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Foreword

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April 2018

Slope & Surface water buffer – A Simplified methodology of Mapping Flood Hotspots

Lameck Phiri[1], Edwin Nyirenda[2]

Abstract

A methodology for locating flood hotspots easily and quickly has been proposed. The method applies remote sensing and geospatial analytical techniques to generate flood hotspots. In this method slope and surface water buffer are combined and processed to create flood hotspots. The method was applied to Kitwe City to identify flood hotspots caused by high rainfall as a result of climate change. The results were satisfactory as flood hotspots were located with an overall accuracy of 73%. The spatial coverage of flood hotspots was 1,383.84ha. The combined spatial coverage of surface water bodies and flood hotspots was found to be 2,957.53ha, which is equivalent to about 4% of the total area of the city. The method can be applied to cities and towns with no flow data and which have similar landforms as Kitwe.

The paper demonstrates a simple approach of locating flood hotspots for areas with no flow data. Maps showing flood hotspots can be used to enlighten the public about areas that are likely to be flooded. The information from flood hotspot maps can enable the public make informed decisions when they want to invest or settle in flood hotspots.

Keywords: Kitwe City, Flood hotspot, Climate Change, Slope, Surface water buffer

1. Introduction

Climate change, a natural phenomenon, led to the increase of rainfall in 2016/17 rain season, generally though out the country in Zambia and floods were the order of the day in many places. This affected economic and social activities negatively not only in flooded areas but also in surrounding areas. Floods were reported throughout the country and some people were displaced from their dwelling places due floods. If the increase in rainfall persists in the coming seasons, floods will recur.

Floods are global problems which need local solutions. For instance, the Water Resources Program of the U.S. Geological Survey in Tacoma, Washington, is studying flood hazards in the Seattle area, as part of a 5-year project designed to broaden the scientific understanding of natural hazards in Snohomish, King, Pierce, Thurston, and Kitsap Counties (USGS, 2017). The major efforts include among others developing new methods for mapping flood hazards.

Economic diversification, poverty and vulnerability reduction as envisaged in the Seventh National Development Plan of Zambia (MNDP, 2017) cannot be achieved if flood control is not taken into consideration in the country. Floods can cause serious local disasters thereby undermining socioeconomic development through destruction of property, environment and life. Recognising the potential danger of floods and other natural disasters, the United Nations (UN) adopted the Sendai

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Framework of Disaster Risk Reduction (UN, 2015) which focuses on disaster risk management as opposed to disaster management.

If reduction of flood disaster risks should be the focus in flood control, there is a need to generate flood hotspot maps which will provide information on areas likely to be flooded. The maps are cardinal for sustainable development as citizens can be informed on the areas likely to be inundated. This will enable the citizens to make wise decisions when they chose to invest in flood hotspots. According to (USGS, 2017) flood maps can be used for preparedness, timely response, recovery, and mitigation and planning.

The most common method used to generate flood hotspots is a top down approach – quantifying rainfall and losses, and then estimating floods. This method requires the creation of surface water models which take time to develop and validate (Chow, et al., 1988). Besides, this approach embraces a lot of assumptions and may be difficult to validate. For example various ways of applying rainfall scenarios can have a major effect on the final results. Therefore simple and quick methods of identifying flood hotspots are needed so as to help classify land in terms of floods in areas with no flow data. These methods can help decision makers on how best to control floods and thereby enable people live in harmony with nature. Moreover, citizen can be provided with information on areas vulnerable to floods.

The objective of this paper is to demonstrate that slope and surface water buffer can be used to locate flood hotspots. This is an easy and quick way of locating flood hotspots especially in areas without stream flow data. The information derived can be used for public enlightenment and flood disaster response planning.

2. Material and methods

2.1 Mapping Flood Hotspots

Mapping of flood hotspots is done here by considering areas with stable slope (slope less than 40%), that is land not susceptible to slope failure. Consider land with a stable slope in the vicinity of a surface water body as shown in the figure 1 below.

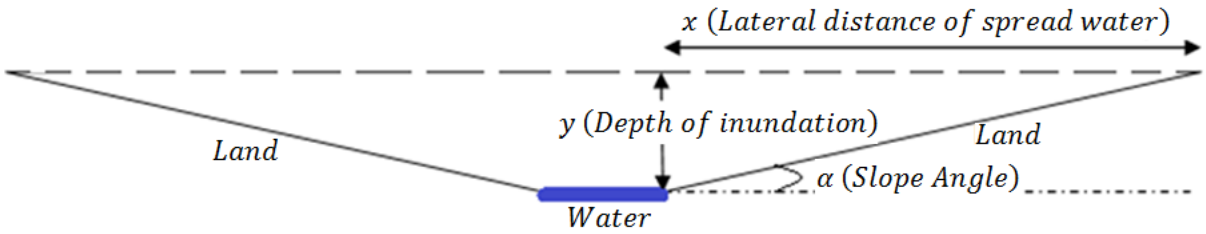

Fig.1: Relationship between depth of inundation and Lateral distance of spread water

In figure 1 above:

$$i.\boldsymbol{Water}\ represents\ surface\ water\ body$$

$$ii.\boldsymbol{Land}\ represents\ Land\ surface$$

Using trigonometry:

$$Tan\ \alpha = \frac{y}{x} \quad \ldots\ldots\ldots\ldots \text{ equation 1}$$

$$x = \frac{y}{Tan\ \alpha} \quad \ldots\ldots\ldots\

i. Lateral distance of spread water *(x)* increase as slope angle *(α)* decrease
ii. Lateral distance of spread water *(x)* decrease as slope angle *(α)* increase

Equation 2 shows that, within the proximity of surface water body, land with small slope angle is more likely to have high spatial coverage of floods than that with large slope angle. Further, it shows that flood hotspots can be identified by considering areas with smaller slopes and which are closer to surface water bodies. By quantifying α of a catchment area and locating surface water bodies, flood hot spots can be revealed.

Alternatively, consider a unit volume of flood water covering the space above the surface water body in figure 1. The cross-section area of the unity volume can be taken to be that of a trapezium. If we take "*w*" to represent the width of the surface water body, then the area "*A*" of the unity volume (assuming a symmetrical trapezium) is given by:

$$Area, A = \left(\frac{(2x+w)+w}{2}\right) y \text{..... equation 3}$$

$$A = \left(\frac{(2x+2w)}{2}\right) y \text{..... equation 4}$$

$$A = (x + w)y \text{..... equation 5}$$

But

$$y = x * Tan \propto \text{..... equation 6}$$

Therefore

$$A = (x + w)x * Tan \propto \text{..... equation 7}$$

Or

$$Tan \propto = \frac{A}{(x+w)x} \text{..... equation 8}$$

Equation 8 shows that for the same unit volume of flood water the spatial coverage, *x*, will be great for small α and vice versa. Furthermore, from Equation 8, flood control means reducing the value of *x*. For instance, by building flood walls along the surface water body, the value of *x* can be reduced to zero.

When there are no control measures the lateral distance of water spread, *x*, will depend on α. This means that flood hotspots can be defined by slope of land $(\propto)$ and the buffer distance from surface water bodies(d). In other words flood hotspots are a function of slope and buffer distance. That is:

$$Flood\ Hotspots, FH = F\{slope(\propto)\ and\ buffer\ distance(d)\} \text{..... equation 9}$$

Therefore for a catchment it is sufficient to find the appropriate slope and the buffer distance to establish flood hotspots. Using remote sensing and GIS equation 9 can be processed so that flood hotspots are identified. In this research paper the equation was solved for Kitwe City and flood hotspots were located for the 2016/17 rain season.

2.2 Application

2.2.1 Study

The methodology was applied to Kitwe City which is located in the Copperbelt Province of Zambia (Fig. 2). The City covers an area of about 79,930ha and has a population of 517,543 according 2010

census (CSO, 2012). The elevation for the City ranges from 1168 to 1316m above sea level (Fig. 3). In term of rainfall, the City has an annual rainfall of above 1000mm.

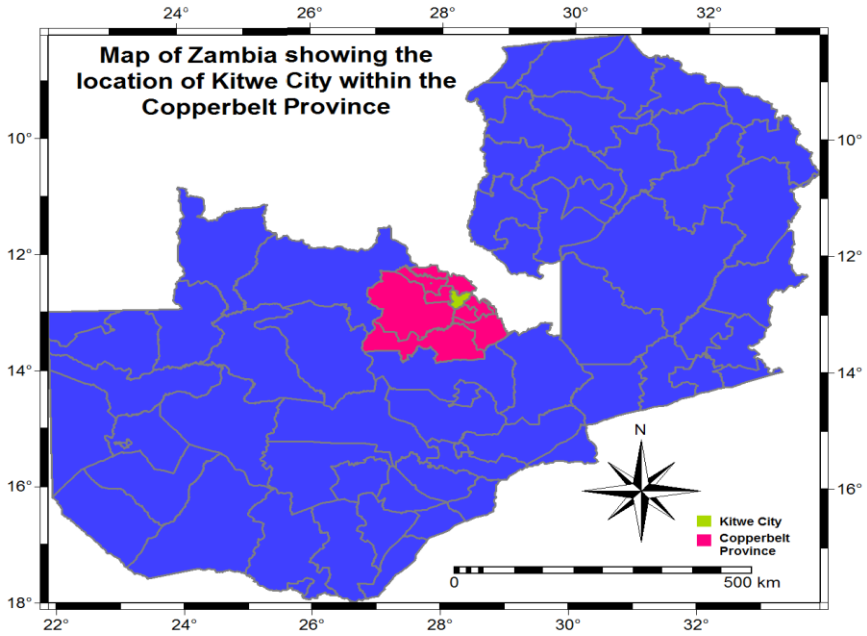

Fig. 2: Location Kitwe City in Zambia

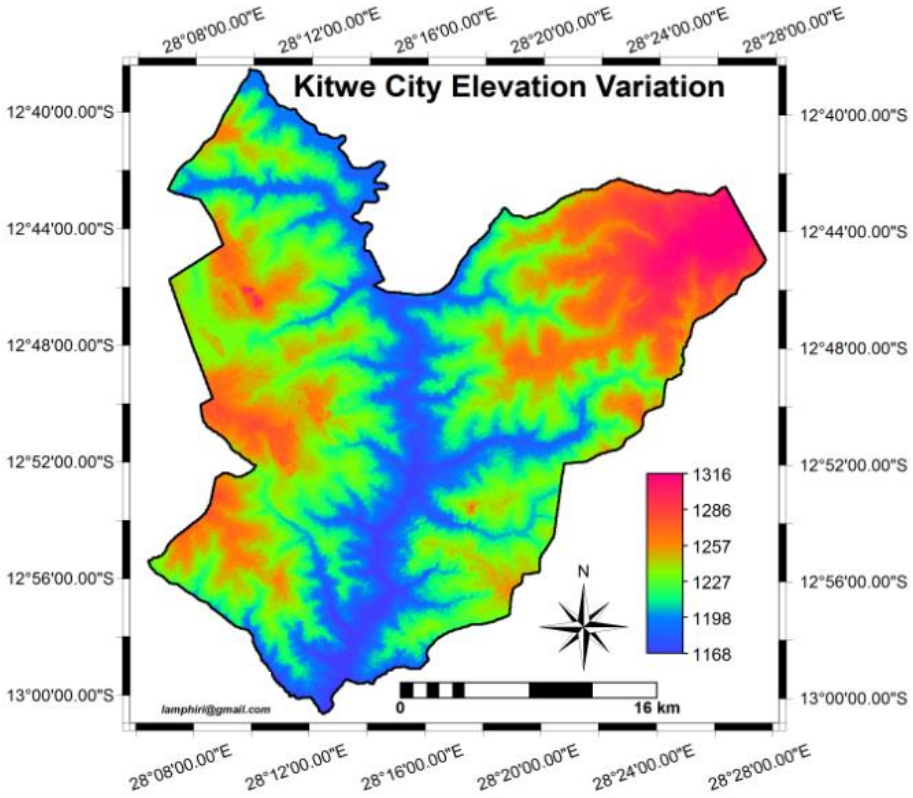

Fig. 3: Kitwe City elevation variation

2.2.2 Data

The digital elevation model (DEM) for Kitwe City was acquired from Global Data Explorer, an online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center.

Landsat Satellite images for the project were acquired from the NASA/USGS Landstat program. Level 1 Product Landsat data of zero percent cloud cover and spectral bands of spatial resolution 30m were downloaded from "Earth Explorer", a USGS website.

Global Positioning System (GPS) was used to capture data from the field for validation.

2.2.3 Geospatial analysis

The analysis was carried out in a geospatial environment using Integrated Land and Water Information System (ILWIS) and QGIS. The process of generating flood hotspots is schematically outlined in the flow chart below (fig. 4). Slope and stream network maps were derived from DEM whilst surface water reservoirs were derived from Landsat imagery. The stream network was generated using steepest slope algorithm in ILWIS.

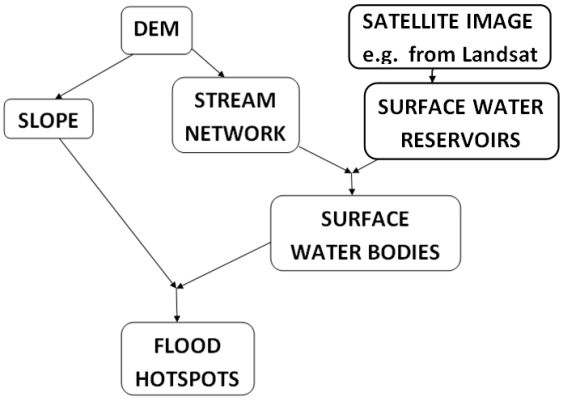

Fig. 4: Flow chart of generating Flood HotSpots

The stream network was combined with surface water reservoirs to produced surface water bodies. Slope map was processed together with surface water bodies to generate flood hotspots. The decisive slope was graded according to the FAO (2006) classification (Table 1). Slope values from 0 to 2% and buffer distance from 60 to 300m were used to generate flood hotspots. The flood hotspots were validated by crossing with ground truth data.

Table 1: Slope Classification

Class	Description	%
1	Flat	0–0.2
2	Level	0.2–0.5
3	Nearly level	0.5–1.0
4	Very gently sloping	1.0–2.0
5	Gently sloping	2–5
6	Sloping	5–10
7	Strongly sloping	10–15
8	Moderately steep	15–30
9	Steep	30–60
10	Very steep	> 60

Source: (FAO, 2006)

3. Results and Discussion

Slope map generated from DEM indicated the slopes for Kitwe City vary from 0 to 24% (fig. 5). This means there are no steep or very steep slopes in Kitwe City.

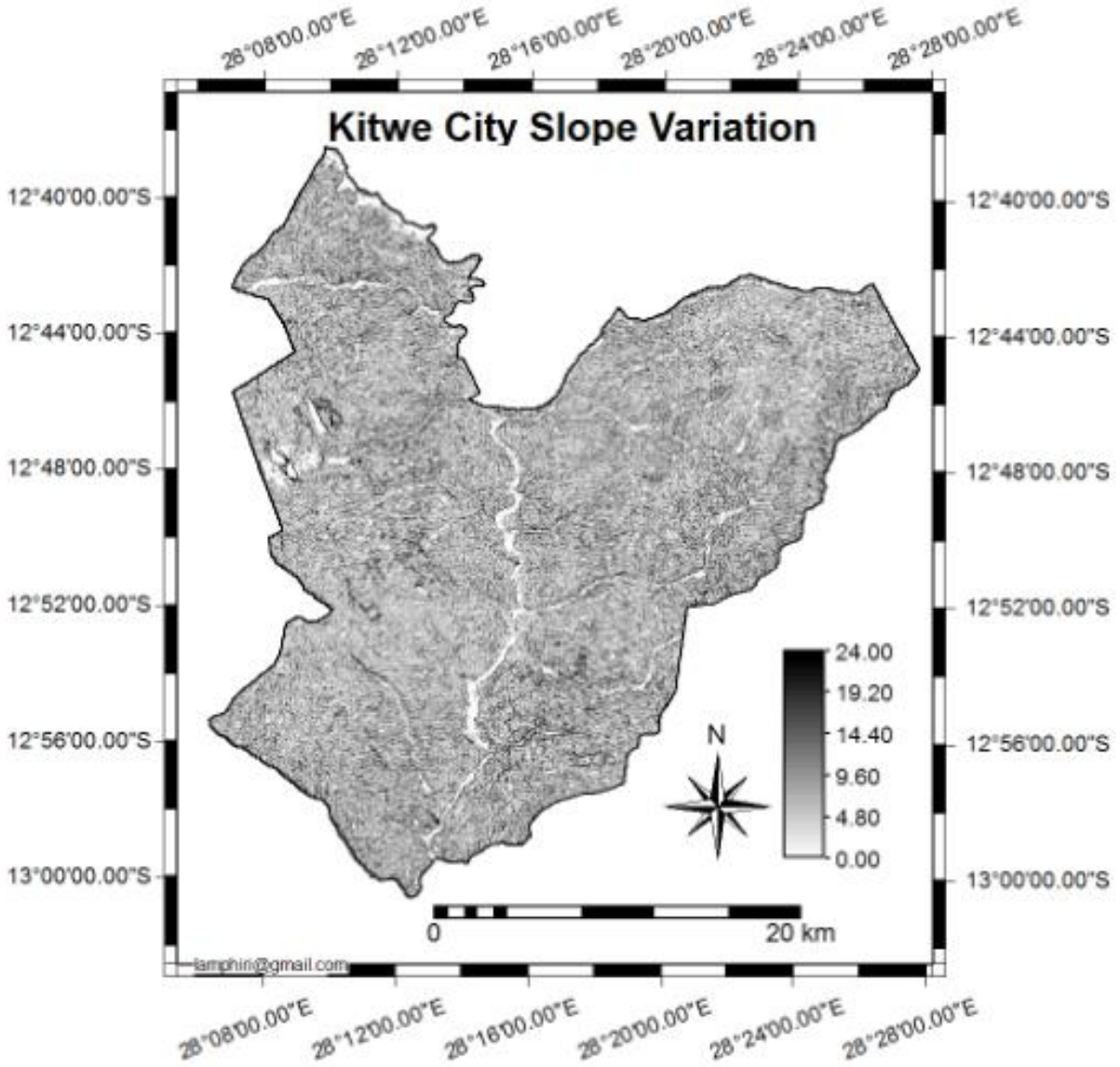

Fig. 5: Slope variation map for Kitwe City

Surface water bodies for Kitwe City are shown in figure 6 below. The surface water bodies, dominated by natural streams and rivers, cover an area of 1,574.10ha, which is equivalent to about 2% of the total area of the City.

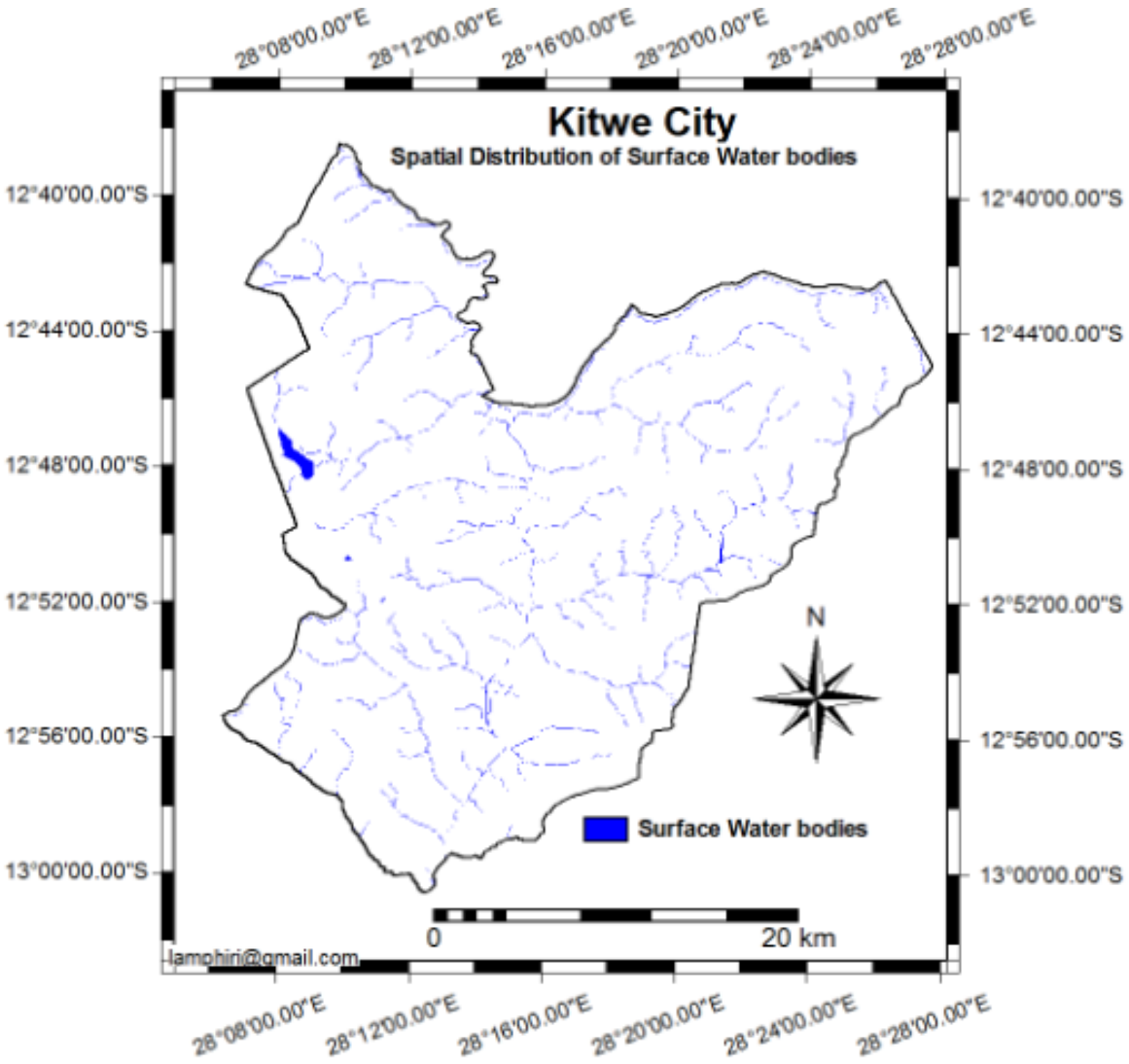

Fig. 6: Spatial distribution of surface water bodies in Kitwe City

Using DEM alone one cannot generate surface water bodies due mainly to inherent nature of algorithms used for creating stream network in GIS. There is no possibility of splitting a stream in to two or more because of the constraint of allowing ONLY one drainage-direction per cell. The single flow direction algorithm used in GIS packages does not allow for river bifurcations. Satellite images or aerial photograph can be used to delineate surface water reservoirs with high accuracy. And so the combined analysis of DEM and satellite images or aerial photographs enhances the accuracy of generating surface water bodies.

Distance analysis for surface water bodies shows that within a radius of two kilometer (2km) there is a surface water body in Kitwe City (fig. 7).

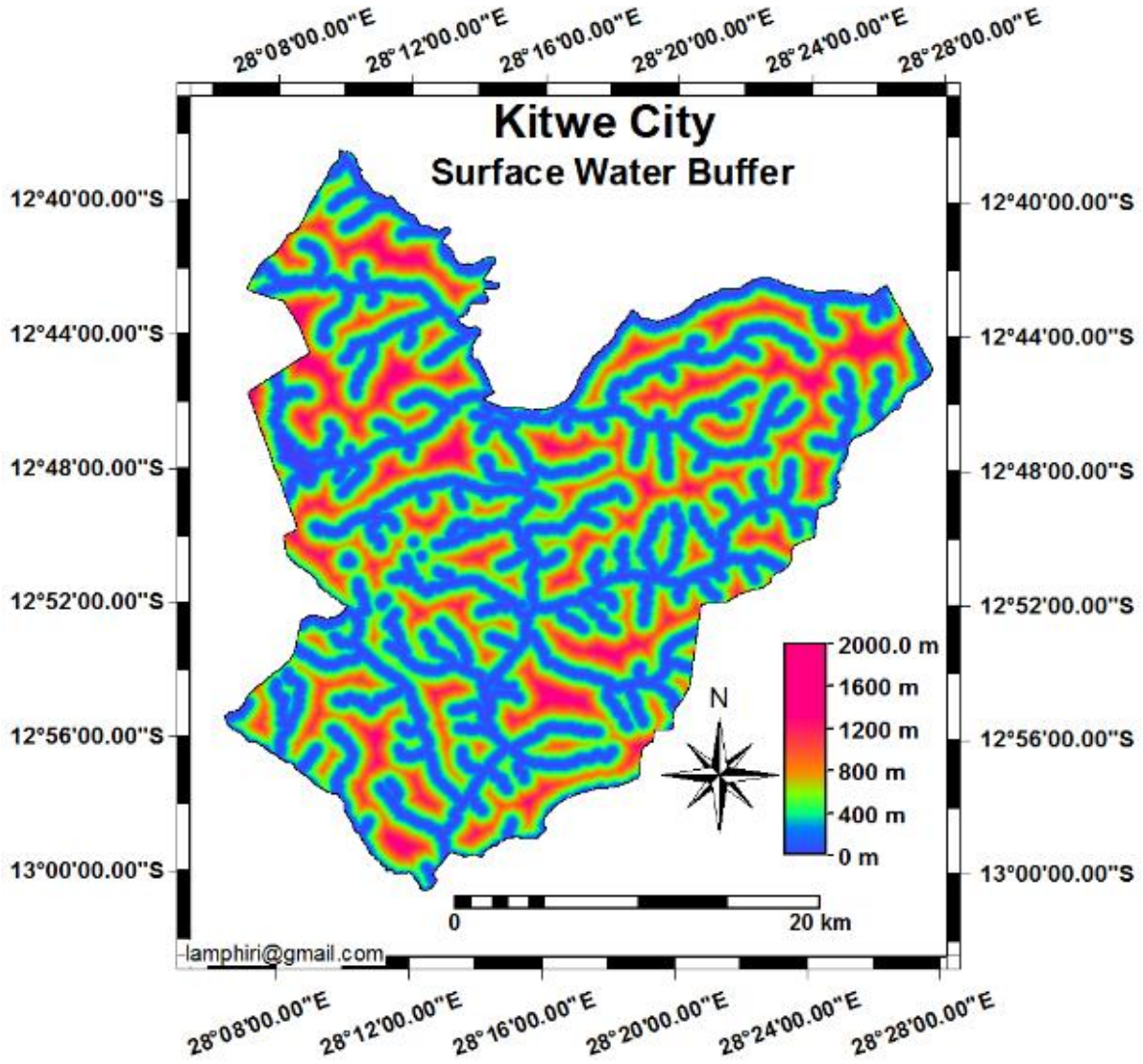

Fig. 7: Kitwe City Surface water buffer

Slope and surface water buffer maps were processed to locate flood hotspots in Kitwe City for the 2016/17 rain season. If was found that land with a gradient of not more than 0.5% and which is within a surface water buffer distance of 210m located flood hotspots with high accuracy (Fig. 8). The overall accuracy with which flood hotspots were mapped was **73%.** The generated flood hotspots cover an area of 1,383.84ha. Land with a gradient of not more than 0.5% has a spatial coverage of 4,851.99ha. This implies that flood hotspots in Kitwe covered 28.5% of flat and level land during the 2016/17 rain season.

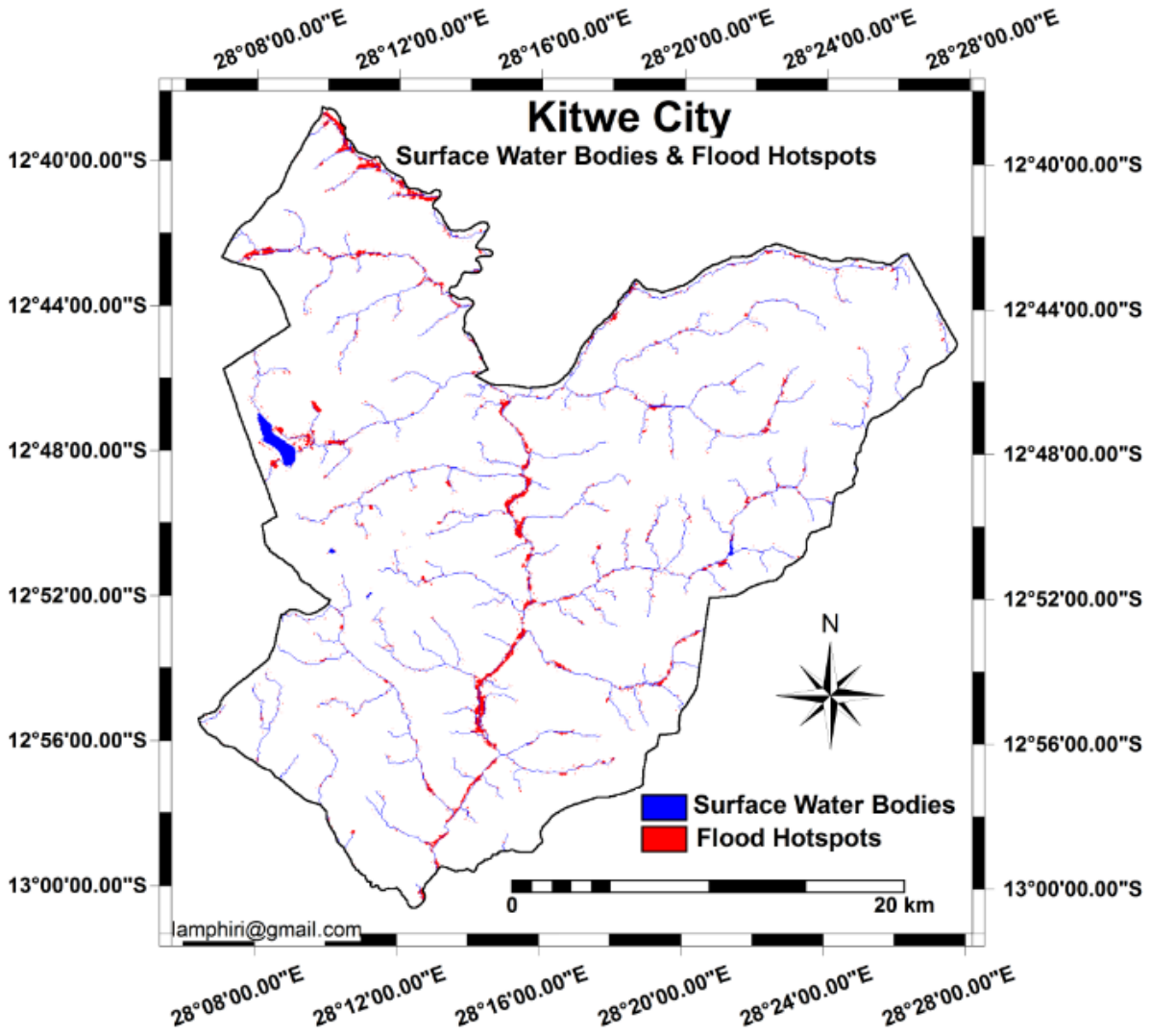

Fig. 8: Map of flood hotspots

From figure 8, areas in blue represent flood hotspots, that is, the area in danger of flooding if the amount of rain exceeds that which fell in 2016/17 rain season. The flood hotspots were found to be located in areas with slope not more than 0.5% which were within a buffer distance of 210m from surface water bodies. In other words, land with flat and level slopes that are within a distance of 210m from surface water bodies was found to be prone to floods. The flood hotspots were cross validated with ground truth data. The overall accuracy for located points was 73%.The identified flood hotspots cover an area of 1383.84ha. As anticipated, most of the flood hotspots were located along the central stream. The combined spatial coverage of surface water bodies and flood hotspots was found to be 2,957.53ha, representing about **4%** of the total area of the city.

A combined analysis of slope and surface water buffer distance generated flood hotspots for Kitwe City. This method can be applied to cities and towns with similar landforms as Kitwe. Maps indicating flood hotspots would enlighten citizens on the area of land that will be inundated, and thereby enable them to achieve a wise and sustainable use of it.

It is worth noting at this point that reducing the value of lateral distance of water spread, *x*, by building flood walls, levees or dykes, is common in developed countries like the USA, Japan and the UK. This technique of flood control when used alone creates a false sense of security in that people tend flock to flood-plains and increase their investments thinking they will be secure forever. Beven (2014) puts it clear: there is nothing like total flood defense. Floods will always occur at one time or another. Knowing

this fact developed countries combine structural measures with non-structural measures like early warning and flood mapping to effectively control floods thereby enabling citizen live in harmony with nature.

The work done to recover an ordinary life after flooding is difficult and expensive, and so with the flood hotspot map produced dwellers of flood hotspots can be notified of eminent danger associated with their dwelling place. People living in flood hotspots can be advised to build flood proof buildings and minimize blocking natural drainage.

4. Conclusion

A simple methodology was developed for mapping flood hotspots and was applied to Kitwe City successfully. The technique combines the analysis of slope and surface water buffer to generate flood hotspots. The analysis revealed that areas with slope of not more than 0.5% and which are within a buffer distance of 210m from surface water bodies represented flood hotspots during 2016/17 rain season. The overall accuracy with which flood hotspots were mapped was 73%**.** Flood hotspots covered an area of about 1,383.84ha. The combined spatial coverage of surface water bodies and flood hotspots was found to be 2,957.53ha, which is equivalent to about 4% of the total area of the city. The method can be applied to cities and towns with no flow data and that have similar landforms as Kitwe. Maps indicating flood hotspots would enlighten citizens about the area of land that would be inundated, and thereby enable them make a wise and sustainable use of it. Maps indicating flood hotspots are cardinal for public enlightenment and flood disaster response planning. They can be used for preparedness, timely response, recovery, and mitigation and planning.

5. Acknowledgement

Level 1 Product Landsat data were downloaded from “Earth Explorer”, a USGS website (http://earthexplorer.usgs.gov/). The DEM was retrieved from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/data_access/data_pool." We thank USGS and NASA for a free policy which allows free download of satellite images.

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Fuel Cell Technology: An Optional Back-Up Power Supply System for Zambia

Enock Mulenga[1]

Abstract

Fuel cell technology is slowly growing in other countries and is being used for power production. In Zambia, the technology is yet to penetrate. The increase in power demand at a time of poor rainfall patterns entail diversification to other power sources. This paper presents knowledge on fuel cell technology, types, applications, sample simulation and its adaptation to Zambia as back-up power supply from literature, applied systems and simulation set-up in matlab-simulink. Massive investment in solar technology, rise in fuel prices for diesel generators and possibility of combining fuel cell with photovoltaics or as storage to store away variability has necessitated the review of this technology as an optional back-up power supply for Zambia. The sample simulation of a 6 kW fuel cell system in Matlab showed results of dc power. The same power type from PV array before power conditioning. Fuel cell technology exist in different types due electrolyte used. These are proton exchange membrane, phosphoric acid fuel cell, alkaline fuel cell, direct methanol fuel cell, solid oxide fuel cell and molten carbonate fuel cell. Systems of sizes up to 59 MW have been installed. The by-products of industrial, mining and metallurgical processes (oxygen and hydrogen) could make implementation much feasible. Large investments in photovoltaics, which could share power conditioning equipment with fuel cell technology, could aids this technology in Zambia. Fuel cell technology system is possible as an optional power source for Zambia. It can be used as a stand-by unit, part of a hybrid system, an independent power plant and storage for photovoltaic (PV) systems.

Keywords: Fuel cell, photovoltaics, power supply, electrolyte, technology

1. Introduction

In Zambia, most of the power is generated from hydropower plants, diesel power plants and recently coal fired plant and solar PV power plants. Solar PV power plants have been applied more for off-grid systems and soon a 100 MW grid-tied system from the Lusaka's multi-facility zone (IDC, 2017). The power is needed for base and peak loads. It is typical for the power demand to increase at peak times. Diesel generators has been used as standby or optional power supply system in such cases, faulty times and when there is load shedding. This is most observable with

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the privately-owned utility company Copperbelt Energy Corporation (CEC) plc which supplies power to mining companies on the Copperbelt. CEC plc owns and operates gas turbine alternators (GTA) at designated places as back-up power.

The increase in investments on solar photovoltaic (PV) power is encouraging for Zambia's power system which is currently being driven by Industrial Development Corporation (IDC) and rural electrification authority of Zambia (REA). However, its uncertainty behaviour in power production with changing climatic conditions at any time of the day, week, month and year requires a look at other emerging technologies to cushion this effect. One solution is to use battery storage banks. This is very feasible for sizes in off-grid systems. On grid systems, the use of storage has not been extensively explored due to large size required and expense. Another solution is to look at the emerging technology of fuel cells that has become popular in other countries.

The paper presents fuel cell technology, its use for stationary power and other applications, its potential challenges and how it could adapt to the Zambian scenario as an optional back-up power supply system especially in cases where solar PV power is involved. The paper contributes to presenting the technology of fuel cell and its potential use for power back-up supply in Zambia to aid growing solar photovoltaics. The sizes ranges from one watt (1 MW) to several megawatts (MW), (Larminie and Dicks, 2003).

2. Fuel Cell Technology

Since the invention of fuel cells, they have been used for various applications. Their application has been largely due to the demand of power and increase in use of electricity in industries. This includes areas in which conventional grid power cannot reach. The development of fuel cell technology has been necessitated with the increase in demand of power globally (OGJ, 2014).

The technology of fuel cells, which is the conversion of chemical energy to electrical energy, has been used for a lot of applications. These applications include portable power, distributed stationary power generation, telecommunications systems power supply, automotive applications, airplane applications and hybrid solutions with other energy sources (EG and G, 2004).

2.1 Fuel Cell Basics

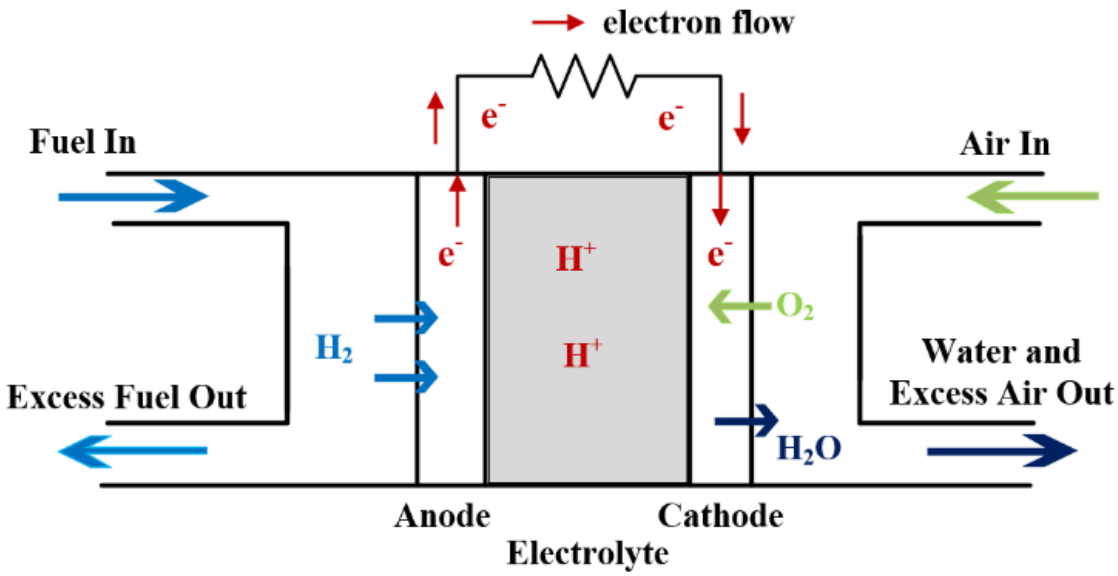
A fuel cell is a device, which is like a battery, which converts chemical energy found in a fuel to electrical energy through a chemical reaction. The fuel is fed at the anode and air or another chemical substance is cathode. The cell and reaction between hydrogen and oxygen in air are shown in Fig. 1. The cell has anode, electrolyte and cathode. Hydrogen (H_2) enters at the anode, a chemical reaction causes the hydrogen molecules to separate into positive hydrogen ions (H^+) and electrons (e^-). This reaction releases heat. The positive hydrogen ions pass through the electrolyte made of a polymer membrane and travel to the cathode. The electrons remain behind and give the anode a negative charge, creating a voltage difference between the anode and the cathode. The electrons travel from negative to positive, they will flow in the external circuit from the anode to the cathode. From air, oxygen (O_2) enters the fuel cell at the cathode and combines

with the electrons/positive hydrogen ions to produce water (H_2O) at the cathode. The voltage produced in a fuel cell is a direct current (dc) voltage like what a PV panel gives out.

