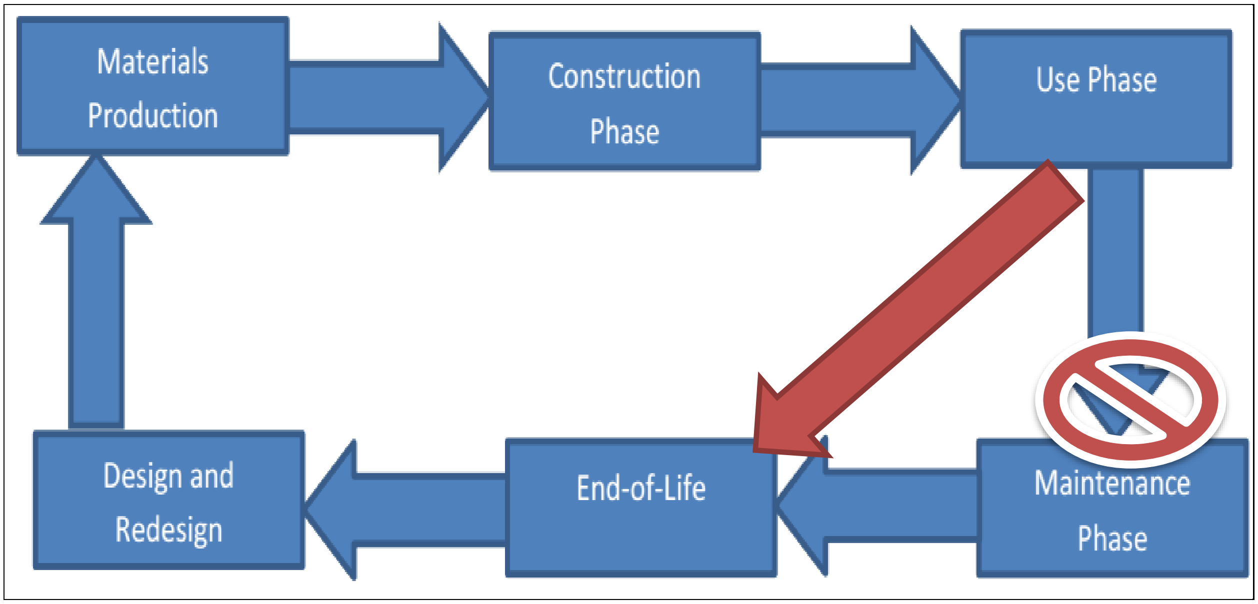


Figure 5.9 LCA in Maseru roads

5.3 Road Users' Impression

5.3.1 Demographic Information

Of the 154 respondents, 38% were female while 62% were male, both ranging between the ages of 18 and 60 years as in Tables 5.1 and 5.2. Table 5.2 gives a high percentage (94% in total) of respondents to the question being between the ages of 18 and 49. Of the 162 respondents, eight did not respond to the question on gender and also in the question of age, nine did not respond. Table 5.3 shows 21% of respondents using mainly private transport while 52% use mainly public and 27% of respondents using both public and private transport.

Table 5.1 Gender statistics of respondents

Gender	Frequency	Valid Percent
Female	59	38
Male	95	62
Total	154	100
Missing	8	
Total	162	

Table 5.2 Age of respondents

Age	Frequency	Valid Percent
18-29	84	55
30-39	30	20
40-49	29	19
50-59	8	5
>60	2	1
Total	153	100
Missing	9	
Total	162	

Table 5.3 Vehicle user respondents

Transport	Frequency	Valid Percent
Both	42	27
Private	33	21
Public	79	52
Total	154	100
Missing	8	
Total	162	

5.3.2 Current state of Maseru roads

For the different roads in Maseru, the conditions are generally poor, as shown in Figure 5.10. These roads are found mainly in the remote areas and the outskirts of Maseru. Both the gravel and the tarred roads are in poor shape and minimal attention is shown as the low-income groups of people live there. The roads here are left to deteriorate fully before they can be maintained. The roads found to be in good and satisfactory conditions are those recently constructed and that have not undergone major distress. These are found mainly in the suburbs and in the heart of Maseru where mainly the high-income class group of people lives. The government draws its attention to these areas in most cases.

Table 5.4 Current Roads Conditions

Condition	Frequency	Valid Percent
Good	13	12.3
Satisfactory	27	25.4
Bad	66	62.3
Total	106	100

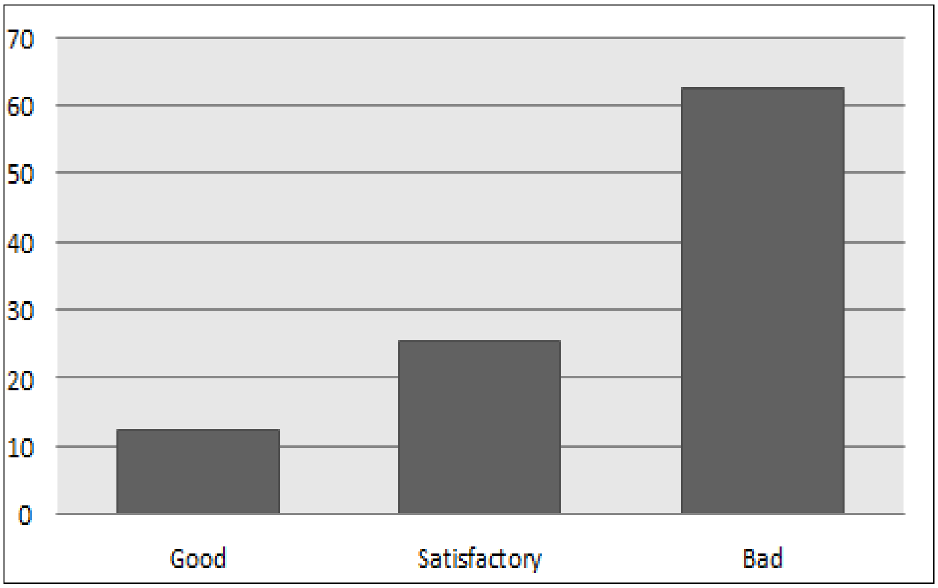


Figure 5.10 The current road conditions in Maseru

5.3.3 Road Markings and Roadside Furniture

In most instances (33%), the markings are not visible due to the type of paint used. The paint used depletes in a short while and the makings become invisible to road users. Most respondents (64%) are aware and have the basic knowledge of road markings and signals. This could be because most respondents being the public transport users and find no need to learn the different markings. The number of signals in the roads are few (20%), as most have been tampered with. The signs are not mounted in most cases and this leads to uncontrolled traffic and movements, as can be elaborated by Figure 5.11.