Fig. 1: Basic fuel cell (Dicks and Larminie, 2003)

For a basic fuel cell shown in Fig. 1, the chemical reactions are (Larminie and Dicks, 2003):

At the Anode;



$$H_{2\,(g)} \longrightarrow 2H^+ + 2e^- \quad (1)$$

At the Cathode;

$$\tfrac{1}{2}O_{2\,(g)} + 2H^+ + 2e \longrightarrow H_2O_{\,(g)} \quad (2)$$

The overall chemical reaction becomes;

$$H_{2\,(g)} + \tfrac{1}{2}O_{2\,(g)}e \longrightarrow H_2O_{\,(g)} \quad (3)$$

The open circuit voltage (OCV) for a general reaction is by (4).

$$\alpha A + \beta B \longrightarrow \gamma C + \delta D \quad (4)$$

Using nerst equation and applying to a fuel cell,

$$E_{cell}\,(OCV) = E^0 - \frac{RT}{n_e F}\ln\left(\frac{P_C^{\gamma} P_D^{\delta}}{P_A^{\alpha} P_B^{\beta}}\right) \quad (5)$$

And the ideal cell voltage can be calculated using (6)

$$E^0 = \frac{-\Delta g^0}{n_e F} \quad (6)$$

Where Δg^0 is Gibb's free energy at standard temperature and pressure.

Using (1) to (6) for a reaction taking place at 100°C according to, the theoretical output voltage from a hydrogen fuel cell would be 1.14 V. The operating voltage, *U*, can be calculated using (7);

$$U = E^0 - ir - A \ln\left(\frac{i+i_{int}}{i_0}\right) - m.e^{ni} \quad (7)$$

In (7), E^0 is the ideal cell voltage, E_{OCV} is the Open circuit voltage, i_0 is the exchange current density, i is the current density, A is the constant-Tafel slope, m and n are constants-fitting parameters, U is the operating voltage at a current density i, i_{int} is the internal losses current and r is the area specific resistance.

Equation (7) considers most conditions in a theoretical fuel cell. A practical operating output voltage for a fuel cell is lower than 1.14 V theoretical expected voltage. For practical operations, fuel cells are connected in series-parallel stacks to increase the voltage, current and power to required values.

2.2 Fuel Cell Stack, PV Array and Hybrid Setup

A fuel stack, 6 kW in this case, was implemented in Matlab to show the expected output. This is shown in Fig. 2. The complete system model was based on typical data set (Fuelcellstore, 2013).

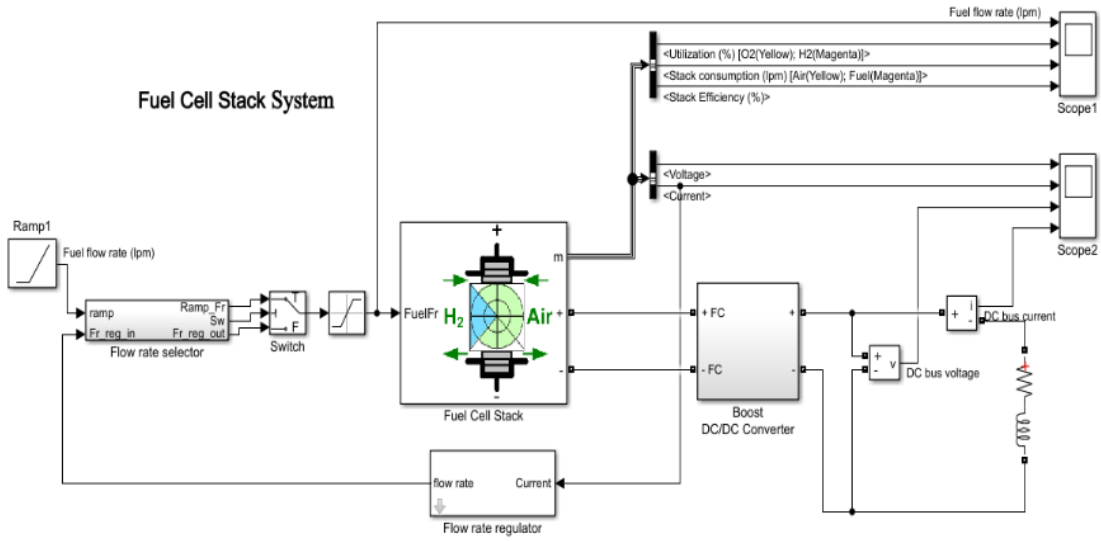


Fig. 2: Fuel cell stack system in Matlab-Simulink

The parameters of the system where adjusted and simulated. The results are shown in Fig. 3. The average voltage of 100 V and current of 60 A at the dc bus was observed.

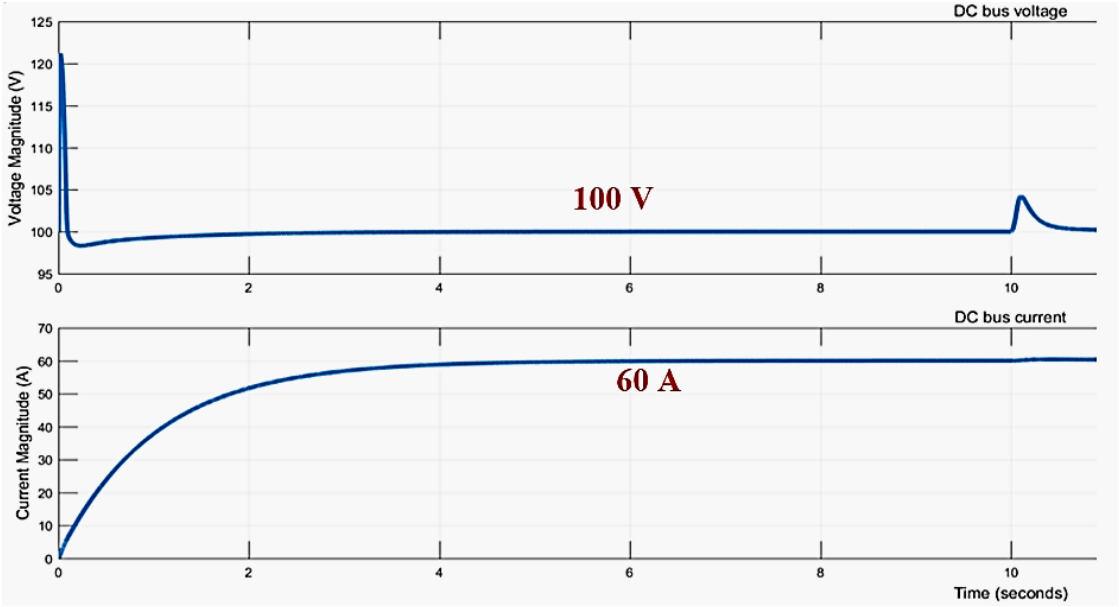


Fig. 3: Fuel cell stack voltage and current waveforms at the DC bus

The simulated fuel cell stack in Fig. 3 could back-up a solar PV array system or storage of excess energy. A setup for solar PV array in Matlab-Simulink was done. The configuration is shown in Fig. 4. The output power at the dc link of the system is of the same type (dc power) as that for fuel cell stack shown in Fig. 3.

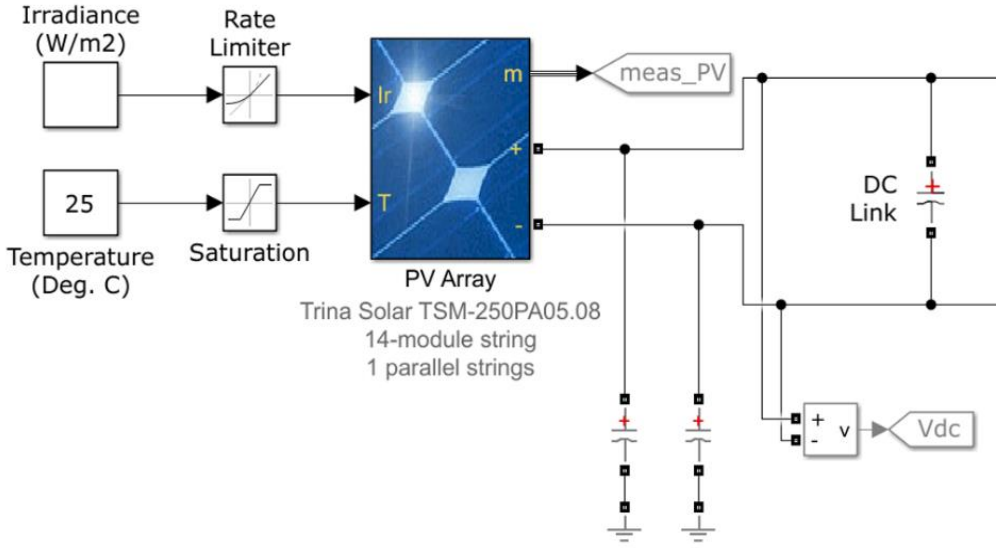


Fig. 4: Solar PV Array system in Matlab-Simulink

The systems for the fuel cell stack and the solar PV array system can be combined to form a hybrid system. Solar PV array could function as the main supply system and the fuel cell stack system functions as the back-up system. Such a system when setup in Matlab-Simulink environment is shown in Fig. 5.

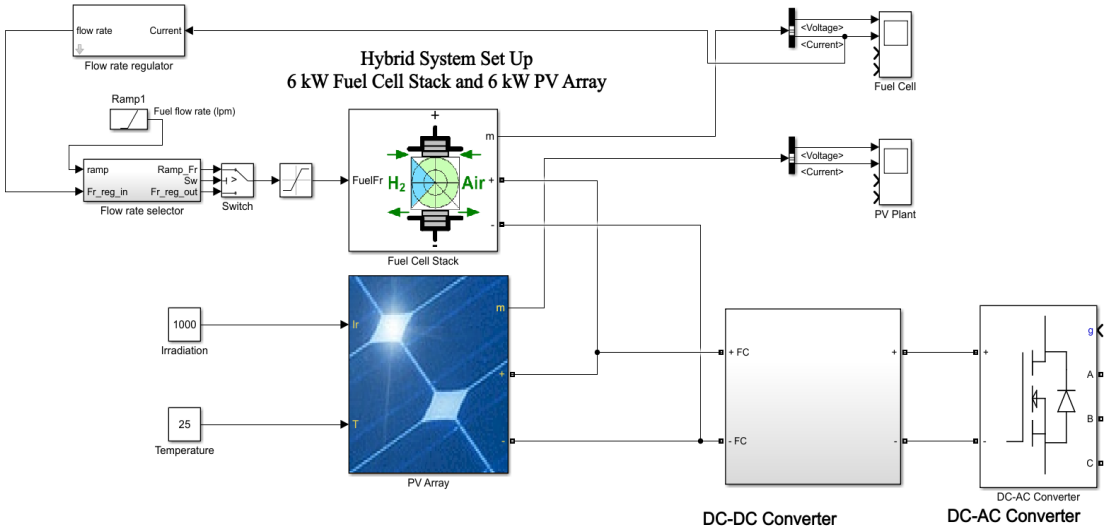


Fig. 5: Solar PV Array and fuel cell stack system in Matlab-Simulink

The hybrid system in Fig. 5 can use a common dc-dc and dc-ac converter as shown or separate system of dc-dc and dc-ac converter depending on the reliability and ease of system maintenance needed. This is the motivation that fuel cell system can operate together with solar PV as a hybrid system (Al-Hallaj and Kiszynski, 2011).

2.3 Fossil Fuel Complete Fuel Cell System

A fuel cell fed from fossil fuel has the complete system architecture of components shown in Fig. 6. The system has three stages. These are fuel processing, power section and power conditioner. The fossil fuel combined with other elements is cleaned by the processing section (Behling, 2013). The power section is the actual fuel cell and the power electronics for conversion of dc to ac power make up the power conditioner section.

Fig. 6 show a complete system that use a fossil fuel for power generation. Most systems in use today us pre-processed hydrogen and reduces the system components to much compact and rugged for use anywhere.

3. Fuel Cell Types

Fuel cells exist in different types. The types differ in the fuels, electrolyte and temperature of operation required. Some fuel cell types operate at low temperature while others operate at high temperatures. The electrolyte can be aqueous, solid, molten, alkaline, neutral, acid, polymer, chemical substance or ceramic.

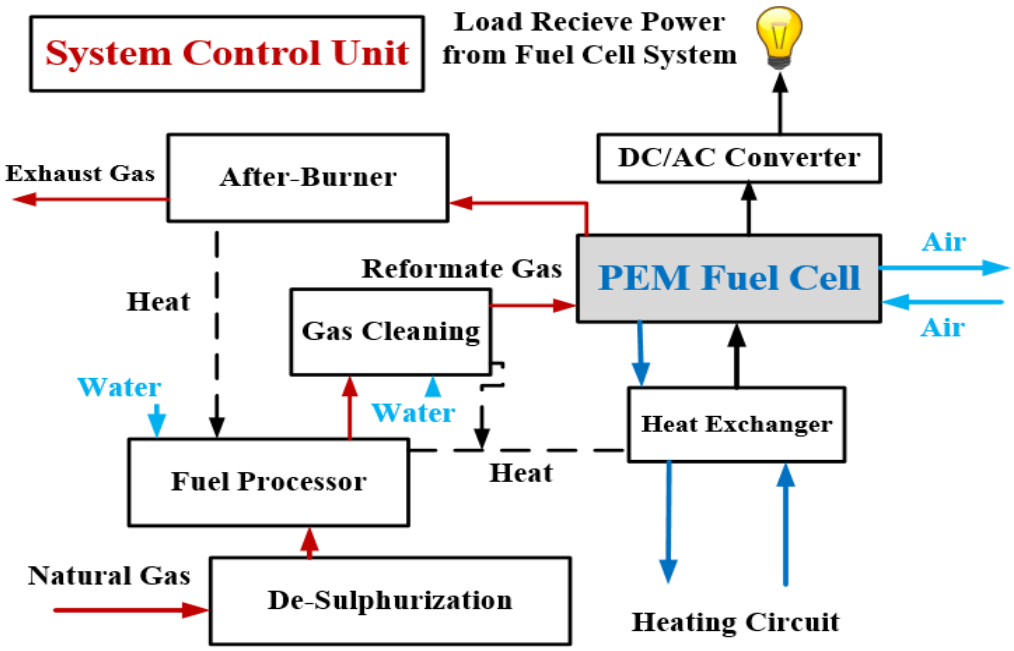


Fig. 6: Fossil fuel complete fuel cell system (Behling, 2013)

The types of fuel cell technologies are proton exchange membrane (PEM), phosphoric acid fuel cell (PAFC), alkaline fuel cell (AFC), direct methanol fuel cell (DMFC), solid oxide fuel cell (SOFC) and molten carbonate fuel cell (MCFC) (Larminie and Dicks, 2003). Of these fuel cell technologies, only alkaline fuel cell cannot be used for stationary power applications while a DMFC is regarded as a subset of a PEM. The PEM, PAFC, SOFC, and MCFC can be used for power supplies. The choices of fuel cell technology for an application depends on the operating temperature and the level of power needed. The choice of fuel cell technology for an application would depend on the operating temperature, power level needed and the cost

3.1 Proton Exchange Membrane Fuel Cell

This type use hydrogen as a fuel and oxygen (pure or in air) to produce electricity by chemical reaction. These create electrochemical reactions using positive hydrogen ions as carrier ions. The direction of the flow of the ions is from anode to cathode.

3.2 Direct Methanol Fuel Cell

This type use methanol as a fuel (hydrogen in methanol through a fuel processor and oxygen to produce electricity by chemical reaction.

3.3 Alkaline Fuel Cell

This type use potassium hydroxide as a fuel which is an alkaline. Oxygen enters the fuel cell at the cathode. Hydroxyl ions (OH^-) are produced at the cathode by a process that includes oxygen, electrons (separated from hydrogen at the anode) and water in the electrolyte. These react to form hydroxyl ions. The hydroxyl ions then migrate to the anode and react with hydrogen, produce water then electrons are released to the external circuit.

3.4 Phosphoric Acid Fuel Cell (PAFC)

The cell has an electrolyte in the name of phosphoric acid for the transport of ions from the anode to cathode. Hydrogen enters at the anode where a chemical reaction separates it into a positive hydrogen ion (H+) and electrons (e-).

3.5 Solid Oxide Fuel Cell (SOFC)

In this fuel cell, a solid oxide ceramic material is used as an electrolyte. The material called ystria stabilized zirconia (YSZ) is used. Oxygen enters the fuel cell at the cathode reacts with the electrons from the external circuit to form oxide ions (O^{2-}). Oxide ions travel to the anode, react with hydrogen to form water and release of electrons.

3.6 Molten Carbonate Fuel Cell

In this type, a molten carbonate, lithium, sodium and / or potassium carbonate soaked in a matrix material is used an electrolyte.

4. Fuel Cell Applications

Fuel cells have been applied for stationary, residential and industrial power use.

4.1 Residential Applications

The fuel cell technology is utilized to generate electric power for residential use. It is often referred to as a home fuel cell. For residential power, the proton exchange membrane is the preferred type. For residential applications that form an integral of the power system, other technologies like Solid Oxide Fuel Cell (SOFC), Phosphoric Acid Fuel Cell (PAFC) and Molten Carbonate Fuel Cell (MCFC) can be used. The power requirement would dictate the typical fuel cell technology to use.

4.2 Stationary, Remote and Distributed Applications

In this application, they are used to supply power for telecommunications towers, base stations, auxiliary for generating stations and rural areas not close to national grid. For remote and distributed application, PEM, DMFC, SOFC, MCFC and PAFC can be used for power up to 3 MW. For stationary power, a PEM is the probable cell.

4.3 Examples of Implemented Systems

For high power applications, systems up to 59 MW are in operation. The vary in sizes. From smaller plug and play units to the biggest recorded unit of 59 MW in South Korea.

In California, a 250 kW PEMFC east Anaheim police department and community centre. The fuel cells produce enough energy to power 250 typical homes of Anaheim and excess power is then fed back into the electric grid (Kubert, 2010).

In Connecticut, a 14.9 MW of continuous power is generated from a 1.5-acre parcel. A Danbury based fuel cell energy completed this fuel cell park system for Bridge-port project. Power is being delivered to the electric grid under a 15-year energy purchase agreement with a Connecticut electric utility and has been in operational since 2013 (FuelCell Energy, 2014).

In south Korea, using MCFC, a 59 MW Gyeonggi Green Energy fuel cell Park has been built. The facility has 21 units of MCFC known as DFC3000 with each capable of 2.8 MW of power output. In addition, the unit supply district heating during winter times (FuelCell Energy, 2014).

5. Adaptation for Zambia and Possible Impacts

The primary fuel used is hydrogen, which can be obtained from natural gas, gasoline, coal-gas, methanol, propane, landfill gas, biomass, anaerobic digester, gas and other fuels containing hydrocarbons which can be harnessed in Zambia as by-products. This increases the market opportunities and possibilities for fuel cells penetration in Zambia.

Zambia has mining companies and fertilizers manufacturing plants. Oxygen, heat and hydrogen are by-products of some of the processes which are raw materials for fuel cells. This has potential of lowering the cost of establishing and operating the fuel cell plants

The costs of fuel cell technology are reducing owing to increased demand. At some point, their prices will become comparable with hybrid systems of diesel and solar PV power's initial investment. The potential to using same power conditioner units with solar photovoltaics as shown in Fig. 5 mean an easier adaptation for Zambia. On the other hand, the fuel cell system can be used as storage. This could make the hybrid solutions with solar PV power attractive and competitive compared to solar PV power/diesel generator system.

The integration to the grid is similar to solar PV and it has no uncertainty in the power production. It could start up changes in government legislations and regulation on energy. Uncertainties in solar production is impetus very for fuel technology breakthrough to cushion variability for grid integrated systems.

The next step, to this paper, will be to analyse the practical suitability using real data (proposals submitted to companies) for existing hybrid systems (solar PV and Diesel generators) and the cost aspects for investments. This will be implemented using the models already set up (Fig. 5 and Fig. 6) and cost optimized (using Homer software).

6. Conclusion

The theoretical background coupled with simulated fuel stack presented in this paper highlights that fuel cell technology is a suitable optional back-up power supply system. The use of the technology as a hybrid solution with solar PV power is attainable.

7. Acknowledgements

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The Importance of Power Quality Monitoring for Modern Network Operators and Industries in Zambia

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Abstract

Modern electricity networks contain a mixture of different types of loads all of which affect the voltage one way or the other. They can either improve or deteriorate the so-called "voltage quality", also known as "power quality" or "quality of power" that is being supplied by network operators and received by their customers. Increased use of power electronic devices for the control of rotating electrical machines and the presence of sensitive electronic equipment has further affected the power quality. The impact of new equipment is rarely an improvement, although it is often less than feared at first. The shortage of rainfall has resulted in a lot of investment in solar photovoltaics power, which has the potential to further worsening the power quality in the Zambian power network. To quantify the impact of these and other changes on the power quality requires monitoring of voltage and current with high accuracy and time resolution. The results of such a power-quality monitoring program will form a base to identify and, when needed, mitigate any problems. The use of class A power monitoring instruments is an important part in such a program. The requirements to which such instrument should comply are in the Zambia grid code, ZS 387 standard and in international standards (EN 50160, IEC 61000-4-30 and IEC 61000-4-7). The investment and use of class A power quality instruments has reported saving gains at Copperbelt Energy Corporation plc in Zambia and by companies around the world. The use of such instruments has resulted in power quality issues being identified, benchmarked, broad exchange of knowledge and remedial actions implementations. This is an indication of the importance of power quality monitoring for network operators and industrial customers in Zambia using class A instruments.

Keywords: Class A instrument, grid code, measurement, power quality monitoring, solar photovoltaics, standard

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1. Introduction

The generation matrix of Zambia had concentrated on hydropower with a share of diesel power in some areas for many years. The droughts and increase in energy demand that the country had experienced of late has led to a revolution in the generation matrix (ZDA, (2014)). Other energy sources are coming on board to supplement the existing generation. The power supplied to residential and industrial customers must meet the criteria set in the Zambian Grid code, power quality standard (ZS 387) and in international standards (EN 50160, IEC 6100-4-30 and IEC 61000-4-7) on power quality. The power quality delivered must comply with requirements defined in the grid code and ZS 387 standard. Any non-compliance (typically, certain limits being exceeded) has the potential to affect customer loads and attract penalties from regulatory, Energy Regulation board.

Integration of solar photovoltaics (PV) power and need for integration studies to establishing and understanding likely impacts to the national grid at transmission and distribution requires data (Bollen, 2003). Accurate, detailed and high-resolution data required. Part of high-resolution input data is obtained through measurements and monitoring of power quality parameters using specialised power quality instruments.

The operations of the utility grid under faulted conditions impacts on the current and voltage waveforms. Distortion in the quality of the current and voltage waveforms. This is a challenge to the utility companies and industries. To address such waveform distortion, power-quality monitoring using dedicated instruments is an important part to the solution. This emphasises the critical need of reliable high-resolution power quality instruments to measure and record all events. High-resolution power quality instruments important for utility companies and industries in Zambia.

Important questions to address are:

1. Which class and type of power quality instruments do power utilities and industries to address power quality challenges and system studies?
2. Why are these class and type of power quality instruments important in power quality monitoring for the utilities and industries?

This paper contributes to addressing the questions, power quality understanding, parameters, good choice of instrument class cases and sample measurements. The sample measurements and cases presented to show why it is important to monitor these parameters using correct class of instrument with high accuracy and resolution to utility companies and industries in Zambia.

1.1 Methodology

The methodology used is measurements of power quality at different locations with a fixed and portable class A instruments. The measurements presented with detailed information from such measurements. Brief theory and cases of class A instrument use presented.

2. Power Quality

Power quality is a term used to describe a deviation from the ideal sinusoidal current and voltage waveforms (Bollen, 2003). Others relate power quality to all possible situations where the supply voltage and load current deviate from the sinusoidal waveform. The deviation is determined at the rated frequency with amplitude corresponding to the rated value of one or all the three phases of a three-phase system.

Figure 1 shows an outline of the concept of power quality for a simple power system having solar photovoltaics (PV) generating plants.

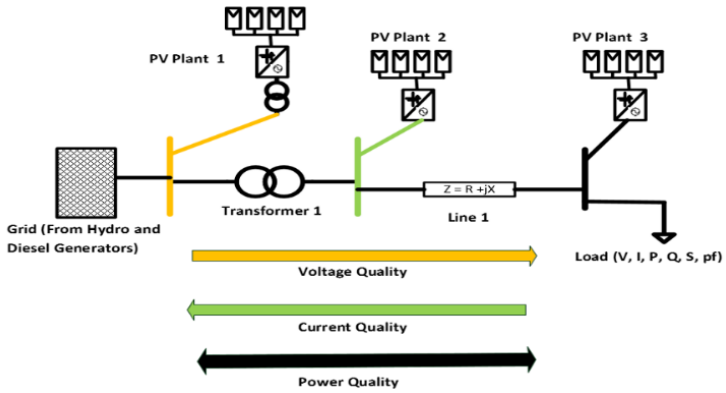


Fig. 1: The concept of power quality in a grid (Axelberg and Bollen, 2002)

The arrows in Fig. 1 show the directional interest of voltage, current and power quality aspects. The term power quality includes the following terms; voltage variations, voltage sags, voltage swells, transients (rapid voltage changes), flicker (fast voltage variations), voltage and current unbalance, harmonics (including interharmonics / supraharmonics), frequency. These phenomena are prominent. Power utility companies and consumers should adhere to the specified limit in a grid.

2.1 Possible Causes

Many factors cause power quality phenomena problems and challenges in an electricity grid and industrial installations. The causes include:

- lightning (transient overvoltages),
- Switching actions. For example, disconnection of lines or capacitor switching (transients),
- short-circuit faults (voltage dips, sags and short interruptions),
- Induction motor starting (transient overcurrent),
- Non-linearity of loads. For example, diode or thyristor rectifiers for smelting process, mining traction process (harmonics) and rapidly varying loads like arc furnaces (periodic current fluctuations leading to light flicker).
- Inverter applications for solar photovoltaics

Figure 2 shows a plotted waveform distortion due to harmonics from power electronics components and Fig. 3 shows plotted distortion in the waveform due to a dip and sag. The dip and sag in Fig. 3 results in unbalance in voltage supply.

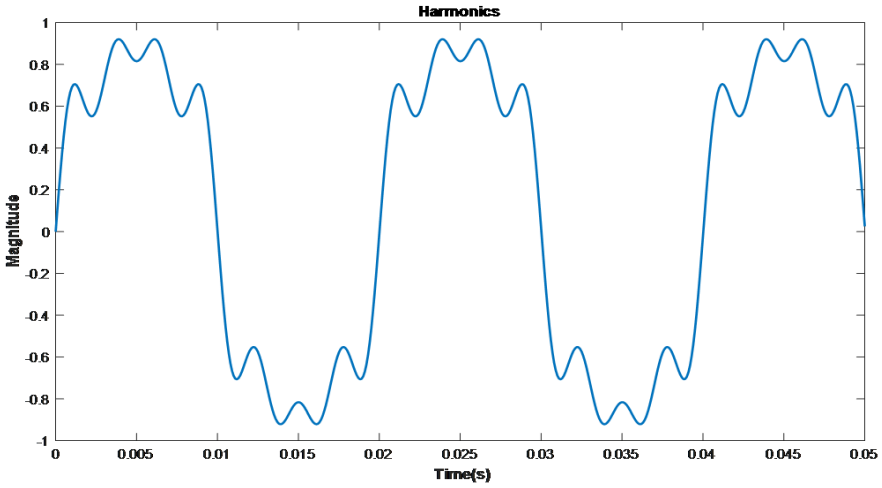


Fig. 2: Effects of frequency converters on the (voltage and current) waveforms (Mohan etaal, 2003)

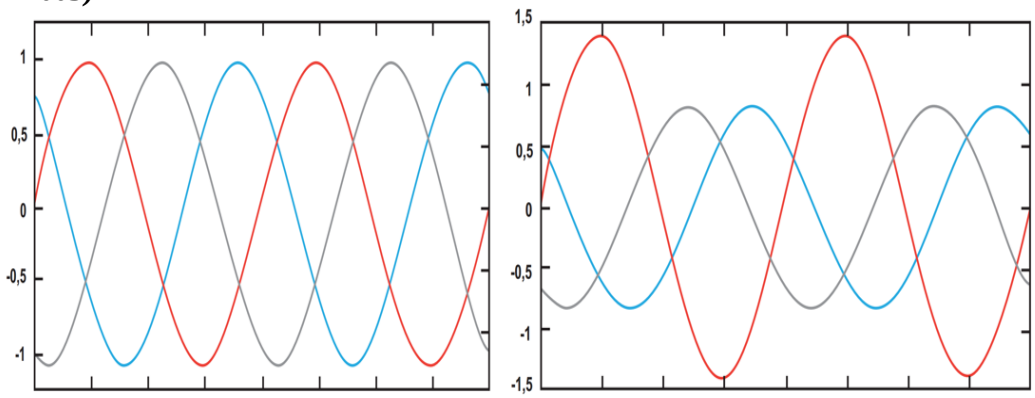


Fig. 3: Three phase balanced and unbalance voltage waveforms (Hingorani and Gyugyi, 2000)

Figure 2 shows the effects of frequency converters' effects on the current and voltage waveforms in industries. The distortions have impacts on the insulation of most electrical machines and sensitive electronic equipment.

Figure 3 shows a shift from the traditional balanced three-phase system desirable for all rotating electrical machines to unbalanced three phase systems. This effect has impact on the rotation and performance of most electrical devices and machines in industry.

The distorted waveform, which deviates from the ideal sinusoidal, composed of the fundamental and individual spectral harmonic components. If the fundamental component of a distorted waveform is A_1, and individual spectral harmonic components are A_2, A_3 up to A_n, The total harmonic distortion mathematically is calculated by equation (1) (Mohan *etaal*, 2003)

$$THD = \left(\sqrt{A_2^2 + A_3^2 + \cdots + A_n^2}\right)/(A_1) \qquad \textbf{(1)}$$

The voltage and current to total harmonic distortion determined using equation (1). For complex system, power quality instruments measures and records the distortion.

2.2 Power Quality Monitoring

Power quality monitoring is important for a power system. The monitoring of voltage and currents give information to the utility companies, industrial and residential customers. The state of the power system, system performance, problems/faults, possible locations and their origin. The Zambia grid code and power quality standard (ZS 387) set required level of quality in power that power supply companies, industrial customers and independent power producers (IPP-Solar power plants) need to adhere to.

3. Power Quality Measurement Architecture

Power quality monitoring requirements are different. Applications for industrial customers and utility customers level of monitoring and data needed differs. Figure 4 show a standard measurement architecture (Music, et al., 2012).

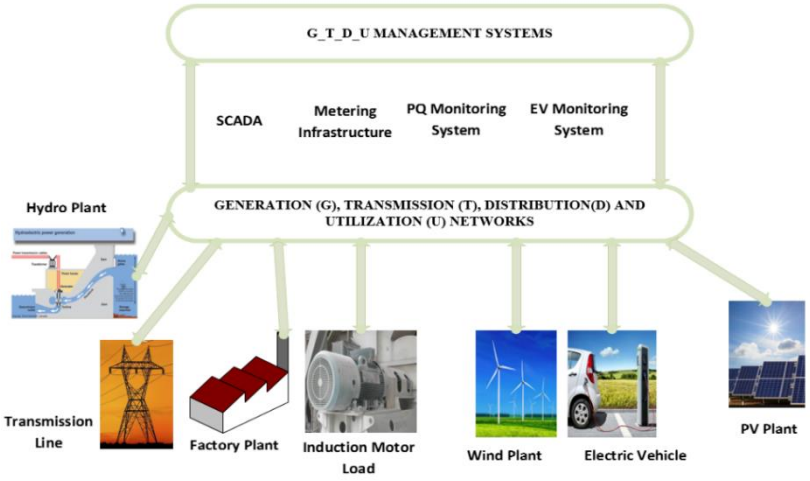


Fig. 6: Power quality monitoring and measurement architecture (Music, et al., 2012)

In Fig. 4, the parts of a modern power system are shown and measurement system. Modern power system for Zambia in years to come will include solar photovoltaics and level of data measurement with high resolution needed. Reliable systems are needed to measure and monitor system parameters. Storage and analysis of measured data needed for technical decision-making. A build-up of generation, transmission, distribution and utilisation management systems results. For small independent system (industrial or residential customer), a combined system into one management unit system. For large aggregated system (utility companies), independent and integrated systems at system voltage transformation, metering and power dispatch points.

3.1 Choice of Power Quality Instrument

Power quality instruments classified as class A, class B or class S instruments.

Class A instruments are normative instruments, recommended and use in Zambian industries limited to utility companies. Class A instruments comply with very strict rules concerning their accuracy and reproducibility. Two Class A instruments will give close to the same results when performing the same measurements. This not only allows comparing results, but also benchmarking with other locations, comparing with objective values in standards and regulations, but also to learn from others for example for interpretation of the results. Non-Class A instruments do have their application areas, for example in research (we use some of them in our laboratory), but they can make the measurements results less useful and much harder to interprete.

Class B instruments are indicative instruments and very common in many industries in Zambia today. Interpretation of the results from Class B instruments is generally difficult; benchmarking and compliance monitoring is not possible. The Class B were introduced in the first edition of IEC 61000-4-30, around 2000, to allow existing instruments to obtain a certification.

Class S instruments are a class used for surveys with limited subset of parameters. Statistical applications use class S instruments and have lower processing requirements than class A instruments. When doing a survey using Class S instruments, it is important to restrict whenever possible to similar instruments throughout the survey.

More recently, even for surveys, there is internationally a strong shift to Class A instruments. One of the reasons being that one is no longer restricted to one manufacturer with future extensions of the survey population.

The selection of the correct instrument type and class for the current/future metering or monitoring needs is critical. The selection could affect the cost of the utility company and industrial customer in more trouble shooting time or loss of revenue in non-compliance. Consideration of the following points needed before selecting the power quality instrument to purchase:

- The goal of the monitoring system for the present and future time
- Power quality parameters of interest
- Whether single phase, three phases, portable or fixed instrument
- Ability to capture events,
- Ability to record and examine power quality issues to standards
- Communications capability (necessity for automation, supervisory centre and data acquisition -SCADA, distributed control system-DCS and managements systems)
- Complexity of associated software and its interpretation
- Storage capacity
- Conformity and certification to international standards
- Monitoring capability in the wake of faults and disturbances

3.2 Standards and Regulations

Regulation of electricity in Zambia done by Energy regulation board (ERB). The instruments associated with the electricity energy sector must conform to these Zambia distribution grid code and ZS 387 standard.

The national standards emanate from international standards. Under power quality monitoring practices, the standards guide on the power quality parameters, measurement methods and lead to instrument class to use.

- Power Quality Measurement Methods: IEC 61000-4-30
- General Guide on Harmonics and Interharmonics Measurements and Instrumentation: IEC 61000-4-7
- Quality of Supply Standard: EN50160

Energy Regulation Board (ERB) and Zambia Bureau of Standards (ZABS) carry out the regulation and enforcement of power quality conformity to standard in Zambia. ZABS provides efficient and effective standardization, quality assurance and metrology to consumers and regulators in Zambia. ERB provides regulation to consumers energy needs. In addition, it ensures that all energy utilities in the energy sector are licensed, monitors levels and structures of competition, investigates and remedies consumer complaints.

4. Cases of Modern Power Quality Monitoring

The benefits of power quality monitoring instruments to identify and reduce losses in the power system. Another story '75% cost reduction offering real savings by Copperbelt Energy Corporation (CEC) plc', a private owned utility company supply power to mining companies on the Copperbelt province of Zambia, appeared on a website of a leading Swedish company specialised in class A power quality monitoring instruments and systems (Metrum AB, 2016).

Modern power quality monitoring also requires continuous capacity building. Kafue Gorge Regional Training Centre (KGRTC) has taken a leading role together with Swedish power quality companies. Power quality training organised in November 2016 with a Swedish company and ABB (Nkole, 2016) and recently in November 2018 with Metrum AB-Sweden.

Power quality class A measuring instruments provide success stories has centred on a utility company (CEC plc). Industrial companies could lower their cost of production and save energy through use of class A power quality measuring and monitoring instruments. Section 4.1-4.3 presents success cases of power monitoring instruments and systems utilizing class A. The cases cover Zambia and Sweden. For Zambia, it is a step worth emulating for industrial companies.

4.1 Case of Copperbelt Energy Corporation (CEC)-Zambia

Copperbelt Energy Corporation (CEC) plc of Zambia desired to invest in a faster and easier power quality solution for efficient trouble shooting, reduction on trouble shooting time, save on energy and compliance report generation. Class A power quality instruments by Metrum AB chosen for this purpose. In 2015, Copperbelt Energy Corporation (CEC) plc of Zambia invested and implemented this power solution. The PQ140/PQR that enables easier and efficient report among its specification with associated components installed and to date seventy are in operation.

By using the class A power quality instruments, reduced trouble shooting time, simple software to use, easy compliance report generation, and 75 % reduction in time spent on power quality

trouble shooting challenges. This translates to financial gains by the utility company. Figure 5 shows a sample of an installation of the power quality monitoring instruments PQ140 class A at CEC plc.

Fig.5: Installed class A power quality monitoring instruments at CEC plc (Metrum AB, 2016)

4.2 Cases at Falbygdens Energi and Sandvik Materials Technology

Similar success stories have been reported at Falbygdens energi and Sandvik materials technology in Sweden. They result from use of class A power quality instruments.

At Falbygdens energi, a case of connecting renewable energy (wind and solar) to a grid with unknown challenges. The challenges with the demand of a utility company to adhere to electricity standard (EN 50160) on the quality of power supply. There was need to measure and monitor the quality of power with high accuracy and resolution. Investment in class A instruments was done by replacing its old energy meters. The shift to class A instruments resulted in monitoring problems caused by addition of wind energy and remedial actions taken. The result was energy saving and continuous monitoring of power quality parameters with high resolution and accuracy.

At Sandvik Materials Technology (SMT), the challenge was high-energy consumption and huge impact on manufacturing processes. SMT decided to implement measurement and monitoring system of their plants using class A power quality instruments. Identification of areas needing improvements in energy consumption reduction achieved and level of harmonics that characterized their system. Significant energy gains of 52 GWh in a year identified from their 600-700 GWh energy consumption per year with 20 GWh achieved on solution implementation.

5. Sample Class A Power Quality Measurements and Monitoring

The problem of total harmonic distortion (THD) shown in Section 2 is measured, shown and identified in this section. Two types of class A power quality instruments used to carry out measurements and monitoring of power quality at different locations. A portable class A instrument and fixed class A instrument at different locations.

The sample monitoring and measurement results shown in section 5.1 and 5.2. The results illustrate the resolution and detail information that a class A instrument presents for analysis and decision-making.

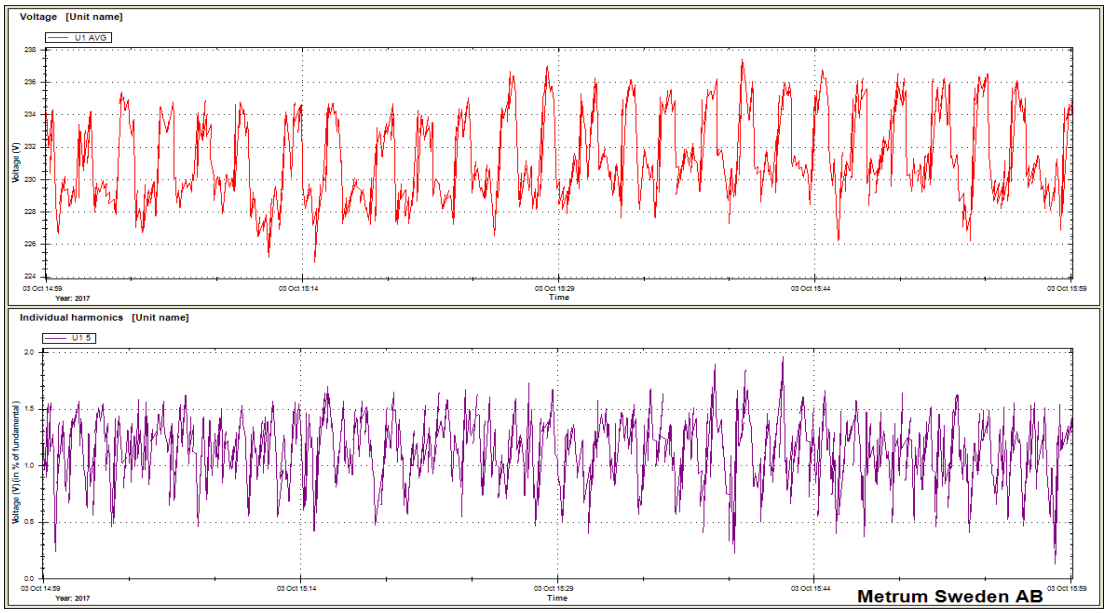
5.1 Measurement Results from a Portable Class A Instrument

The portable class A instrument was set up as shown in Fig. 6. This is a single phase unit and very easy to connect and setup for measurements and monitoring.