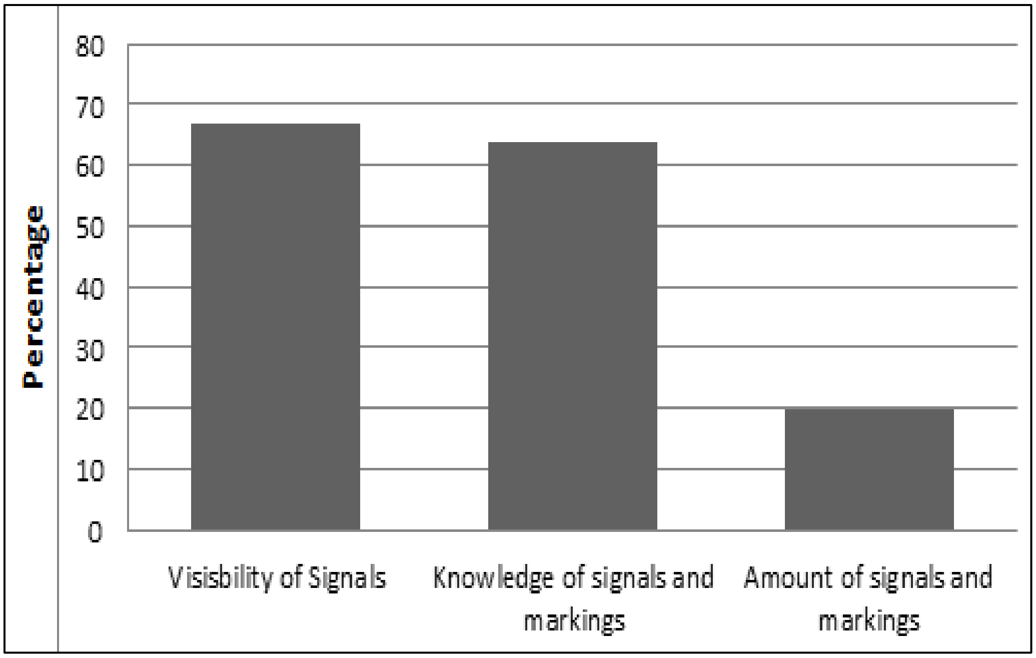


Figure 5.11 Road signals and markings

Traffic signals placed in the road junctions are in most cases not designed to control some movements and the right-turning traffic causes havoc. The signals are designed to control the straight-moving traffic and the turning traffic not monitored by arrows. In the gravel roads, there are no markings and signs to control traffic. The tarred roads are also the bare minimal or with no markings and signs at all. This results in road traffic not being well controlled, leading to a high rate of accidents. The signal colors fade and become invisible and sometimes become unfunctional due to damage in accidents. The markings fade in a short while. There are respondents with minimal knowledge of road signs and markings, as indicated in figure 5.13.

5.3.4 Adequacy of road widths

The road widths are of minimal ranges and mostly narrowed so much that in a normal drive, no two vehicles can pass in different directions at once. The roadsides are mainly private properties that do not allow for pavement widening to accommodate heavy traffic. This causes a delay in vehicular movement. The roadside furniture is distracted by the nearby properties that include trees and buildings. Figure 5.12 shows low percentages (22%) of the roads with adequate road widths from good to excellent. The remaining 78% is of poor to fair road widths. This shows the inadequacy of the widths that could have been due to unplanned townships. The roads are being developed only after properties have been erected and inadequate space has been left to allow for the construction of roads.

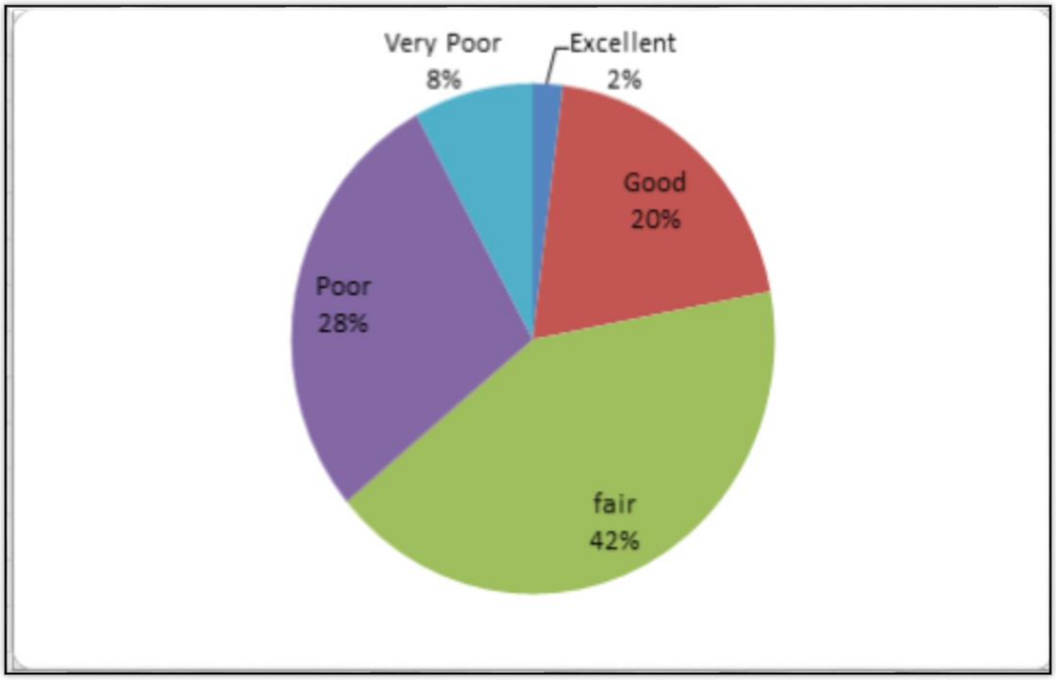


Figure 5.12 Validity of road widths

5.3.5 Construction of highway facilities

Figure 5.13 gives an illustration of the facilities found on the Maseru roads. The roadside furniture is 9%; speed-humps 18%; pedestrian ways 27% and 12% are water channels. This poses a concern to the authorities that the roads are failing dismally as proper facilities are not incorporated.

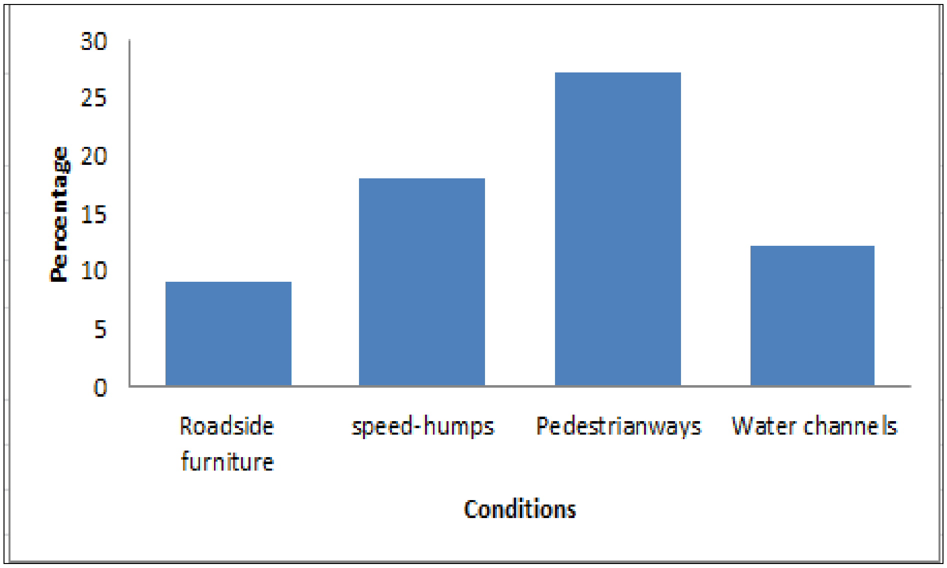


Figure 5.13 Highway facilities in the road carriageways

5.3.6 Road construction working conditions

Figure 5.14 proves poor working conditions in construction: 62% of the personnel in construction has proven to have minimal knowledge of what is expected of them on construction sites, so the required productivity is met by 22% at 27% quality expected; 39% of the respondents feel it is the responsibility of the stakeholders to ensure good working conditions for the laborers and the nearby facilities. The 58% of the respondents felt the supervisory skills are inadequate as most contractors use unskilled labor for the works; 53% of the respondents are for the idea that the health and safety measures are not adhered to.

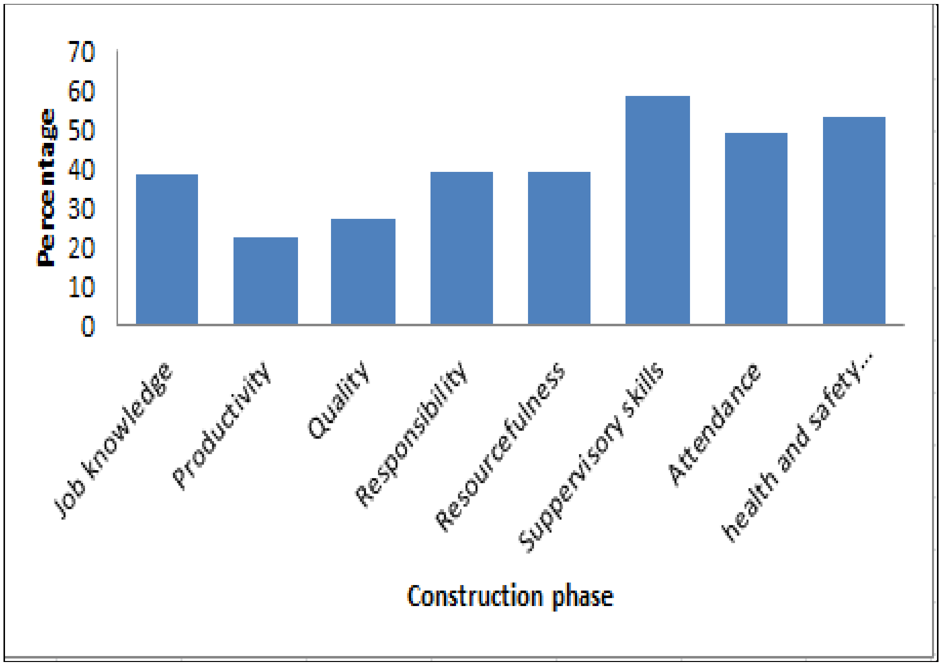


Figure 5.14 Construction working conditions

5.4 Summary

The data was collected using qualitative approach methods. The study considered both skilled and unskilled personnel. The prevailing conditions of both the gravel and tarred roads are generally poor as per questioned respondents in the study. The 12.3% roads that are in good condition have either been lately maintained or have been constructed recently. The 23.4% roads that are satisfactory, refers to roads of low-volume traffic and the respondents in those sections do not experience heavy traffic. It could be that they are always going against traffic and the roads they use are low-volume ones that can take time before being maintained. Of the respondents, 62.3% have seen the worst scenario in the road infrastructure. These roads are so bad they require rehabilitation.

CHAPTER SIX: DEVELOPMENT AND COMPARISON OF GUIDELINES

6.1 Introduction

This chapter is aimed at developing guidelines for the LCA Reference Method into the transportation systems based on the information from the literature review, case studies, legislation and data collected. These guidelines developed are to be compared later with the already existing ones in other countries. They serve as guidance to an improved life cycle of a project. The guidelines' main Importance is to assist with bringing forth the important factors to be considered before implementing the LCA Reference method in transportation construction.

6.2 Guidelines

6.2.1 Legislations and policies

Policies and recommendations of law governing the construction sectors should be revised regarding construction practices and handing-over of projects, and be followed accordingly. Sanctions should be implemented on all the involved parties in construction for any road not meeting the required standards or even the design life of the roads. The stakeholders should take a longer period still maintaining the roads they took part in, most especially the contractors involved and engineers' supervisors. Only competent stakeholders should be involved. This shall lead to the local constructors being forced to implement the required methods and standards.

6.2.2 Standards of practice

Revision of the standards of practice to meet Lesotho needs in construction at large is required. In Lesotho, mainly the practices South Africa utilizes have been formed based on South African landscapes and formations. All practices should be revised to meet Lesotho needs. This calls for engineers to consider modifying these methods to meet the required spans in our construction culture.

6.2.3 Government assistance

The government should assist with plant machinery, especially to small growing contractors, and introduce compulsory training for all that are to take part in the new or roads opened for construction. In case the required standards are still not met afterward, harsh penalties should be implemented to such stakeholders.

6.2.4 Decentralization

Looking at a wider range of the country, a good variety of major economic centers is found in the heart of the CBD. This poses a call to decentralization. This would lead to services in the remote areas and the already constructed roads and those to be constructed may not experience as much heavy traffic as those in the capital. Not only the capital city should be reaping benefits, but also the other districts should enjoy the benefits. This would help in reducing congestion in confined areas and space.

6.2.5 Relief roads construction

Efforts must be made to maintain and construct relief roads passing through the nearby villages. This would lead to main road traffic being minimized and controlled. These roads should also meet the utmost standards as the major ones do.

6.2.6 Bicycle lanes introduction

Introduction of bicycle lanes is recommended to mainly the Central Business District (CBD) area where there is congested traffic, to minimize accidents occurrences. The lanes should also be restricted to both private and public transport. The public should be restricted to using the outer lanes and not follow the inner lanes in the case of multiple lanes. There should also be marked and clear routes for private vehicles to minimize congestion in the main CBD.

6.2.7 Pedestrianized walkways in pavements

Pedestrian walkways should be clearly marked and there should be punishment for those people that do not obey road signs and markings, as most accidents are caused by bad practices of pedestrians.

6.3 Comparison between Developed Guidelines and Existing Guidelines

6.3.1 Legislations and Policies

The Green Paper on the National Transport Policy has been produced in South Africa. The policy ensures that the needs of the people are met. The Constitution of South Africa ensures that the powers and responsibilities are shared among different levels of the government.

6.3.2 Standards of Practice

In the United States, the transportation infrastructure has standards that govern structure implementation, material specifications, drainage and erosion, subsurface condition cross-sections and standard dimensions. These aid in proper design standards and serve as guidance to the transportation sector.

6.3.3 Government Assistance

In the reduction of harmful pollutants from vehicle exhausts, the vehicles are contributors to poor air quality, therefore the biofuels may be preferred to the petroleum-based fuels.

6.3.4 Decentralization

This has become a recurring theme in the policies of international assistance agencies. It is necessary to accelerate the benefits of growth in the country.

6.3.5 Relief Roads Construction

These are a network of roads that are aimed to minimize urban traffic. The municipal roads bring a huge change to cities in relieving traffic congestion on the major roads.

6.3.6 Bicycle Lanes Introduction

Introduction of bicycle lanes leads to an increased number of cyclists. As the number of cyclists grows, the number of vehicles is reduced. These lanes are helpful in reducing vehicle and cyclists accidents as all are to use their respective lanes and do not interact often.

6.3.7 Pedestrianized walkways in pavements

These walkways are separated from the roadway to allow for easy movement of pedestrians. These walkways reduce vehicle-pedestrian accidents, as they provide a safe way for walking.

6.4 Summary

The developed guidelines followed are to minimize the chances of early deteriorations of the pavement. The guidelines look into legislation and policies, standards of practice, government assistance, decentralization, relief roads construction, the introduction of bicycle lanes and pedestrianized walkways.

All stakeholders need to be informed of their different tasks and their expected duties in the construction sector to meet the required outcomes. The LCA methods adopted should be effective enough to meet the improved transportation system. The results will be the prolonged life span of the pavement.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The study is aimed at improving the roads in Lesotho and maximizing their life-span. The different case studies have been studied to help improve the situation in the transportation sector in Lesotho. It investigated the reasons for early failure of roads and what can be done to minimize this. The different LCA methods were studied and the most applicable one chosen for this research. The LCA reference method was found suitable for this study as it incorporates all the five phases of LCA: the material extraction phase, construction phase, use phase, maintenance phase ant end-of-life phase. It studies the environmental impacts of LCA in all the phases of the project.

7.2 Conclusions

Life Cycle Assessment is an evaluation of pavement products from their birth to end of life. The LCA reference method has been utilized to improve the life span of roads. This network goes through five different phases looked into independently and their environmental impacts. In each phase, the assessment is done and the negative impacts are minimized accordingly. The extraction phase focuses on the quarrying of materials and transporting them from the quarry site to the construction site. The construction phase looks into all the processes that are carried out on site for the product to be achieved. The use phase focuses on all the processes that take place after the product has been delivered and the impacts brought about the particular product. The maintenance phase focuses on prolonging the life of a product still in the useful state. The end-of-life phase focuses on the product that has reached its end of time and needs to either be disposed of or recycled.