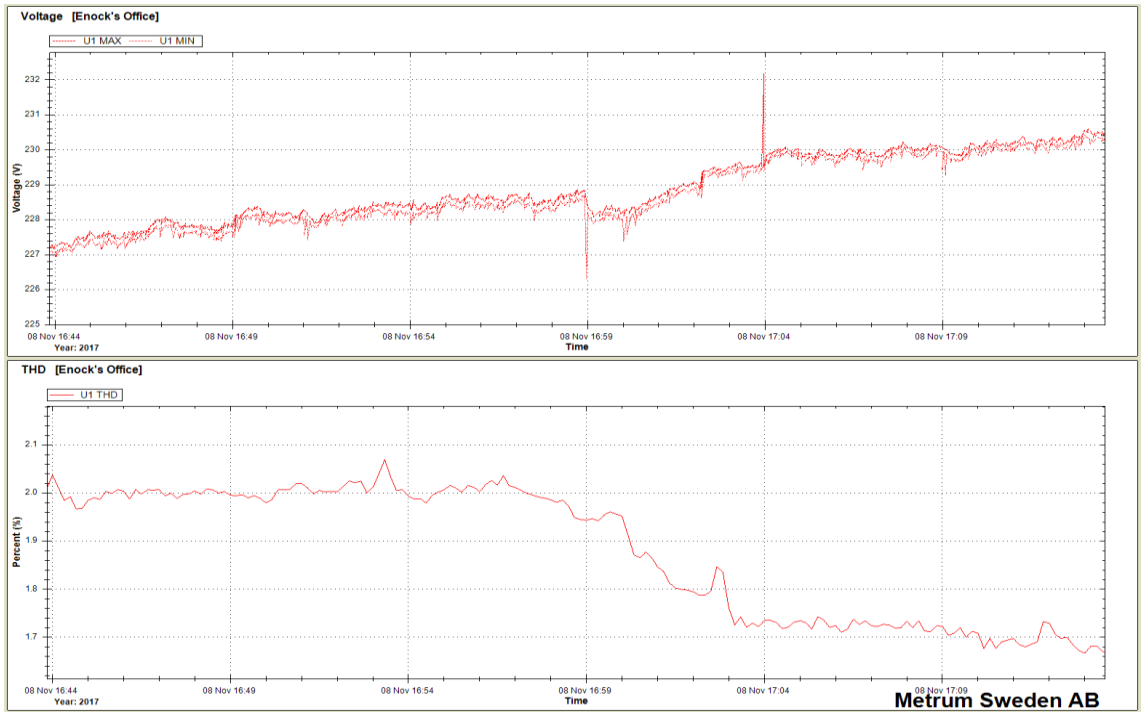
Fig.6: Measurement and Monitoring setup of a Class A portable instrument

Figure 7 show measurement of the supply voltage quality with use of Fig. 6 set-up. The measurement shows the minimum and maximum supply voltage and the total harmonic distortion (THD). The plots shows fluctuations in the rms voltage and in the harmonic voltage components in an office and building. Both voltage and harmonics measurements recorded with 1-second time resolution allowing for detailed study of the phenomenon of total harmonic distortion with class A instrument.

From the measurements, the theoretical calculation of equation (1) for THD obtained direct from the instruments software PQ web.



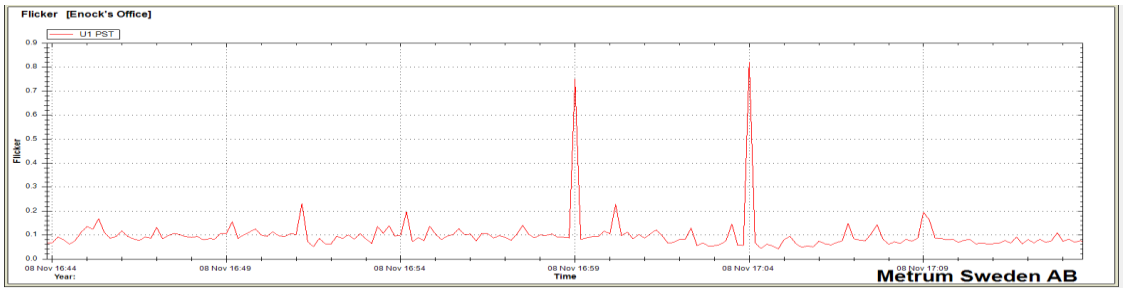
(a) Measurements in a building



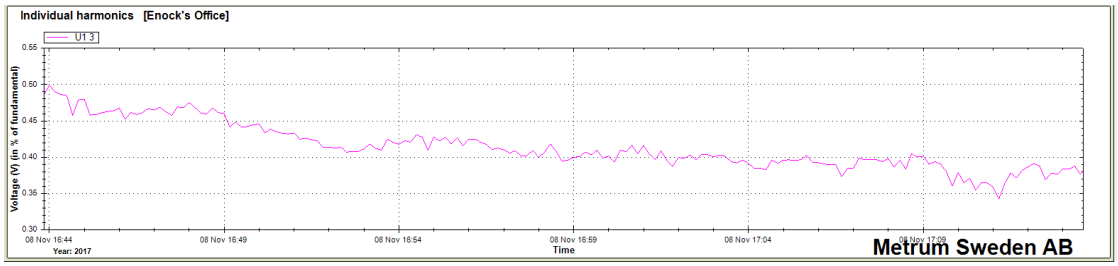
(b) Measurements in an office

Fig.7: Voltage measurement showing maximum and minimum values with THD

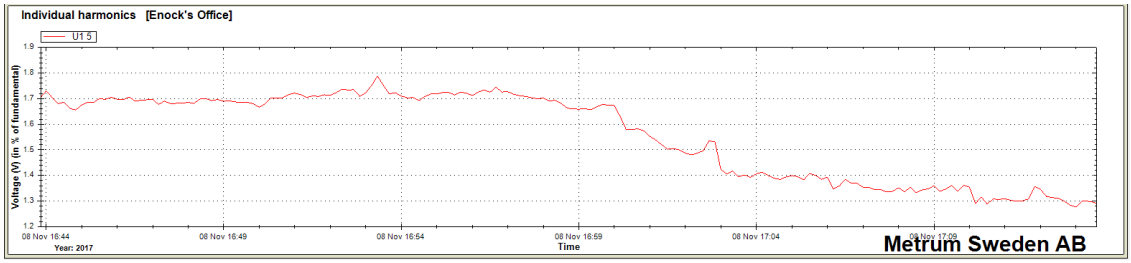
Obtaining additional information for further supply voltage assessment possible. Figure 8 shows selected individual harmonic components from the supply voltage.



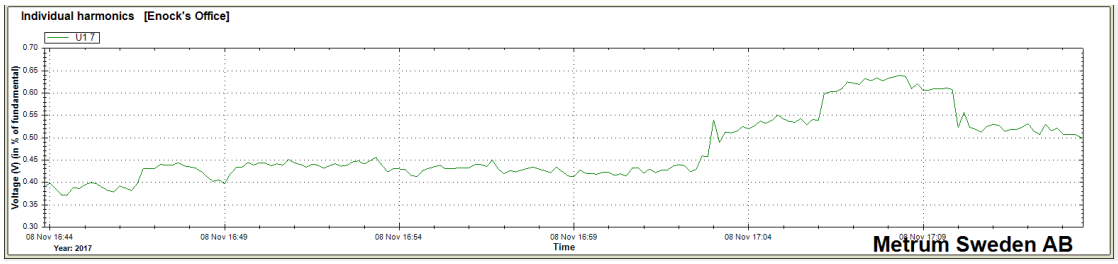
(a) Detailed Measurement showing the level of flicker



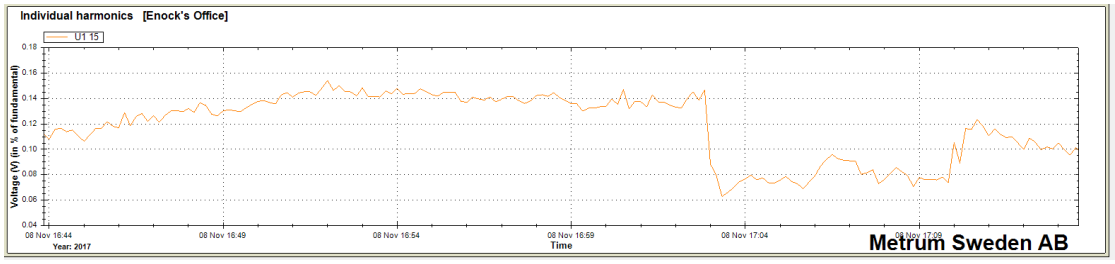
(b) Detailed measurement showing the percentage level of the 3rd harmonic component



(c) Detailed measurement showing the percentage level of the 5th harmonic component



(d) Detailed Measurement showing the percentage level of the 7th harmonic component



(e) Detailed Measurement showing the percentage level of the 15th harmonic component

Fig.8: Detailed measurements showing additional information of the voltage quality using a class A power quality instrument for further assessment and analysis

The results in Fig. 8 show detailed additional information and form the basis of investigation of the quality of voltage using measurements of a class A instrument. The percentage of individual harmonic components obtained and measures taken if it is higher than the limit.

Fig. 9 shows frequency measurements using a class A instrument.

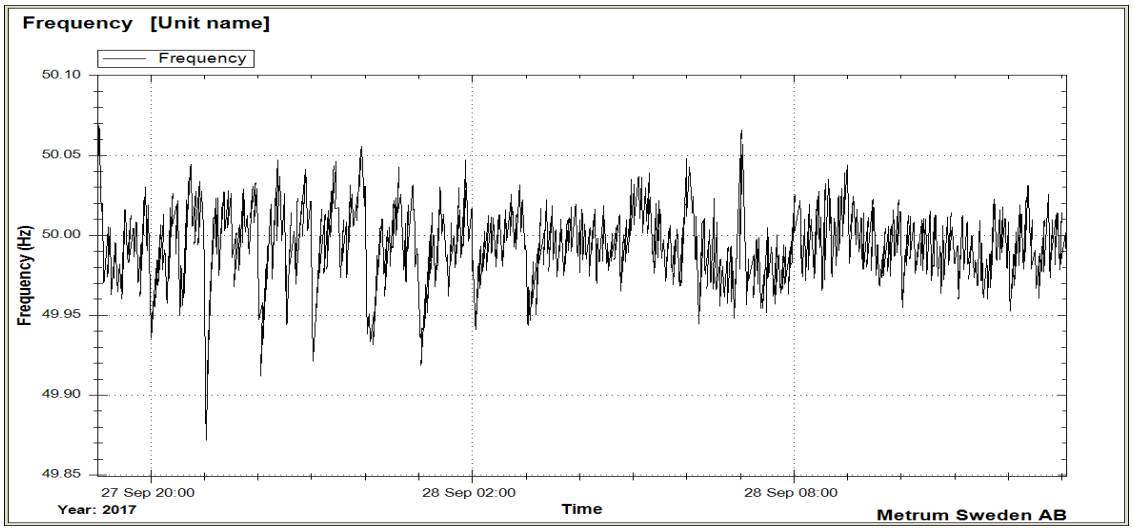
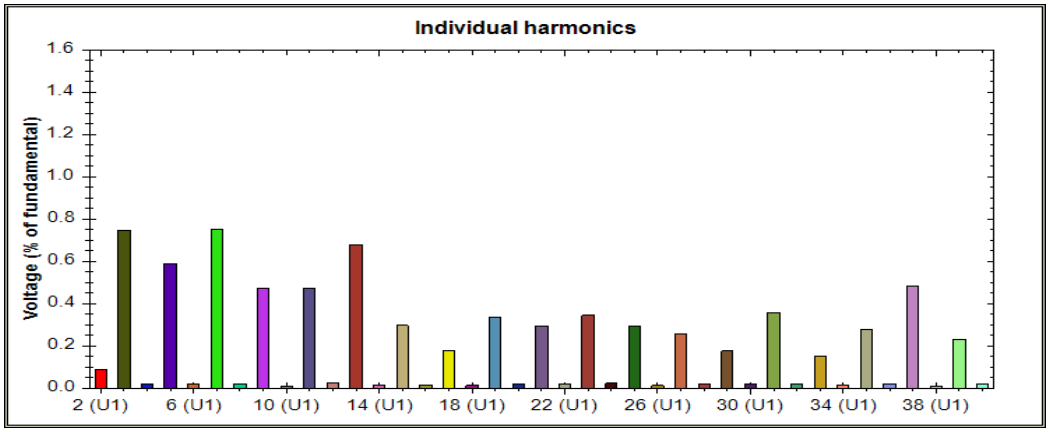


Fig.9: Frequency measurements in a European interconnected power system

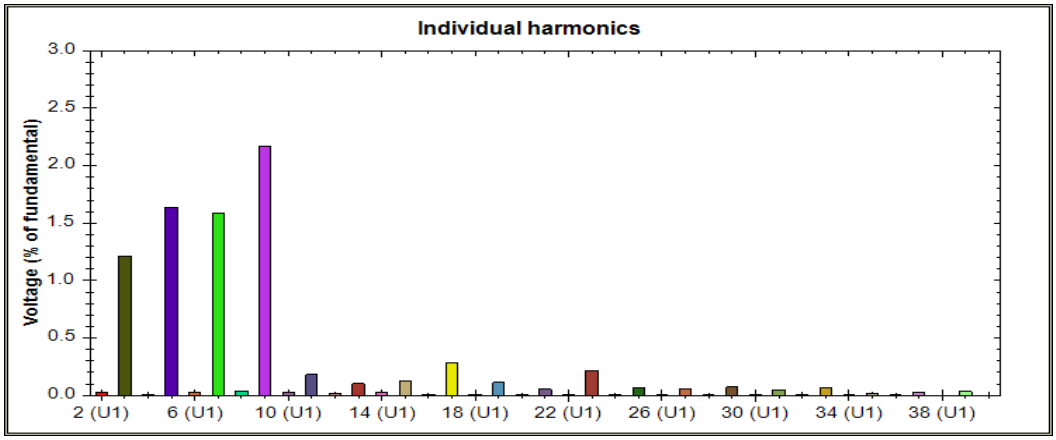
The frequency measurements in Fig. 9 shows severe swings in frequency in the European interconnected power system due to market operation. The swings are strong in the late evening and in the early hours of the morning. Large amounts of wind and solar production expected to make these swings more severe. This case could prevail when solar photovoltaics integrated to the Zambian power system. Identification and class A instrument key to this problem.

With class A instruments, comparison of harmonic spectrum achievable. Figure 10 shows plots of individual harmonics for two buildings.

The measurements in Fig. 10 used to compare the harmonic spectrum between two office buildings. From Fig.10, one has a low THD but with high levels of high-order harmonics while the other (office 2) has a high THD but low levels of high-order harmonics. This illustration shows that it is important to get sufficient details in the measurements.



(a) Individual harmonics measurements for Office 1



(b) Individual harmonics measurements for Office 2

Fig. 10: Comparison in harmonic spectrum between two office buildings

Measurements from a microgrid shown in Fig. 11. Individual harmonics measurement from one six-pulse inverter shown. The characteristic harmonics (5, 7, 11 and 13) and the switching frequency (harmonic 38) are clearly visible with high level of even harmonics 8, 10 and 12. This is obtainable from a class A power quality instrument with its analysis software.

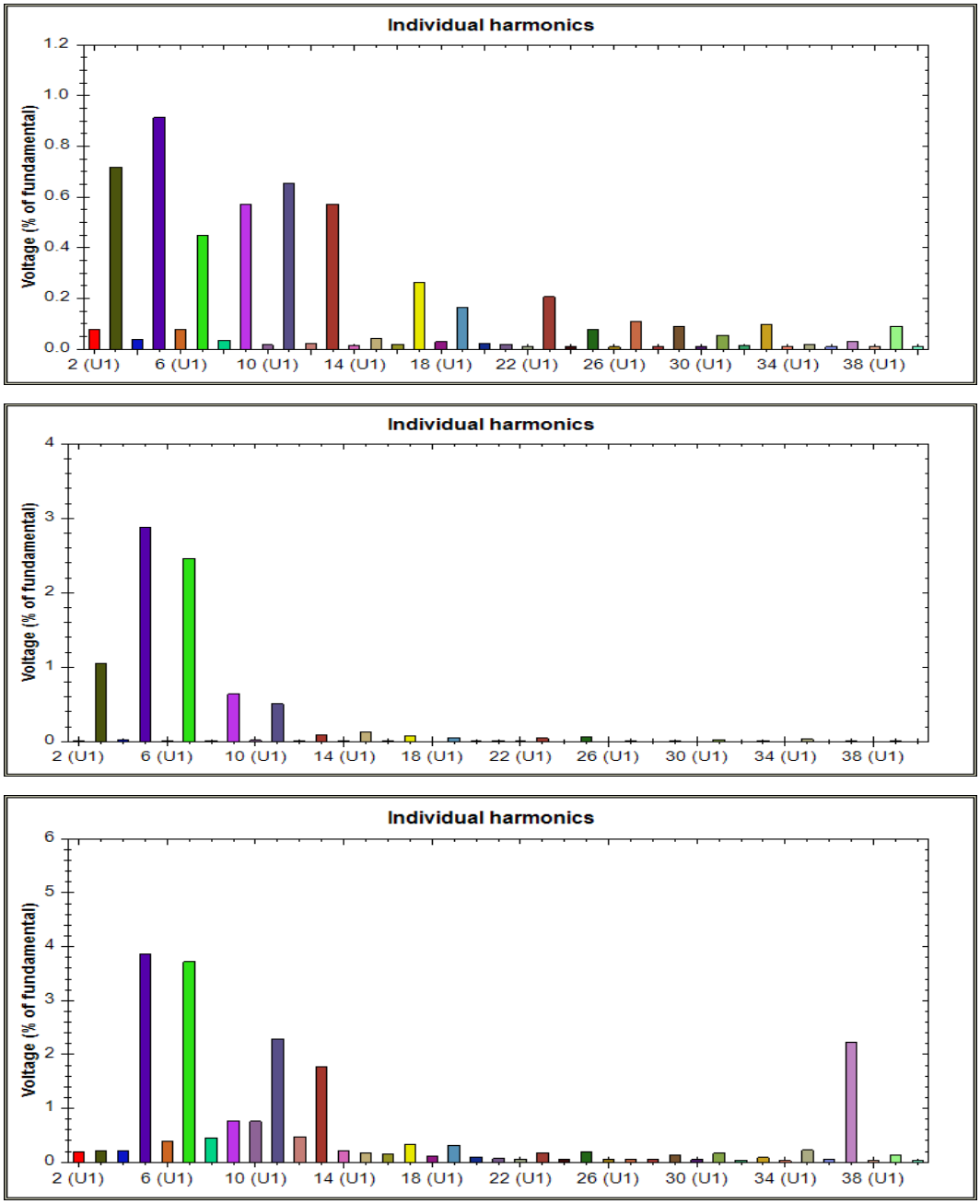


Fig.11: Individual harmonics measurements in a small microgrid at different points

5.2 Measurements from Fixed Class A Field Instruments

Measurements for a period of one hour at a solar PV plant located in Piteå, northern Sweden with a class A fixed power quality instrument shown Fig. 12.

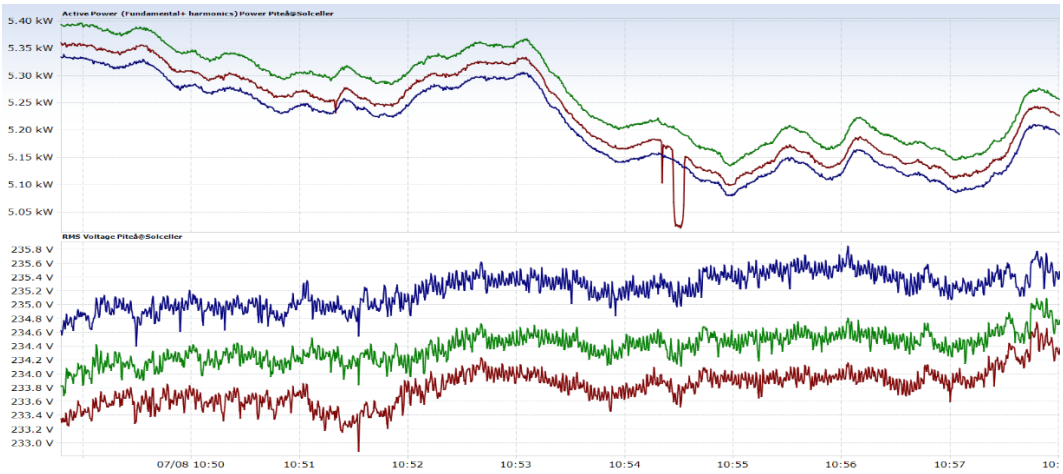


Fig.12: Solar PV production and voltage for 1 hour at Piteå in northern Sweden.

The power and voltages at the point of common connection to a grid monitoring shown in Fig. 12 measurements. The power quality measuring and monitoring instruments can give measured data with high accuracy and resolution of one second (1 s) useful for network and industrial system studies. Table 1 shows sample results from a class A measurement with one-second resolution values.

Table 1: Fundamental and harmonics power measurements to 1-second resolution

Date	1-Second Time Resolution	Min-Power (W)	Max-Power (W)	Average-Power (W)
18-06-13	00:00:00.000	7.4690242	8.3002920	7.8395162
18-06-13	00:00:01.000	6.4313149	7.4690242	6.9914680
18-06-13	00:00:02.000	5.8243799	6.4313149	6.0468850
18-06-13	00:00:03.000	5.4417758	5.8243799	5.7523751

6. Conclusion

Power quality problems, need for high-resolution data and detailed analysis with success case at CEC show the important need of class A power quality instruments. Solar photovoltaic integration studies' need of high resolution data lead to need of class A power quality instruments at power utility and industrial companies level. This require huge investments in class A measurements and morning instruments and systems. Class A power quality monitoring instruments and systems needed in the modern power system of Zambia for network operators and industry.

7. Acknowledgements

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A Review of Potential Generation of Electricity from Biogas for Rural Development in Zambia

Ronald Ngulube[1], Musango Lungu[1] and Lloyd Mukoshya[1]

Abstract

Although the demand for the electricity in Zambia has been growing at an average of about 3% per annum mainly due to the increased economic activity in mining, agriculture and manufacturing sectors, nearly 95 – 96% of rural Zambians that accounts for over 65% of the country's population have no access to electricity. The cost of extending grid electricity to remote areas in the country is too high, seven times more than supplying urban areas, and the low demand for the rural areas cannot justify the cost of electrification projects. Electricity generation from biogas using anaerobic co-digestion process could be an alternative solution to the energy crisis for the rural development in Zambia. This study reviewed the biogas potential, from anaerobic co-digestion process, for electricity generation in rural areas of Zambia and identified obstacles to adoption and implementation of biogas technology and made recommendations. In this study, various biogas production information and data available from scientific research reports, journal publications and organizational reports available in Zambia were reviewed. The study shows that a theoretical biogas potential of 75 PJ per annum from animal manure and crop residues could be generated. This amount of energy is sufficient to provide energy for cooking and lighting to more than 3 million households (having six members per household). In order to realize this theoretical biogas potential, various technical, political and socioeconomic constraints that have derailed full adoption and sustainability of biogas production in Zambia need to be addressed for the energy sector to flourish.

Keywords: Biogas, Electricity Generation, Co-digestion, Rural Development

1. Introduction

Zambia's electricity is estimated to be 95% hydroelectric from Zambezi river making hydro power the most important energy source (CFA, 2011). According to the report by Intergovernmental Panel on Climate Change (2001), Zambezi river basin exhibits the "worst" potential effects of climate change among eleven major African basins, due to the resonating effect of increase in temperature (0.3–0.6ºC) and decrease in rainfall (10–15%) leading to drier and more prolonged drought periods. Furthermore, the cost of extending grid electricity to remote areas in the country is too high and the low electricity demand in rural areas cannot justify the cost of electrification projects (Machungwa, 2005). The effect of climate change on the country's water resources and continued large scale usage of wood for energy and non-energy tasks may eventually lead to an energy crisis in the near future. It was reported that in Southern Africa, the rate of deforestation is highest in Zambia (2.4%) and over 300,000 ha of forest land is lost per annum (FAO, 2003). These situations provide good justification for research in the areas of alternatives energy. Many countries are interested in sustainable renewable energy sources such as; geothermal power, wind power, small-scale hydropower, solar energy, biomass energy, tidal power, and wave power (Berndes et al., 2003).

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Biogas produced from anaerobic co-digestion (AcoD) could be an alternative solution to rural development and energy crisis in Zambia. Biogas is a combustible gas, which can be used as a fuel for co-generation or combined heat and power (CHP) plant to simultaneously produce electricity and heat by means of gas or dual fuel engines (Abeliotis and Pakula, 2013; Ward et al., 2008). In recent years, AcoD has been applied worldwide. AcoD is defined as a waste treatment method in which two or more substrates are mixed and treated together, so the biogas production is improved through their joint treatment (Khalid et al., 2011; Mata-Alvarez et al., 2011). The greenhouse gas (GHG) emission can be greatly reduced through the AcoD process (Ward et al., 2008). AcoD offers significant benefits including: reduction in the greenhouse gas (GHG) emission, low cost and cheap technology system to supply energy for rural areas in developing and underdeveloped countries (Esposito et al., 2012), reduced disposed waste volume and weight to be landfilled (Ward et al., 2008), The semi-solid by-product, digestate, can be used as fertilizer due to its high nutrients content and minimal odor emissions (Esposito et al., 2012; Ward et al., 2008; Smet et al., 1999). Diversifying electricity generation and reducing over dependency on hydropower through exploitation of on-grid and off-grid renewable energy technologies should be promoted. This study reviewed the biogas potential, from co-digestion process, and identified obstacles to adoption and implementation of biogas technology and made recommendations.

2. Anaerobic digestion

2.1 Biochemical Process of Anaerobic Digestion

The conversion of complex organic compounds into methane and carbon dioxide requires a mixture of bacterial species and occurs by four reactor steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Kashyap *et al.*, 2003). A schematic diagram of AD process is shown in Figure 1.

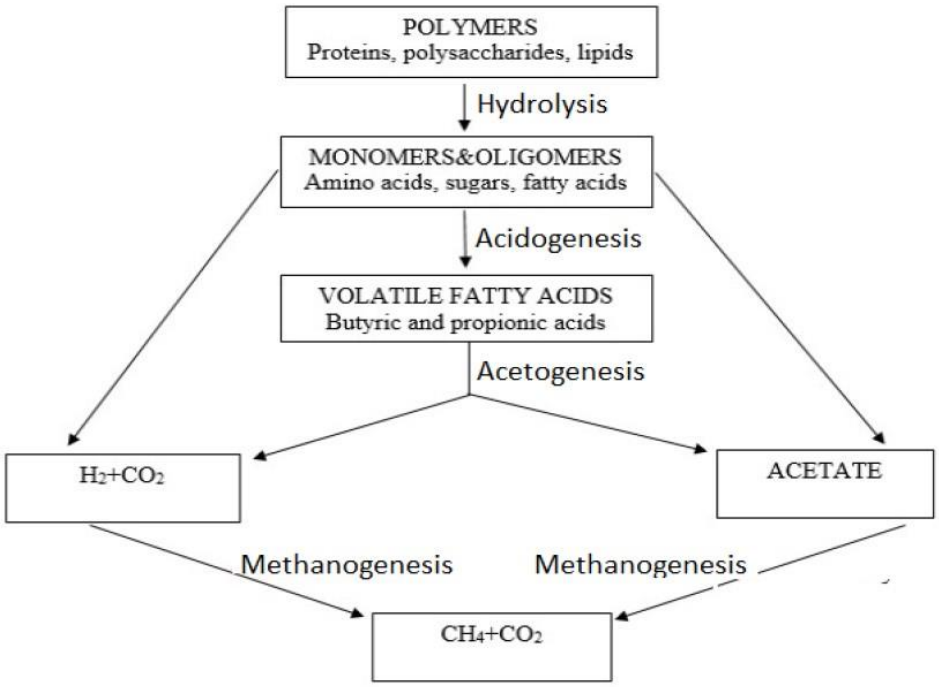

Figure 1: Anaerobic digestion of organic materials into biogas (O'Flaherty et al. 2006).

Original organic wastes usually contain large-molecule compounds such as proteins, polysaccharides and lipids. In the hydrolysis step, complex organic polymers are hydrolyzed to monomers by fermentative bacteria. The monomers are converted into volatile fatty acids through

the acidogenesis process. These fermentation products are further degraded to acetate and hydrogen by hydrogen-producing acetogenic bacteria through acetogenesis process. Acetate production from hydrogen and carbon dioxide by acetogens and homoacetogens are also included in the acetogenesis process. Finally, the acetoclastic methanogens convert the acetate to methane and carbon dioxide through the methanogenesis process.

2.2 Anaerobic digesters

Many different types of anaerobic digesters are currently in use but the three major types are batch reactors, one-stage continuously fed digesters and two-stage continuously fed digesters (Khalid et al., 2011).

2.2.1 Batch reactors

The batch reactor is the cheapest to build and easiest to operate among all reactors. It has a lower loading rate and the contents within the digester are completely mixed (Suryawanshi *et al.,* 2010). Compared with continuous digester, it is more resistant to the inhibition, however, there is potential risk of explosion during unloading (Vandeviviere *et al.*, 2002). The batch system can be categorized into three subtypes which are single-stage batch digestion, sequential batch digestion and hybrid batch up-flow anaerobic sludge blanket (UASB) digester. In a single-stage batch digester, the substrates are thoroughly mixed and digested. When the biogas production stops, the whole system is emptied and loaded again (Suryawanshi *et al.,* 2010). The schematic of the singestage batch digester configuration is shown in Figure 2 (a). In the sequential batch digestion, two or more digesters are used at the same time. The sludge in the first digester is injected into the second digester, then the leachate from the second digester is injected into the first digester (Suryawanshi *et al.,* 2010). The methane production is optimized through the transition of microorganisms and nutrients (Suryawanshi *et al.,* 2010). A hybrid batch UASB is composed of a batch digester and a UASB digester and it is used to treat organic acids wastewater at high loading rates (Vandeviviere *et al.,* 2002). This type of digester is widely applied to treat large volume of wastewater in industries (Suryawanshi *et al.,* 2010).

2.2.2 One-stage continuously fed digesters

In one-stage continuously fed system, all biochemical reactions take place in the same reactor (Suryawanshi *et al.,* 2010). The substrates are continuously fed into the reactor with the most common period being once a day (Gunaseelan, 1997). In the continuously stirred tank reactor (CSTR), the influent with a total solids of 3-8% is added daily into the reactor and an equal amount of effluent is withdrawn at the same time to maintain the working volume of the reactor (Gunaseelan, 1997). The schematic of the one-stage continuously fed digester configuration is shown in Figure 2 (b).

2.2.3 Two-stage continuously fed digesters

In a two stage system, the fermentation and methanogenesis are separated by using different retention times (Gunaseelan, 1997). Liquefaction and acidification take place in the first reactor while the methanogenesis is accomplished in the second reactor (Gunaseelan, 1997). The schematic of the two-stage continuously fed digester configuration is shown in Figure 2 (c). According to Demirer *et al.* (2005), the two-stage digesters have several advantages over the conventional single-stage digester: firstly, it allows the selection and enrichment of different bacteria in each phase; secondly, it increases the stability of the process by controlling the acidification-phase in order to prevent overloading and the build-up of toxic material and at last, the process is cost-efficient and size of the reactors can be smaller.

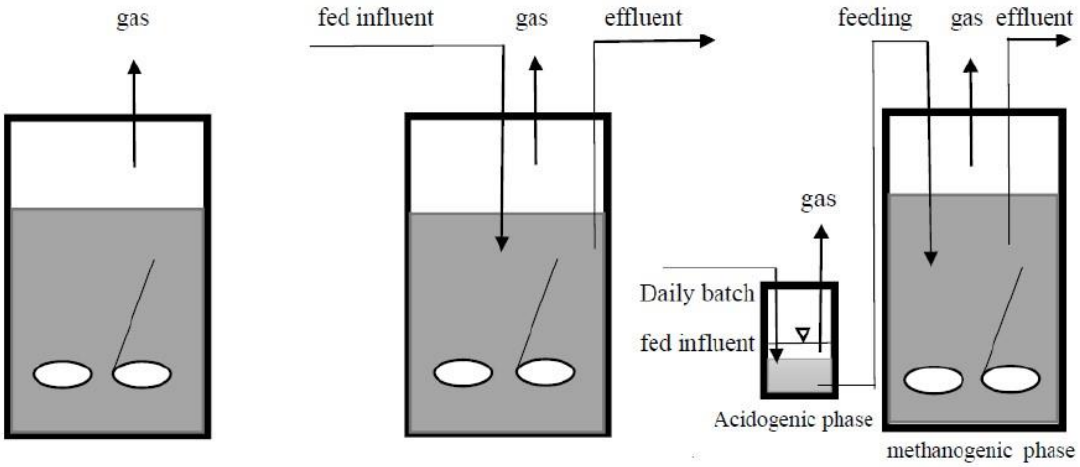

Figure 2: schematic of reactor configurations for anaerobic digestion (Kim et al., 2002)

3. Biogas Potential from Anaerobic co-digestion

Animal and agricultural wastes constitute a high proportion of biomass and their utilization and recycling is important for economical and environmental aspects. The digestion of multiple feedstocks (co-digestion) has the potential to increase methane productivity and yield through synergistic interactions. According to Umetsu *et al*. (2006) co-digestion with animal manure or sewage sludge as base feedstock and an addition of readily biodegradable organic matter such as agricultural residue is an effective way to significantly improve the process performance due to changes of feedstock characteristics Other benefits of co-digesting multiple waste streams include the improvement of nutrient balance and digestion, equalization of particulate, floating, settling, acidifying, etc. The concept of co-digestion of animal manure and crop residues is not new. Early references to this procedure using swine manure with corn stover (Fujita *et al.,* 1980), dairy manure and barley straw (Hills, 1980), swine manure and wheat straw (Fischer *et al.,* 1983), beef cattle manure with wheat straw (Hashimoto, 1983) appeared in the early 1980s. In the past thirty years, codigestion of animal manure with various crops and crop residues had been intensively studied.

3.1 The Theoretical Biogas Potential from Animal Waste

In order to determine the theoretical biogas potential from animal wastes, statistical data on livestock production in Zambia were used (FAO, 2013; CSO, 2012). The theoretical biogas potential from animal dung was determined using equation (1).

$$BP = \frac{N \; x \; VS \; x \; B_o \; x \; 365 \; x \; 1.65 \; x \; 23}{} 10_6 \; TJ/Y \; \ldots\ldots\ldots\

Table 1: Theoretical Biogas Potential from Animal Waste

Animal Name	Population (Million)	VS (kg/d)	B_o (m^3/kg)	BP (TJ)
Cattle	3.250	2.67	0.20	24,331
Goats	2.350	0.33	0.31	3,370
Pigs	0.725	0.59	0.31	1,859
Sheep	0.230	0.30	0.31	300
Chicken	36.500	0.02	0.18	1,842
Humans	10.400	0.06	0.20	1,729
Total				**33,431**

Source: Animal and human populations (CSO, 2012; FAO, 2013) VS and B_o (Okello *et al.*, 2013)

3.2 The Theoretical Biogas Potential from Residue Crops

In order to determine the theoretical biogas potential from agricultural residues, statistical data on crop residue production in Zambia were used (FAO, 2013; CSO, 2012). The bioenergy potential from residue crops was estimated using equation (2).

$$R = C_P \, x \, RPR \; \ldots\ldots\ldots\

Table 2: Theoretical Biogas Potential from Crop Residue

Crop Name	Product (10^6kg)	RPR	Residue (10^6kg)	TS (%)	VS (%)	MP (m^3/kgVS)	TBP (TJ/y)
Sugarcane bagasse	2,798	0.33	923.34	24	87	0.45	3,332
Sugarcane top leaves		0.05	139.90	90	98	0.33	1,564
Maize stalk	1,780	2	3,559.15	74	82	0.28	23,227
Maize cob		0.3	533.87	30	94	0.6	3,470
Wheat stalk	154	1	153.60	94	87	0.26	1,254
Cassava peels	1,115	0.15	167.31	35	97	0.377	823
Groundnut shell	108	1	108.01	94	93	0.3	1,088
Groundnut stalk		2	216.01	91	93	0.3	4,982
Other crops							
Total							**41,847**

Source: RPR (Cooper CJ, Laing, 2007; Duku *et al.*, 2011) TS, VS and MP (He et al., 2008; GRZ, 2008)

3.3 Total Biogas Potential

The total biogas potential from animal waste and agricultural crop residues was estimated to be 75 PJ/y. This is equivalent to about 3.507×10^9 m^3 of biogas per year. In Zambia a family of six requires between 2.0 to 2.5 m^3 of biogas for cooking and lighting (Kasali, 2008). The estimated theoretical biogas potential would serve cooking and lighting purposes for more than 3,000,000 households (6 members per household) if each household consumes 3 m^3 (18 kWh) of biogas per day. Therefore the estimated theoretical biogas potential is more than adequate to supply energy to these smallholder households as there are a total of 2,491,000 households and out of these only about 1,600,000 are actively into livestock raring and agricultural farming (CSO, 2012).

4. Technical, Political and Social economical Challenges

4.1 Research and Development

Zambia, presently, is not equipped as far as renewable energy research and development is concerned. Research funds are often not adequate or are misapplied (Suberu and Mustafa, 2013). According to the report carried out by Mukumba *et al.* (2012), there has not been enough research in higher learning institutions on biogas technology due to non-support from responsible government ministries. The reason could be that the authorities, planners and implementers of biogas projects regard universities as being too academic such that they ignore their contribution. Due to weakened government and donor support, there has been a continuous decline in agriculture R&D investment. It is reported that funding for agricultural research has been on the decline from the 1980s (Flaherty and Mwala, 2010)

4.2 Inadequate Expertise and Training

Lack of skilled and experienced masons to undertake the construction and maintenance of biogas plants is a constrain hindering the fully dissemination and adoption of biogas production in developing countries. Higher learning institutions in Zambia have not designed and implemented appropriate programs to teach and train students in biogas technology (Surendra and Takara, 2014).Sometimes there is a lack of basic technical skills to operate and maintain a biogas digester (Gebreegziabher et al., 2014). Poor quality plants due to inexperienced consultants and contractors, poor quality construction materials and lack of knowledge on biogas production

systems have impacted negatively on biogas adoption and implementation. A study conducted by Lewanika and Mulenga (1994) suggested that Zambia has not been able to adopt biotechnology due to lack of a biotechnology policy, an insufficient number of trained personnel, a poor science and technology base and very little basic research in universities and research institutions. This has led to inadequate expertise in biogas production because the few experts that are available are expatriates or they are with learning and research institutions. The hands-on skills and experiences are inadequate.

4.3 Policy and Strategy

Biogas technology transfer requires good fiscal policies which provide incentives. There are no such fiscal policies to encourage investment in biogas technology in Zambia (Mwirigi and Makenzi , 2009). Energy policies and strategies put in place by governments are not focused and thereby fail to achieve their intended goals of attracting both domestic and foreign investments in biogas production (Mwakaje, 2008). In Zambia, the national energy policy makes mention of promoting renewable energy, particularly biofuels. It also makes mention of biogas and other forms of renewable energy but mostly puts more emphasis on hydroelectricity (GRZ, 2008). Sometimes the systems are so bureaucratic that policy implementation is slow and almost impossible and have affected both policy formulation and implementation (Osafa, 1988).

4.4 Management and Monitoring of Installed Biogas Digesters

It is reported that there are some instances where subsidies were provided and biogas digesters installed but they have still failed to operate sustainably because of lack of proper after services management and monitoring (Surendra *et al.*, 2014). The beneficiaries of these biogas digesters need help in terms of how to operate these digesters, until such a time when they are ready and familiar with daily operations (Mukumba et al., 2012). In Zambia, most installed domestic biogas digesters are non-operational (Amigun et al., 2012). The National Institute for Scientific and Industrial Research installed 18 domestic digesters ranging between 4-26 m3 during 1982 to 2004. The installations were funded by donors, but are currently non-operational (Kasali, 2008). From 2008 to date, the Water and Sanitation Council of Zambia and its co-operating partners have installed more than 60 biogas digesters of size between 4-80 m^3 with funding from donors, individual companies and clients (Graefnitz et al., 2012). Biogas production projects have been unsuccessful and can mainly be attributed to of proper after services management and monitoring.

4.5 Economic Challenges

In the Zambian, the incentives as regards to promotion of the bioenergy sector let alone biogas production are simply not there, though the Biofuels Association of Zambia has been lobbying for some incentives from the government. Bureaucracy due to growth in the size of government departments, expansion of government social services and due to the complexity of policy issues of modern government is the worst form of disincentive to both domestic and foreign would be investors in biogas production and other energy sectors (Osafa, 1988). Financial institutions often perceive the bioenergy sector as high risk, making it very challenging for investors to obtain funds (Hofmann and Khatun, 2013). Inadequate funds to finance power generation, transmission and distribution coupled with low rates of returns due to high operating costs and low consumption are some of the challenges faced by the developing contries in the sounthern Africa region (Gujba et. al., 2012). Universities and research institutions such as the University of Zambia, Copperbelt University, National Institute for Scientific and Industrial Research and many others involved in energy research are grossly underfunded and as such are unable to effectively carryout research projects (Mfune and Boon, 2008).

5. Conclusion

It is clear that Zambia has adequate availability of feedstock for biogas production for biogas production that can play a significant role in meeting the energy needs of the country. This is vital in achieving the National Vision 2030 of becoming a prosperous middle income country whose objective is to increase access to electricity by 66% national wide level, 91% in urban and 51% in rural areas. The potential of 75 PJ per annum of biogas via AcoD is able to cater for more than three million households (18 million people). In order to realize this theoretical biogas potential, various technical and socioeconomic constraints that hinder full adoption and sustainability of biogas production in Zambia need to be addressed. inadequate research and development due to insufficient funding, Inadequate expertise and training, lack of policy, strategy and regulations in biogas production, lack of management and monitoring of installed biogas digesters as well as other socioeconomic issues are some of the major constraints. There is no doubt that these technologies can play a significant role in the development of rural areas in Zambia. Despite the fact that renewable energy technologies are poorly integrated in development plans, there are signs of a growing desire by energy policy makers and planners at the national level to integrate these technologies in policies and plans in Zambia.

6. Recommendations

In order to overcome the above mentioned challenges, the following recommendations are proposed:

- Promotion of rural electrification projects should not just be limited to hydro power, solar home systems and wind machines. Studies need to be conducted on how best to exploit biomass in order to improve on the biogas yield.

- To stimulate research and development in biogas technologies, government should create an R&D fund to be used by the University of Zambia Energy Research Centre and the National Council for Scientific Research. The research should be centred on development of appropriate and affordable biogas technologies for rural areas. In addition, collaboration between researchers, policy makers and planners should be strengthened for the common purpose of promoting biogas technologies.

- The national energy policy and plans need to establish annual investment goals, strategies and targets for biogas technology deployment to rural areas. Energy planners need to be actively involved in development planning at all levels (national, provincial and district) for rural energy technologies to be properly integrated in development planning.

- The government needs to create incentives for the private sector's participation in biogas technologies in rural areas. Further efforts should be targeted towards the involvement of credit or financial institutions in financing renewable energy projects

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Retrospective Analysis of Failure Causes of Small and Medium Enterprises (SMEs) in Construction Sector in Zambia

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Abstract

It is imperative for a country to make relevant and business friendly legislation that would enable SMEs growth in the country. This should be so as SMEs contribute greatly in job creation hence contributing significantly to the country's GDP. According to Nuwagaba (2015), the SMEs in Zambia employ 50 percent of the working class, similar to countries like Indonesia, Tanzania and Kenya. Over 90 percent of SMEs operate in the informal sector and this makes it difficult for the government to support the sub sector efficiently. So, SMEs especially construction sector's contribution to the country's development is not very clear. Since the majority of SMEs operate in the informal sector, attracting funding from micro finance institutions (MFIs) is a challenge and this makes (SME) sector weak. In undertaking this study, primary and secondary data were collected using questionnaires, interviews and observation. Data is presented using tables and other Microsoft applications. From the study, it is evident that the growth of the sector has been constrained by among other factors the following: difficulties by SMEs in accessing meaningful jobs from both the public and private sectors; difficulties in obtaining payment in time from government; lack of experience in in the firm's line of business; lack of financing modalities; and lack of managerial experience in construction sector.

Keywords: Construction, Contractor, Severity Index, Factors, Construction

1. Introduction and Background

Small and Medium Enterprises (SMEs) are very important for the development of an economy as they contribute meaningfully in the creation of employment, increasing tax base for the country, improving incomes for the low earners among other benefits. This is more so in the construction sector because the sector by nature is labour intensive. The above contributions of the construction sector to the growth of many economies have been acknowledged worldwide. In Zambia, the sector has seen massive numbers of entrants who according to National Council for Construction (NCC) number around 3,641 with 95% being local contractors while the remaining 5% are foreign owned.

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2. Aim of the Study

The main of this study is to identify the factors that have the potential to cause contractors' business failure in Zambia and determine their impact level from the contractors' point of view of the contractors, the NCC and other stakeholders

3. Objectives of the Study

The objectives of this research are to study is to (1) determine factors that contribute to business failure by SMEs in the construction sector and (2) identify the most severe factors causing contractor failure in Zambia

4. Statement of the Problem

The construction industry is dominated by small and medium scale contractors who face unique challenges in the implementation of projects. In 2014-15 registration there were 3861contractors registered with NCC, (*constructionreviewonline.com/2015/07/national-council-for-construction-ncc-in-zambia*). The former National Council for Construction Executive Director. Charles Mushota lamented that out of the large number of local companies, the bulk of contracts were awarded to foreign owned companies, (Zambia daily mail, 2015). The number of companies registered in 2016/17declined to 3643 representing a 6% dropout. The government has provided incentives to help and build capacity for local contractors such as the establishment of a training school for contractors at the NCC to help the local contractors upgrade their standards in service delivery, and the requirement by foreign contractors to award at least 20% of the foreign contractors contract to locals. The problem therefore is why local SME construction companies fail despite the incentives that the government has put in place to aid them blossom?

5. Literature Review

SMEs in general and construction sector in particular have been at the forefront of accelerating economic growth in many countries and economic blocs. For example, the majority of the SMEs do employ at least about 50 employees in Southern African countries depending on their sizes and this helps to take a sizeable chunk of the employment burden from states, Tshuma & Jari, (2013). Looking at South Africa, SMEs operates in every city and they provide employment for people and about 4 million jobs are created through this sector which in some cases may be regarded as informal sector and the formal sector just provides only 7 percent Thamas, (1989) and Aymes (1988).

In this paper, discussion of performance inhibiting factors on construction projects has centred, mainly, on some of the studies conducted in the sub-Saharan region. A number of researchers had studied the causes of contracting business failure. Argenti (1976) summarized what was written on failure. He concluded six main causes for company failure: top management, accounting information, accounting manipulation, rapid expansion and economic cycle. Dun and Bradstreet (1986) have identified the major causes of business failures. They are: economic factors, inexperience, contractor's business failure, poor sales, expense, customers, fraud and neglect, assets and capital, and disaster. They found the most significant failure cause to be economic factors. Within the

economic factors category, there are five subcategories: bad profit, high interest rates, loss of market and low customer spending

Further, Abidali and Harris (1995) listed the common managerial characteristic of failed companies as follows: autocratic chief executive, the same person as both chief executive and chairman, the company board, lack of engineering skills, lack of a strong financial director, defective managerial skills, incomplete accountancy system, defective bidding system, poor marketing skills, over-trading ,and losses in projects.

Kangari (1988) found that more than half of business failures in construction were due to unrealistic profit margins. Osama (1997) presented a study of the factors that contribute to the failure of construction contractors in Saudi Arabia and found that the most important factors were: difficulty in acquiring work, bad judgment, lack of experience in the firm's line of work, difficulty with cash flow, lack of managerial experience, and low profit margins.

Arditi et al. (2000) found budgetary and macroeconomic issues as the main reasons for construction company failure in the USA. Over 80 per cent of failures were causedby five factors, namely: insufficient profits (27 per cent), industry weakness (23 per cent), heavy operating expenses (18 per cent), insufficient capital (8 per cent); and burdensome institutional debt (6 per cent). Schaufelberger (2003) studied business failure at the subcontractor level and found that the primary causes of subcontractor business failure were insufficient capital/excessive debt, lack of managerial maturity, lack of early warning measures, increase in project scope, poor billing procedures, failure to evaluate project profitability, unfamiliarity with new geographical areas, and poor use of accounting systems.

Other authors such as Davidson and Martin (2003) identified the ten most common causes for contractor failure: growing too fast, obtaining work in a new geographic region, dramatic increase in single job size, obtaining new types of work, high employee turnover, inadequate capitalization, poor estimating and job costing, poor accounting system, poor cash flow; and buying useless stuff. Enshassi et al. (2006) concluded that the main causes of contractors failure are: delay in collecting payments from clients (donors), closure, depending on banks and paying high profits, lack of capital, cash flow management, lack of experience in the line of work, absence of construction regulations, low margins of profit due to competition, awarding contracts to the lowest price; and lack of experience in contracts.

Kivrak and Arslan (2008) examined the critical factors causing the failure of construction companies through a survey conducted among 40 small to medium-sized Turkish construction companies. A lack of business experience and the country's economic conditions were found to be the most influential factors in company failure. Arslan et al. (2006) concluded that difficulties with cash flow and poor relationship with the client drove the contractor failure. In addition, preparing an accurate and realistic bid proposal with the profit margin being carefully determined is highly critical. However, due to high competition, companies are usually forced to reduce their profit in order to win the bid, and this will increase the default risk substantially.

Chan and Kumaraswamy (2014) compared the results of the research in Hong Kong with researches done in Saudi Arabia and Nigeria and found that the respondents' interpretation of causes and their importance were different. Furthermore, Elhag et al (2016) observed that factors identified in Okpala and Aniekwu's (2014) study of causes of high costs of construction in Nigeria were largely influenced by the locality of the country in which the research was conducted. It was noted that underdeveloped

economies tend to exert different influences on construction costs compared to developed economies such as the UK.

Consequently, for purposes of this study, a review of factors involving countries in the sub-Saharan region was considered more relevant than a review of factors from countries from other regions.

The Majority of the SMEs in South Africa operate in the informal sector and there are about 700,000 such business contributing between 16 to 40 percent of the country's gross national product DeSmidt (1990); Thamas, (1989). The SMEs have played and continue to play a bigger role in the social economic development of the country. From previous studies by Kromberg (2005) on South African SMEs, it was found out that they contribute 30 percent to gross national product considering SMEs that are registered with the government, though the percentage could be higher if you consider SMEs that could be operating but not formally registered because of fear to pay state taxes, Skinner (2006).

6. Research Methodology

Using extensive literature review from several countries such as UK, Indonesia, Iran and Gaza ten factors affecting the failure of contracting businesses were defined. Among them Abidali and Harris (1995); Osama (1997); Arditi et al., (2000); Schaufelberger, (2003); Davidson and Martin, (2003); Enshassi et al., (2006); Kivrak and Arslan, (2008) and Arslan et al., (2006). The factors were tabulated in questionnaire form. Related factors were grouped under one main group. The factors were divided into three groups – i.e. managerial, financial, and external.

The questionnaire was reviewed by some parties involved in the construction industry to test the validity of its content. This test led to the introduction of minor modifications – to better suit the Zambian market conditions – prior to sending out the questionnaire to the target research population. The studied target population includes contractors who hold valid registration from the NCC, officials from Ministry of Works other former contractors whose businesses has long closed down or were on the verge of collapsing, summarized in Figure 1.

Table 1: (Study Population)

SN	Category of Registration	Number on Register
1	Manufacturing	26
2	Contractors	3,517
3	Others	98
	Total	**3641**

Source: NCC publication (October, 2017)

Considering that the sector populations being at 3,641, a systematic random sample at significance level of 95%, with Z-score of 1.96 was selected which gave a sample size of 380 using the sampling equations as below:

$$S = Sample\ Size = (Z\text{-}score)^2 * Std\ Dev*(1\text{-}StdDev) / (margin\ of\ error)^2,$$ Krejcie and Morgan (1970)

$$S = required\ sample\ size.$$

Z-score) ² *= How confident we wanted be that the actual mean falls within the confidence interval, in this case, 95% interval.*

Std Dev *= This is how much variance expected in the responses. The safe decision is to use 0.5 as this is the most forgiving number and ensures that the sample will be large enough.*

Margin of error *= How much higher or lower than the population mean the researcher was willing to let the sample mean fall.*

Based on the population of 3,641 with a confidence level of 95%, the sample size was therefore computed as follows:

$$S = 1.96^2 \text{ X } (3{,}641 \text{ X } 0.5) / 0.5^2 \text{ X } (3642\text{-}1) + 1.96 \text{ X } (1\text{-}0.5)$$

S = 357 respondents

357 questionnaires were sent to respondents and 246 were returned representing a 68% response rate as shown in Figure 2.

Table 2: Questionnaire distribution Schedule

SN	Sample	Number
1	SMEs in Construction sector Lusaka/Copper belt	270
2	NCC and other stake holders	60
3	Failed SMEs in construction	17
	Total	**347**

Questionnaire Design

The designed questionnaire sought to explore the possible causal relationships between the variables Gall, Borg & Gall (1996). The chosen design was retrospective, causal-comparative or non-experimental. According to Charles (1998), causal-comparative research highlights cause-and-effect relations. The retrospective or *ex post facto* design is specific for the collection of data. Thornhill & Amit (2003) are of the opinion that a post-mortem analysis is preferred to other methodologies in investigating failure mainly because it deals with instances of failure, as already stated. In using the variables collected from the field to build causal models, it was ensured first that the variables selected complied with the principles of empirical associations, appropriate time order, non-spuriousness, the identification of a mechanism and external validity.

The questions asked evolved around the major suspected reasons for SME failure, ranking the 10 factors identified in terms of severity using an ordinal scale. The ordinal scale was as given in Figure 3:

Table 3: (Ordinal Scale)

Scale	Interpretation
0	No influence
1	Very low influence
2	Low influence
3	Moderate influence
4	High influence
5	Very high influence

For analysing data by ordinal scale, a Severity Index (SI) was used. This index was computed using the following equation (Lim and Alum, 1995):

$$\frac{[(5\,n_5 + 4\,n_4 + 3\,n_3 + 2\,n_2 + n_1)\,x100]}{[5(n_1 + n_2 + n_3 + n_4 + n_5 + n_0)]}$$

Where n_0 is the number of respondents who answered "no influence", n_1 is the number of respondents who answered "very low influence", n_2 is the number of respondents who answered "low influence", n_3 is the number of respondents who answered "moderate influence", n_4 is the number of respondents who answered "high influence", and n_5 is the number of respondents who answered "very high influence".

Accordingly, if all participants answer one factor to be "no influence", then the importance index is 0, which means that this factor is not relevant and the last in rank. On the other hand, if all answer "very high influence", then the importance index is 100, which means that this factor has very high relevance and is the first in rank. Table II shows the possible ranges for the importance index and the corresponding impact levels.

The importance index for all factors was calculated. The group index was calculated by taking the average of factors in each group. The weighted mean, standard deviation, standard error of the mean, 95 per cent confidence interval, and coefficient of variation are calculated in order to measure the dispersion and homogeneity of the data.

Table 4: Severity Index

Rank	Reason	Severity Index
1	Difficult in acquiring work	94
2	Difficult getting payment from client	92
3	Lack of experience in the firm's line of business	89
4	Lack of managerial experience	81
5	Political interference	77
6	Misapplication of funds	75
7	Lack of qualified staff	73
8	Buying jobs	72
9	Change in type of work	70
10	Size of work program	31

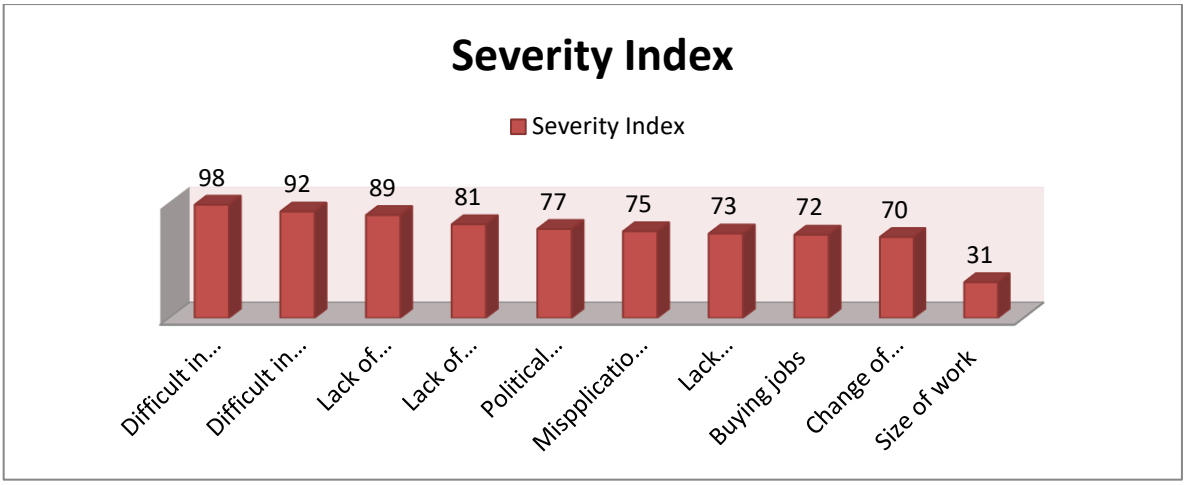

Figure I (Response Severity Index)

7. Results and discussion

Ranking method used to analyze the collected data. The results of data analyses are presented in below:

Ranking

The factors under each group were ranked by the measurement of importance index according to equation. Table III shows the importance index value and ranking of each factor under the managerial group from the contractors' point of view. Table III shows that difficult in getting jobs is the top factor, with a very high impact level on the failure of contracting businesses. This can be attested by the lamentation of Mr Mushota that 95% of government contracts go to 5% foreign owned contracting companies. Next is difficult in getting payment especially from government. This factor is the second ranked factor among overall factors as listed in Table III. It is closely followed by lack of experience in contracts, which also has very high impact and is the third ranked factor overall, as listed in Table III The results are in line with those of Enshassi et al. (2006), as the delay in collecting payments from clients and inexperience in contracts are the top factors that affect the failure of contracting businesses. The third ranked factor in this group is lack of experience in the line of work. This result is in line with the result of Dun and Bradstreet (1986); Osama (1997), Enshassi et al. (2006), Kivrak and Arslan (2008) and Arslan et al. (2006), that lack of experience in the line of work is one of the factors most affecting in the failure of contracting businesses.

8. Conclusions and Recommendations

The study found that the main inhibitors to performance and survival of (SMEs) in construction could be grouped as follows:

8.1 Business Environment

Among the key inhibitors under this variable were; procuring work, scarcity of openly advertised tenders, stringent conditions for small- and medium-scale contractors to access capital, shortage of skilled labour. Others are uncertainty in prices of materials due to the instability of the local currency the kwacha, lack of detailed deliberate construction policy to develop indigenous contractors, limited access to hire plant or equipment and failure to meet contract deadlines by suppliers as well as political interference.

8.2 Clients or client representative

Under this category, key inhibiting factors were failure to pay interim certificates for contractors, inappropriate contract conditions, incomplete contract documents, inadequate supervision by the client, and breach of contract by mostly government, nonperformance of nominated subcontractors or nominated suppliers and discrepancies in contract documentation. Others under this variable were extensive use of competitive tendering in construction contracts and also the involvement of some chiefs who frustrate contractors by making unreasonable demands such as corporate social responsibility that raises the cost of the project.

8.3 Variables to do with contractors' deficiencies

Under this category, failure to provide required quality of work, lack of technical know-how, deviations from plans and specifications, failure to meet deadlines, poorly prepared tenders or estimates and poor financial management. Others are poor company organization, poor personnel management and lack of commitment to construction or abandoning site. The other variable cited was prevalence of HIV/AIDS that ravage the critical skilled human resource and also the retrogressive cultural and religious attitudes (e.g., prioritisation of petty cultural practice at the expense of productive undertakings or loss of man hours by going to church on Saturday and Sunday and the expense of productivity) (The author may need to rephrase this example since consideration of non-working days should be made at the planning stage)

The research lays the foundation for further understanding of inhibitors on performance of SMEs in an evolving world which is being impacted by global factors and punctuated by sudden changes. The identification of the underlying factors that specifically undermine performance of SMEs could help stakeholders to reasonably deal with inhibiting factors to performance more accurately and instructively. The inhibiting factors following a financial theme could be utilised to fill the gap of evaluating the performance with empirical method for SMCs.

The following recommendations are suggested:

1. The Zambian government and the NCC should continuously conduct capacity building which should include imparting technical knowledge as well as sustainable business development services as construction is a serious business requiring managerial skills.

2. . The government should put in place a deliberate policy to give priority when awarding contract and tenders to Zambian or local companies as this is the sure way of capacitating the local contractors.

3. The government should ensure that the foreign contractors award at least 20% of their contract to local contractors and where necessary, partner with local contractors as this will capacitate the local contractors with the much needed skills.

4. The government must ensure prompt payment of invoices to local contractors as this will enable local contractors pay their debts on time to avoid accumulation of interest

5. The government should adopt the model being implemented in South Africa where public officers who delay paying contractors on timer are penalised

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RFID Based: Livestock Routine Operations Monitoring for Disease Control

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Abstract

Validating the impact of using Radio Frequency Identification (RFID) technological advances for the benefit of the livestock production sector is key to the adoption of the technology for improved remote extension operation. Generally, the sector is characterised by long distances to and from production areas and markets which also negatively affects the availability of veterinary extension services. The sector's success then depends, among other factors, on the control of disease and parasites which pose a serious hindrance to its growth. In addition, there has been an over dependence on the public sector for the delivery of these services which unfortunately has negatively impacted the quality and quantity of the available service due to the geographical challenge of remote production areas and available number of extension officers. The use of RFID for routine monitoring of disease vector control is one of the mitigation options available to address this challenge and encourage sustained economic importance of the sector. RFID has been predominantly used for animal traceability. The importance of RFID stems from its notable advantages that include non-line of sight operation, faster tag reading rates that may exceed 100 tags per second and longer reader range of up to 100m. These advantages are harnessed in the routine RFID monitoring of vector control using dip tanks constructed with specific interest by the public sector. This paper validates the benefit of implementing an RFID based system in remote livestock production, with an emphasis on cattle. It also evaluates appropriate RFID proposed system, discussing them in relation to the type of tags used, the applicable frequency ranges and data transmission standard available.

Keywords: RFID, Tags, Data, Livestock, Dip tanks.

1.0 Introduction

RFID (Radio Frequency Identification) is budding technology that has steered numerous opportunities in a number of applications ranging from automatic toll collection, security systems – access control, library management and the food sector value chain. In the livestock production industry, the technology has been in use since 1970 for purposes of animal identification and traceability (Leong,

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Mun, & Cole, 2007). The technology is also used for real time monitoring, quality control, intelligent transportation and online information systems for end-users (Kumari, Grewal, & Anurag, 2015). The benefits of RFID systems usage include, among others, the enhancement of efficiency and speed of operations, improved accuracy of information, and optimization of labour cost and reduction of inventory losses (Kumari, Grewal, & Anurag, 2015). The intention of this paper is to provide readers an overview of the benefit of implementing a RFID based system in livestock, specifically cattle, production and how the obstacles hampering its widespread public application in Zambia can be resolved. To help with choice of appropriate RFID system, the paper also discusses RFID systems in relation to the type of tags used, the applicable frequency ranges and data transmission standard available.

2.0 Livestock Production - Beef

The importance of cattle production to the livelihood and economy of the country cannot be over emphasised. It is a source of income, employment for farmers and their supporting staff as well as other players in the related value chains. For the poor communities in the rural areas it is a fundamental asset and an important source of nutrition (Herrero, et al., 6 – 9th September 2011).

According to the 2014 - 2015 Post Harvest Survey (PHS) report (Central Statistical Office, 2016), the country had 3,946,348 heads of cattle of which 184,905 heads were sold, consequently generating K389,898,647.13, which was approximately US$45 million (using the rate of US$1 at K8.6). The same year (Statista), the country's gross domestic product (GDP) was US$21.24 billion which translates to a 0.2% GDP contribution by cattle production alone. The 2014 -2015 season cattle production details with associated GDP are as summarised in table 1 below. At 0.2% GDP and with only 330,582 households raising cattle, the sector has great potential to enhance the economic performance of Zambia if the production systems are supported by modern technologies such as RFID.

Table 1: 2015 Cattle production and annual GDP

Total Country's Head	3,946,348
Number of households raising cattle (countrywide)	330,582
Heads sold in production year	184,905
Value of heads sold	K389,898,647.13
Approximate US$ equivalent of sold head (in Millions)	US$45
Country's annual GDP (In Million Dollars)	US$21,240
Cattle contribution to GDP	0.2%

On the other hand, livestock production, like the general agricultural sector, is influenced by factors such as weather conditions, spread of disease, pests and parasites, vast distances from areas of production to market, and many other related significant factors (Lehmann, Reiche, & Schiefer, 2012). Effectively addressing these challenges then is significant to the sustained economic importance of the sector. In livestock production, prevalence of vectors and disease is wide spread and presents a greater constraint to the development of the sector (Perry & Young, 1995). Control of disease and vectors then

is necessary to safeguard livestock sector in the light of availability of quality and quantity of veterinary services. According to (Woodford, 2004), the dependency on the public sector for the delivery of these services has negatively impacted the quality and quantity of service delivery. The foregoing holds true for our country; it is reported that the spraying method is largely used to control vectors which directly harm animals and spread diseases that pose a major challenge to veterinary services provision, which is done by the public sector in this case (Central Statistical Office, 2016).

It then is imperative to validate the impact of RFID technological advances in the sustainability of the livestock sector, that is, how effective will it help address the monitoring of control of vector population given the challenge of scarcity of veterinary services owing to long distances to production area. The motivation to consider RFID is because of its wide spread usage in retail businesses application, supply chain management and monitoring. When compared to other candidate technologies such as barcodes, RFID presents the following advantages; its non-line of sight operation and faster tag reading rates that may exceed 100 tags per second (Finkenzeller, 2010), and its longer reader range of up to 100m (Ruiz-Garcia & Lunadei, 2011).

3.0 RFID Technology

Figure 1 below shows the generic block diagram for any RFID system.

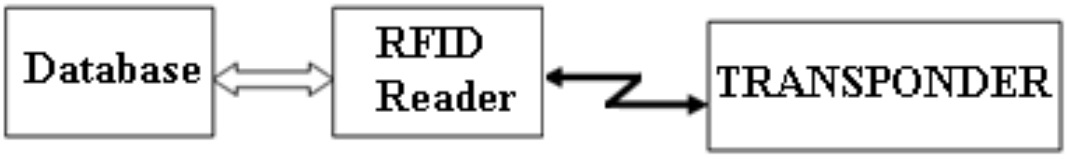

Figure 1: RFID System block diagram (Authors)

As can be seen in Figure 1, the key components of the system include the transponder, reader and software. The functions of these components are as described below (Aguzzi, et al., 2011):

Transponder which is also known as the tag is an electronic data carrying device used for information storage. It's made of an integrated circuit chip (IC) with an encapsulated antenna. It has a coupling element that employs magnetic or electromagnetic fields to power up and exchange data with the reader (Finkenzeller, 2010), using the principle of load modulation or back scatter as employed in radar engineering.

Transponders used in livestock RFID system can be grouped into three main types; ear tags, boluses and injectable glass tags. Ear tags are attached to the animals ear, boluses are retain in the rumen (First stomach of ruminants) and the injectable transponders are applied at preferred locations based on animal species (Voulodimos, Patrikakis, Sideridis, Ntafis, & Xylouri, 2010)

Reader, also known as the interrogator is used for the collection of data stored by the tag. To realise this function, the reader has three key functional block namely the control unit, the radio frequency module and the coupling element. The control unit decodes the read data, while the radio frequency

module is used to transmit and receive information carrying electromagnetic waves to and from the tag through the coupling element to the transponder as shown in Figure 2 below. The reader may also have additional interface serial ports such as RS232 that is used for serial transmission of data to another system or database. Depending on the design and technology used, these ports allow the interrogator to be used to read and write (Finkenzeller, 2010),

Database: this constitutes the software that manages the operations of both reader and tag, and also the received data.

For typical operation, whenever a tag comes into the reading range of a reader, it gets energized. On energizing, the tag sends information stored in it to the reader and does so by employing either the load modulation or the backscatter at its antenna to send the data. Reader receives the information signal sent by tag and further sends it to the computer containing specific software. The Software manages the information in database; it can also contain the details of tags and readers. Energizing signal sent by the reader can be used to write new information in memory of a tag depending on the tag type. Each tag contains the encrypted code that uniquely identifies the object to which it is attached.

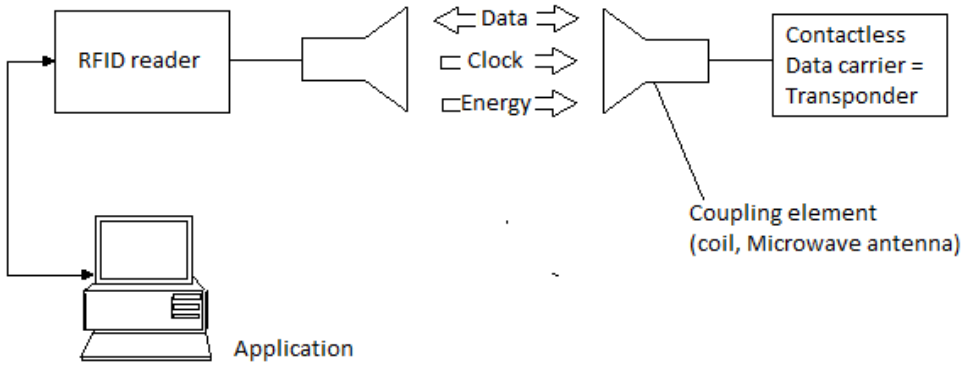

Figure 2: Basic RFID system (Finkenzeller, 2010)

RFID tags can generally be classified as active, passive and semi-passive (Kumari, Grewal, & Anurag, 2015);

Active tags, as the name suggest have an embedded battery that enables them to communicate at any time with the reader. They can read/write and have higher read range. They are bulky and quite expensive.

Passive tags have no external source of power and become activated only when in the RFID reader's interrogation range. When these tags are powered using the coupling unit by the electro-magnetic field generated by the reader, they activate and reflects back the information stored on the chip. Compared to active tags, their reading range and cost are shorter and lower, respectively.

The Semi-passive tags use an external power source to energize the chip's circuitry but use the readers electromagnetic field generated during interrogation to communicate. In the absence of a signal from the reader, the battery in these tags remains inactive and thus saves battery power. The classification of tags based on power and frequency is shown in figure 3.

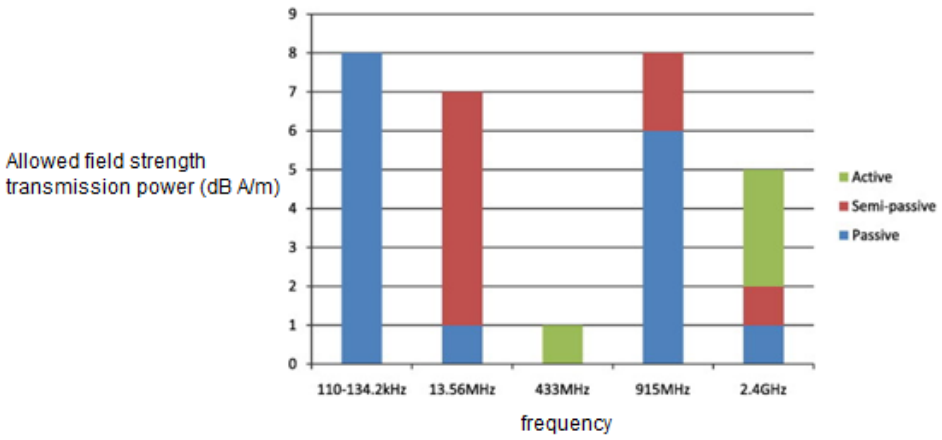

Figure 3: RFID classification of tags by power source and frequency (Ruiz-Garcia & Lunadei, 2011)

According to (Ruiz-Garcia & Lunadei, 2011), a notable number of RFID applications use Low Frequency (LF), High Frequency (HF) and UHF (Ultra High Frequency) bands. The operation frequency range for LF, HF and UHF are 110 KHz to 134.2 KHz, 13.56 MHz, and 433 MHz respectively. Although UHF frequencies offers better range and faster data transfer compared to low- and high-frequencies, they use more power and are easily absorbed when they pass through materials. Generally, it can be concluded that with higher frequencies there is a trade-off between communication range and the throughputs.

3.1 Proposed Public RFID System for Livestock Operations Monitoring

For purposes of helping the public sector in monitoring field operations such as routine dipping of animals for vector control and annual vaccinations programs to contain infectious diseases such as East Coast Fever, lumpy skin, and black quarter to mention a few (Worthington & Bigalke, 2001), the proposed deployment shown in Figure 4, would be ideal. To provide a technology for remote areas which are hard to reach, the motivation of providing a low cost off grid system is of utmost importance. To mitigate possibilities of error reading of tags, the reader is placed on the outlet of the facility sufficiently separated from the location of the routine operation. Further, the antenna is oriented in such a way that the reading range of the interrogator (RFID reader) is limited only to the tags passing below it, otherwise tags elsewhere would be read consequently affecting the accuracy of the monitoring system.

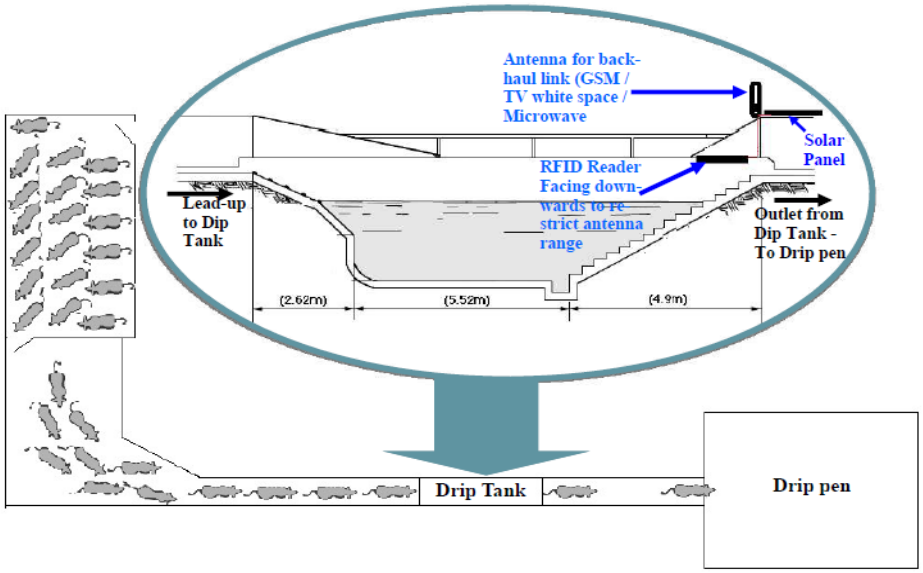

Figure 4: Public Facility (Dip Tank) remote deployment of RFID (Authors)

To monitor other types of operations, similar positioning of a reader can be employed so that treated animals are accurately accounted for as they move out. The network can easily be deployed and maintained even in the absence of specialised personnel. This deployment effectively addresses the challenges of poor access roads, scarcity of veterinary services, and absence of technical expertise faced by remote production areas. A comprehensive architecture of the system is shown in fig. 5.

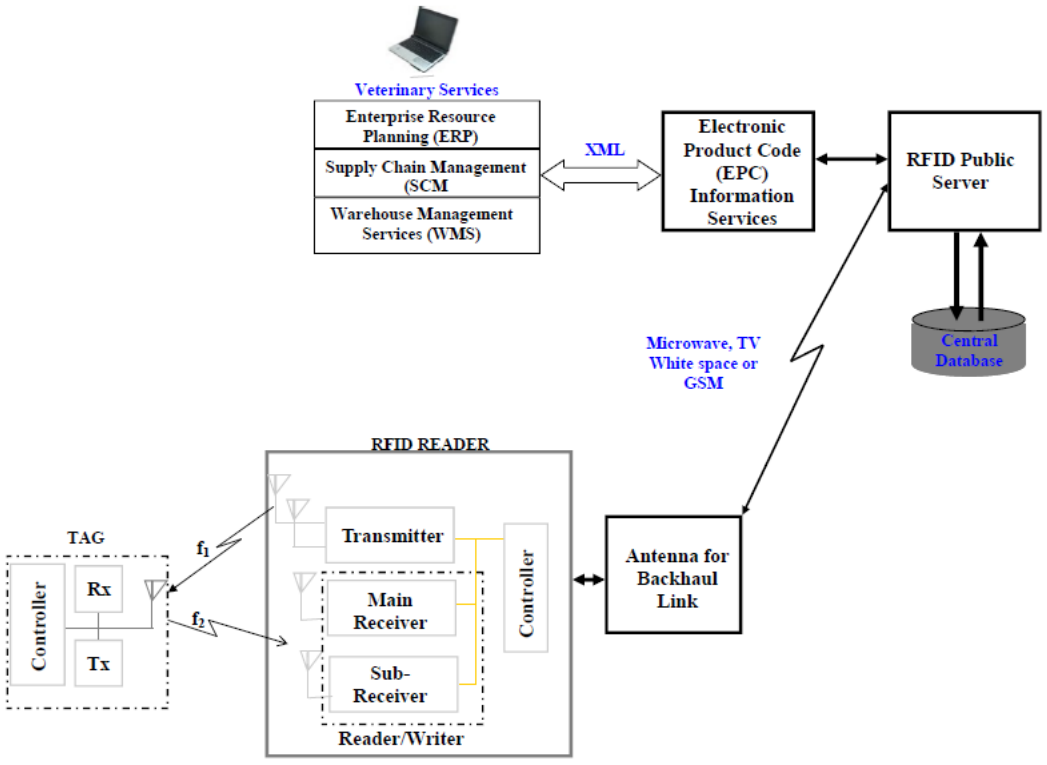

Figure 5: End to end RFID Network Architecture (Authors)

Figure 5 shows a comprehensive RFID based system layout for monitoring and managing bulky animal related data. The animal parameters are stored in the tag which has a unique ID that is mapped to the animal and the owner or holding facility. It therefore means that each animal's movement parameters can be traced.

For monitoring purposes, each time the animal is subjected to specific disease control operations, such as vaccination and dipping, by the local farming community; the readers interrogate the tag and transmit the information collected to the central database for remote access by the public authorities using an appropriate backhaul communication link. Candidate communication links may include Mobile Network Services (if available), Television White Space communication (TVWS), or Microwave link. For rural facilities, TVWS may be ideal because of its non-line-of-sight properties, increased range and low power requirements, making off-grid operation possible (Flynn, 2013).

The RFID public server houses the central database which is used to store the livestock operations management information. Sample data stored may include farm units and other details as may be required by the Livestock Department. It therefore is a repository of all registered farmers and their livestock management practices which are necessary for monitoring purposes.

Integration of Electronics Product Code Information System (EPCIS) extends the system allowing for Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Warehouse Planning Services (WPS).

EPCIS (GS1) enables the creation and sharing of visibility event data by different applications both inside and outside the enterprise. The sharing of data provides a shared view of objects within the livestock sector consequently allowing for;

1. Enterprise Resource Planning (ERP) which basically integrates information and information-based processes within and across functional areas in an organization (Kumar & Van Hillegersberg, 2000). The public sector (Livestock department) would therefore have field based information at the fore in the planning process. For example the ratio of livestock officers to the farms serviced, provision of tools of trade such as transport and general veterinary services.
2. Supply Chain Management (SCM) helps understand the relationships between practices of the supply chain, supplier performance and organisation performance (Tan, Kannan, & Robert, 1998). In the context of this paper, SCM provides transparency and confidences in the quality of the livestock products to the external customers who are pivotal to the overall economic performance of the sector.
3. Warehouse Planning Service (WPS) helps gain the competitive advantage by implementation of a management information system for high performance of warehousing operations required in today's marketplace (Faber & de Koster, 2002). The usage of WPS would make the overall performance of the sector efficient especially in relation to knowing supply timelines of commodities used in the sector, for example vaccines and drugs for disease treatment.

For integration of extended functionalities, Extensible Markup Language (XML) is the programing platform of choice. It is a simpler, generic, and usable language across the Internet (Bray, Paoli, Sperberg-McQueen, Maler, & Yergeau, 2013). It defines a set of rules that are used for encoding documents in a human and machine readable format. It is a textual data format, has strong support by using Unicode for a number of human languages and is extensively used for arbitrary data structures representation making it the language of choice for web services (Fennell, 2013).

4.0 Relevance of System

From the applications end, the relevance of the RFID technology in the livestock sector goes beyond the well-known application for animal tagging. In the context of this paper, the key benefits to the public sector, given appropriate policy framework, are as summarised below;

- Farm data management– the system will provide real-time data regarding the engagement of farmers in proper livestock management practices. It will further provide a database of all farmers and help among other ways with planning of extension services and training of extension officers.
- Monitoring of adherence to livestock management operations - IDs are assigned to the farms – with supporting policy framework, all public dip-tanks can then be allocated to a number of farms in an area. The facility then is assigned RFIDs tags that are mapped to the farms to monitor which farms have high prevalence of disease.
- Insertion of an animal record to the databases –The history of the animal floated on the market can then be availed leading to confidence in the quality of beef products on the market.

Tracking of prevention and disease control activities – the routine vaccinations for contagious diseases treatment can also be tracked. The consistence of such programs is vital if the economic losses experienced from outbreak of diseases are to be contained. In the case of disease treatment, usage of public drugs may be measured against the head treated.

5.0 Conclusion

From the foregoing, it can be conclude that tapping into the RFID technological advancement is needed to enhance the optimisation of the efficiency of the routine operations that would sustain the economic growth of the cattle production in the country. At 0.2% GDP contribution and with only slightly more than 330,000 households involved in production in 2014 – 2015 farming season, the sector has great potential.