There are different methods for LCA to be a success. These methods are essential for road improvement in Lesotho. The methods include the Reference methods that focus on all the phases, the Greet method that focuses on both the use phase and end-of-life phase. The NonRoad method focuses on material extraction, construction, and end-of-life phases. The Miscellaneous method focuses on the use phase and end-of-life phase and the Mobile method focuses on the construction phase, maintenance phase and end-of-life phase. Guidelines have been developed to improve the life cycle of pavements in Maseru roads networks. This study evaluates the causes of failure in roads that have been found to be mainly by a result of improper maintenance. The maintenance culture has to be reviewed and be followed to minimise early deriorations that are costly.

7.3 Recommendations

1. The day-to-day running of the projects should be done by skilled personnel and should be held accountable for any failure that may occur due to negligence and practices outside of scope or design.
2. Road signs and markings are left to fade and the paints used are mainly of poor quality in most cases. This leads to drivers not following the necessary means of travel in such areas.
3. The government needs to be stricter in the legal reinforcements and ensuring longevity in the pavement and construction structures.
4. For any major construction to take place, there are ethics to be followed that include the fact that private properties should not encroach into the highway as in the above picture. Large structures are permitted to be built by the roadside whereby parking is done just within the road corridors. These ethics have proven not to be taken note of or implemented. There are laws governing the construction and these are not followed accordingly. In any construction, there is the scope of work to be carried out, objectives to be met and the legislative framework of the contract agreement. All parties and stakeholders involved in the construction are expected to adhere accordingly.
5. Speeding should be taken as a legislative offence and the drivers should be liable to a fine to reduce unnecessary accidents.
6. Drinking and driving is associated with speeding and no use of safety belts in cars. When one is drunk or on drugs, one tends to lose vision as eyes become blurry, leading to vehicles crashing or unnecessary accidents on the carriageway

or with properties in the roadside. There should be legislative measures to reduce drugs and drink-driving. Enforcement of laws is a critical measure to follow. Technological measures should be implemented to test for the blood-alcohol percentage and only a limited amount should be allowed in the body to drivers.

7. In the case of incompetent stakeholders, there should be laws that govern incompetency.
8. Decentralization in the business centers is essential, as there will be minimal traffic into the main CBD and the traffic movements will not be confined to a specific direction.
9. There is a need for relief roads to minimize traffic on the main roads.
10. To control car-pedestrian accidents, bicycle lanes and pedestrianized walkway constructions are needed.

7.4 Further studies

This research was conducted in a limited period, so further studies on technological improvements need to be looked into to overcome the prevailing problems. The already existing technologies may need to be studied and further improved to meet the Lesotho needs. A calculatory model for protective structures and the civil engineering field works need to be developed to provide an easy visualisation of environmental impacts of structures. This would enable decision making for the entire life cycle on environmental impacts easy.

7.5 Summary

There is an extensive need for regravelling, followed by the need for gravel rehabilitation in the gravel roads. For the paved roads, there is a great need to resurface most pavements. Regular maintenance culture should be followed to meet the life span of any construction to avoid unbudgeted for costs. The road markings need to be maintained on a regular basis to control traffic smoothly. The road lengths need to be further revised to meet the current and future traffic predictions to avoid havoc in the road corridors. The guidelines to be followed are to improve the construction sector and lead to a long life of roads in the country. The construction sector in Lesotho needs government assistance to have the necessary material and plant to meet the required standards.

The performance concept describes aspects that are needed to ensure prolonged life of a product. The personnel used in construction needs to be skilled enough to produce the required standards and follow the specified designs and binding laws and legislations. The results from methodologies carried out under this study have proven inadequacies in the transportation system. The gap is exposed while comparing Maseru to other developed and developing countries. The different methods come as guidance to a sustainable LCA. The different phases serve as assistance to different processes that are carried out for a product to be achieved. It is essential to follow the required ethics in a project and adhere to binding laws that come with it.

References

Abaza, H. (2000). Strengthening future environmental assessment practice: an international perspective. *Environmental assessment in developing and transitional countries*, pp.271-282.

Abbasi, T. and Abbasi, S.A., (2010). Biomass energy and the environmental impacts associated with its production and utilization. Renewable and sustainable energy reviews, 14(3), pp.919-937.

Achenbach, H., Wenker, J.L. and Rüter, S., (2018). Life cycle assessment of product-and construction stage of prefabricated timber houses: a sector representative approach for Germany according to EN 15804, EN 15978 and EN 16485. European journal of wood and wood products, 76(2), pp.711-729.

Ackoff, R., (1970). A concept of corporate planning. Long Range Planning, 3(1), pp.2-8.

Adedeji, J.A., 2015. Simulation of flexible pavement utilizing fly ash as alternative stabilizer (Doctoral dissertation, Bloemfontein: Central University of Technology, Free State).

Allen, C., (2014). Attractive efficiency: The emerging energy crisis & strategies for energy efficient urban design.

Appleton, C.C. and Stiles, G., (1976). Geology and geomorphology in relation to the distribution of snail intermediate hosts of bilharzia in South Africa. Annals of Tropical Medicine & Parasitology, 70(2), pp.189-198.

Arena, U., Mastellone, M.L. and Perugini, F. (2003). The environmental performance of alternative solid waste management options: a life cycle assessment study. Chemical Engineering Journal, 96(1-3), pp.207-222.

Bansal, P., (2005). Evolving sustainably: A longitudinal study of corporate sustainable development. Strategic management journal, 26(3), pp.197-218.

Barth, F., 1998. Ethnic groups and boundaries: The social organization of culture difference. Waveland Press.

Baumann, H. and Rydberg, T. (1994). Life cycle assessment: A comparison of three methods for impact analysis and evaluation. Journal of Cleaner Production, 2(1), pp.13-20.

Baum-Snow, N., Brandt, L., Henderson, J.V., Turner, M.A. and Zhang, Q., (2017). Roads, railroads, and decentralization of Chinese cities. Review of Economics and Statistics, 99(3), pp.435-448.

Bazzan, A.L. and Klügl, F., (2013). Introduction to intelligent systems in traffic and transportation. Synthesis Lectures on Artificial Intelligence and Machine Learning, 7(3), pp.1-137.

Birgisdóttir, H. and Christensen, T.H. (2005). Life cycle assessment model for road construction and use of residues from waste incineration (Doctoral dissertation, Technical University of DenmarkDanmarks Tekniske Universitet, Department of Environmental Science and EngineeringInstitut for Miljøteknologi).

Braungart, M., McDonough, W. and Bollinger, A., (2007). Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design. Journal of cleaner production, 15(13-14), pp.1337-1348.

Bribián, I.Z., Capilla, A.V. and Usón, A.A., (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. Building and environment, 46(5), pp.1133-1140.

Burroughs Jr, E.R. and King, J.G., (1989). Reduction of soil erosion on forest roads.

Cabeza, L.F., Rincón, L., Vilariño, V., Pérez, G. and Castell, A., (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and sustainable energy reviews, 29, pp.394-416.

Carlson, A. (2011). Life cycle assessment of roads and pavements: Studies made in Europe. Statens väg-och transportforskningsinstitut.

Celik, T., (2014). Developing a building construction associated social cost estimation system for Turkish construction industry(Doctoral dissertation, University of Salford).

Chan, A.W.C., (2007). Economic and Environmental Evaluations of Life-Cycle Cost Analysis Practice: A Case Study of Michigan DOT Pavement Projects (Doctoral dissertation).

Chapman, L., (2007). Transport and climate change: a review. Journal of transport geography, 15(5), pp.354-367.

Chevalier, J., Rousseaux, P., Benoit, V. and Benadda, B. (2003). Environmental assessment of flue gas cleaning processes of municipal solid waste incinerators by means of the life cycle assessment approach. Chemical Engineering Science, 58(10), pp.2053-2064.