The integration of RFID for remote monitoring would positively address cattle production in the following ways;

RFID would unravel the challenges related to costs of provision of extension services to remote farming areas. A huge cost is associated to accessing remote areas due inaccessible and poor access roads. This challenge which is further compounded by scarcity of veterinary officers who if available have a large number of farmers to service over an expanse. With RFID technology, the local farming management operations may be effectively monitored and mitigation measures instituted. The technology therefore would provide insights on non-conformity to management practices which leads to disease outbreak and enforcement of stock movements from affected areas.

Generally, the huge capital expense involved in the deployment of monitoring systems has hindered the widespread deployment. With RFID, its scalability and cost effectiveness allows for its widespread usage. The installation can be done by an individual and there is little maintenance involved. Its low power application allows for deployment off grid. A comprehensive RFID system also promotes timely end to end enterprise resource planning and provision of real-time parameters during the execution of livestock field operations.

Last but not the least, the realised transparency with usage of RFID technology would raise the quality of beef products and increase customer confidence and trust in the value chain. Customer satisfaction would lead to attractive beef markets and overall increase in the GDP contribution of the sector.

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Mineral Resource Diversification: The Key Role of Industrial Minerals towards Sustainable Development of the Zambian Mining Industry.

Ebelia Manda Mvula[1], Mwema Wanjiya[2], John Mvula[3]

Abstract

Zambia is abundantly blessed with mineral resources, some of which are still undiscovered. The economy has been dependant on copper mining, but unfortunately, the high-grade ore is slowly depleting since it is a non-renewable resource. Another major bottleneck is the fluctuations in the commodity prices on the world market, for example 2008-recession period, which saw the prices of copper dropping from about $8500 per tonne to $5164 per tonne. Recently in 2016, the prices again went down to $4863 from peak of $8871 in 2011.

Apart from base metals mining, there are abundant industrial minerals throughout the country, which are not fully exploited. This research undertaking highlights the economic potential and importance of the industrial minerals towards sustainable development of the mining sector. The industrial minerals holds the future of sustainable mining for the Zambia's mining industry. A simple revenue analysis of the three minerals indicates viability, for example the prices of gypsum is approximately $6.9-20 with the tonnage of 11000 can generate approximately$75,900-220,000 in revenue. Kaolin is selling at $160/ton, with the tonnage of can generate approximately $32,000 in revenue and talc is $327/ton with the tonnage of 80 can generate approximately $ 26,160 in revenue if fully exploited they can generate extra revenue for the country.

The industrial minerals once commercialised will significantly shape the future of mining such that Zambia may become a major producer of agricultural fertiliser from the processing of phosphate and gypsum. The production of phosphoric acid from phosphate can be of great economic value to Zambia and other sectors of the economy such as in construction, pharmaceutical, cosmetics, ceramics, paints, electronics, filtration, plastics, glass, detergents and paper industries. The economic potential of industrial minerals is viable and sustainable if fully exploited.

Keywords: Industrial Minerals, Mineral Resources, Sustainable Development, Diversification, Economic Viability

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1.0 Introduction

Zambia is a mineral resource rich country with a variety of minerals such as copper, cobalt, Zinc, Manganese, Tin, Uranium, Lead, etc, some of which are still undiscovered. It had been the world's second producer of copper from Chile and first in Africa until in 2014 when DRC took over, (African Business Magazine, 2014). It also produces precious metals (gold, silver), gemstones (amethyst, aquamarine, emerald and tourmaline), Coal and industrial minerals. For many years, Zambia has been heavily dependent upon the mining of copper, which, combined with cobalt production, represents over 98% of mineral sales and 75% of export earnings (Mitchell, 2000). The copper prices on the world has been fluctuating in the past decade as shown in the figure 1 below, thereby affecting the country's Gross Domestic Product revenue base.

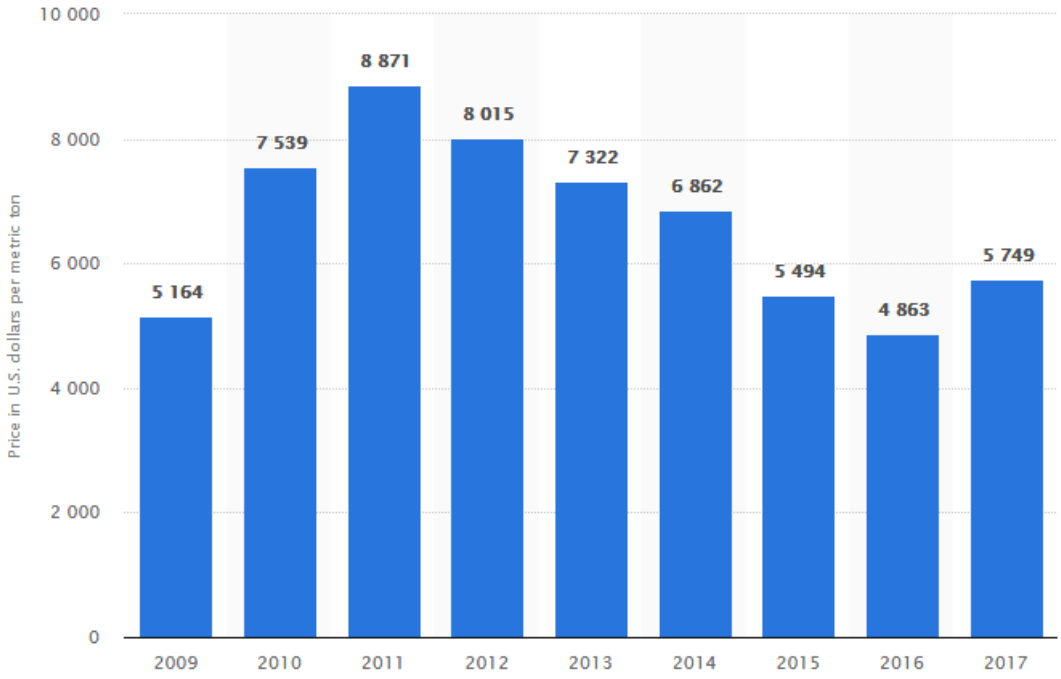

Figure 1: The annual average Copper prices from 2009 to 2017 (www.statista.com/stastistics/533292/average-price-of-copper)

This simply means that the mining industry and the government have to find ways of survival especially through diversification from copper mining to industrial minerals mining. The industrial minerals sector is, however, under explored and underdeveloped. Industrial minerals may be defined as minerals mined and processed (either from natural sources or synthetically processed) for the value of their non-metallurgical properties, which provides for their use in an extremely wide range of industrial and domestic applications. As a general rule, they can also be defined as being non-metallic, non-fuel minerals(Muibeya, 2000).Typical examples of industrial minerals in Zambia are limestone, clays, sand, gravel, feldspar, kaolin, bentonite, silica, barite, gypsum, and talc.

This paper describes how the industrial minerals can contribute to sustainable development of mining, their uses and the economic viability.

2.0 Sustainable development through industrial minerals mining

The world is calling for sustainable mining, meaning that there is need of intensive control in the use of mineral resources for the future generation. Mineral resources mined and used by man have always conditioned the economic and civilizational development of societies and states, which was very clearly emphasised in the motto of the 18thWorld Mining Congress, held in 2000 in the USA – Everything begins with mining (Dubiński, 2013).

The Figure 2 below shows the three pillars on which Sustainable development in mining hinges.

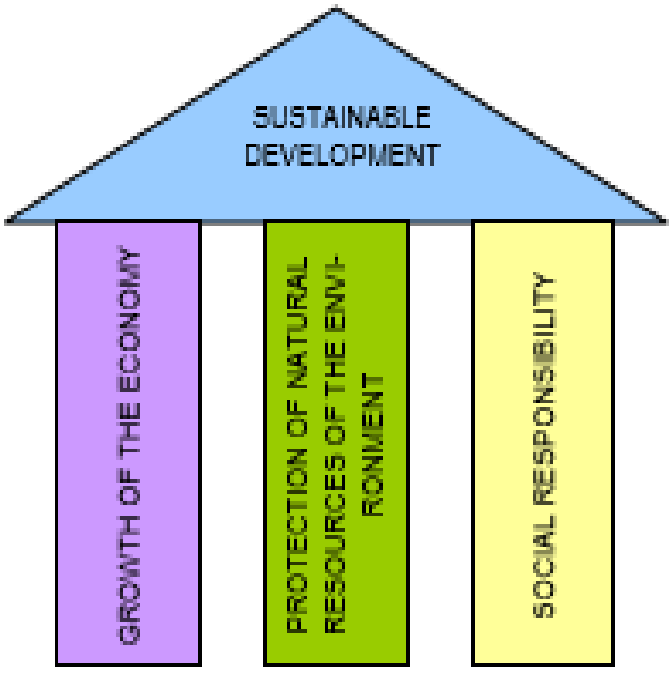

Figure 2: Showing the three pillars of sustainable development (Dubiński, 2013).

Economic growth is the first pillar of sustainable development, which means achieving long-term sustainability both in regards to planned production volumes, and in meeting the needs of customers, as well as achieving economic efficiency obtained from the sale of the excavated mineral (Dubiński, 2013). To achieve the economic growth, Zambia needs to diversify into industrial mines found in all parts of the country to enhance even distribution of the wealth and development of the communities.

The second pillar is Protection of natural resources of the environment. This means taking measures that minimise the negative impact of the different processes related to the extraction of mineral resources on the various forms of the geological environment and natural environment on the surface (Dubiński, 2013). To minimise the quick depletion of copper deposits, there is need to develop the industrial minerals. In as much as the industrial minerals would foster development and economic growth of the nation, it is important to extract these resources responsibly without damaging the environment. There is need for a full environmental impact assessment (EIA) before conducting any project to enhance proper planning of the mining activities.

Social responsibility means, taking into consideration the nature of the mining environment and above all ensuring safe working conditions, but also concern the social aspects of mining, including the families of miners, the mining environment, etc.(Dubiński, 2013). Social responsibility is an ethical theory, in which individuals are accountable for fulfilling their civic duty; the actions of an individual must benefit the whole of society (Hebestreit, 2011). In this

way, there must be a balance between economic growth and the welfare of society and the environment. In mining this can also be referred to as Corporate Social Responsibility (CSR) meaning voluntary actions undertaken by mining companies to either improve the living conditions (economic, social, environmental) of local communities or to reduce the negative impacts of mining projects. As individuals or companies are exploring the industrial minerals, this pillar needs consideration for the wellbeing of the communities.

3.0 Industrial Minerals

The base metals industry overshadows industrial minerals in Zambia. There is minimal exploitation of industrial minerals as shown in Table 1 below.

Table 1: Production of industrial minerals in Zambia (Mitchell, 1991, 2013)

Industrial mineral / product	Production figure (tonnes)
Aggregate (crushed limestone)	700,000 †
Agricultural lime (2000 estimate)	~20,000 ‡ (~100,000 – 150,000)
Building stone (inc. dimension stone)	700,000 †
Cement	206,266 *
Clay for brick-making	3000 †
Clay for building	30,000 †
Feldspar (last production data 1993)	- (100)
Gypsum	11,000 †
Hydrated lime	16,103 *
Kaolin	200 †
Limestone	412,238 *
Magnetite	1000 †
Pyrite (for H_2SO_4 production)	70,000 †
Quick lime	145,102 *
Sand & gravel	200,000 †
Talc	80 †

There is no geological map of Zambia showing the industrial minerals. Therefore, Table 2 shows the commonly used industrial minerals and their location in Zambia based on literature survey (Ministry of Mines and Mineral Development, 1999).

Table 2: Summary of industrial minerals found in Zambia

Industrial Minerals	**Location (Site, Province Of Occurrence)**
Limestone & dolomite	Throughout Zambia, especially along the line of rail from Livingstone to North-Western Province, as well as in Luapula, Northern and Eastern provinces.
Barite	Mkushi district, Central; Lundazi, Eastern; Chipili, Luapula; Lutoka Hill, Northern ; Kafue and Chirundu, Southern
Talc	Lilayi and Chipapa, Lusaka; Ndola, Copperbelt; Mkushi, Central; Ch isasa and Ntambu, North-Western and Kalinku, Eastern
Feldspar	Siavonga-Kariba,Southern; Chilulwe Central; Serenje, Mkushi and Mita Hills areas, Central; Shiwa Ngandu, Northern, Lundazi ,Eastern
Silica sand	Throughout Zambia
Phosphate	Nkombwa Hill, Northern; Chasweta, Mwambuto, Nachomba and Kaluwe Hill in the Luangwa-Rufunsa area, Chilembwe, near Petauke, Eastern; Sugar Loaf, near Mumbwa, Lusaka;and Keshya ravine carbonatite, Kafue, Southern.
Kaolin	Chlilulwe and Kapiri Mposhi, Central; Twapia Copperbelt, Choma southern,
Graphite	Mwinilunga and Solwezi, North Western; Mkushi,Central and Petauke and Lundazi, Eastern.
Gypsum	Lochinvar National Park, Southern and Chifungwe p lain, Northern
Fluorite	Gwembe and Siavonga district, Southern Province
Asbestos	Chinkombe and Mwatezi area, Eastern
Clay: Ball clay	Chamba Valley, Lusaka; Solwezi, NorthWestern; Loshi, Luapula.
Clay: Bentonite	Luano Valley, Central.
Clay: Brick clay	Dambo clay throughout Zambia
Clay: Fireclay	Maamba colliery, Southern Province
Corundum	Rufunsa, Lusaka Province.
Dimension stone: Black granite	Chipata, Eastern Province; Lusaka, Lusaka Province.
Dimension stone: Marble	Carbonate deposits across Zambia.
Dimension stone: Syenite	West of Solwezi and Mumbwa, Central Province.
Kyanite	Kafue, Leopards Hill, Mwembeshi River and Chalenga River, Lusaka Province.
Magnesite	Leopards Hill, Lusaka Province.
Mica	SE of Serenje, Central Province; Lundazi, Eastern Province; SE of Choma, Southern
Salt	Northern, Luapula, NorthWestern, Western and Southern Provinces.
Vermiculite	Kankomo dambo, Kalulushi, Copperbelt Province.
Zeolite	Dombwe Hill, Kafue and Singwe Gorge, Livingstone, Southern; Mongu, Western.

3.1 Uses and Application of Industrial Minerals of Zambia

The uses of the industrial minerals are interdependent on each other as a single mineral in one production process often involves the use of several others. Each mineral can serve up to 4-20+ different markets and each market can demand a range of different minerals, for example, the

production of glass from silica sands may require the use of soda ash, limestone, dolomite, feldspar, borax, gypsum and fluorspar. Hence, a single mineral or rock may form the basis for a large number of industries as illustrated in the Figure 3.

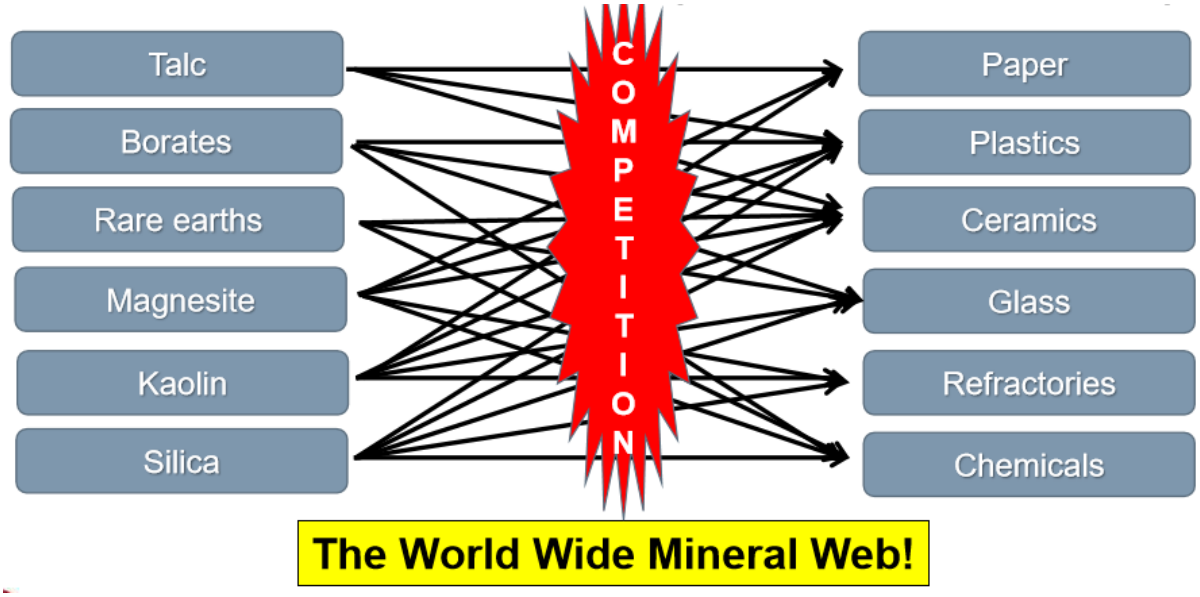

Figure 3: The interrelationships of the different usages of some industrial minerals (Mike, 2015)

3.1.1 Barite

It has several applications in well drilling fluids as a major ingredient by weight percent. In glass, making barite saves fuel by reducing the heat-insulating froth on the melt surface. It also acts as an oxidizer and decolouriser, making the glass more workable. In Coatings, Paints and primers, barite provides resistance to corrosion by acids and alkalis. Finely ground barite is used in rubber, where its weight, inertness, isometric particle shape, and low binder demand are advantageous. It is used in acid-resistant compounds, in white sidewalls for tires, and in floor mats. Barite is used in PVC and polyurethane foam backings for carpeting and sheet flooring because of its ability to form dense coatings due to its high specific gravity and its ability to be used at high loadings. Natural barite is used in concrete for the construction of facilities handling nuclear materials because it absorbs gamma radiation. (Ciullo, 1996)

3.1.2 Feldspar

Feldspar is used primarily in container glass, followed by flat glass and glass fibber. Feldspar is used mainly as a source of alumina, which improves both the workability of the glass melt and the chemical and physical stability of the finished product. It is used in sanitary ware, tiles, electrical porcelain, tableware, and glazes. Feldspar is used as a flux in welding electrodes. In filler applications it offers low vehicle demand, high dry brightness with low tint strength, and resistance to abrasion and chemical degradation (Ciullo, 1996). In coatings it also provides good film durability and high resistance to chalking and frosting.

3.1.3 Gypsum

Gypsum is used in based wallboard commonly in developed countries like the US and Canada. The gypsum core provides a strong, fire-resistant, and inexpensive construction material. It is used with Portland cement to retard the setting time of concrete. Gypsum rock is used in treating alkaline, saline, and clayey soils, and as a source of sulphur. Other uses include glassmaking, board chalk and as a white filler in paint and paper.

3.1.4 Kaolin

It is used in paper coatings, the high-brightness, low abrasion water-washed and delaminated kaolins are used in coatings for acid-sized paper to improve brilliance, gloss, smoothness, and ink receptivity. Also used as paper fillers due to its high-brightness, low-abrasion air floated, water-washed and delaminated it is used as pulp extenders in acid-sized paper, where they improve opacity, smoothness and ink receptivity. In ceramics, white-wares use a combination of china clay (usually air float) and ball clay selected for consistent chemical composition so that firing and vitrifying characteristics of the body are controlled, colour and translucency of the fired ware are satisfactory. Used in refractories to give a dense, strong product able to withstand much higher temperatures than ordinary clay-based refractories. It is also used in coatings, plastics, in agricultural polyethylene films to improve infrared absorption characteristics and in engineering resins, in rubber, adhesives and sealants to control flow, penetration, and specific adhesion on application, and adhesive strength, tear strength, tensile strength, and elongation after cure. In fibre glass and in the manufacture of aluminium chemicals, bricks, cements, cosmetics, pharmaceuticals, animal feeds, fertilizers, catalysts, wallboard, printing ink, linoleum, flexible tile, pesticides, and roofing granules.

3.1.5 Limestone & Dolomite

These are carbonate rocks known to occur throughout Zambia. There is a wide range of uses, in paper it is used in alkaline papermaking, calcium carbonate is used as a paper filler and coating. In coatings, the ground natural calcium carbonate is the most widely used white pigment in paints because it is available at relatively low cost and has high brightness for TiO2 extension, high purity, low abrasivity, and resistance to weathering (Ciullo, 1996). It is also used in adhesives and sealants, in polymers because of its low cost, low abrasion, low oil absorption, low moisture, high brightness, and easy dispersion with conventional mixing equipment. Among the other uses are, a therapeutic source in antacids and calcium supplements and as a tableting excipient. Fine particle size products are used as a fire extinguisher foam filler, as an abrasive in household cleaners, as a flux in welding rod coatings, as a diluent in agricultural pesticide dusts, and as a dusting agent to mitigate the explosion potential of coal dust generated during underground mining. Substantial quantities of crushed and ground limestone are also used in the manufacturing of Portland cement, lime, glass, and metallurgical fluxes, as well as in flue gas desulfurization processes and as a soil amendment.

3.1.6 Mica

The mica is used in joint cements especially in fine dry-ground (fluid energy-milled) muscovite is used in drywall joint compounds, where it contributes to consistency and workability, smooth surface finish, and resistance to shrinkage and cracking. In coatings, the fine-ground mica grades are used in paint as a pigment extender and for dry film reinforcement. While in plastics the finely ground micas are used in plastics to improve electrical, thermal, and insulating properties. It is also used in drilling fluids to prevent fluid loss into porous rock formations. The coarse mica flakes bridge openings and seal porous sections of the drill hole against loss of circulation. Mica's platy nature also aids in the suspension of drilling fluid solids and cuttings. Ground mica is used as an asbestos substitute in certain thermal boards, brake linings, gaskets, and cement pipes.

3.1.7 Phosphate

The phosphate resources of Zambia have over the years attracted a great deal of attention as a possible source of fertiliser raw materials. Research has focused upon five igneous deposits, where the main phosphate mineral (apatite) occurs in carbonatite or syenite, or in associated pegmatites. These are some of the uses of phosphate, it is used in container glass as a source of

alumina, which improves both the workability of the glass melt and the chemical and physical stability of the finished product. It is used in ceramics, sanitary-ware, tiles, electrical porcelain, tableware, and glazes as an alternative to feldspar. It acts as a flux in ceramic bodies to lower firing temperatures and allow faster firing schedules. In coatings, as a filler in plastics, rubber, and adhesives because of its low vehicle demand, high dry brightness with low tint strength, nearly lamellar shape, and resistance to abrasion and chemical degradation. It is used as a sandblasting medium due to its absence of crystalline silica.

3.1.8 Silica Sand

Natural silica products are crystalline and are classified for most of their uses under the term "sand and gravel". Silica sand of varying quality occurs throughout Zambia. It has so many uses and applications like in ceramics; the low-iron ground silica is used in white-ware formulations to facilitate drying of the body, to control expansion characteristics and compatibility between the body and glaze to prevent crazing, and to provide whiteness and acid resistance. It can be used in coatings, rubber, plastics, adhesives and sealants. The uses for Synthetic silicas are thickeners in printing inks, as carriers for liquid and active ingredients, and as anti-caking and moisture control agents. Fumed and precipitated silicas are used in high-temperature silicone greases. Silica gel is used as a thickening and polishing agent in dentifrices and as the abrasive agent in silicon wafer polishing compounds.

3.1.9 Talc

Talc occurrences have been recorded in the Lusaka, Central, Copperbelt, North-Western and Eastern Provinces of Zambia. It has found its use in ceramics, coatings especially in architectural paints, paper industry, in roofing because of its low-cost, off-colour platy talc is used in roofing felts to add weight, to provide UV protection, to prevent oil penetration and migration, and to increase fire resistance. Talc is used in thermoplastics to control melt flow, reduce creep in moulded parts, increase moulding cycles, increase heat deflection temperature, and improve dimensional stability. It is commonly used in cosmetics and pharmaceuticals. In cosmetics, talc is used in makeup and dusting powders while in pharmaceuticals it is used in tablet manufacturing as a filler and lubricant, and as a reinforcing agent in film coatings. Talc is used for flow control in animal feeds, as a dusting agent for rubber, as an anti-caking agent for fertilizers, as a carrier for insecticides, as a filler in carpet and textile backings, in wallboard joint compounds and grouts, and in adhesives and sealants.

3.1.10 Vermiculite

Vermiculite is a platy sheet silicate that is similar in appearance to the mica. It is used in agricultural products as a fertilizer carrier, in horticultural products, and as a soil conditioner. It is used in plaster and cement premixes due to the laminar nature of the mineral to protect against cracking and spalling of these coatings when subjected to temperature extremes and mechanical shock. Vermiculite is also used in fire protection boards at loading levels of up to 90%. These boards are used as cladding for structural steel and in residential and commercial buildings as more aesthetic alternatives to sprays. Vermiculite is used in thermal and acoustical insulation boards (e.g., ceiling tiles), lightweight insulating blocks, refractory blocks, and firebricks. Expanded vermiculite is used as an aggregate in ready-mix and preformed concrete to reduce weight and improve insulation properties. Expanded vermiculite is also used as an absorbent for industrial spill containment and clean up, in ground form as an alternative to asbestos for brake linings, in refractory mould releases, and as a water filtration medium in aquaculture. Unexpanded vermiculite is used to cover molten metal prior to casting, where the heat of the metal expands the mineral into an insulating layer.

3.1.11 Zeolite

Zeolites are microporous, alumino silicate minerals commonly used in aquaculture to remove ammonia from water at fish hatcheries and farms, in aquaria, and in live fish transport systems. This prevents the eutrophication of such systems and thereby enhances fish mortality and growth. In agricultural products, zeolites, principally clinoptilolite, are used as vehicles for the controlled release of ammonia in fertilizers and as carriers of insecticides, herbicides, and fungicides. They also are added to contaminated soils to scavenge radioactive materials such as caesium (Cs137) and strontium Sr90, plus lead (Pb), cadmium (Cd), and other toxic heavy metals. Zeolites are used as animal feed supplements to improve nutrient efficiency and growth rates for poultry and swine while reducing manure moisture and odour. It is used in waste treatment of sewage and industrial waste streams to remove ammonia and heavy metals. Used for gas adsorption in the air to generate relatively pure oxygen for medical and industrial uses. It is used in detergents, as a catalyst in petroleum cracking, whereby crude oil is broken down into gasoline and fuel oils. Zeolite has found additional uses as desiccants, heat storage media, filters for air cleaning, and as paper fillers.

In summary, these industrial minerals form part of our daily essentials as shown in figure 4.

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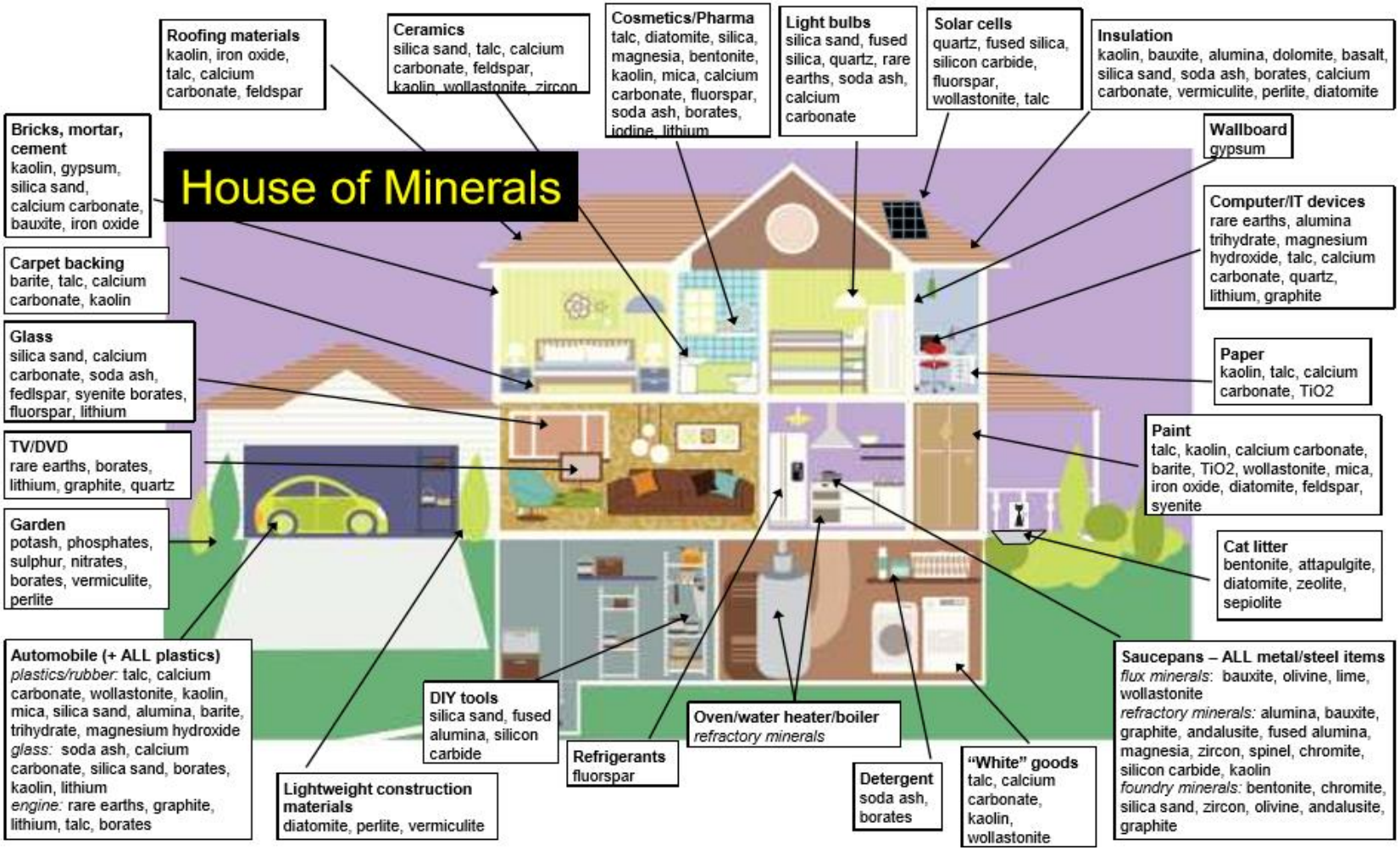

Figure 4: Showing the many uses and application of industrial minerals (Informed, 2015)

4.0 Economic Viability

For developing countries, the prospects for selling industrial minerals on the export market are good (Wilson, 2007). Industrial minerals are commonly occurring minerals and rocks that are widely used in industry, sometimes undergoing very little processing. Most are high volume and low unit value commodities and their economic importance depends on the availability of markets, market location, transportation costs, their physical and chemical characteristics, and the degree of processing required for end use. So far, the demand for industrial mines has been increasing on the world market due to the growing need of infrastructure development and advancement in technology. The value of these minerals has been steadily increasing worldwide as depicted in Figure 5 below

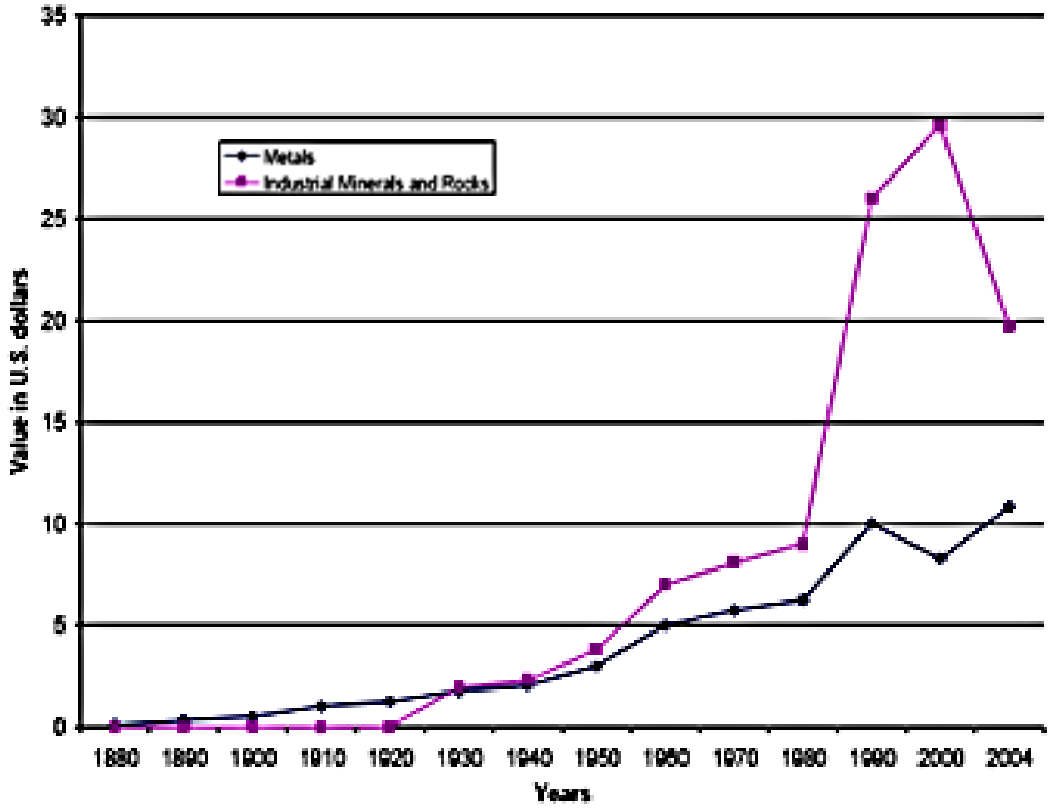

Figure 5: The worldwide value of metals and industrial minerals (Wilson 2007)

Product marketability is a critical element in the process of evaluating the economic viability of an industrial mineral. This suggests that deposits must also meet specifications laid down by consumers, and that production and transportation costs must not be excessive. However, even when the conditions for a profitable operation are met, a producer may face a continually changing market in which the demand for his product may be rising or falling. Hence, the necessary adjustments must be made to ensure the survival of the business (Wilson 2007)

To analyse the economic viability easily, the minerals need to be can be categorised into groups. According to the paper by Amavilah (2007), the industrial minerals can be categorised into three groups. It is on these three groups that the economic viability analysis for the Zambian scenario is based.

The first group, known as construction materials, includes sand, gravel, clays and stone (e.g., limestone, dolomite, granite, serpentinite and quartzite). Stone is both a source of crushed and dimension stone. Materials that are valued for their physical attributes characterize this group.

They are very widespread in nature, are very bulky, and have low unit value, even as they require minimal processing before use. These attributes have a profound effect on the economic value of industrial mineral deposits. Commodities with high bulk and low unit value must be located close to markets to be economic, while less common materials with unique properties have a high unit value and may be profitable at high prices in distant markets (Amavilah, 2007). Since most of these construction materials are profound along the line of rail in Zambia, it makes them potentially viable for profitable investment.

The second group, referred to as process materials, includes a wide range of minerals and rocks possessing special characteristics that allow them to be used in specialized areas. This group includes;

(i) ceramic materials made up mainly of clays but also silica, limestone, dolomite, feldspar, quartz, and bauxite;
(ii) abrasive materials like garnet, silica, and especially chalcedony, chert, quartz, quartzite, sandstone, and silica sand; and
(iii) Refractory and metallurgical materials like magnesite, fire clay, graphite, bauxite, silica, and dolomite. The potential for this group is high in Zambia but more technology and investment is required to achieve profitability.

Materials in the third group include optical materials like quartz; absorbent materials like bentonite and diatomite; fillers like asbestos, bentonite, gypsum, kaolin, limestone, and vermiculite; glass materials like glass sands, soda ash, limestone, dolomite, feldspar, borax, and gypsum; and oil drilling materials like asbestos, barite, bentonite, limestone and dolomite. Materials in this group are valued mostly for their physical properties. They are less bulky, have higher unit values than construction materials and can be sold on the export market. Zambia hosts many of these minerals but requires the commercial investment. The Table 3 below highlights potential revenue that be realised from few selected industrial materials in Zambia

Table 3: Potential Revenue of few selected industrial minerals

Construction Minerals	Estimated Tonnages	Market Price ($)	Potential Revenue($)
Sand and Gravel	200,000	5 -7	1000000 -1400000
Limestone/Granite/Quartzite	412,238	3	1,236,714
Aggregate Stones	700,000	4 - 9.7	2800000 - 6846000
Clay for making bricks	3000	41	12300
Gypsum	11000	6.9 – 20	75900 – 220,000
Kaolin	200	Average 160	32000
Talc	80	87 - 327	6960 - 26160

5.0 Discussion

The world is in pursuit of sustainable mining that recognises environmental accountability, social responsibility and commercial success throughout the mining life cycle. Mining generates strong and sustainable benefits for Zambia through exports, revenue, business, employment and technology transfer. Zambian's economy is highly dependent on base metals mining whose resource is unfortunately slowly but surely depleting. For this mining to cater for the future generation, it is important that Zambia diversify from base metal mining to development of the industry minerals at a large scale.

The industrial minerals have a potential to spring up new industries, which can fully exploit the minerals and add value to it locally. For example phosphate rock, can be used to make phosphoric acid which can be used as an electrolyte in copper electro-polishing , in dentistry to make dental cement for filling and for food processing(www.sciencestruck.com). The production of fertiliser from phosphate rock can be maximised. The country imports many Ceramics from China when we have a lot of unexplored clay. The Kapiri foundry industry for ceramics should be boosted to add value to the abundant Clay thereby creating employment for the locals. One of the Strategic Development Goal for 2030, SDG8 -Decent Work and Economic Growth and another one is SDG1 -End Poverty. If this industry is commercialised, job will be created, and achieve the two SDGs.

The industrial minerals have the potential of broadening the revenue base and contribute to the economic growth of Zambia through the potential revenue, which can be generated from full exploitation as analysed in the Table 3 above. This can fully contribute to the country‘s GDP. The government should find ways of maximising the full potential of this under developed resources. Once developed, these resources can attract a lot of foreign investment in the country and fully contribute to the country‘s GDP. It can attract foreign investment once developed, thereby improving the forex.

6.0 Conclusion

To achieve sustainability and economic growth in the industrial minerals mining sector, the Zambian government should encourage the establishment of small scale mining operations and should be ready to provide miners with technical assistance in the areas of exploration, extraction, and product marketing. For instance the abundant limestone, can initially be uses as the resource for construction material (cement, aggregate and dimension stone) and later as a raw material for agricultural, metallurgical, and chemical industries. Earnings from foreign trade could be increased by limiting exports of unprocessed raw materials. For example, a government may decide to export less phosphate rock while increasing exports of phosphoric acid and phosphatic fertilizers. The industrial minerals holds the future of sustainable mining for the Zambia's mining industry for example the prices of gypsum is approximately $6.9-20, kaolin is $160 and talc is $327/ton if fully exploited they can generate extra revenue for the country . The economic potential of industrial minerals is viable and sustainable if fully exploited.

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Medical Application of the Internet of Things (IoT): Prototyping a Telemonitoring System

Fredrick Chisanga[1]

Abstract

The Internet of Things (IoT) is a technological paradigm that is an evolution of the traditional Internet. It presents massive potential for innovation and efficiency in industrial processes. While a number of industries have taken it on board to reap its benefits, the medical sector, in its long-standing adoption of ICTs, is yet to shift from silos to systems that offer a common horizontal platform for various vertical applications. This work presents the prototyping of a telemonitoring system that adopts the design approaches of the IoT thus enabling a shift from silos through the use of standards-compliant Machine-to-Machine (M2M) middleware. The analysis carried out in this work shows how such a system can be highly usable while reliably performing its tasks.

Keywords: Internet of Things, Telemonitoring, Efficiency, Machine-to-Machine (M2M) middleware.

1. Introduction

The Internet of Things (IoT) is a technological paradigm that is an evolution of the traditional Internet (Evans, 2011; Holler *et al.*, 2014; Perera *et al.*, 2014; Jadoul, 2015; Whitmore, Agarwal and Da Xu, 2015). It is a shift from the traditional way of connecting devices to the internet, both in terms of the number and diversity of connected devices. This significant and marked growth in the number and diversity of devices connected to the internet has prompted a rethink of approaches of interconnecting devices (OneM2M, 2015; OpenMTC, 2016). The growth in the number of connected devices is driven by emerging applications and business models and supported by falling device costs. While the growth in the diversity is driven by the reduction in the cost of manufacturing these devices (Ericsson, 2016). Therefore, this has led to an increase in the number of users (not limited to people) on the internet. According to statistics by the International Telecommunication Union (ITU) (International Telecommunication Union (ITU) Planning Team, 2015), by the end of 2015, about 3.2 billion people were using the Internet. Significantly, 34% of households in developing countries had Internet access, with more than 80% of households in developed countries. This indicates that it is realistic to leverage the IoT in living spaces.

Appreciating this potential, many sectors of society are already positioning themselves to reap the benefits of this great promise (Cisco, no date), (NetApp, 2016). Therefore, the health sector would do well to adopt this technological paradigm to enhance service delivery. According to Grand View Research, the IoT-in-Healthcare market is projected to be worth $409.9 billion by the year 2022 (Grand View Research, 2017). One specific area where the health sector can benefit from the adoption of the IoT is in telemonitoring and its associated early response to medical emergencies (Wellens, 2012).