Chowdhury, R., Apul, D. and Fry, T. (2010). A life cycle based environmental impacts assessment of construction materials used in road construction. Resources, Conservation and Recycling, 54(4), pp.250-255.

Christmann, P., (2000). Effects of "best practices" of environmental management on cost advantage: The role of complementary assets. Academy of Management journal, 43(4), pp.663-680.

Clift, R., Doig, A. and Finnveden, G. (2000). The application of life cycle assessment to integrated solid waste management: Part 1—Methodology. Process Safety and

Environmental Protection, 78(4), pp.279-287.

Cobbe, J. (1983). The changing nature of dependence: economic problems in Lesotho. The Journal of Modern African Studies, 21(2), pp.293-310.

Colledani, M., Tolio, T., Fischer, A., Iung, B., Lanza, G., Schmitt, R. and Váncza, J., (2014). Design and management of manufacturing systems for production quality. CIRP Annals, 63(2), pp.773-796.

Corbin, J.M. and Strauss, A., 1990. Grounded theory research: Procedures, canons, and evaluative criteria. Qualitative sociology, 13(1), pp.3-21.

Crawford, R., (2011). Life cycle assessment in the built environment. Routledge.

Dawson, A. ed., (2008). Water in road structures: movement, drainage & effects (Vol. 5). Springer Science & Business Media.

De Silva, S.S. and Soto, D., (2009). Climate change and aquaculture: potential impacts, adaptation and mitigation. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper, 530, pp.151-212.

Delatte, N., 2018. Concrete pavement design, construction, and performance. Crc Press.

Ding, G.K., (2008). Sustainable construction—The role of environmental assessment tools. Journal of environmental management, 86(3), pp.451-464.

Douglas, R.A. (2016). Low-volume road engineering: design, construction, and maintenance. CRC Press.

Ekvall, T. and Finnveden, G. 2000). The application of life cycle assessment to integrated solid waste management: part 2—perspectives on energy and material recovery from paper. Process Safety and Environmental Protection, 78(4), pp.288-

294.

Ekvall, T. and Weidema, B.P. (2004). System boundaries and input data in consequential life cycle inventory analysis. The International Journal of Life Cycle Assessment, 9(3), pp.161-171.

Ellingwood, B., (1980). Development of a probability based load criterion for American National Standard A58: Building code requirements for minimum design loads in buildings and other structures (Vol. 13). US Department of Commerce, National Bureau of Standards.

Eriksson, E., Blinge, M. and Lövgren, G. (1996). Life cycle assessment of the road transport sector. Science of the Total Environment, 189, pp.69-76.

Esin, T. and Cosgun, N. (2007). A study conducted to reduce construction waste generation in Turkey. Building and Environment, 42(4), pp.1667-1674.

Fogelman, C. and Bassett, T.J., (2017). Mapping for investability: Remaking land and maps in Lesotho. Geoforum, 82, pp.252-258.

Fowler, M. and Foemmel, M., (2006). Continuous integration. Thought-Works) http://www. thoughtworks. com/Continuous Integration. pdf, 122, p.14.

Frankl, P. and Rubik, F., 1999. Life cycle assessment in industry and business: adoption patterns, applications and implications. Springer Science & Business Media.

Giani, M.I., Dotelli, G., Brandini, N. and Zampori, L. (2015). Comparative life cycle assessment of asphalt pavements using reclaimed asphalt, warm mix technology and cold in-place recycling. Resources, Conservation and Recycling, 104, pp.224-238.

Goudie, A.S., (2018). Human impact on the natural environment. John Wiley & Sons.

Guinee, J. and Heijungs, R. (1993). A proposal for the classification of toxic substances within the framework of life cycle assessment of products. Chemosphere, 26(10), pp.1925-1944.

Gupta, M.C., (1995). Environmental management and its impact on the operations function. International Journal of Operations & Production Management, 15(8), pp.34-51.

Hall, C.M. and Sharples, L., (2004). The consumption of experiences or the ce of consumption? introduction to the tourism of taste. Food tourism around the world, 1.

Hamdar, Y., Kassem, H., Srour, I. and Chehab, G. (2015). Performance-Based Specifications for Sustainable Pavements: A Lean Engineering Analysis. Energy Procedia, 74, pp.453-461.

Harvey, J., Meijer, J. and Kendall, A. (2014). Life Cycle Assessment of Pavements (No. FHWA-HIF-15-001).

Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A., Ansems, A.M.M., Eggels, P.G., Duin, R.V. and De Goede, H.P., (1992). Environmental life cycle assessment of products: guide and backgrounds (part 1).

Heijungs, R., Huppes, G. and Guinée, J.B., (2010). Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. Polymer degradation and stability, 95(3), pp.422-428.

Herold, A. (2003). Comparison of CO2 emission factors for fuels used in Greenhouse Gas Inventories and consequences for monitoring and reporting under the EC emissions trading scheme. ETC/ACC technical paper, 10, p.2003.

Horvath, A. (1998). Estimation of environmental implications of construction materials and designs using life cycle assessment techniques.

Horvath, A., (2004). Construction materials and the environment. Annu. Rev. Environ. Resour., 29, pp.181-204.

Hossain, A.S., Salleh, A., Boyce, A.N., Chowdhury, P. and Naqiuddin, M., (2008). Biodiesel fuel production from algae as renewable energy. American journal of biochemistry and biotechnology, 4(3), pp.250-254.

Huang, Y. (2007). Life cycle assessment of use of recycled materials in asphalt pavements.

Huang, Y., Bird, R. and Allen, B. (2006). A life cycle assessment tool for recycling in pavement construction. In SETAC Europe 13th LCA Case Study Symposium with Focus on the Building and Construction Sector, Stuttgart, Germany.

Huang, Y., Bird, R. and Heidrich, O. (2009). Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. Journal of Cleaner Production, 17(2), pp.283-296.

Huang, Y., Bird, R.N. and Heidrich, O., (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, Conservation and Recycling, 52(1), pp.58-73.

Huo, H., Wang, M., Bloyd, C. and Putsche, V. (2008). Life-cycle assessment of energy use and greenhouse gas emissions of soybean-derived biodiesel and renewable fuels. Environmental science & technology, 43(3), pp.750-756.

International Organization for Standardization, (2006). Environmental Management: Life Cycle Assessment; Principles and Framework (No. 2006). ISO.

Jacobson, M.Z., (2009). Review of solutions to global warming, air pollution, and energy security. Energy & Environmental Science, 2(2), pp.148-173.

Jullien, A., Dauvergne, M. and Cerezo, V., 2014. Environmental assessment of road construction and maintenance policies using LCA. Transportation research part D: transport and environment, 29, pp.56-65.

Kaewunruen, S., 2007. Experimental and numerical studies for evaluating dynamic behaviour of prestressed concrete sleepers subject to severe impact loading.

Kayhanian, M., Vichare, A., Green, P.G. and Harvey, J.,(2009). Leachability of dissolved chromium in asphalt and concrete surfacing materials. Journal of environmental management, 90(11), pp.3574-3580.

Kemp, R., Loorbach, D. and Rotmans, J., 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. The International Journal of Sustainable Development & World Ecology, 14(1), pp.78-91.

Kendall, A., Harvey, J. and Lee, I.S. (2009), October. A critical review of Life Cycle Assessment practice for infrastructure materials. In Proceedings of US-Japan Workshop on Life Cycle Assessment of Sustainable Infrastructure Materials. Sapporo, Japan.

Kennedy, C., 2013. Projecting the adjective: The syntax and semantics of gradability and comparison. Routledge.

Kennedy, J., Woodward, P.K., Medero, G. and Banimahd, M., (2013). Reducing railway track settlement using three-dimensional polyurethane polymer reinforcement of the ballast. Construction and Building Materials, 44, pp.615-625.