Telemonitoring, which is the remote monitoring of a patient's vital signs (Paré *et al.*, 2007), has been recognized as a significant approach towards reducing the impact of disease (McKinstry *et al.*, 2013). Past experiences have shown that the use of vital signs data can speed up the detection and eradication of epidemics such as Ebola, Influenza, SARS, etc. (Malone *et al.*, 2009; Frieden and Damon, 2015; Selvey, Antão and Hall, 2015; Kaushik *et al.*, 2016).

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With the advancement in technologies such as cloud computing (Apostu *et al.*, 2013), Wireless Body Sensor Networks (WBAN), virtualization (Hao and Foster, 2008), and networking, among others, it is possible to create telemonitoring systems that would leverage the design approaches (shift from silos, reuse of applications and software, etc.) and benefits of the IoT. The prototyping of such a system and contribution towards reducing the total time of the chain of survival is the undertaking of this work.

2. Related Work

The medical sector has a long-standing history of the use of ICT particularly in telemonitoring (World Health Organisation, 2010).

For example, Mukherjee et al. (Mukherjee, Dolui and Datta, 2014), discuss an architecture that highlights and builds on the design and benefits of the works in (Popescu *et al.*, 2011) and (Lv *et al.*, 2010). They posit that telemonitoring solutions can enable parents to monitor their children as well as offer emergency response services (ERS). In their work, they identify the perception, middleware and APIs, and the application and services layers, as shown in Figure 1, as the building blocks of such an architecture. Cloud servers, the authors posit, are used for data storage, because of ease of access to data by stakeholders, and the offered processing for prognosis of future complications. The cloud server acts as both a provider of APIs and the application and services for the system. It performs key processes such as analysis of data for emergency response and enables the physician to send real-time advice to the patient. This massive dependency on the cloud servers implies a huge dependency on the availability of internet connectivity, which cannot always be guaranteed. In effect, the architecture presented consists of three components as presented in Figure 2.

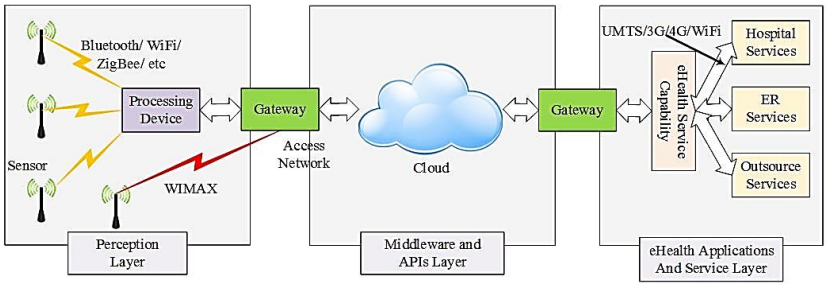


Figure 1: Illustration of the eHealth Monitoring Architecture (Mukherjee, Dolui and Datta, 2014)

On the other hand, Szakacs-Simon et al. (Szakacs-Simon, Moraru and Perniu, 2013) extend the use of context - particularly the use of location sensors for the purpose of tracking patients. This was achieved through the use of an android application to extend the monitoring devices' coverage area and enable real-time tracking of patients. They use the smartphone as a tracking device. Additionally, the authors emphasize the utilization of the functions of a smartphone - such as sending text message alerts (SMS). The authors implement their system using three component (RMD, smartphone, and central server) as shown in Figure 2.

Finally, Suryani et al. (Suryani *et al.*, 2013) present a solution, that uses middleware (an OpenMTC platform (OpenMTC, 2016)), for the monitoring of heart activity. The use of middleware in the presented system is to enable point-to-multipoint electrocardiography (ECG) data transmission and using smartphones to display the output. They present a system that consists of an ECG device, a data transmission module, a middleware and an Android application to connect with the middleware, receive patient's data and display the ECG output. In their design, the middleware serves as a storage location for ECG measurements data, which can then be retrieved and displayed using an android application. Figure 3 shows the monitoring system architecture.

While the authors acknowledge that middleware should enable mobile devices/sensors to communicate to a central server environment as they provide ubiquitous access to data in a highly scalable manner, their design utilizes the middleware for data storage or as a central server. Despite the experiments that were carried out indicating that ECG data could be successfully sent to the client's devices via middleware and displayed in accepted form, the middleware would best serve as a horizontal layer providing common services to various devices and applications while specialized tasks such as data storage could be moved to specialized applications and platforms (Yi and Saniie, 2016). The Android application is only intended for use by healthcare providers to view the ECG readings. The gateway acts as an initial storage of data and subsequently forwards it to the middleware when a suitable communication channel is available. The authors, just like (Popescu *et al.*, 2011; Mukherjee, Dolui and Datta, 2014; Yi and Saniie, 2016), and (Lv *et al.*, 2010) also submit that there is value in adding more sensors to the system though they do not itemize this value.

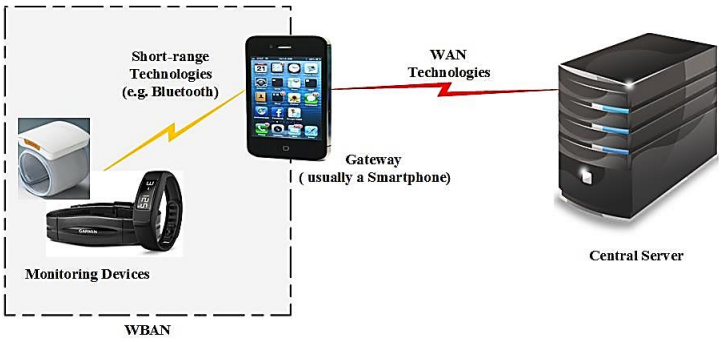


Figure 2: Three components architecture

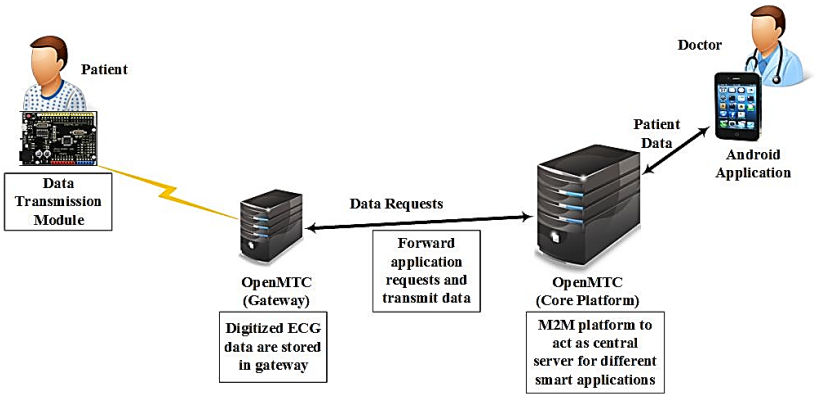


Figure 3: The ECG Monitoring System Architecture (Suryani *et al.*, 2013)

Through the use of a use case approach, this work seeks to propose a telemonitoring system that adopts the above-highlighted design approaches while adopting the IoT design approaches (a shift from silos to a common horizontal platform) that are not currently implemented in the existing systems.

3. Use Case Definition and Requirements

3.1 Use Case Description

At the highest level, the use case focuses on the communication of the patient's RMD readings to the EHR system and the notification of the patient of their vital signs readings. The use case is focused on the transmission of messages from the RMD to the MA, the transmission of messages between the MA and the distributed M2M middleware, and the transmission of data between the distributed M2M middleware and the EHR system. The preconditions of this use case are that:

- the MA is able to communicate with and is already authenticated and registered to the M2M gateway,
- the MA has already retrieved the initial patient data (physician's details and caregiver's details) from the EHR system via the distributed M2M middleware, and
- the M2M middleware is able to communicate with the EHR system.

3.2 Stakeholders and Their Requirements

In an IoT system, stakeholders range from end-users to devices and applications. However, only end-users (particularly the patient, physician, and caregiver) are considered in this work.

3.2.1 **Patient:** The "patient" may be any individual or surrogate, who could use an RMD to take measurements, gather data or monitor events. The measurements may be taken in various settings such as hospitals or nonclinical settings such as homes, at work, at school, while traveling, or in assisted living facilities (European Telecommunications Standards Institute (ETSI), 2013). Patients are mainly concerned with the obtrusive nature of the RMDs, the ease of use and setup of the telemonitoring system/process, the security of the data transmitted, and the demand on the resources of the smartphone. Therefore, the RMDs must be lightweight and non-obtrusive.

3.2.2 **Physician:** The "physician" includes medical practitioners, medical doctors, nurses, nurse practitioners, health assistants, psychologists, and other clinical personnel who clinically evaluate the remote measurements to determine appropriate clinical interventions, if needed, to deliver healthcare (European Telecommunications Standards Institute (ETSI), 2013). The physician is particularly interested in the reliability of the system to enable data harvesting for predictive health and diagnosis.

3.2.3 **Caregiver:** The "caregiver" includes personal care aides, home health aides, patient advocates, surrogates, family members, and other parties who may be acting for, or in support of a patient receiving healthcare services (European Telecommunications Standards Institute (ETSI), 2013). The caregiver, just like the physician, is interested in the reliability of the system to allow for a peace of mind in the provision of care to the patient.

3.3 Information Exchange

The exchange of information in this use case is between the RMD and the MA, the MA and the M2M middleware, and the M2M middleware and the EHR system. These exchanges can be broadly categorized into two categories as follows:

- Periodic transmission of physiological data (from the RMD to the MA and from the MA to the M2M middleware) based on preset intervals
- Event-based updates of data (e.g., when there is an update of patient data in the EHR system, during MA registration and authentication, etc.)

Figure 4 summarizes the flow of messages in this use case.

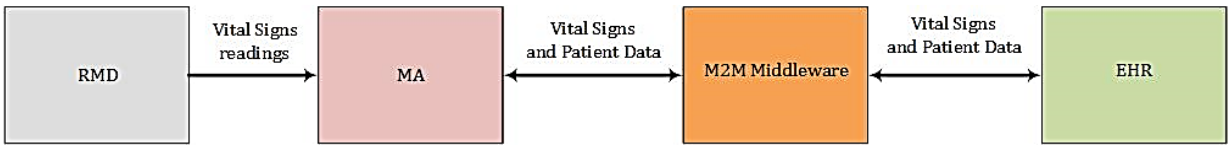


Figure 4: Message flow diagram illustrating the communication between components

3.4 System Requirements

Based on this use case and the requirements of stakeholders, the following system requirements have been identified:

3.4.1 **End-to-End Communication**: The system shall support communication by using multiple communication means as follows: Bluetooth communication and IP communication between the various applications, devices or system components, as will be required by the system.

3.4.2 **Time Stamping:** The system shall be able to support accurate, secure and trusted time-stamping. Applications and the M2M middleware may support this requirement.

3.4.3 **Data Collection and Reporting:** The system shall support the collection and reporting of data from specific applications and devices in a way requested by the system's applications as listed below:

- A periodic reporting with the time period determined by the RMD or the MA;
- An event-based reporting.

3.4.4 **Monitoring and Sensing**: The system shall be able to sense the vital signs (e.g., heart rate) of a patient and transmit the data to the MA for processing and further propagation.

3.4.5 **Reliability:** It is essential that the system should not alter the vital signs reading. Therefore, the system shall deliver data reliably to the stakeholders and applications or devices.

3.5 Proposed System

Based on the system requirements and the use case discussed in the previous sections, the proposed high-level telemonitoring system's architecture is shown in Figure 5.

The proposed architecture highlights the possibility of other applications, such as traffic monitoring and ambulance system applications, being able to make their data and resources available to the telemonitoring system by APIs, through the middleware. It is an adaptation of the ETSI use case #2 as defined by ETSI (European Telecommunications Standards Institute (ETSI), 2011) and shown in Figure 6.

Through the adoption of the above ETSI use case, the resultant functional architecture of the proposed telemonitoring system is shown in Figure 7. As can be seen, the interaction of the MA and the EHR with the M2M middleware is accomplished using dIa and mIa interfaces, respectively. The dIa interface between the M2M gateway and the EHR system is utilized during the MA registration and authentication process to query the user table in the centralized MySQL DB. The mId interface is utilized during the interaction within the distributed M2M middleware.

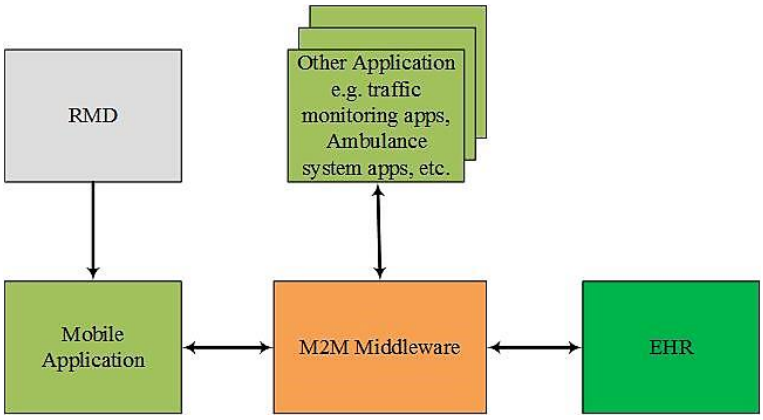


Figure 5: Proposed high-level telemonitoring system's architecture

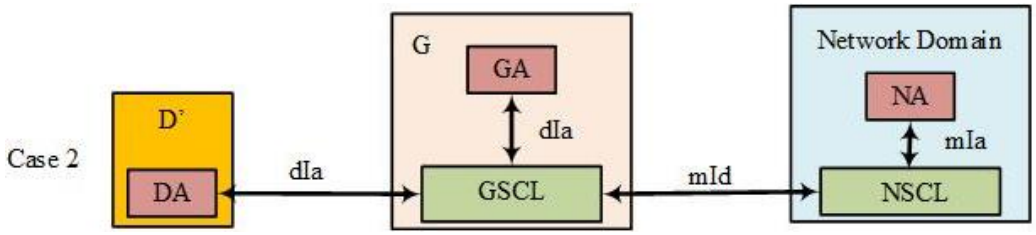


Figure 6: The ETSI M2M use case #2 (adapted from (European Telecommunications Standards Institute (ETSI), 2011))

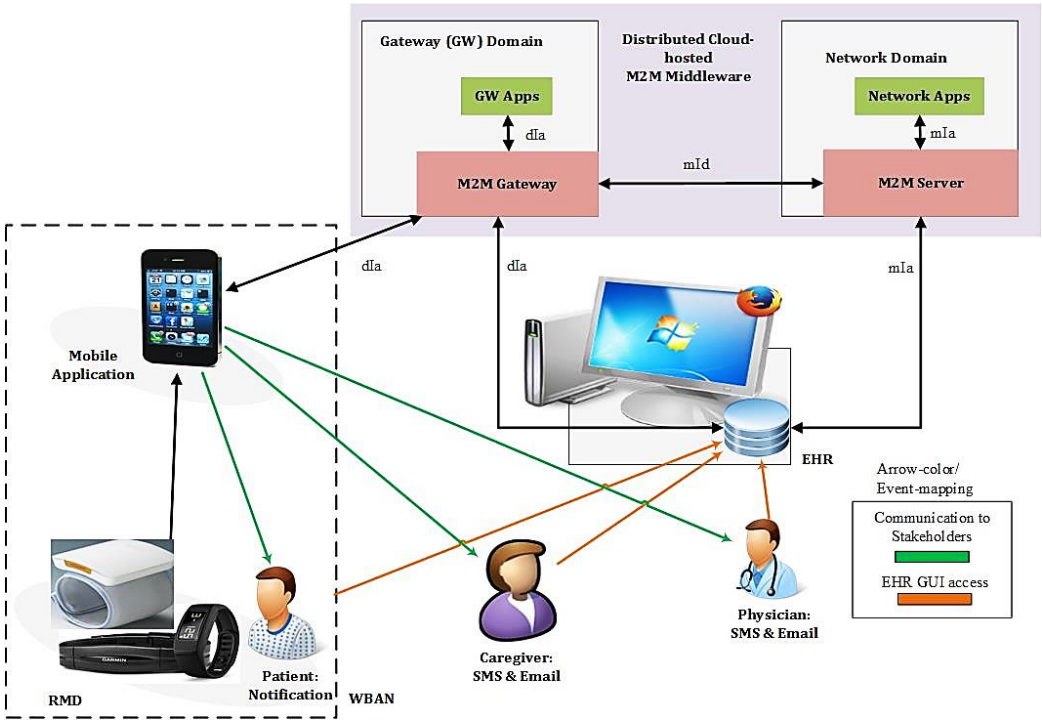


Figure 7: The proposed telemonitoring Functional Architecture

4. Prototype Implementation

This section presents a discussion of the implementation of the components of the prototype of the proposed telemonitoring system.

4.3.1 **Remote Monitoring Devices (RMDs)**: While numerous vital signs could have been studied, heart rate was considered due to the ready availability of a heart rate monitoring device. The heart rate data was captured using the Zephyr HxM BT heart rate monitor – an off the shelf RMD. The heart rate monitor has a fixed data capture and transmission rate of one reading per second. However, to enable reasonable time to study the data, a delay of 10s was implemented.

4.3.2 **Mobile Application (MA):** The MA was developed using Java programming language and the Android SDK, in Android Studio. For the implementation of the MA, Android API level 15 (Ice Cream Sandwich/version 4.0.3) or newer was targeted as it is estimated that this would cover about 97% of Android devices (Android Developers, 2017a). The MA was implemented using the Model-View-Controller (MVC) design approach that promotes reuse of classes. To implement the views (various instances of the GUI), Activity and Fragment classes were used as the controllers. An Activity is an instance of the Activity class in the Android SDK and is responsible for managing user interaction with a screen of information. While a Fragment is a controller object that can deputize an Activity, to perform tasks. Fragments are agiler and better suited to implement frequently changing GUIs compared to Activities (Phillips and Hardy, 2013).

Figure 8 summarizes how the activities and fragments are implemented and how they interact to present varying screen graphics.

4.3.3 **Distributed M2M Middleware:** The distributed M2M middleware is an implementation of two instances of the OpenMTC platform which complies with the ETSI and oneM2M standards, thus making it a preferred candidate for prototyping an IoT-based telemonitoring system. The OpenMTC platform mainly consists of a front-end (that this work refers to as the M2M gateway) and a back-end (that this work refers to as the M2M server) server. In the proposed telemonitoring system, the implementation of the distributed M2M middleware is as summarized in Figure 9. The M2M gateway is located at the edge of the cloud, to leverage the benefits of edge-computing, while the M2M server is located within the cloud. The two instances are identical in detail, i.e. the gateway applications are similar to the network applications. The applications that reside on the M2M middleware instances are summarized in Table 1.

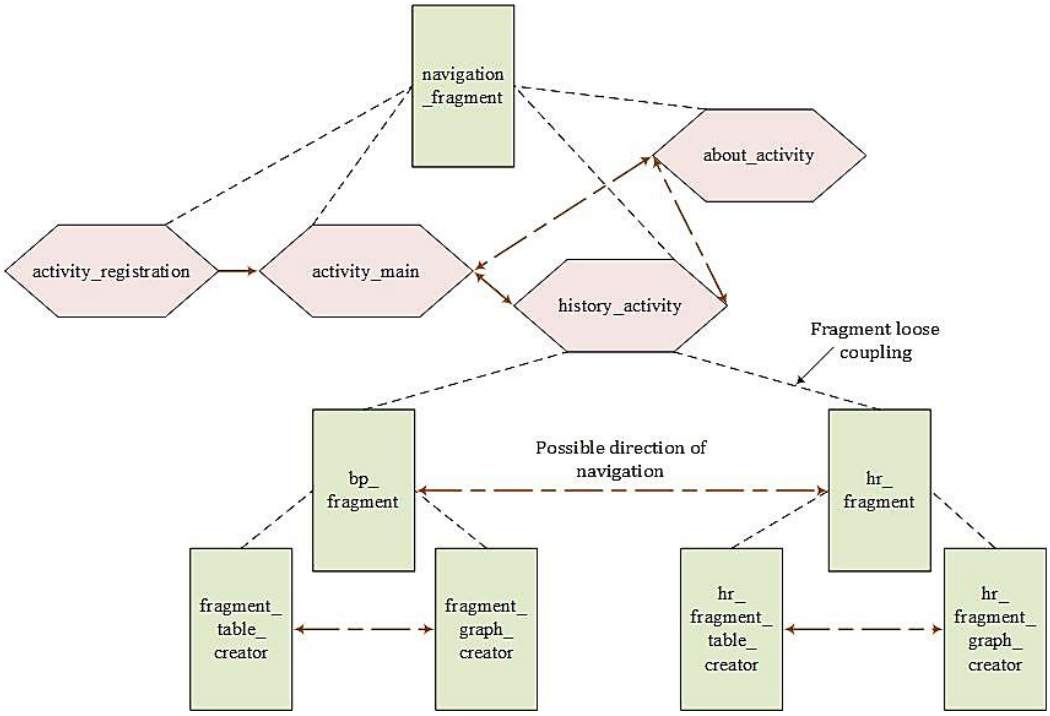


Figure 8: The MA's Activities and Fragments interaction

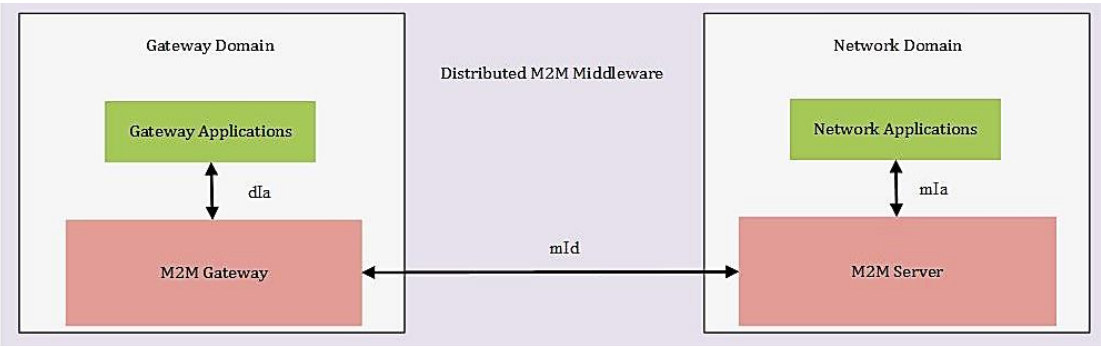


Figure 9: The distributed M2M middleware

Table 1: The Python scripts/applications implemented and their roles in the prototype

Script	M2M Gateway	M2M Server	Role
Handler	Implemented	Implemented	1. Listens on TCP port 9998 2. Handles registration and authentication requests (at the M2M gateway) 3. Calls the Plumbing Script to build M2M interfaces 4. At the M2M server, calls the Scl_Webbapp_Sync script to update the M2M gateway and server interfaces
Plumbing	Implemented	Implemented	1. Builds the M2M interfaces 2. Maintains the M2M interfaces
Scl_Webbapp_Sync	-	Implemented	1. Retrieves initial data from the EHR 2. POSTs initial data to the M2M interfaces
VitalSignsHandler	Implemented	Implemented	1. Listens on TCP port 9999 for vital signs data 2. Transmits data to the M2M server or EHR (for M2M gateway or M2M server, respectively)
RandomGen	Implemented	-	1. Simulates BP RMD by generating BP data (systolic and diastolic values, time, and location) 2. Ensures the systolic reading is always greater than the diastolic reading
UpdateHandler	-	Implemented	1. Listens on TCP port 9997 for updates from EHR 2. Updates data on M2M server interface and POSTs data to M2M gateway interface

4.3.4 **Electronic Health Record (EHR) System:** The electronic health record (EHR) system consists of a web application, a database management system (DBMS), and a MySQL DB. The web application (implemented using the Yii framework) is the GUI that enables authenticated users to create and manage users, and stakeholders to view and manage some personal records. The DBMS (implemented using the Yii framework) manages and controls access to the DB by managing users' ability to define (using Data Definition Language (DDL)) the schema and, using a Data Manipulation Language (DML), to create, retrieve, update and manage data in a DB, as per the requirements (Garcia-Molina et al., 2010). The DBMS is an intermediate layer between programs (e.g., a web application) and the data as shown in Figure 10.

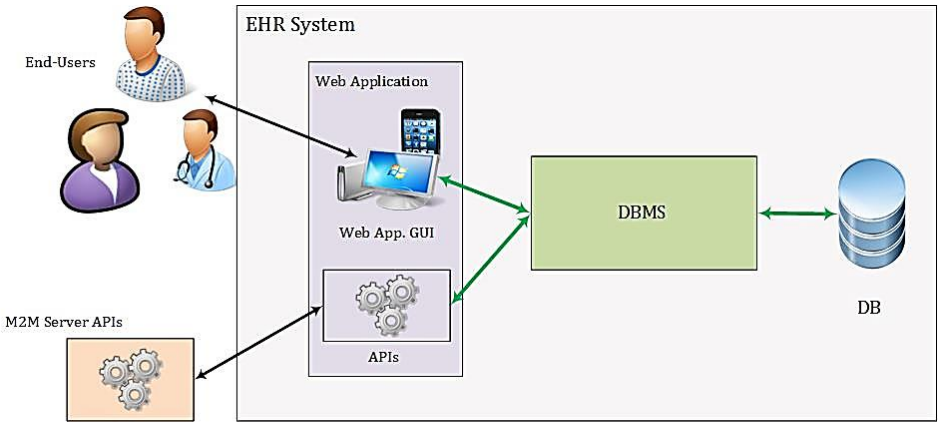


Figure 10: The EHR system architecture.

The web application and the DBMS are implemented using the Yii framework. The Yii framework was chosen because it is a high-performance PHP framework for developing Web 2.0 applications and is open source. In addition, it provides the following benefits: MVC, data access object (DAO)/active record (AR), caching, authentication and RBAC, scaffolding, etc. The framework enables the creation of secure (through input validation, output filtering, SQL injection and Cross-site scripting prevention) and agile (through caching and its efficient working with asynchronous JavaScript and XML (AJAX)) applications while ensuring a clear separation of logic and presentation through the use of the MVC design approach (Yii Software, 2017).

5. Prototype Evaluation and Analysis

This section highlights how the proposed prototype meets specific stakeholders' and system requirements. The exchange of messages during this use case is summarized in Figure 11. This work only considers the reliability, usability, and demand on host resources of the proposed system.

The proposed telemonitoring system implements three categories of messaging methods, i.e. SMS, local notifications, and email alerts as shown in Figure 12.

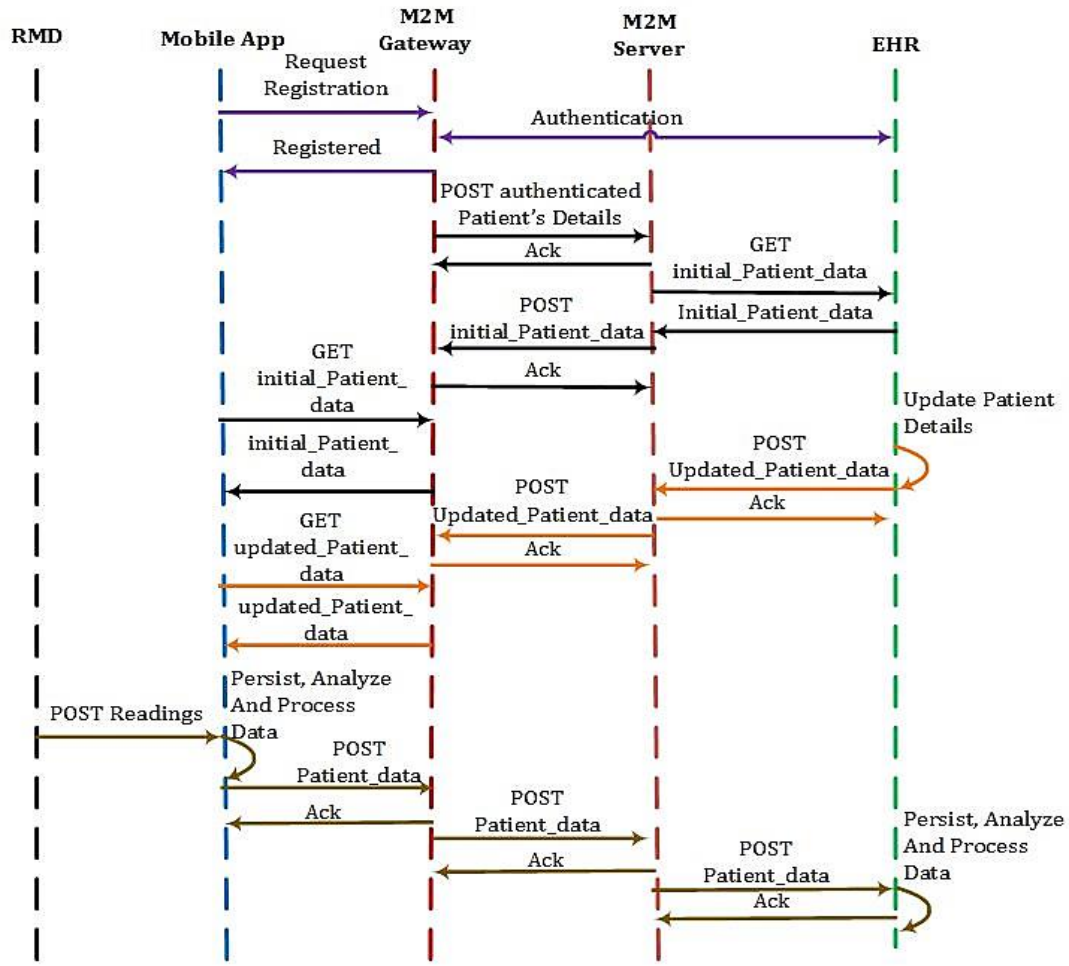


Figure 11: Exchange of messages among the various components

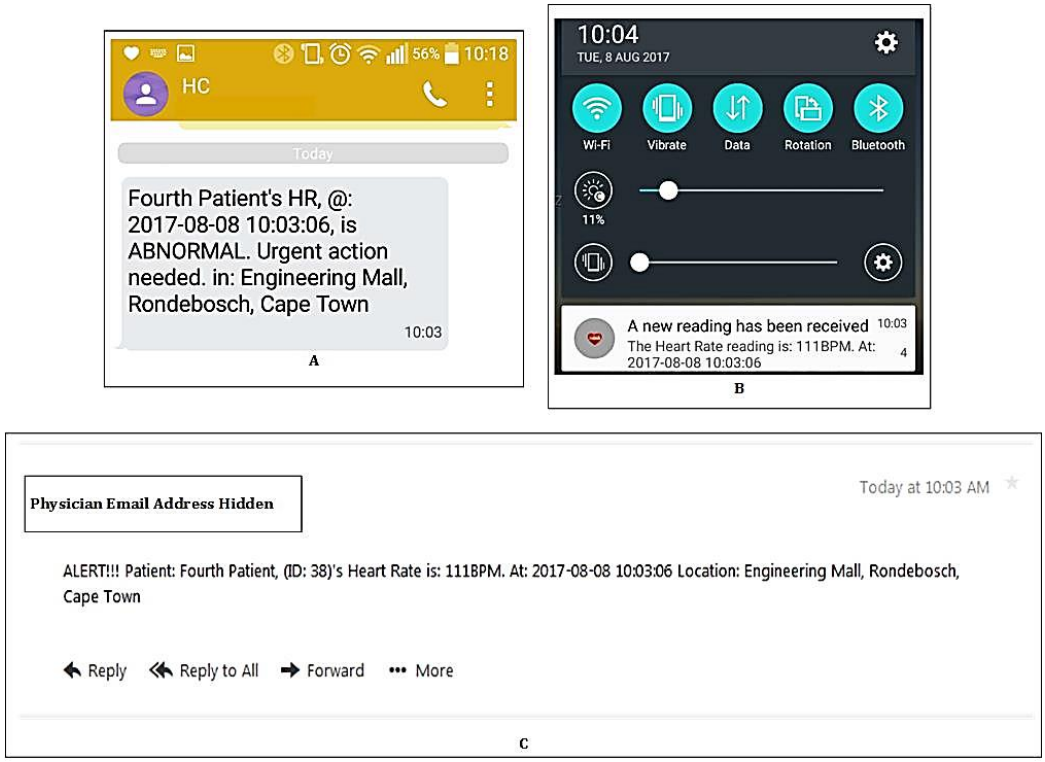


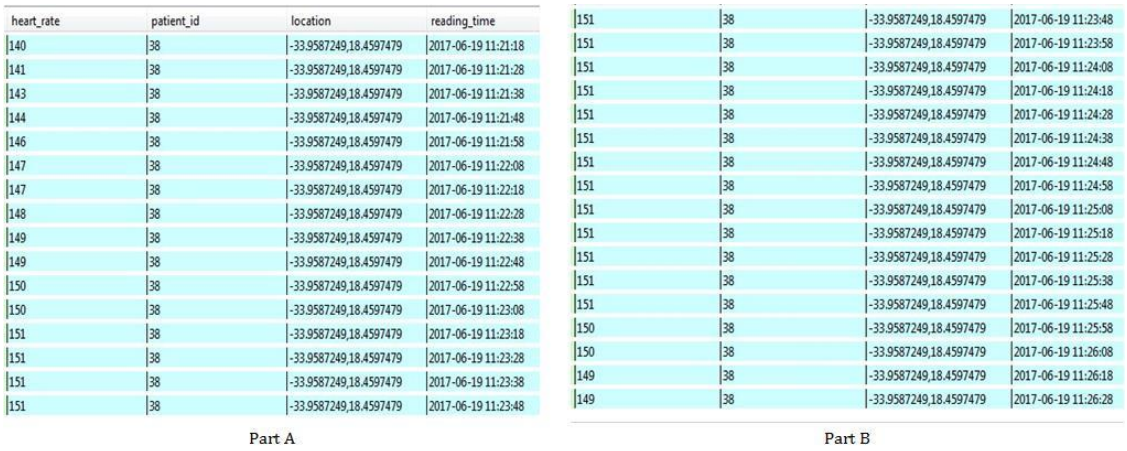
Figure 12: Sample event-based messages (A. SMS message, B. Local notification, C. Email message)

5.3.1 **Reliability of the System:** Reliability is a key requirement that is common to all the stakeholders. Albert Meyers defines it as the probability that a system will accomplish its assigned task within a specified time (Myers, 2010). Therefore, a reliable system is one that consistently performs according to its specifications, under stated conditions, for a specified period of time. In this work, to test for reliability, the task chosen was the delivery of unaltered vital signs data from the MA to the EHR. This task is measured over a period of 5 minutes 23 seconds (amounting to a data sample of 32 heart rate readings) with the condition being that there must be end-to-end connectivity. Therefore, if there is a failed delivery, or altered vital signs record, it will be categorized as a system failure thus count against the system's reliability score.

To make the assessment, data was analyzed at the following points of the prototype: in the SQLite DB (of the MA) and in the MySQL DB (of the EHR). The heart rate data as viewed in the SQLite DB is shown in Figure 13.

The data as viewed from the MySQL DB are shown in Figure 14. All the 32 heart rate data records were delivered with the exact details (heart rate value, patient ID, reading location, and reading time) as transmitted from the MA (see Figure 13).

From the reliability test carried out, it was concluded that as long as there is end-to-end connectivity between the components of the prototype the system reliably delivered all the 32 heart rate data records. Additionally, it was observed that there were no alterations to the delivered data. This could be attributed to the M2M middleware's use of Base64 data encoding, which is optimized for reliable data delivery.



heart_rate	patient_id	location	reading_time
140	38	-33.9587249,18.4597479	2017-06-19 11:21:18
141	38	-33.9587249,18.4597479	2017-06-19 11:21:28
143	38	-33.9587249,18.4597479	2017-06-19 11:21:38
144	38	-33.9587249,18.4597479	2017-06-19 11:21:48
146	38	-33.9587249,18.4597479	2017-06-19 11:21:58
147	38	-33.9587249,18.4597479	2017-06-19 11:22:08
147	38	-33.9587249,18.4597479	2017-06-19 11:22:18
148	38	-33.9587249,18.4597479	2017-06-19 11:22:28
149	38	-33.9587249,18.4597479	2017-06-19 11:22:38
149	38	-33.9587249,18.4597479	2017-06-19 11:22:48
150	38	-33.9587249,18.4597479	2017-06-19 11:22:58
150	38	-33.9587249,18.4597479	2017-06-19 11:23:08
151	38	-33.9587249,18.4597479	2017-06-19 11:23:18
151	38	-33.9587249,18.4597479	2017-06-19 11:23:28
151	38	-33.9587249,18.4597479	2017-06-19 11:23:38
151	38	-33.9587249,18.4597479	2017-06-19 11:23:48

Part A

151	38	-33.9587249,18.4597479	2017-06-19 11:23:48
151	38	-33.9587249,18.4597479	2017-06-19 11:23:58
151	38	-33.9587249,18.4597479	2017-06-19 11:24:08
151	38	-33.9587249,18.4597479	2017-06-19 11:24:18
151	38	-33.9587249,18.4597479	2017-06-19 11:24:28
151	38	-33.9587249,18.4597479	2017-06-19 11:24:38
151	38	-33.9587249,18.4597479	2017-06-19 11:24:48
151	38	-33.9587249,18.4597479	2017-06-19 11:24:58
151	38	-33.9587249,18.4597479	2017-06-19 11:25:08
151	38	-33.9587249,18.4597479	2017-06-19 11:25:18
151	38	-33.9587249,18.4597479	2017-06-19 11:25:28
151	38	-33.9587249,18.4597479	2017-06-19 11:25:38
151	38	-33.9587249,18.4597479	2017-06-19 11:25:48
150	38	-33.9587249,18.4597479	2017-06-19 11:25:58
150	38	-33.9587249,18.4597479	2017-06-19 11:26:08
149	38	-33.9587249,18.4597479	2017-06-19 11:26:18
149	38	-33.9587249,18.4597479	2017-06-19 11:26:28

Part B

Figure 13: The heart rate data as stored in the SQLite (*hc_companion*) DB

5.3.2 **System Usability:** The usability of a system is an attribute that is not easy to quantify because it is generally a subjective experience, different for each individual user. According to the International Standards Organization (ISO), usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (International Standards Organization (ISO), 1998). It usually has to do with the users' experience as they interact with the GUIs. Whitney Quesenbery (Quesenbery, 2001) gives definitions of the three aspects (effectiveness, efficiency, and satisfaction) of usability as follows:

- Effectiveness is the completeness and accuracy with which users achieve specified goals.
- Efficiency is the speed (with accuracy) in which users can complete the tasks for which they use the product. This can be quantified by a count of clicks required or pages viewed to accomplish a task.
- Satisfaction is a measure of how engaging an interface is. This is a measure of how pleasant and satisfying to use the interface is. The visual design of an application or system is the most obvious element of this characteristic.

Therefore, this work evaluated the usability of the system, for the patient, by considering these three aspects. Effectiveness, as defined above, was assessed by considering the accuracy of the data presented to users by the GUIs (MA GUI and web application GUI). As discussed earlier, the prototype was 100% accurate in its transmission of data captured by the RMD. This data as saved in the respective DBs (SQLite and MySQL) was accurately displayed by the GUIs. Therefore, the system effectively performed its tasks.

Efficiency, as has been mentioned, can be quantified by the number of clicks or pages viewed to accomplish a task. To assess this aspect, two tasks were identified i.e. viewing of the last 4 heart rates and initiating the monitoring of heart rates.

To initiate the monitoring of heart rates, the precondition was that a user has the Zephyr HxM BT heart rate monitor properly worn and activated. It took a minimum of three clicks to complete this task. The first click started the MA, while the second click (click on the "*START HR*" button in Figure 15) prompted the user to activate Bluetooth on the Android device. Clicking the "*Yes*" button of the prompt initiated the monitoring. However, when Bluetooth was already activated, it took a minimum of two clicks to complete the same task. This is because the authentication and pairing between the RMD (Zephyr HxM BT heart rate monitor) and the MA is automated. Additionally, to offer efficiency in terms of response speed, the MA implements *AsyncTasks* (separate threads) to free the main thread of any tasks that could slow it down. This contributes to better user experience.

The final aspect of usability is harder to measure as it is very subjective. However, the MA implements two data presentation approaches to increase its appeal and offer options to the end-user.