Kolk, A., Levy, D. and Pinkse, J., (2008). Corporate responses in an emerging climate regime: The institutionalization and commensuration of carbon disclosure. European Accounting Review, 17(4), pp.719-745.

Kothari, C.R., (2004). Research methodology: Methods and techniques. New Age International.

Latham, S., Petley, L.J., Hickman, A.J. and Cloke, J. (2000). A review of available road traffic emission models. TRL REPORT 457.

Lemer, A.C., (1996). Infrastructure obsolescence and design service life. Journal of Infrastructure Systems, 2(4), pp.153-161.

Lesotho Bureau of Statistics. (2006). Census. Maseru.

Lewis, I.M., Watson, B., White, K.M. and Tay, R., (2007). Promoting public health messages: Should we move beyond fear-evoking appeals in road safety?. Qualitative Health Research, 17(1), pp.61-74.

Li, X., Zhu, Y. and Zhang, Z. (2010). An LCA-based environmental impact assessment model for construction processes. Building and Environment, 45(3), pp.766-775.

Loijos, A., Santero, N. and Ochsendorf, J. (2013). Life cycle climate impacts of the US concrete pavement network. Resources, Conservation and Recycling, 72, pp.76-83.

Loijos, A.A.N. (2011). Life cycle assessment of concrete pavements: impacts and opportunities (Doctoral dissertation, Massachusetts Institute of Technology).

Mao, Z. (2012). Life-Cycle Assessment of Highway Pavement Alternatives in Aspects of Economic, Environmental, and Social Performance (Doctoral dissertation, Texas A & M University).

Marsh, J.S., Hooper, P.R., Rehacek, J., Duncan, R.A. and Duncan, A.R., (1997). Stratigraphy and age of Karoo basalts of Lesotho and implications for correlations within the Karoo igneous province. GEOPHYSICAL MONOGRAPH-AMERICAN

GEOPHYSICAL UNION, 100, pp.247-272.

Matthews, D.E. and Farewell, V.T., (2015). Using and understanding medical statistics. Karger Medical and Scientific Publishers.

McDonough, W. and Braungart, M., (2010). Cradle to cradle: Remaking the way we make things. North point press.

McKinnon, A., (2010). Environmental sustainability. Green logistics: improving the environmental sustainability of logistics. London.

Milani, E.J. and De Wit, M.J., (2008). Correlations between the classic Paraná and Cape–Karoo sequences of South America and southern Africa and their basin infills flanking the Gondwanides: du Toit revisited. Geological Society, London, Special Publications, 294(1), pp.319-342.

Misra, V. and Pandey, S.D., (2005). Hazardous waste, impact on health and environment for development of better waste management strategies in future in India. *Environment international*, *31*(3), pp.417-431.

Mittal, A., Kurup, L. and Gupta, V.K., (2005). Use of waste materials—bottom ash and de-oiled soya, as potential adsorbents for the removal of amaranth from aqueous solutions. Journal of Hazardous Materials, 117(2-3), pp.171-178.

Mokhehle, L. and Diab, R. (2001). Evolution of environmental impact assessment in a small developing country: a review of Lesotho case studies from 1980 to 1999. Impact Assessment and Project Appraisal, 19(1), pp.9-18.

Mroueh, U.M. and Wahlström, M., (2002). By-products and recycled materials in earth construction in Finland—an assessment of applicability. Resources, Conservation and Recycling, 35(1-2), pp.117-129.

Mroueh, U.M., Eskola, P. and Laine-Ylijoki, J. (2001). Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste management, 21(3), pp.271-277.

Murphy, P., Pritchard, M.P. and Smith, B., (2000). The destination product and its impact on traveller perceptions. Tourism management, 21(1), pp.43-52.

Optis, M. and Wild, P., (2010). Inadequate documentation in published life cycle energy reports on buildings. The International Journal of Life Cycle Assessment, 15(7), pp.644-651.

Page, T., (2013). *Conservation and economic efficiency: an approach to materials policy*. RFF Press.

Pfister, S., Koehler, A. and Hellweg, S., (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental science & technology, 43(11), pp.4098-4104.

Pickett, S.T., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C. and Costanza, R., (2001). Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual review of ecology and systematics*, *32*(1), pp.127-157.

Poizot, P. and Dolhem, F., (2011). Clean energy new deal for a sustainable world: from non-CO 2 generating energy sources to greener electrochemical storage devices. *Energy & Environmental Science*, *4*(6), pp.2003-2019.

Porter, M.E. and Van der Linde, C., (1995). Toward a new conception of the environment-competitiveness relationship. Journal of economic perspectives, 9(4), pp.97-118.

Porter, M.E., (1981). The contributions of industrial organization to strategic management. Academy of management review, 6(4), pp.609-620.

Rothwell, R., (1992). Successful industrial innovation: critical factors for the

1990s. R&d Management, 22(3), pp.221-240.

Frischknecht, R., Jungbluth, N., Althaus, H.J., Hischier, R., Doka, G., Bauer, C., Dones, R., Nemecek, T., Hellweg, S., Humbert, S. and Margni, M., 2007. Implementation of life cycle impact assessment methods. Data v2. 0 (2007). Ecoinvent report No. 3 (No. INIS-CH--10091). Ecoinvent Centre.

Labeckas, G. and Slavinskas, S., (2006). The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions. Energy conversion and Management, 47(13-14), pp.1954-1967.

Langer, W., (2009). Sustainability of aggregates in construction. In Sustainability of construction materials (pp. 1-30). Woodhead Publishing.

Laszlo, C., (2003). The sustainable company: How to create lasting value through social and environmental performance. Island Press.

Leong, G.K., Snyder, D.L. and Ward, P.T., (1990). Research in the process and content of manufacturing strategy. Omega, 18(2), pp.109-122.

Nagarajan, S.K., (2016). Impact of Forecasted Freight Trends on Highway Pavement Infrastructure. Arizona State University.

Peattie, K. and Charter, M., (2003). Green marketing. The marketing book, 5, pp.726-755.

Reap, J., Roman, F., Duncan, S. and Bras, B., (2008). A survey of unresolved problems in life cycle assessment. The International Journal of Life Cycle Assessment, 13(5), p.374.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.P., Suh, S., Weidema, B.P. and Pennington, D.W., (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment international, 30(5), pp.701-720.

Reeves, G.M., Sims, I. and Cripps, J.C. eds., (2006). Clay materials used in construction. Geological Society of London.

Remennikov, A.M. and Kaewunruen, S., (2008). A review of loading conditions for railway track structures due to train and track vertical interaction. Structural Control and Health Monitoring: The Official Journal of the International Association for Structural Control and Monitoring and of the European Association for the Control of Structures, 15(2), pp.207-234.

Richter, K., (1998). Life cycle assessment of wood products. In Carbon dioxide mitigation in forestry and wood industry (pp. 219-248). Springer, Berlin, Heidelberg.

Roads Directorate, 2015.

Robertson, A.B., Lam, F.C. and Cole, R.J., (2012). A comparative cradle-to-gate life cycle assessment of mid-rise office building construction alternatives: Laminated timber or reinforced concrete. Buildings, 2(3), pp.245-270.

Rogerson, C.M., (2009). Tourism development in Southern Africa: patterns, issues and constraints. Sustainable tourism in Southern Africa: Local communities and natural resources in transition, pp.20-41.

Rosen, M.A. and Kishawy, H.A., (2012). Sustainable manufacturing and design: Concepts, practices and needs. Sustainability, 4(2), pp.154-174.

Rowntree, K.M., Ntsaba, M.M. and Weaver, A.V.B., (1991). Changing patterns of erosion in a peri-urban catchment, Maseru, Lesotho. IAHS PUBL, IAHS, WALLINGFORD,(ENGL), 1991,, (203), pp.93-102.

Santero, N. (2010). Life cycle assessment of pavements: a critical review of existing literature and research. Lawrence Berkeley National Laboratory.