Therefore, the MA through the implementation of the features discussed above and the tests carried out was deemed to be usable.

heart_rate	patient_id	reading_location	reading_time ▼ 1
149	38	-33.9587249,18.4597479	2017-06-19 11:26:28
149	38	-33.9587249,18.4597479	2017-06-19 11:26:18
150	38	-33.9587249,18.4597479	2017-06-19 11:26:08
150	38	-33.9587249,18.4597479	2017-06-19 11:25:58
151	38	-33.9587249,18.4597479	2017-06-19 11:25:48
151	38	-33.9587249,18.4597479	2017-06-19 11:25:38
151	38	-33.9587249,18.4597479	2017-06-19 11:25:28
151	38	-33.9587249,18.4597479	2017-06-19 11:25:18
151	38	-33.9587249,18.4597479	2017-06-19 11:25:08
151	38	-33.9587249,18.4597479	2017-06-19 11:24:58
151	38	-33.9587249,18.4597479	2017-06-19 11:24:48
151	38	-33.9587249,18.4597479	2017-06-19 11:24:38
151	38	-33.9587249,18.4597479	2017-06-19 11:24:28
151	38	-33.9587249,18.4597479	2017-06-19 11:24:18
151	38	-33.9587249,18.4597479	2017-06-19 11:24:08
151	38	-33.9587249,18.4597479	2017-06-19 11:23:58

Part A

151	38	-33.9587249,18.4597479	2017-06-19 11:23:58
151	38	-33.9587249,18.4597479	2017-06-19 11:23:48
151	38	-33.9587249,18.4597479	2017-06-19 11:23:38
151	38	-33.9587249,18.4597479	2017-06-19 11:23:28
151	38	-33.9587249,18.4597479	2017-06-19 11:23:18
150	38	-33.9587249,18.4597479	2017-06-19 11:23:08
150	38	-33.9587249,18.4597479	2017-06-19 11:22:58
149	38	-33.9587249,18.4597479	2017-06-19 11:22:48
149	38	-33.9587249,18.4597479	2017-06-19 11:22:38
148	38	-33.9587249,18.4597479	2017-06-19 11:22:28
147	38	-33.9587249,18.4597479	2017-06-19 11:22:18
147	38	-33.9587249,18.4597479	2017-06-19 11:22:08
146	38	-33.9587249,18.4597479	2017-06-19 11:21:58
144	38	-33.9587249,18.4597479	2017-06-19 11:21:48
143	38	-33.9587249,18.4597479	2017-06-19 11:21:38
141	38	-33.9587249,18.4597479	2017-06-19 11:21:28
140	38	-33.9587249,18.4597479	2017-06-19 11:21:18

Part B

Figure 14: Heart rate data as stored in the MySQL (*h_companion*) DB at the EHR

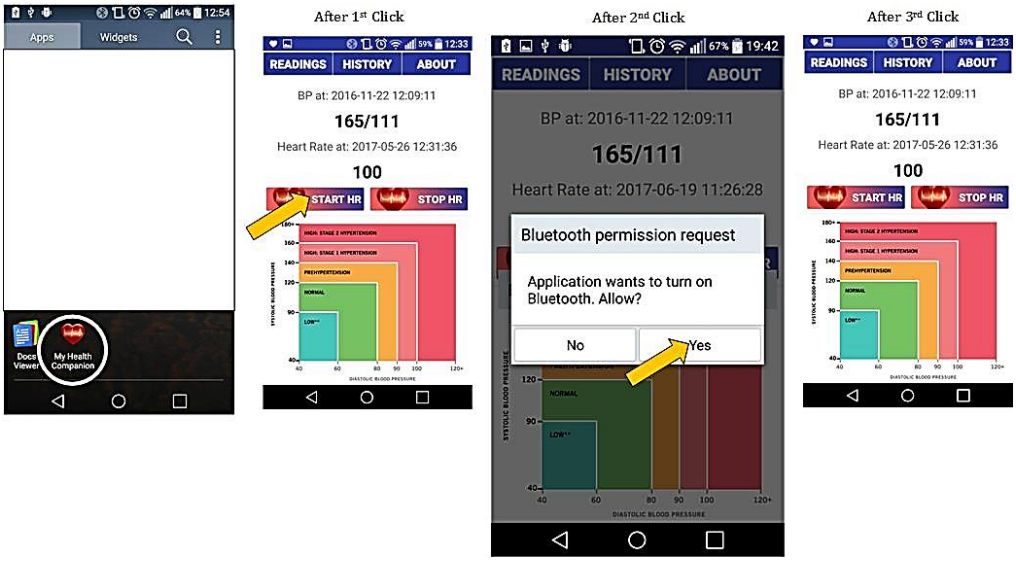


Figure 15: Steps (clicks) required to initiate heart rate monitoring

5.3.3 **Demand on Host Resources**: The extent of the MA's use of host (smartphone) resources is of particular interest to the patient and the adoption of the proposed telemonitoring system. While the other components (the distributed M2M middleware and the EHR system) are deployed on hosts with relatively superior and sufficient compute resources, the smartphones do not offer a similar luxury. Therefore, it is important to evaluate the performance of the MA with regard to the utilization of host resources. This work does not assess the use of the Bluetooth resource nor does the use of the phrase "network resource" incorporate the Bluetooth resource.

Figure 16, shows the MA's use of the host resources while monitoring vital signs with the user not actively using the GUI (interacting with the application). Three resources are monitored, i.e. memory, central processing unit (CPU), and network resources using memory, CPU, and network monitors, respectively.

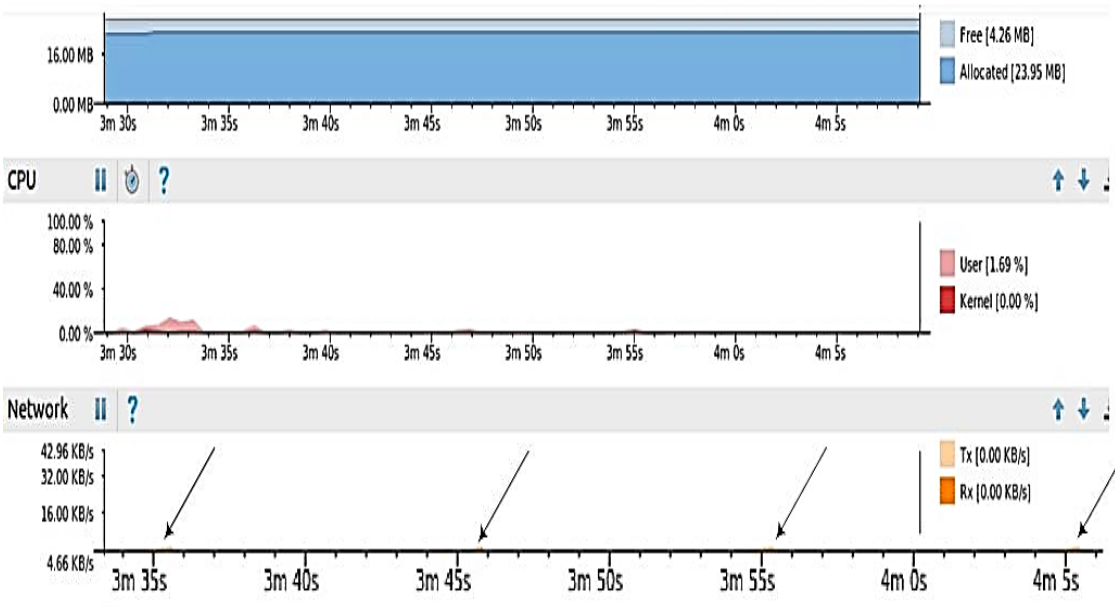


Figure 16: Resource utilization during heart rate monitoring (Note: Network resources zoomed in for clarity)

The memory monitor shows the memory usage during the monitoring period. The CPU monitor displays CPU usage in real-time and the percentage of total CPU time (including all cores) used in user and kernel mode. The Network Monitor shows network requests, including when the MA transfers data.

As highlighted by the arrows (see Figure 16), the network resource is only utilized at 10 seconds intervals during the monitoring process. This is when the MA was sending POST requests to the M2M gateway. The small amount of data sent out is because of the lightweight nature of JSON data formatting. Over the same time period, the MA utilizes CPU and memory resources to keep the application alive. The memory resources are always utilized during the lifecycle of the MA as it provides the runtime environment for the application. The high use of CPU between times 3m 30s and 3m 35s was due to interaction with the GUI to initiate the monitoring.

The experiment showed that the MA uses the most resources at startup, as can be seen at time 3m 20 sec, in Figure 17. This could be attributed to the process of sending GET requests to the M2M gateway and the attendant data transfers that occur at startup. After the MA starts, the resource utilization reduces significantly. It is important to also note that of the three resources analyzed, the network resource has the most direct effect on the battery life (Android Developers, 2017b). Therefore, to preserve battery power, the network resources should be least utilized.

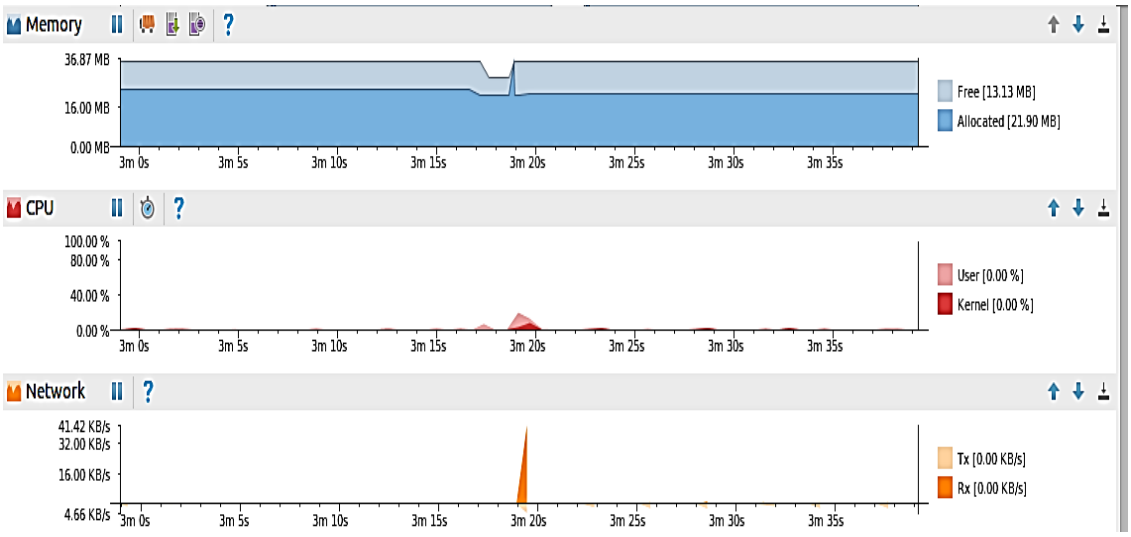


Figure 17: Resource utilization at MA startup

However, if the user interacts with the MA e.g., move between pages/views, the CPU utilization is significantly higher than when the MA is only monitoring vital signs with no user interaction with GUI. Notably, no network resources are utilized during this time. This is because the interaction between the MA and the M2M gateway is not always active.

Therefore, it is clear that as long as the MA is not active (user interacting with it) it does not utilize CPU and network resources. This indicates that it is unlikely to affect the other applications installed on the host device, thus not frustrating the end-user. This also shows the positive effect of implementing passive retrieval of data from the M2M gateway as opposed to maintaining a continuous connection between the MA and the M2M gateway.

6. Conclusions

This work showed that while the health sector has a long-standing history in the use of ICT, the current implementations of eHealth solutions have not widely adopted the present evolution of the internet - the IoT. It further showed that the use of IoT design approaches can deliver largely reliable and automated telemonitoring systems that offer end to end communication of vital signs data.

The conclusions drawn from the design, implementation and evaluation of the prototype showed that the proposed telemonitoring systems can reliably manage and transmit vital signs data as required by stakeholders. Additionally, it was shown that the use of a smartphone leverages the benefits of its inherent functions to the telemonitoring process. These inherent functions, particularly for the delivery of messages to stakeholders, rendered the prototype more efficient than previous work.

Furthermore, this work showed that it is possible to implement the MA in such a way that it does not needlessly utilize the smartphone's resources. This was achieved by minimizing the needless use of network resources and automating some processes thus reducing the time required for the user to interact with the MA when performing tasks such as initialization of the monitoring process.

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CFD simulation of pseudo 2D gas-solid fluidized bed for biomass gasification

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Abstract

This work explores the ability of the two-fluid-model (TFM) to model the complex dynamics and turbulent flow of a pseudo 2D gas-solid fluidized bed for biomass gasification. Particle velocity data from the NETL small scale challenge problem measured with HsPIV is processed to obtain turbulent properties including the anisotropy coefficients, normal Reynolds stresses and turbulent dispersion coefficients. It is observed that the model captures the lateral transport of the particles poorly which results in the TFM model over prediction of turbulent properties. The work also demonstrates that mean profiles alone are not sufficient to validate TFM. The TFM captures the trends of the various turbulent properties quite well including the wavelet energy distribution of the fluctuating velocity. The numerical simulations further reveal that mixing in the slugging bed is due to bubble oscillations rather than individual particles as revealed from the computed granular temperatures.

Keywords: Biomass, gasification, fluidized bed, mixing, simulation

1.0 Introduction

The global demand for energy has been steadily rising globally due to rapid industrialization and improved quality of life. However of late emphasis has been on the provision for clean and renewable energy to mitigate the effects of global warming Computational fluid dynamics (CFD), a physics based approach has now become an indispensable tool in the design, optimization and scale up of gas-solid devices (Pannala et al., 2011) thus overcoming the limitations of empiricism however several theoretical and numerical challenges still exist. One such challenge is the systematic validation and uncertainty quantification of computer models. This exercise is required before the models can be used with a high degree of confidence for solving real life industrial scale

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design problems. For the purpose of validating computer models, so called pseudo 2D rectangular fluidized beds experimental set ups are frequently employed. These set ups are usually rectangular, transparent and have a small thickness and due to their simplicity are ideal for collecting data on bubble properties, jet penetration, solids clustering , solids flow patterns and solids mixing and segregation (Li and Zhang, 2013) which can be ultimately used for validation and dvelopment of computational models. In their latest challenge problem, the National Energy Technological Laboratory (NETL) generated high fidelity particle velocity and pressure drop experimental data in a pseudo 2D gas-solid fluidized bed employing Geldart D particles and availed it publicly to modelers. The objective of the challenge problem is to foster the systematic validation and uncertainty quantification of CFD models of multiphase flows. From the literature surveyed, most validation studies have mostly focused on mean profiles of velocity, solids concentration, solids mass flux and pressure drop. However instantaneous or dynamical features of fluidized beds are equally important for an in depth analysis of hydrodynamics due to the fact that fluidized beds are operated under turbulent conditions with flow structures of different length and time scales influencing the mixing and transport mechanisms.

(Jiradilok et al., 2008) computed turbulence properties including dispersion coefficients, Reynolds stresses ,energy spectra and granular temperature in an NETL riser using the two fluid model (TFM) with closures from the kinetic theory of granular flow (KTGF). The computed axial solids dispersion coefficients agreed reasonably well with experimental measurements from the NETL riser within the bounds of experimental errors. (Sun et al., 2012) used the wavelet technique to investigate particle vortex phenomena from the simulated particle vertical fluctuating velocity in a gas-solid bubbling fluidized bed. The study revealed that the time scale of a particle vortex has a linear relationship with the wavelet scale. Computation of turbulent properties using the TFM with closures from the KTGF has also been reported in several other studies (Chalermsinsuwan et al., 2009, Chalermsinsuwan et al., 2011, Kashyap et al., 2011b, Kashyap and Gidaspow, 2011a). Most of these studies however have focused on turbulent and CFB risers whereas the present work is based on a pseudo 2D bubbling fluidized bed operated under slugging conditions. Moreover from most of the previous studies no attempt was made to directly compare measured and predicted turbulent parameters probably due to the scarcity of high fidelity particle velocity data which is quite challenging to obtain using conventional particle imaging methods especially for dense beds such as bubbling fluidized beds (Gopalan et al., 2016, Naoko, 2003). For this particular challenge problem, NETL used a novel high speed particle image velocimetry technique capable of high data sampling rates and suitable for dense beds. The measured particle velocity data is processed to extract the fluctuating velocity, turbulent granular temperature, turbulent kinetic energy and turbulent dispersion coefficients. These quantities are compared against results obtained from CFD simulations based on the Euler-Euler approach with closures from the KTGF. Unlike previous studies the multi-scale nature of fluidization is considered in our study by applying the wavelet decomposition to the solid particle velocity data. The remainder of the paper is organized as follows; section 2 describes the experimental bubbling fluidized bed test rig, section 3 is a description of the CFD model and the simulation set up, results are reported and discussed in section 4 and finally the conclusions drawn from the work are given in section 5.

2.0 Experimental

The experimental set up consists of a thin rectangular bubbling fluidized bed, 0.075 m depth, 0.23 m width and 1.22 m length. Figure 1 shows the schematic diagram of the 2D geometry.

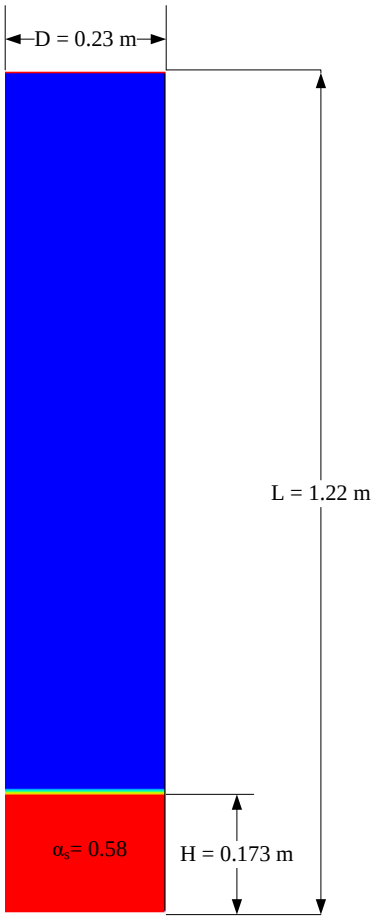


Fig. 1: 2D schematic of the rectangular bubbling fluidized bed.

Nylon-beads with a Sauter mean diameter of 3256 µm and particle density of 1131 kg/m^3 classified as Geldart D type particles were used in the experiments fluidized by air at ambient conditions. The complete physical properties of the particles are presented in Table1. Three experimental runs were carried out at superficial gas velocities of 2.19 m/s, 3.28 m/s and 4.38 m/s corresponding to roughly 2U_{mf}, 3U_{mf} and 4U_{mf} respectively. These runs are also referred to as case 1, case 2 and case 3 respectively in the text. Eulerian particle velocity measurements were taken at five lateral positions of 0.02356 m, 0.06928 m, 0.115 m, 0.16072 m and 0.20644 m at a height of 0.0762 m above the gas distributor using HsPIV (Gopalan and Shaffer, 2012) at sampling rates of 1, 1.2 and 1.5 kHz respectively corresponding to the three cases. Granular temperatures were calculated from the Eulerian particle velocity measurements following (Gopalan and Shaffer, 2012) and provided by NETL. A low pressure transducer (1Hz) was used to measure the mean pressure drop while a high pressure transducer (1 kHz) was used for rms and time series measurements at the taps located at heights of 0.0413 m and 0.3461 m above the distributor plate.

Table 1:Particle properties

physical property	units	Nylon beads
minimum fluidization velocity	m/s	1.05
bed height at minimum fluidization	m	0.173
void fraction (fluffed)	-	0.42
particle density	kg/m^3	1131
particle size (Sauter mean diameter)	µm	3256
sphericity	-	0.94
particle-wall coefficient of restitution (normal)	-	0.92
particle-particle coefficient of restitution (normal)	-	0.84
terminal velocity	m/s	9.94

3.0 CFD model and simulation set up

A two fluid model (TFM) with closures from the KTGF (Ding and Gidaspow, 1990) was utilized for this work. Momentum and continuity equations were solved for the gas and solid phases on a 2D mesh created using **GAMBIT 2.4.6** and exported into **ANSYS Fluent 15**, a commercial CFD software package used to run the simulations. The second order upwind scheme was used to discretize momentum and granular temperature equations; QUICK scheme for the spatial discretization of the volume fraction, the first order implicit scheme was used for the transient formulation and Phase Coupled SIMPLE for pressure–velocity coupling. The Syamlal O'Brien drag correlation (Syamlal and O'brien, 2003) tuned based on the measured minimum fluidization velocity was used to model the interaction between the gas and solid phases. An initial mesh sensitivity study revealed that a mesh size of 5 mm is sufficient to guarantee mesh independence. Moreover preliminary simulations using both 2D and 3D geometry showed that 2D simulations gave better predictions of the dynamical features such as the dominant frequencies of the pressure drop and particle velocity. The full granular temperature partial differential equation was used. Case 1 i.e. $U_g = 2U_{mf}$ was initialized using the minimum fluidization condition while the second and third cases corresponding to $U_g = 3U_{mf}$ and $U_g = 4U_{mf}$ respectively were initialized from the corresponding previous final converged solutions and all the cases were run for a total of 40 s with data sampling for time statistics activated after 15 s at which the flow achieved pseudo steady state as monitored from the pressure drop fluctuations. The velocity inlet and pressure outlet boundary conditions were specified at the bed inlet and outlet respectively meanwhile the Johnson and Jackson boundary condition (Johnson and Jackson, 1987) was imposed for the solid phase at the walls while the gas phase was modeled using the no-slip boundary condition. A Specularity coefficient of 0.5 was used for case 1 and 0.05 for case 2 and 3 respectively. These values were arrived at by conducting a parametric study of different specularity coefficient values for each case. A summary of the CFD model is given in Table 2 below.

Table 2: CFD model equations

Mass conservation of phase k

(k = g for gas and s for solid phase)

$$\frac{\partial}{\partial t}\left(\alpha_k \rho_k\right)+\nabla\cdot\left(\alpha_k \rho_k \mathbf{u}_k\right)=0$$

$$\sum_{k=1}^{n}\alpha_k = 1$$

Momentum conservation for solid phase:

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s \mathbf{u}_s\right)+\nabla\cdot\left(\alpha_s \rho_s \mathbf{u}_s \mathbf{u}_s\right)=\nabla\cdot\overline{\overline{\tau}}_s-\alpha_s\nabla p\text{-}\nabla p_s+\beta_{gs}\left(\mathbf{u}_g-\mathbf{u}_s\right)+\alpha_s\rho_s\mathbf{g}$$

Momentum equation for gas phase:

$$\frac{\partial}{\partial t}\left(\alpha_g \rho_g \mathbf{u}_g\right)+\nabla\cdot\left(\alpha_g \rho_g \mathbf{u}_g \mathbf{u}_g\right)=\nabla\cdot\overline{\overline{\tau}}_g-\alpha_g\nabla p-\beta_{gs}\left(\mathbf{u}_g-\mathbf{u}_s\right)+\alpha_g\rho_g\mathbf{g}$$

Granular Temperature equation

$$\frac{3}{2}\left[\frac{\partial}{\partial t}\left(\alpha_s \rho_s \Theta_s\right)+\nabla\cdot\left(\alpha_s \rho_s \mathbf{u}_s \Theta_s\right)\right]=\left(-p_s\overline{\overline{I}}+\overline{\overline{\tau}}_s\right):\nabla\mathbf{u}_s+\nabla\cdot\left(\kappa_s\nabla\Theta_s\right)-\gamma_s-3\beta_{gs}\Theta_s$$

Constitutive equations for interphase momentum transfer

Syamlal O'Brien drag model

$$\beta_{gs}=\frac{3}{4}\frac{\alpha_s\alpha_g\rho_g}{v_{rs}^2 d_s}C_D\left(\frac{Re_s}{v_{rs}}\right)\left|\mathbf{u}_g-\mathbf{u}_s\right|$$

$$C_D=\left(0.63+\frac{4.8}{\sqrt{Re_s/v_{rs}}}\right)^2,\quad Re_s=\frac{\rho_g\left|\mathbf{u}_g-\mathbf{u}_s\right|d_s}{\mu_g}$$

$$v_{rs}=0.5\left[A-0.06Re_s+\sqrt{\left(0.06Re_s\right)^2+0.12Re_s\left(2B-A\right)+A^2}\right]$$

$$A=\alpha_g^{4.14}\text{ and }B=P\alpha_g^{1.28}\text{ for }\alpha_g\le 0.85$$

$$A=\alpha_g^{4.14}\text{ and }B=\alpha_g^{Q}\text{ for }\alpha_g>0.85$$

P=0.932 and Q=1.713

Constitutive equations based on the KTGF

Solid phase stress tensor

$$\overline{\overline{\tau}}_s=\alpha_s\mu_s\left[\nabla\mathbf{u}_s+\left(\nabla\mathbf{u}_s\right)^T\right]+\alpha_s\left(\lambda_s-\frac{2}{3}\mu_s\right)\nabla\cdot\mathbf{u}_s\overline{\overline{I}}$$

Gas phase stress tensor

$$\overline{\overline{\tau}}_g=\alpha_g\mu_g\left[\nabla\mathbf{u}_g+\left(\nabla\mathbf{u}_g\right)^T\right]-\frac{2}{3}\alpha_g\mu_g\left(\nabla\cdot\mathbf{u}_g\right)\overline{\overline{I}}$$

Solids pressure

$$p_s=\alpha_s\rho_s\left[1+2\left(1+e\right)\alpha_s g_0\right]\Theta_s$$

Bulk solid viscosity

$$\lambda_s=\frac{4}{3}\alpha_s^2\rho_s d_s g_0(1+e)\sqrt{\frac{\Theta_s}{\pi}}$$

Shear viscosity of solids

$$\mu_s = \mu_{s,kin} + \mu_{s,col} + \mu_{s,fr}$$

Kinetic viscosity, $\mu_{s,kin}$

$$\mu_{s,kin} = \frac{10\rho_s d_s\sqrt{\pi\Theta_s}}{96\alpha_s(1+e)g_0}\left[1+\frac{4}{5}(1+e)g_0\alpha_s\right]^2\alpha_s$$

Collisional viscosity, $\mu_{s.col}$

$$\mu_{s.col} = \frac{4}{5}\alpha_s\rho_s d_s g_0(1+e)\sqrt{\frac{\Theta_s}{\pi}}\alpha_s$$

Frictional viscosity $\mu_{s,fr}$

$$\mu_{s,fr} = \frac{p_s\sin\phi}{2\sqrt{I_{2D}}}$$

Diffusion of granular temperature

$$\kappa_s = \frac{150\rho_s d_s\sqrt{\Theta_s\pi}}{384(1+e)g_0}\left[1+\frac{6}{5}\alpha_s g_0(1+e)\right]^2 + 2\rho_s d_s\alpha_s^2 g_0(1+e)\sqrt{\frac{\Theta_s}{\pi}}$$

Collisional dissipation of solid particle fluctuating energy

$$\gamma_s = \frac{12(1-e^2)g_0}{d_s\sqrt{\pi}}\rho_s\alpha_s^2\Theta_s^{3/2}$$

Radial distribution function

$$g_0 = \left[1-\left(\frac{\alpha_s}{\alpha_{s,max}}\right)^3\right]^{-1}$$

wall boundary conditions

$$\overset{\mathrm{r}}{\tau}_s = -\frac{\pi}{6}\sqrt{3}\phi\frac{\alpha_s}{\alpha_{s,\max}}\rho_s g_0\sqrt{\Theta_s}\overset{\mathrm{r}}{U}_{s,\mathrm{P}}$$

$$q_s = \frac{\pi}{6}\sqrt{3}\frac{\alpha_s}{\alpha_{s,\max}}\rho_s g_0\sqrt{\Theta_s}\overset{\mathrm{r}}{U}_{s,\mathrm{P}}\cdot\overset{\mathrm{r}}{U}_{s,\mathrm{P}} - \frac{\pi}{4}\sqrt{3}\frac{\alpha_s}{\alpha_{s,\max}}\left(1-e_{sw}^2\right)\rho_s g_0\Theta_s^{\frac{3}{2}}$$

4.0 Results and Discussion

4.1 Fluctuating particle velocity

Turbulence is generally defined as fluctuations around a mean flow (Joshi et al., 2009) . In multiphase reactors such as gas-solid fluidized beds random particle velocity fluctuations are useful for characterizing turbulence. The values of the second (standard deviation or root mean square), third (skewness) and fourth (kurtosis also known as flatness factor) of the fluctuating velocity give valuable information about the nature of the flow. Moreover turbulent properties such as Reynolds stresses, turbulent granular temperature, turbulent kinetic energy and eddy diffusivities are computed from the

fluctuating velocity. In addition the fast Fourier transform (FFT) applied to the time series of the fluctuating velocity yields an energy spectrum which gives a picture of the energy interplay between different flow structures as already demonstrated in our previous works (Lungu et al., 2014, Lungu et al., 2016) . The fluctuations are believed to arise as a result of the passage of coherent structures and random irrational motion (Joshi and Nandakumar, 2015b). The coherent structures appear at the low frequencies of the energy spectrum as dominant peaks meanwhile at the high frequency end of the spectrum there is a sharp fall off which obeys a power fall off law due to the dissipation of the turbulent kinetic energy into thermal energy.

From the foregoing it is quite clear that the fluctuating particle velocity data contains plethora of information for characterizing turbulence in multiphase reactors. Figure 2 shows the comparison of the predicted and measured particle fluctuating velocity at d/D = 0.0 and height 0.0762 m for the three cases. The fluctuating velocity is calculated by subtracting the instantaneous velocity from the mean velocity for a given particle velocity time series. As aforementioned in the experimental section, the measured particle velocity was sampled at 1000 Hz, 1200 Hz and 1500 Hz for total sampling times of 21.096 s, 17.88 s and 14.665 s respectively for the three cases. Meanwhile, from the simulations the particle velocity was extracted at a rate of 200 Hz. The measured particle was resampled at a rate of 200 Hz using a MATLAB standard built in resampling function and there after the fluctuating velocity was computed and compared with the numerical predictions. The simulations and measurements alike show severe slugging from the fluctuating particle velocity data for all the three cases which is quite typical for Geldart D particles. Qualitative agreement between the simulations and experimental measurements is quite reasonable especially for cases 1 and 2 whereas for case 3 the fluctuating intensity of the predicted fluctuating velocity seems more pronounced. The discrepancy might be due to uncertainties in the handling of the experimental data because with increasing superficial gas velocities, larger voids and slugs are expected which seems to be bot the case with the measured data. For all the three cases, the fluctuations from the simulations are larger probably due to the 2D geometry used in the modeling work neglecting the front and back wall friction which then results in slightly higher particle velocities.

Eddies are multi-scale consisting of different length and time scales and with different energy contents. The discrete wavelet analysis is a powerful tool for studying the multi-scale scale of fluidization and which is yet to reach its full potential (Van Ommen et al., 2011) . For the purpose of demarcating the three principal scales in fluidized beds, that is the micro scale associated with individual particle motion, meso-scale structures associated with particle clusters and bubbles and the macro-scale linked to the equipment/unit (Zhao and Yang, 2003, Breault et al., 2012, Chew et al., 2012), an analysis of the normalized wavelet energy is necessary. The objective here is to assess the accuracy of the TFM in capturing the multi-scale nature of fluidization. The description of the procedure for evaluating the normalized wavelet energy is reported in our previous work (Lungu et al., 2016). A 9 scale 1D DWT was performed on the predicted and measured fluctuating velocity signals at different lateral positions in both the lateral and axial directions. A sampling frequency of 200 Hz gives a Nyquist frequency of 100 Hz which is sufficient for the study of the phenomena at the 3 different scales. Table 3 below gives the frequency bands for the 9 level wavelet decomposition.

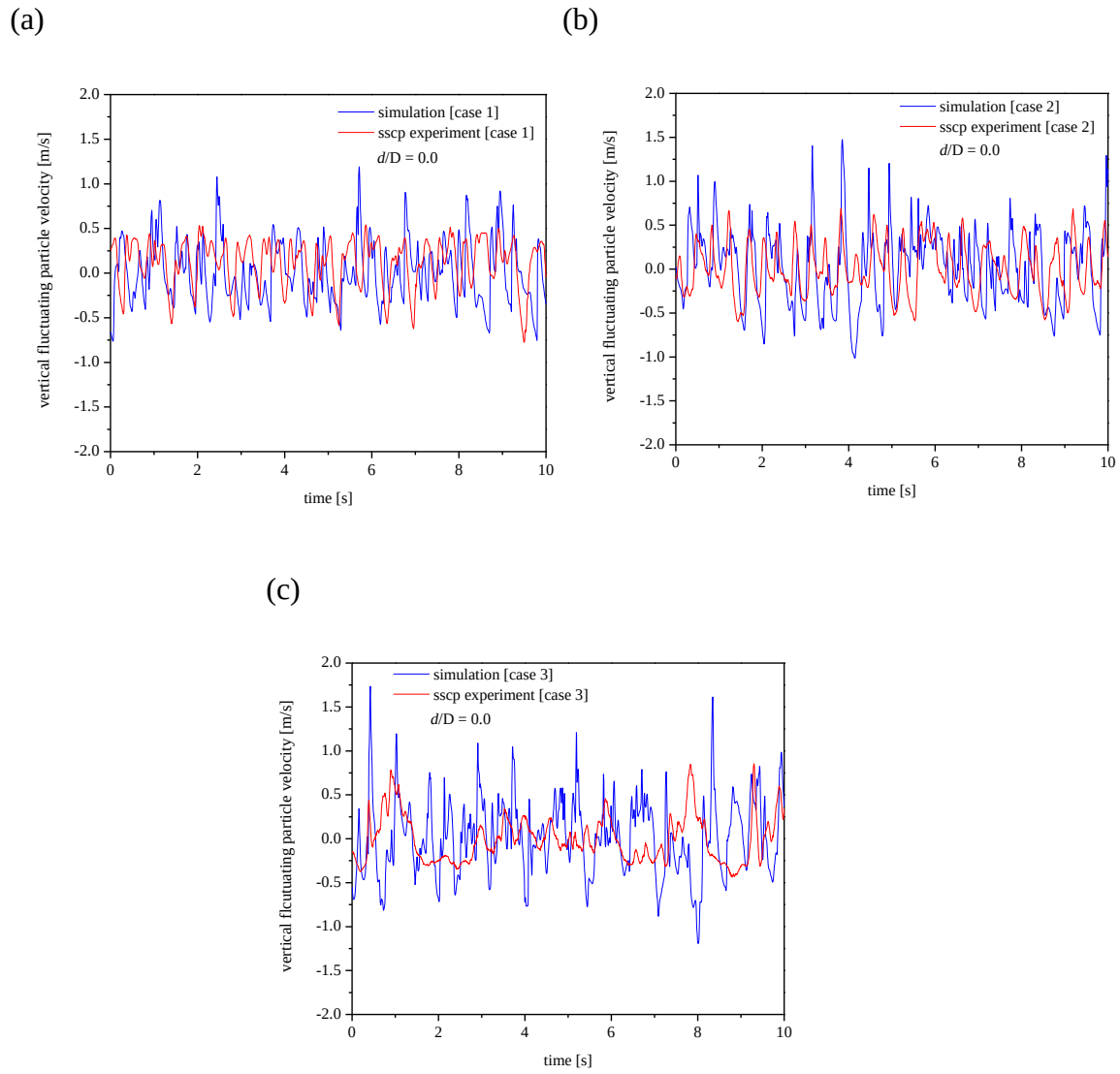


Fig. 2: Comparison of the particle fluctuating velocity computed from measurements and simulations at d/D = 0.0 for the three cases.

Table 3:Frequency bands of the 10th scale wavelet decomposition of signal sampled at 200 Hz

D_j	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*	*A9*
f [Hz]	50-100	25-50	12.5-25	6.25-12.5	3.13-6.25	1.56-3.13	0.78-1.56	0.39-0.78	0.20-0.39	0-0.20

Figure 3 compares the normalized wavelet energy of the predicted and measured fluctuating particle velocity signals in the axial directions at a height of 0.0762 m above the distributor at the bed center (*d*/D = 0.0) and near the wall (*d*/D = 0.795). It can be seen from the figure that most on the energy content lies in the level *D*4-*D*8 for both the positions in the bed. This range corresponds to the meso-scale and in bubbling beds it is associated with the bubble motion as demonstrated by Zhao and Yang (Zhao and Yang,

2003). In column type equipment, energy is supplied through the introduction of phases (Joshi and Nandakumar, 2015a) and in the case of gas-solid fluidized beds, the gas is supplied against the static pressure of the bed. This explains why this scale has the bulk of energy content. A closer inspection of the levels within this scale shows that level *D*6 is the most dominant particularly for the experimental measurements. Spectral analysis of the pressure drop fluctuations between the taps 0.0413 m and 0.3461 m above the distributor plate gives a dominant frequency of 1.61 Hz from the CFD predictions and 1.71 Hz from the experimental measurements which further confirms that the meso-scale is associated with the bubble oscillation in the case of bubbling beds.

(a) (b)

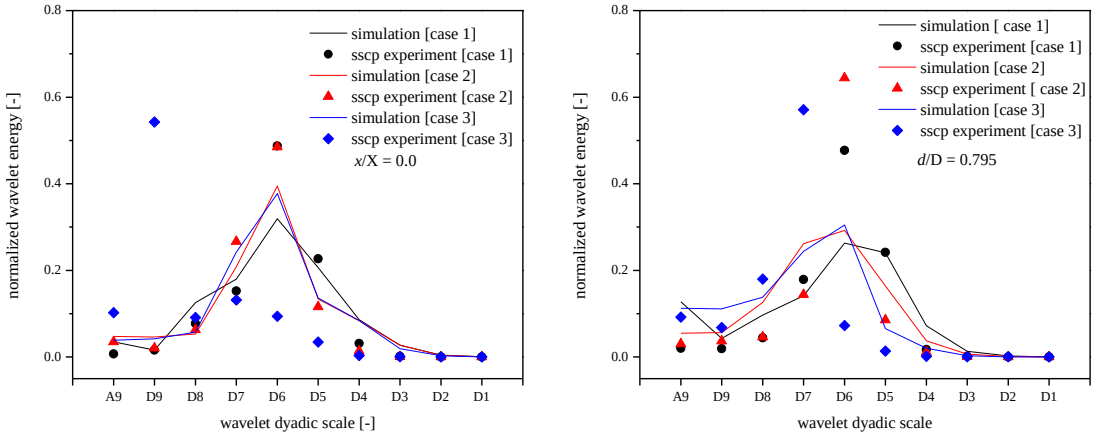


Fig. 3: Comparison of predicted and measured particle velocity normalized wavelet energy at (a) d/D = 0.0 and (b) d/D = 0.795 at a height of 0.0762 m above the plate distributor.

Levels *D*1-*D*3 corresponds to the high frequency micro-scale associated with individual particle movement while level *D9* and *A*9 are assigned to the low frequency macro-scale associated with the whole system. The energy content of the micro-scale represents a tiny fraction of the total energy because this is typically the energy dissipation region with the primary scale of turbulence in the order of a particle diameter (Joshi and Nandakumar, 2015a). The general trend of the energy distribution between the different scales from the numerical predictions and measurements are in reasonable agreement though the energy distribution of the measured signal peaks at a higher maximum in comparison to the predicted energy distribution. The discrepancy between the two might be attributed to the inadequacy of the CFD model to describe the interaction between the emulsion and bubble phases (meso-scale).

4.2. Mean particle velocity profiles

Figure 4 displays lateral profiles of the predicted and measured mean lateral and axial particle velocities computed at a height of 0.0762 m above the plate distributor. The predicted lateral and axial mean particle velocities agree reasonably well with the experimental measurements. In Figure 4a the lateral velocity switches from positive to negative moving from the left to the right plane of the bed due to circulation cells rising in the middle and falling down near the walls.

(a) (b)

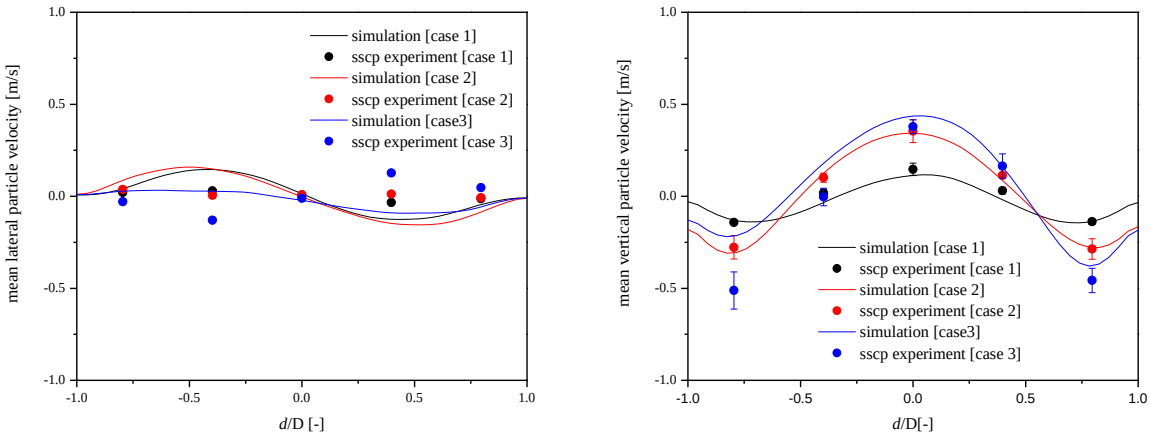


Fig. 4: Comparison of predicted and measured (a) mean lateral particle velocity and (b) mean axial particle velocity at a height of 0.0762 m above the plate distributor.

From Figure 4b, the CFD model gives better prediction of the mean velocity profile in comparison to the lateral profiles for all the three cases. The axial particle velocity parabolic profile implies that the voids and slugs move upwards at the center carrying the particles along with them and upon bursting on the surface the particles are released and fall downwards near the wall under the influence of gravity.
To get a better view of the solids circulation pattern, vector plots of the predicted mean velocity magnitude of the solids are given in Figure 5 for the three cases investigated. From the figure it can be seen that the particles move predominantly downwards near the walls and upwards in the center thus creating two counter rotating gross circulation cells and with increasing superficial gas velocity, the cells become larger thus promoting mixing in the fluidized bed. In contrast to Geldart B type particles which exhibit multi-circulation patterns that is a low circulation pattern and the main circulation pattern (Wang et al., 2009).