Santero, N.J. (2009). Pavements and the environment: a life-cycle assessment approach. University of California, Berkeley.

Santero, N.J., Harvey, J. and Horvath, A. (2011a). Environmental policy for long-life pavements. Transportation Research Part D: Transport and Environment, 16(2), pp.129-136.

Santero, N.J., Masanet, E. and Horvath, A. (2011b). Life-cycle assessment of pavements Part II: Filling the research gaps. Resources, Conservation and Recycling, 55(9), pp.810-818.

Santero, N.J., Masanet, E. and Horvath, A. (2011c). Life-cycle assessment of pavements. Part I: Critical review. Resources, Conservation and Recycling, 55(9), pp.801-809.

Sarewitz, D., (2004). How science makes environmental controversies worse. Environmental science & policy, 7(5), pp.385-403.

Scaltriti, M., Bettuzzi, S., Sharrard, R.M., Caporali, A., Caccamo, A.E. and Maitland, N.J., 2004. Clusterin overexpression in both malignant and nonmalignant prostate epithelial cells induces cell cycle arrest and apoptosis. *British journal of* cancer, 91(10), p.1842.

Schadt, E.E., Linderman, M.D., Sorenson, J., Lee, L. and Nolan, G.P., (2010). Computational solutions to large-scale data management and analysis. Nature reviews genetics, 11(9), p.647.

Sharma, A., Bullock, D.M. and Bonneson, J.A., (2007). Input–output and hybrid techniques for real-time prediction of delay and maximum queue length at signalized intersections. Transportation Research Record, 2035(1), pp.69-80.

Smith, B.N., Montagno, R.V. and Kuzmenko, T.N., (2004). Transformational and servant leadership: Content and contextual comparisons. Journal of Leadership & Organizational Studies, 10(4), pp.80-91.

Smyth, A.J. and Dumanski, J., (1993). FESLM: An international framework for evaluating sustainable land management (p. 76). Rome: FAO.

Soutsos, M.N., Tang, K. and Millard, S.G., (2011). Use of recycled demolition aggregate in precast products, phase II: Concrete paving blocks. Construction and Building Materials, 25(7), pp.3131-3143.

Stripple, H. (2001). Life cycle assessment of road. A pilot study for inventory analysis. Rapport IVL Swedish Environmental Research Institute, 96.

Suh, S., Lenzen, M., Treloar, G.J., Hondo, H., Horvath, A., Huppes, G., Jolliet, O., Klann, U., Krewitt, W., Moriguchi, Y. and Munksgaard, J. (2004). System boundary selection in life-cycle inventories using hybrid approaches. Environmental Science & Technology, 38(3), pp.657-664.

Swan, G. (1998). Evaluation of land use in life cycle assessment. Chalmers University of.

Talawar, M.B., Sivabalan, R., Mukundan, T., Muthurajan, H., Sikder, A.K., Gandhe, B.R. and Rao, A.S., (2009). Environmentally compatible next generation green energetic materials (GEMs). Journal of Hazardous Materials, 161(2-3), pp.589-607.

Taylor, M.A. and Khosla, N.P., (1983). Stripping of asphalt pavements: State of the art (discussion, closure) (No. 911).

Tennis, P.D., Leming, M.L. and Akers, D.J., (2004). Pervious concrete pavements (No. PCA Serial No. 2828). Skokie, IL: Portland Cement Association.

Thakkar, C., (2016). Development of life cycle assessment tool for pavement sustainability analysis. Rutgers The State University of New Jersey-New Brunswick.

Tiruta-Barna, L., Benetto, E. and Perrodin, Y. (2007). Environmental impact and risk assessment of mineral wastes reuse strategies: Review and critical analysis of approaches and applications. Resources, Conservation and Recycling, 50(4), pp.351-379.

Tunnell, M. and Brewster, R. (2005). Energy and emissions impacts of operating higher-productivity vehicles. Transportation Research Record: Journal of the Transportation Research Board, (1941), pp.107-114.

Vachon, S. and Klassen, R.D., (2006). Extending green practices across the supply chain: the impact of upstream and downstream integration. International Journal of Operations & Production Management, 26(7), pp.795-821.

Vernon, R., (2017). International investment and international trade in the product cycle. In International Business (pp. 99-116). Routledge.

Vieira, C.S. and Pereira, P.M., (2015). Use of recycled construction and demolition materials in geotechnical applications: A review. *Resources, Conservation and Recycling*, *103*, pp.192-204.

Wackernagel, M. and Rees, W., (1998). *Our ecological footprint: reducing human impact on the earth* (Vol. 9). New Society Publishers.

Wang, T., Xiao, F., Zhu, X., Huang, B., Wang, J. and Amirkhanian, S., (2018). Energy consumption and environmental impact of rubberized asphalt pavement. Journal of cleaner production, 180, pp.139-158.

Wenger, E., McDermott, R.A. and Snyder, W., (2002). Cultivating communities of practice: A guide to managing knowledge. Harvard Business Press.

Wenzel, H., Hauschild, M.Z. and Alting, L. (2000). Environmental Assessment of Products: Volume 1: Methodology, tools and case studies in product development (Vol. 1). Springer Science & Business Media.

Worrell, E., Price, L., Martin, N., Hendriks, C. and Meida, L.O., (2001). Carbon dioxide emissions from the global cement industry. Annual review of energy and the environment, 26(1), pp.303-329.

Yang, R., (2014). Development of a pavement life cycle assessment tool utilizing regional data and introducing an asphalt binder model.

Yoder, E.J. and Witczak, M.W., (1975). Principles of pavement design. John Wiley & Sons.

Yu, B. and Lu, Q. (2012). Life cycle assessment of pavement: Methodology and case study. Transportation Research Part D: Transport and Environment, 17(5), pp.380-388.

Zamel, N. and Li, X., 2006. Life cycle analysis of vehicles powered by a fuel cell and by internal combustion engine for Canada. Journal of Power Sources, 155(2), pp.297-310.

Zapata, P. and Gambatese, J.A., (2005). Energy consumption of asphalt and reinforced concrete pavement materials and construction. Journal of infrastructure systems, 11(1), pp.9-20.

Zhang, M. and Ma, J., (2008). Developing calibration tools for microscopic traffic simulation final report part 1: Overview methods and guidelines on project scoping and data collection. University of California, Tech. Rep.

Zhu, Y., Ahmad, I. and Wang, L. (2009). Estimating work zone road user cost for alternative contracting methods in highway construction projects. Journal of Construction Engineering and Management, 135(7), pp.601-608.

APPENDICES

Appendix A: Requisition Letter

May, 2016

TO WHOM IT MAY CONCERN

Re: USE OF LIFE CYCLE ASSESSMENT REFERENCE METHOD TO IMPROVE LIFE SPAN IN MASERU ROADS

This serves to inform you that Ms Moliehi Monts'i is a registered Civil Engineering, M-Eng student at the Central University of Technology. She works towards studying usage of “life cycle assessment models to enhance roads life in Lesotho” and, therefore, is in need to access data related to road network conditions and similar related information. This study requires her to carryout interviews and questionnaires with the Transport and Road planners, The Public, The Local Contractors and the general road users. The supplied data will be used for her study dissertation only and not for public use. Any publications based on his study will acknowledge your contribution.

May I ask you to provide Ms Monts'i with the needed help. I believe that her study is of most importance to the development of Lesotho and will contribute to enhancing sustainability of roads in Lesotho, thereby, improvement in the country’s economy. All ethical considerations shall be duly observed in the study. This is inclusive of confidentiality of information and voluntary participation.

Should you have queries, please do not hesitate to contact the supervisor of the study on the below contacts.

Thank you for the anticipated consideration of this request.

Kind regards

Dr. M. Mostafa

E-mail: mmostafa@cut.ac.za

Tel: +27 (0)515073454

Appendix B:

First Questionnaire

The Questionnaire should take maximum of 20 minutes of your time

USE OF LIFE CYCLE ASSESSMENT REFERENCE METHOD TO IMPROVE LIFE SPAN OF ROADS IN MASERU

Biodata Information

Date:______________________

Name:____(Optional)

Occupation:_______________________________________ Gender:_____

Job Title:____

Age (Tick):

18-29		30-39		40-49		50-59		≥ 60	

INSTRUCTIONS:

Thank you for participating in this study. Your confidential response will help this research in terms of improving the life span of Maseru roads.

Where applicable please tick your answers. ✕

You may give further comments where necessary.

Where information may not be clear or unknown to you please skip.

Rate the general roads' performance in Maseru by checking the most appropriate rating. Make an explanatory comment to support your rating, and where possible cite specific examples of behavior that led to the rating. When performance does not meet expectations, list specific goals for improvement.

What Mode of Transport do you use?

Public Transport	
Private Transport	

SECTION 1: ROAD CONDITIONS

CONDITIONS	EXCELLENT	GOOD	FAIR	POOR	VERY POOR	REASONS FOR YOUR SPECIFIC RESPONSE
Your eyesight conditions						
Traffic signals						
Traffic lights						
Roadside markings visible enough						
Road widths adequate						
Roadside Furniture visibility						
Speed humps						
Pedestrian Ways						
Water Channels						
Road signs						
Traffic in Maseru roads						

SECTION 2: WORKING CONDITIONS

COMMENTS	1	2	3	4	REASONS FOR YOUR SPECIFIC RESPONSE
Job Knowledge: The extent to which the stakeholders are familiar with policies and procedures applicable to the position and able to work independently.					
Productivity: The rate of acceptable work produced. Ability to organize and prioritize work; utilize time well and fully meet deadlines.					
Quality: The ability to complete work accurately and neatly to meet the required standards.					
Responsibility/Initiative: Acceptance and fulfilment of work assignments.					
Adaptability/Resourcefulness: The Ability to contribute useful ideas for improved performance on construction site.					
Supervisory Skills: The ability to get effective results from others.					
Attendance/Punctuality: Lateness and absence of supervisors on construction site.					
Selection of Borrow Pits:					
Health and Safety Measures: Handling of construction site to not bring harm to both the public and workers.					

Key:

1	Not Applicable
2	Does Not Meet Expectations
3	Meets Expectations
4	Exceeds Expectations

Section 3: Overall Evaluation

Further Comments

Please include if in any ways, the consent and involved stakeholders need to do to improve the roads' conditions and what can be accomplished afterwards.

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……………………………………………………………………………

In the upcoming review period, what should this client do to develop greater effectiveness in the construction of roads in Maseru so they can meet the required life span before deterioration?

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………
………
………………………………………………………………

Please comment on the overall engineers' and contractors' performance from your perspective.

………
………
………
………
……

THANK YOU FOR YOUR SUPPORT

Second Questionnaire

The Questionnaire should take maximum of 10 minutes of your time

USE OF LIFE CYCLE ASSESSMENT REFERENCE METHOD TO IMPROVE LIFE SPAN OF ROADS IN MASERU

Biodata Information

Date:______________________

Name:____(Optional)
Occupation:_______________________________________ Gender:_____

Job Title: ____

Age (Tick):

18-29		30-39		40-49		50-59		≥ 60	

INSTRUCTIONS:

Thank you for participating in this study. Your confidential response will help this research in terms of improving the life span of Maseru roads.

Where applicable please tick your answers. ✕

You may give further comments where necessary.

Where information may not be clear or unknown to you please skip.

Rate the general roads' performance in Maseru by checking the most appropriate rating. Make an explanatory comment to support your rating, and where possible cite specific examples of behavior that led to the rating. When performance does not meet expectations, list specific goals for improvement.

What Mode of Transport do you use?

Public Transport	
Private Transport	

Do you have a personal vehicle?..☐ No ☐ Yes ☐

Are you a commercial driver?..☐ No ☐ Yes

How long have you been driving?

1 – 5Years ☐; 6 – 10Years ☐; 10Years and above ☐

Section 1: State of Maseru Roads

How will you rate the travel condition of Maseru Roads: ....☐ Good ☐ Bad ☐ Satisfactory

Are road markings visible? ....☐ No ☐ Yes ☐ Don't know

Do you understand the markings? ....☐ No ☐ Yes ☐ Don't know

Are there enough traffic signals? ....☐ No ☐ Yes ☐ Don't know

Do you understand the traffic signals? ....☐ No ☐ Yes ☐ Don't know

Are there enough road marking and signs? ....☐ No ☐ Yes ☐ Don't know

Are the markings and signs visible enough? ....☐ No ☐ Yes ☐ Don't know

Do you understand the road markings and signs? ....☐ No ☐ Yes ☐ Don't know

Do you understand the different colours in the traffic signals? ....☐ No ☐ Yes ☐ Don't know.

Section 2: Working Conditions

COMMENTS	1	2	3	4	REASONS FOR YOUR SPECIFIC RESPONSE
Job Knowledge: Do you feel the work is done to meet your expectations as the local resident?					
Productivity: The volume and rate of acceptable work produced.					
Quality: The ability to complete work accurately and neatly to meet the required standards.					
Responsibility/Initiative: Acceptance and fulfillment of work assignments.					
Adaptability/Resourcefulness: The ability to adjust to change with a minimum of disruption to productivity. Ability to contribute useful					

ideas for improved performance on construction site.					
Supervisory Skills: The ability to get effective results from others.					
Selection of Borrow Pits: Are you as residents involved in the quarry borrowing?					
Health and Safety Measures: How are you affected by the state of roads in construction and afterwards?					

Key:

1	Not Applicable
2	Does Not Meet Expectations
3	Meets Expectations
4	Exceeds Expectations

THANK YOU FOR YOUR SUPPORT

Appendix C:
INTERVIEW GUIDE

1. To your best knowledge, does Lesotho have enough required skills to undertake the construction projects?
2. What policies are being followed in the implementation of roads construction?
3. How do you acquire materials to be used in the construction of roads and who is responsible to accept them for use?
4. What tests are run to these materials?
5. How do you grade the composition of materials to be used?
6. Does the government set aside the budget for maintenance of the roads?
7. For how long are our roads designed? Whose responsibility is it to ensure that this life is achieved?
8. How would we improve the prevailing conditions in our construction environments?
   Please include if in any ways, the consent and involved stakeholders need to do to improve the roads' conditions and what can be accomplished afterwards.
9. In the upcoming review period, what should this client do to develop greater effectiveness in the construction of roads in Maseru so they can meet the required life span before deterioration?
10. Please comment on the overall engineers' and contractors' performance from your perspective.
11. Quality seems to be a measure concern, how do you ensure it is met?

THANK YOU FOR YOUR SUPPORT

Appendix D:

CONSENT LETTER

Central University of Technology, Free State.

May 2016

CONSENT LETTER FOR PARTICIPATION IN RESEARCH QUESTIONNAIRE ON USE OF LIFE CYCLE ASSESSMENT REFERENCE METHOD TO IMPROVE LIFE SPAN IN MASERU ROADS

Dear sir/madam,

My name is Moliehi Monts'i and I am a Civil Engineering student at the Central University of Technology in Bloemfontein. The research I wish to conduct for my Master's dissertation involves "life cycle assessment models to enhance roads life in Lesotho" and, therefore, is in need to access data related to road network conditions and similar related information. This project is conducted under the supervision of Prof M.H. Mostafa (CUT, South Africa).

I am here requesting your signature to show you have responded to the issued questionnaire voluntarily and you are aged not below 18 years.

If you require any further information, please do not hesitate to contact me on +266 63660134 or +27 78 122 8268 or email address moliehimontsi@gmail.com.

Signature **…………………………………………..**

Thank you for your time and consideration in this matter.

Yours sincerely
Moliehi Monts'i
Central University of Technology