4.3 Anisotropic coefficient

The degree of anisotropy in the turbulent flow can be described using the anisotropy coefficient which is simply the ratio of the axial second order statistical particle velocity moment (axial rms particle velocity) to the lateral second order statistical particle velocity moment (lateral rms particle velocity) . The closer the ratio to 1, the lesser the anisotropy of the flow. From Figure 5, simulations and experiments alike show that the lateral profile of the anisotropic coefficient is relatively flat in the core of the bed and then sharply increases approaching the walls. The presence of the slugs and voids predominantly passing through the center of the column results in the flat profile of the coefficient unlike near the walls where the bubble motion is restricted which then leads to a sharp increase in the anisotropy.

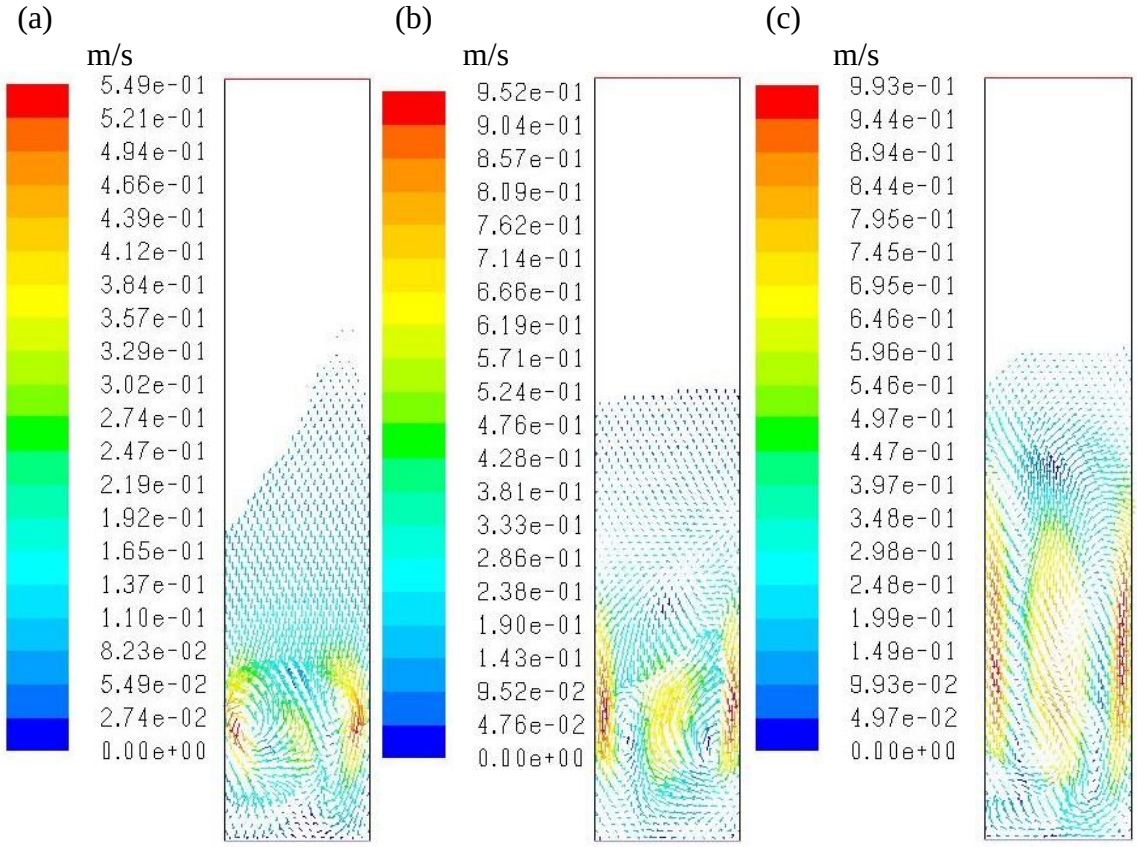


Fig. 5: Vector plots of predicted mean velocity magnitude for Nylon beads at superficial gas velocities of (a) 2.19 m/s (b) 3.28 m/s and (c) 4.38 m/s.

Moreover the coefficient reduces with increasing superficial gas velocity especially in the bed core. This can be explained by appreciating the fact that higher superficial gas velocities result in larger voids and slugs which dampens the anisotropy. Therefore in the bed center the voids are responsible for a high degree of mixing which brings about the uniform flat profile unlike near the wall where clustering of particles takes place. Although the numerical simulations captures the profile of the anisotropy from experimental measurements quite well, the actual values are under predicted which infers that the predicted anisotropic coefficients approaches 1 due to similar magnitudes of the lateral and axial particle fluctuations. This can be attributed to the current isotropic KTGF closure model which is based on the Maxwellian particle velocity distribution. The underlying assumption of the Maxwellian function is the homogeneous distribution of particles which is in contradiction to observed particle velocity probability distributions from experimental setups (Wang et al., 2016).

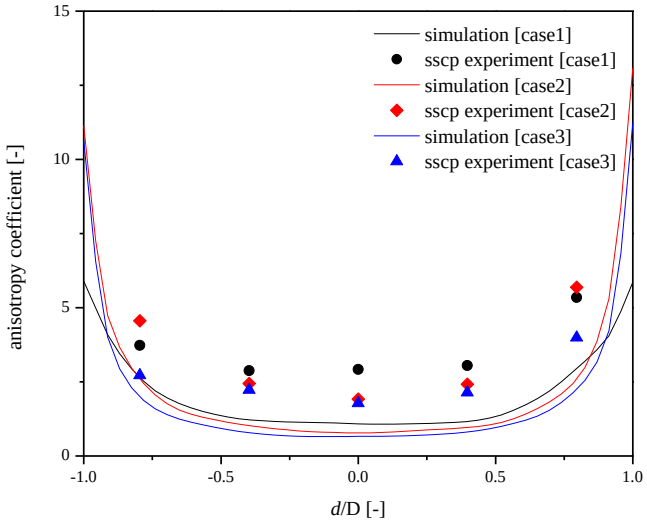


Fig. 5: Lateral profiles of predicted and measured anisotropy coefficient at a height of 0.0762 m above the distributor for the three cases.

4.4 Reynolds Stresses

One of the prominent features of turbulent flow is the occurrence of additional stresses due to random velocity oscillations (Jiradilok et al., 2006). Reynolds stresses are defined as normal if the same direction of flow is considered and as shear if two different directions of flow are under consideration, i.e. normal Reynolds stresses are defined as:

$$\overline{u_i' u_i'} = \frac{1}{m}\sum_{k=1}^{m}\left(u_{ik}(x,t) - \bar{u}_i(x)\right)\left(u_{ik}(x,t) - \bar{u}_i(x)\right) \tag{1}$$

where

$$\bar{u}_i(x) = \frac{1}{m}\sum_{k=1}^{m} u_{ik}(x,t) \tag{2}$$

and shear Reynolds stresses are defined as:

$$\overline{u_i' u_j'} = \frac{1}{m}\sum_{k=1}^{m}\left(u_{ik}(x,t) - \bar{u}_i(x)\right)\left(u_{jk}(x,t) - \bar{u}_j(x)\right) \tag{3}$$

similarly

$$\bar{u}_j(x) = \frac{1}{m}\sum_{k=1}^{m} u_{jk}(x,t)$$

(4)

Figure 6 displays the lateral and axial normal Reynolds stresses computed from measured and predicted hydrodynamic particle velocities. From the figure it is quite evident that numerical simulations significantly over predict the stresses. The deviation between measurement and predictions is more pronounced in the lateral direction and this can be explained by the inability of the CFD model to capture the lateral particle velocity adequately, an observation made in previous challenge problems (Breault et al., 2010). The stresses terms are squared terms and thus the difference between the measurements and predictions become quite appreciable in comparison to the mean velocity profiles. Nonetheless, the CFD model qualitatively captures the profiles of the normal stresses quite well. The lateral normal Reynolds stresses exhibit a maximum at the center (Figure 6a) whereas the axial normal Reynolds stresses exhibit a maximum near the wall region (Figure 6b).

(a) (b)

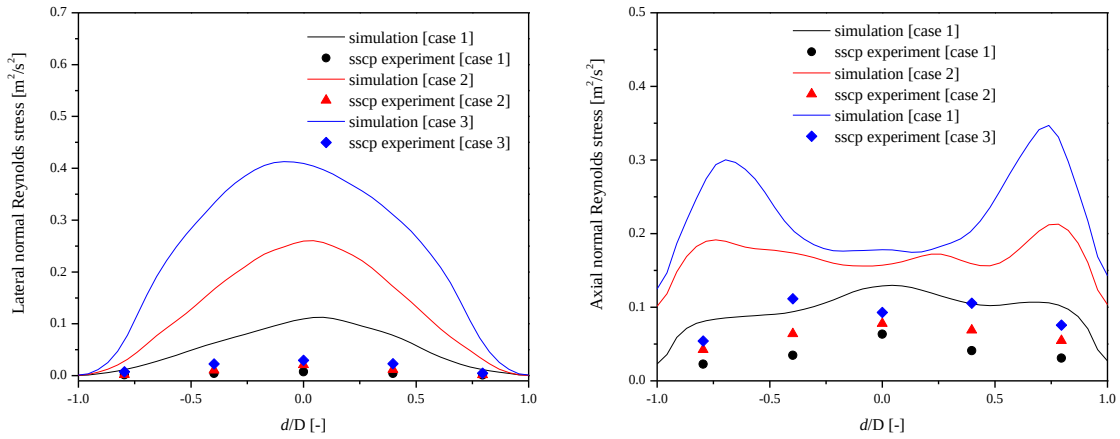


Fig. 6: Lateral profiles of (a) lateral and (b) axial normal Reynolds stresses computed from measurements and numerical simulations.

A similar observation was made in bubble columns (Mudde et al., 1997 , Pan et al., 1999) and PSRI riser (Chalermsinsuwan et al., 2009). The characteristic shape of the profiles reflect the oscillation of the large scale structures in the fluidized bed which rise upwards at the bed center and dynamically change direction from upwards to downwards near the wall. In the case of the lateral Reynolds normal stress profile, the maximum peak at the center is a result of the lateral velocity magnitude which is maximum at the center. Moving towards the walls, the magnitude of the lateral normal Reynolds stresses reduces owing to the diminishing contribution of the lateral fluctuations. On the other hand the axial Reynolds stress peaks near the wall region particularly for cases 2 and 3 from the numerical predictions are due to the switching of the flow from upwards (positive direction) to downwards (negative direction). Thus the solids velocity fluctuations in this region are rather intense resulting in higher axial stresses. The axial normal Reynolds

stresses computed from experimental measurements are larger than the corresponding lateral stresses unlike the stresses from the simulations which are nearly of the same magnitude. This is consistent with the anisotropy coefficient computation in Figure 6 which is higher in experimental measurements and attributable to the isotropic KTGF. Thus alternative kinetic theories which take into account the highly anisotropic nature of the gas-solid flow are required to improve the model predictions. Efforts are underway be different research groups to develop such models.

4.5 Turbulent eddy diffusivity

The normal Reynolds stresses along with the characteristic time estimated from the autocorrelation function (acf) of the fluctuating velocity are used to compute the turbulent dispersion coefficient or eddy diffusivity (Kulkarni and Joshi, 2005, Jiradilok et al., 2006, Kashyap et al., 2011a) expressed as:

$$D_i = \overline{u_i' u_i'} T_L \tag{5}$$

where D_i is the dispersion coefficient or eddy diffusivity, $\overline{u_i' u_i'}$ is the normal Reynolds stress or the variance of the particle velocity at a particular location and T_L is the Lagrangian time scale mathematically expressed as (Jiradilok et al., 2006, Kashyap et al., 2011a):

$$T_L = \int_0^\infty R_L(i,\tau)\, d\tau \tag{6}$$

where

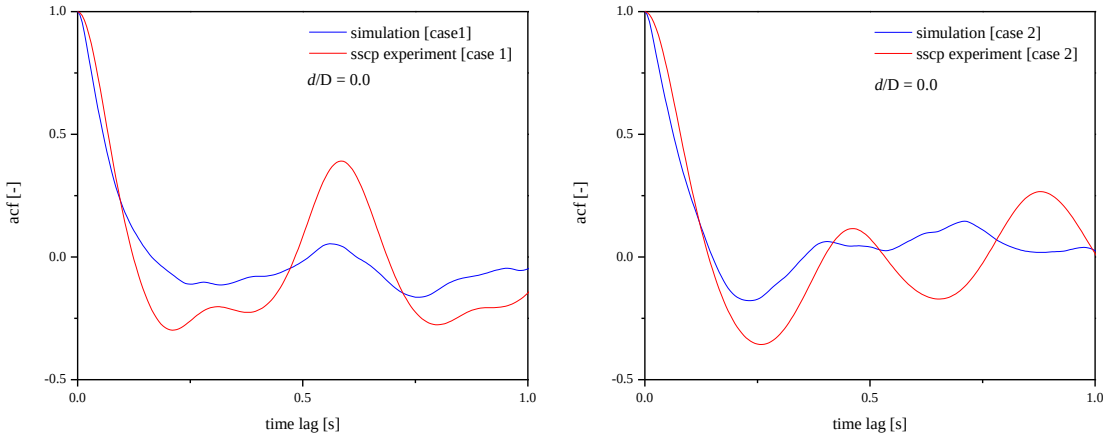
$$R_L(i,\tau) = \frac{\overline{u'(t)u'(t+\tau)}}{\overline{u'^2}} \tag{7}$$

That is the acf of the particle fluctuating velocity. T_L is simply the area under the acf versus time lag curve up to the first zero crossing (Breault et al., 2008), other researchers like (Bai et al., 2012) estimated T_L as the time for the acf to decrease to 1/*e* of its initial value. The assumption underlying the use of this method is that the time step is sufficiently small and the length of time under which the computation is done is $10T_L$ (Breault et al., 2008) , both criteria are satisfied in our work. It is worth mentioning that although the experiments and simulations were carried out in a Eulerian framework, the Lagrangian integral time scale is equated to the Eulerian integral time scale according to the expression $T_L = \beta_{HP} T_{L,}$ where β_{HP} is the so called Hay and Pasquill coefficient and is equated to 1(Kashyap et al., 2011b, Kashyap et al., 2011a). The subscript *i* denotes the Cartesian coordinate i.e. *x*-coordinate or *y*-coordinate. Figure 7 compares the acf of the axial particle fluctuating velocity at the bed center computed from CFD simulations and measurements for the three superficial gas velocities. The acf is unity at a time lag of zero (non-mixed) and decays to zero (mixed) with increasing time lags however we have shown the acf only up to a time lag of 1 s for clarity.

A trend can be observed in the acf from both the predictions and simulations in which the periodicity of the function increases moving from case 1 to case 2 and then decreases

going to case 3. A similar trend was observed in the acf of the pressure drop fluctuations (Lungu et al., 2016) and it signals a transition in the fluidization regime from bubbling/slugging to turbulent. Another noteworthy observation between the predicted and measured acf of the fluctuating velocity is that the measured acf exhibits strong correlation in comparison to the predicted acf implying lower quality of mixing in comparison to the predictions and this is reflected in the higher predicted dispersion coefficients as will be later on demonstrated.

(a) (b)



(c)

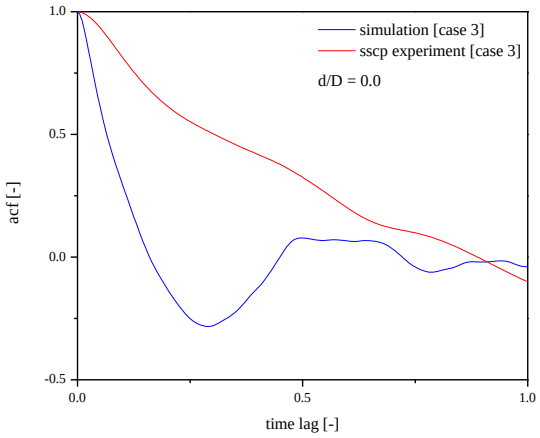


Fig. 7: Comparison of the autocorrelation function of the measured and predicted axial particle fluctuating velocity at the bed center for (a) case1 (b) case 2 and (c) case 3.

A trend can be observed in the acf from both the predictions and simulations in which the periodicity of the function increases moving from case 1 to case 2 and then decreases going to case 3. A similar trend was observed in the acf of the pressure drop fluctuations (Lungu et al., 2016) and it signals a transition in the fluidization regime from bubbling/slugging to turbulent. Another noteworthy observation between the predicted and measured acf of the fluctuating velocity is that the measured acf exhibits strong correlation in comparison to the predicted acf implying lower quality of mixing in comparison to the predictions and this is reflected in the higher predicted dispersion coefficients as will be later on demonstrated.

Figure 8 compares the turbulent dispersion coefficients with some literature values (Thiel and Potter, 1978, Avidan and Yerushalmi, 1985, Du et al., 2002, Jung et al., 2005, Jiradilok et al., 2008, Chalermsinsuwan et al., 2011, Kashyap et al., 2011a). Dispersion coefficients values in the literature vary widely albeit due to the different methods used in acquiring the coefficients, operating conditions, physical properties of the materials and so on. Of the different approaches to computing dispersion coefficients either from experimental measurements or CFD simulations, the acf method just outlined seems to be the most widely used (Breault et al., 2008, Jiradilok et al., 2006, Jiradilok et al., 2007, Jiradilok et al., 2008, Chalermsinsuwan et al., 2009, Kashyap and Gidaspow, 2011b, Kashyap et al., 2011b, Kashyap et al., 2011a, Chalermsinsuwan et al., 2011). The axial dispersion coefficient of the Nylon beads (Geldart D) used in this study is quite low compared to the reported values in the literature from the figure possibly due to the measurement location i.e. in the dense bed at a height of 0.0762 m above the distributor. The axial dispersion coefficients reported by (Kashyap et al., 2011a) are the only values that are lower compared to our results. These authors similarly used the acf method to compute the dispersion coefficients. They attributed the low values to low Lagrangian/Eulerian time scales and the non-ideal measuring location i.e. near the wall, besides they used high superficial gas velocities of 7.56 m/s and 7.57 m/s.

(a) (b)

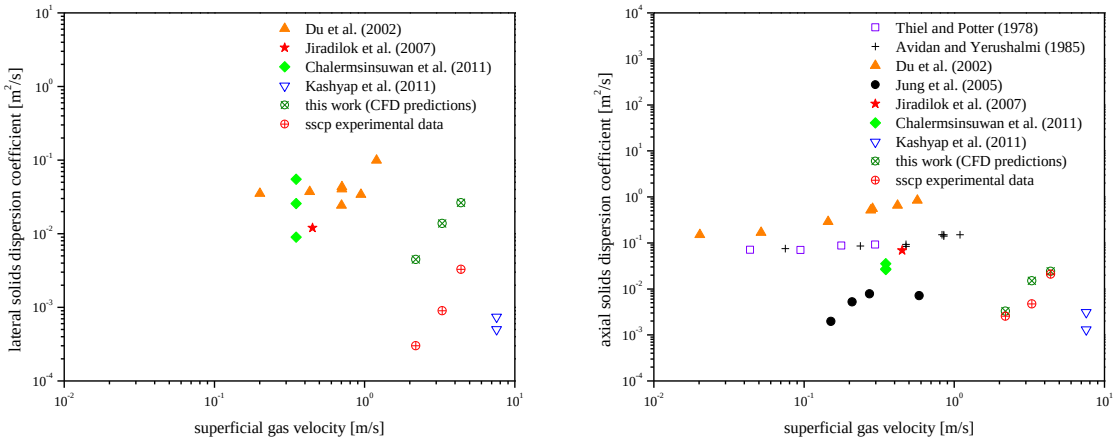


Fig. 8: Variation of (a) lateral and (b) axial solids dispersion coefficients (predicted and measured) with superficial gas velocity.

A similar observation can be made regarding the lateral dispersion coefficients. The difference between lateral dispersion coefficients computed from the CFD simulations and experimental measurements is quite significant once again revealing the poor capturing of the lateral transport mechanism by the CFD model.

4.6 Granular temperature

There exists two types of granular temperatures in gas-solid fluidized systems (Jung et al., 2005, Gidaspow and Arastoopour, 2014), the first kind is associated with individual particle oscillation and is termed laminar granular temperature or better known as the classical granular temperature. It is computed from the common CFD codes by solving the granular temperature equation in Table 2 while it is experimentally determined particle velocity measurements from PIV techniques (Kashyap et al., 2011a, Gopalan and Shaffer, 2012, Gopalan et al., 2016). The second type of granular temperature is associated with particle clusters or bubbles and is known as the turbulent granular temperature and it is computed from the normal Reynolds stress per unit bulk density. Similar to the laminar granular temperature, it is experimentally calculated from PIV data. The turbulent granular temperature is calculated from the normal Reynolds stresses as aforementioned and for a 2D geometry it is expressed as (Jiradilok et al., 2006)**:**

$$\theta_{turbulent} = \frac{1}{3}\overline{u_y' u_y'} + \frac{2}{3}\overline{u_x' u_x'} \tag{8}$$

where u_y' and u_x' are the fluctuating velocities in the vertical and lateral directions respectively and the overbar implies time averaging. Figure 9 displays the contour plots of the predicted laminar and turbulent granular temperatures for the three test cases. The laminar granular temperature is low in the dense bed and high in the dilute upper portion of the column as can be seen from Figure 10a. Meanwhile Figure 10b shows the opposite trend that is the turbulent granular temperature is high in the dense bed and low in the upper dilute portion of the bed. This result is consistent with previously reported work in the literature (Lungu et al., 2014, Chalermsinsuwan et al., 2011). This implies that mixing in the dense bed is primarily due to the bubble oscillations while in the dilute bed it is due to individual particle motion.

With increasing superficial gas velocity, the laminar granular temperature passes through a maximum as interpreted from the legend of the contours in Figure 10a. This might be probably due to the regime transition from bubbling/slugging to turbulent as previously demonstrated for this particular challenge problem (Lungu et al., 2016, Gopalan et al., 2016). On the contrary there doesn't seem to be such a transition or trend with the turbulent granular temperature in Figure 9b, instead an increase is observed in the magnitude of the turbulent granular temperature with increasing superficial gas velocity. This is expected since the bubble size increases with increasing superficial gas velocity and therefore an increase in the turbulent granular temperature due to the bubble oscillations is observed. The relationship between the turbulent granular temperature and turbulent kinetic energy (TKE) is $\theta_{turbulent}=2/3E$ (Jiradilok et al., 2006) , thus the contour plots of the turbulent granular temperature and TKE are similar differing only in the magnitudes.Mixing in the bed is predominantly in the center of the column which is the preferred path of the bubbles and nearly zero in the bottom corners of the wall i.e. the dead zones.

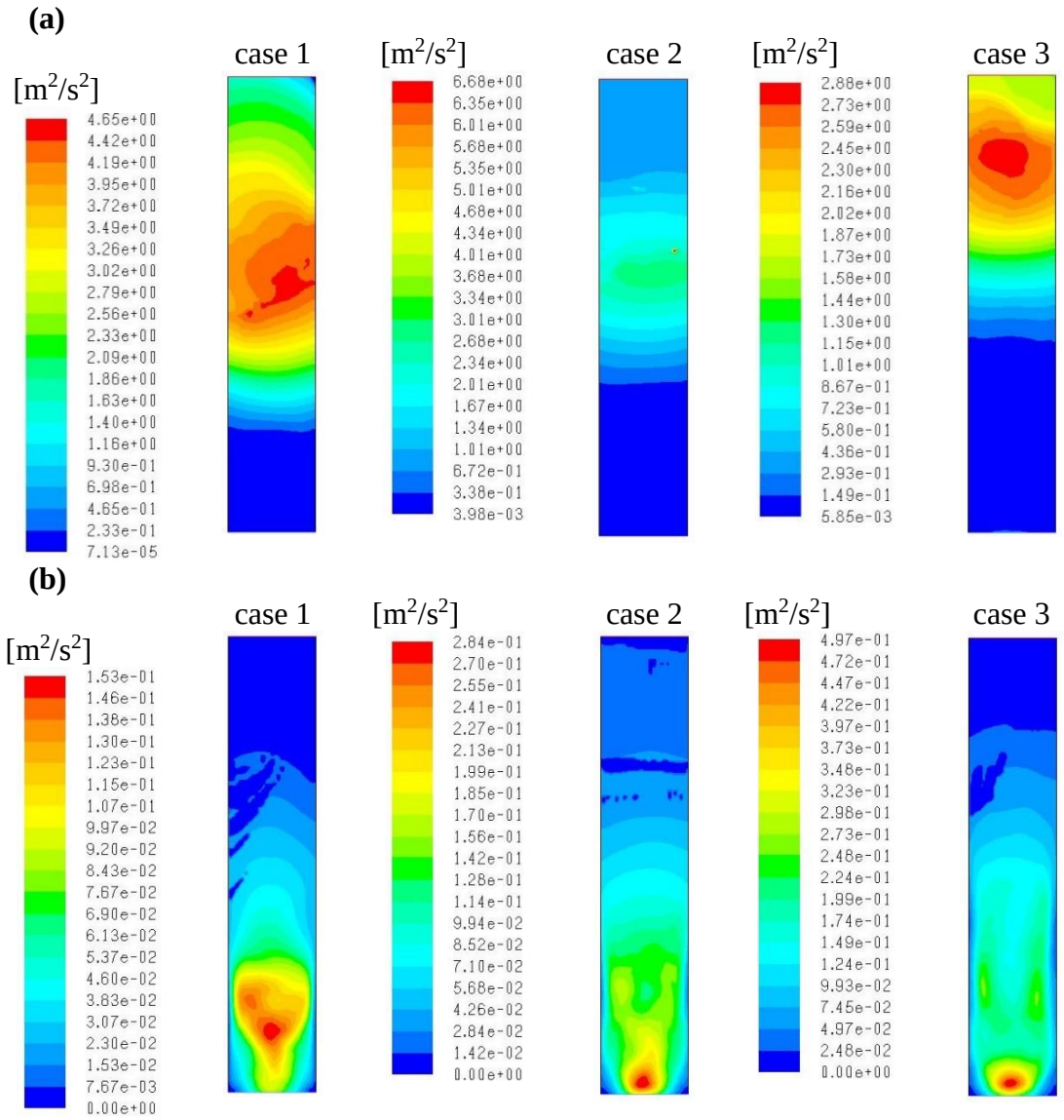


Fig. 9: Contour plots of predicted (a) classical granular temperature (b) turbulent granular temperature for cases 1, 2 and 3.

5.0 Conclusions

In this work we have performed 2D CFD simulations using the Eulerian-Eulerian framework based on the experimental set-up of the National Energy Technology Laboratory small scale challenge problem. Particle velocity data from the experimental measurements and CFD simulations are processed and used to characterize and compare the turbulence structures with the aim of testing the capabilities of the CFD code and to gain fundamental understanding of the role of the turbulent structures on mixing and transport phenomena. The normalized wavelet energy distribution of the fluctuating particle velocity can be separated into 3 principle scales, *D1-D3* representative of the micro scale, *D4-D8* representing the meso-scale and *D9-A9* representing the macro scale. The meso-scale contains the bulk of the energy and it is due to the bubble oscillation in the bed which is further confirmed by spectral analysis. The numerical simulations capture the lateral profiles of the anisotropic coefficient reasonably well however the actual values are under

predicted due to poor modeling of the lateral transport mechanism. Compared to literature values, the computed turbulent dispersion coefficients in this study are much lower probably due to the measurement location used in this study in comparison to the reported values in literature and the particle type employed i.e. Geldart D as opposed to mostly Geldart A and B reported in literature. Mixing in the dense bubbling bed is on the level of bubbles and not individual particles as revealed by comparing the two granular temperatures which is consistent with the computed dispersion coefficients. Overall the CFD model shows great promise in the validation of turbulent properties and model predictions can be greatly improved with better understanding of the lateral transport mechanism. Efforts are underway by our research group in partnership with other researchers to improve the modeling for lateral solids movement.

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Nomenclature

e particle-particle restitution coefficient [-]
E normalized wavelet energy [m]
f dominant frequency [Hz]
g acceleration due to gravity [m/s^2]
g_0 radial distribution function [-]
H bed height [m]
P pressure [pa]
Re_s particle Reynolds number [-]
t time [s]
U superficial gas velocity [m/s]
u' fluctuating velocity in the i^{th} direction [m/s]
x time series of parameter of interest

Greek symbols
α volume fraction [-]
$\alpha_{s,max}$ packing limit [-]
β_{gs} gas/solid momentum exchange coefficient [kg/m^2 s]
γ_s collisional energy dissipation [J/m^3 s]
λ_s bulk viscosity [Pa s]
θ, Θ granular temperature [m^2/s^2]
$\theta_{turbulent}$ turbulent granular temperature [m^2/s^2]
ρ density (kg/m^3)
μ viscosity (Pa s)
τ_k stress tensor of phase k (pa)

Subscripts

s	solid
g	gas
x	lateral coordinate
y	vertical coordinate
mf	minimum fluidization

Abbreviations

acf	autocorrelation function
CFB	circulating fluidized bed
CFD	computational fluid dynamics
DWT	discrete wavelet transform
FFT	fast Fourier transform
IWT	inverse wavelet transform
rms	root mean square

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Apprenticeship Training for Industrialisation: A Critical Review and Analysis

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Abstract

Technology and globalisation are significantly shifting business models in all sectors of industries, and has affected the pace of job creation as well as skills development needed for the industrialisation. There is need to promote the development of skills that should respond to the need of industry through investment in human capital. Aim of this paper is to identify the critical benefits of apprenticeship training. Methodology of Systematic Literature Review (SLR) was adopted to expand existing knowledge on apprenticeship. Secondary information from literature was collected and subjected to validation survey for raking and analysis. The findings show that ultimate benefit of apprenticeship foster innovation, productivity and quality improvements. Apprenticeship model of training provides a possible solution to increase pace of industrialisation and open up new opportunities; in aligning company practices, public policy, and training systems in-order to upswing skills needed for industries. The findings may help policy makers adopt implementation of apprenticeship training to mitigate the skills gaps.

Keywords: Apprenticeship, industrialisation, innovation, productivity, quality

1. Introduction

Technology and globalisation are significantly shifting business models in all sectors of industry and has affected the pace of job creation. Implementation of industrialisation that will help accelerate job creation and value addition in Zambia has been on priority list for the government. To achieve this vision government, launched the 7th National Development Plan (NDP) covering years from 2017 to 2021, as a guiding framework to foster development (Ministry of Finance and National Planning budget, 2018). To implement this vision, government need to promote the development of skills that should respond to the need of industry through investment in human capital. Apprenticeship model of training provides a possible solution for increasing pace of technology and open up new opportunities.

This paper focus more on identifying the critical benefits of apprenticeship, illustrated by case studies. Apprenticeship training, like other type of education, is a form of investment in human capital and has long been regarded by policy-makers in different countries as essential to both national competitive advantage and necessary for development of critical talent pool of skills.

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Apprenticeship is a unique form of education where apprentices not only learn skills in an academic setting but also learn in a practical work-based environment. The goal of the apprenticeship model is to educate the workforce in a broad range of practical skills needed for successful careers.

2. Literature review

Productivity growth in the pre-industrial era, helped achieve industrialisation because of apprenticeship training contributed to the transmission of tacit knowledge between generations. The application of tacit knowledge resulted in innovation and creation of entirely new inventions. The importance of highly skilled craftsmen who were trained through apprenticeship performed innovative activities that led to the growth of industries and technology. According to (Croix. et.al, 2017) some scholars have argued that rising artisan's skill levels and innovation fostered the industrial revolution. In many branches of production, the skills of the craftsman and the engineer, were acquired through apprenticeship, because this method of training generated ideas of inventors.

Modern scholars' advocates enhancing both apprenticeship system, as well as other forms of education in the training of skilled labour for industrialisation. Apprenticeship emphasises the notion of "learning by doing," but in combination with a theoretical understanding of the subject at hand, while the other education path combines less practical skills development acquisition, but more emphasis is applied on formal theoretical knowledge (Schuetze and Sweet, 2003).

Learning by doing generates cumulative ideas over time that can raise productivity and distribution of knowledge across workers. When young workers learn from multiple old workers, they adopt the best technique to which they have been exposed. Through this process, it triggers productivity in the industry. Croix. et.al.(2017) suggested that much of the learning occurred through apprentices learning mostly through observation, imitation, and experimentation. Apprentices spent most of their working hours in the presence of superiors and possibly more with their fellow experienced apprentices.

Apprenticeship candidates are different from one another; the differences in talent is observable. During training, most talented apprentices would be allocated to the most productive trainers. Example of this scenario: the great London machine-tool maker Joseph Bramah trained the equally famous Henry Maudslay, who in turned trained some of the best mechanics and engineers of the nineteenth century. Such level of talents in apprentices themselves is an interesting advantage of apprenticeship models studies (Croix et.al, 2017).

Policy-makers in many countries have increasingly turned towards the Germany system of apprenticeship as a model, as it is perhaps "the most comprehensive and detailed regulatory system for apprenticeship training in Europe" (Muehlemann and Wolter, 2014). It has been associated with high levels of skilled labour, superior competitive advantage and even the moderation of trends towards rising wage inequality. The system is generally viewed as an important contributor to Germany's economic success, resulting in much lower youth unemployment than other European countries.

Germany's vocational training, is implemented in a dual system that combines education and training. The country's Vocational Training Act provides for more than 500,000 company-based training contracts a year. Apprentices divide their days between classroom instruction and on the job training at a company, typically spending 3-4 days a week at a company acquiring practical skills required for their field work which is about 80% of available training time. This also gives them an opportunity to learn work habits and absorb the culture of the company. The duration of the apprenticeship training is generally between 2-3 years and during this period, the trainees are also paid for their time. Employers in Germany have demonstrated that such practical applications help develop the skills of the critical talent pool, allowing trainees to make an easier transition from classroom to a work environment in all sectors of industries.

Companies such as Bosch engaged 1,500 apprentices for their training program in 2017. Within this company program, applicants choose from 30 different professions including those in the area of engineering, industrial mechanics, and electrical engineering for automation technology. Bosch's program focused on providing autonomy and encourages cross-functional collaboration with other business units. The private sector plays a critical role as the entities that provide the on-the job training and thereafter employ these apprentices allowing the system to be driven and moulded by the needs of different industries while ensuring quality control and recognition is achieved. (World Economic Forum ,2017)

Germany helps every young person to be a productive member of their advanced economy. They introduce the concept of careers to students and their families as early as kindergarten. They knit together educational and vocational programs and practical experience to build numerous pathways for both blue collar and white collar careers. Germany companies not only invest in the latest technologies and equipment; they prioritise skilled labour force training. Companies regularly hire former apprentices, who work closely with trainees and classroom instructors to make sure every young adult successfully passes their programs and attains relevant credentials (European training foundation, 2013).

Modern industries require working with highly technical and complex processes that give individual workers autonomy and responsibility. Development of these skills within a practical setting is a way to overcome the mismatch between the skills acquired by the potential workforce in a classroom and those that are required on the job.

Skills development through apprenticeships is closely suited to the needs of employers and the job market. Apprenticeship provides trainees with a natural mentoring process, and allows them to earn wages while learning occupational skills; this raises the quality of the work force and productivity levels (Hilary, 2012). Apprenticeship helps produce self-confidence, promote good attitude towards work and high self-esteem. This results in development of soft skills, good attitude and taking responsibility when doing the actual work. Apprenticeships can also be used as a screening method to reduce the risk of employing bad workers; and lessens possible dismissal costs (Gopaul, 2013).

Apprenticeship cultivates entrepreneurship skills: research from the United Kingdom (UK) show that former apprentices between the ages of 25 and 27 were almost three times more likely to set up their own businesses than their peers who followed other education paths. The theory they

learn in class is reinforced by the practice at work places. They also learn work habits and responsibility and understand the culture of the industry; on how to solve problems, be thoughtful, self-reliant; and prepare themselves as future employees who understand the company's goals. They learn firm culture; methods of working to improvise when things go wrong or when they see an opportunity to make something work better (Smith and Kemmins, 2013)

1.1 Case studies review

To illustrate the importance of apprenticeship training and how to contributed industrialisation, two (02) case studies have been reviewed;

1.1.1 Shoe making industry

In 1980s, China started its transition from a command economy to a market economy. Footwear products were in seriously short supply. This strong market demand prompted many employees, especially technicians, to set up their own footwear stalls or family workshops and produced shoes by themselves. Possessing the experience of apprenticeship training was a major asset in setting up shoe making businesses. Mr. Yu Ashou, the founder of Jierda Footwear company limited in China, had 16 apprentices and he trained all of them, 15 had managed to set up their own companies, while the last one worked for his company (IFPRI ,2007). Most apprenticeship factories trained a large number of technical workers, marketing specialists, in various skills including in management talents. Those who considered starting similar industries, apprenticeship experience was a key asset than a formal education in transformation and application of knowledge. Majority of footwear entrepreneurs, were former apprentices who had worked for many years and accumulated valuable experience. The knowledge gained through apprenticeship was an asset for business development. More importantly, former apprentices were exposed to market information that helped them grasp emerging market opportunities more quickly.

1.1.2 Ceramic industry

Learning different models of apprenticeship determined the paths of transmission of practical knowledge in China. Mid-1990s workers had started to setup private workshops, often in their own homes, and had started teaching their own sons or daughters the framework of the family-owned businesses. Mr. Tao, having had experiences as an apprentice potter in the 1970s he inspired many in teaching and transmission of knowledge. He owed part of his success to having been the student and close friend of one of the greatest masters of pottery of the 20th century. Tao started his career in the same way as many artisans of his generation. He was an apprentice worker in a co-operative factory. During his apprenticeship, Tao first learnt how to make ceramic products. Then afterward he taught and transferred his knowledge to many apprentices in a classroom of 20 students. Factory students were recruited across social class, background, and gender, and many individuals who previously did not have craft knowledge joined the factory as apprentices. Apprenticeship training in groups of 20 students was intended to redistribute technical knowledge across the students. The creation of new cooperatives and factories helped the opening up and access to more knowledge, especially when masters and former students were re-grouped to assist new apprentices. Mr. Tao, helped and supported each student, and this led

not only to more effective learning dynamics but also to the creation of strong bonds between classmates (Gowlland, 2012).

2. Research Methodology

This paper used systematic literature review (SLR) to identify and expand existing knowledge on apprenticeship. The secondary data collected was used as a source of information. A purposive, non-probability sampling method was then used to select a validation survey sample for raking and analysis the benefits of apprenticeship identified from literature review. Ten (10) industry practitioners were identified based on their working experience and qualifications. According to Kitchemanham (2007), systematic literature review is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. It is also a form of secondary study that uses a well-defined methodology to identify, analyse and interpret all available evidence related to a specific research question. Systematic literature reviews can also be undertaken to examine the extent to which empirical evidence supports or contradicts theoretical hypotheses, or even to assist the generation of new hypotheses.

The following steps were adopted: planning, review and; reporting of results. Process frame work adopted for the research is shown in Table 1. Wallimann (2011) argued that scientific methods of logical reasoning are deductive or inductive. Deductive reasoning begins with an expected pattern that is tested against observations, whereas inductive reasoning derives a theory from observations.

Table 1: Process framework adopted

Stages	Method process
Planning	Development of research objectives
Review of Documents	Selecting relevant documents that are relevant to industrialisation
Reporting results	Collect research results , analyse and conclude

3. Results and Discussions

The literature that was reviewed reported in Table 2; provides objectives of their study, methodology used, comments, conclusion, critique and analysis to identify gaps in knowledge. The benefits of apprenticeship training were identified and subjected to validation survey by ten (10) industry practitioners, who were purposively sampled. The questionnaire was administered by email. The respondents were requested to rank the benefits of apprenticeship training. Validation is used by researchers to help improve accuracy and credibility of data obtained. Validation should be done by people who are experts in area of study (Eddy et. al, 2012). Findings are presented in Figure 1 of the ranked benefits of apprenticeship training based on significance of frequency index responses. The data collected from a survey is presented in Table 3.

Table 2: Content analysis of technical papers reviewed

Author	Objective(s)	Methodology	Conclusions	Analysis / critique
Hilary (2012)	Overview of existing apprenticeship	Case studies in G20 countries	Apprenticeship provides motivation for skills developments, with structure of training: 20% theory and 80% learning by doing	Emphasis on practical training enable employees develop superior skills that are practical and solution oriented to the industry
Gopaul (2013)	Asses apprenticeship and work place training	Survey interviews of academics and practitioners	Apprenticeship contributes to resolving of youth un employment and provide trained productive workforce	Skills levels of workforce are significantly improved through apprenticeship training
Smith and Kemnins (2013)	Review experiences of apprenticeship and identify good practices	Case study	Strengths and weakness of apprenticeship systems was studied	Apprenticeship model used depends on what type of skills are being trained
Croix *et.al* (2017)	Examine role of apprenticeship institutions and growth in pre-industrial economy	Survey and case studies	Apprenticeship is source of productivity, and transmission of tacit knowledge from person to person	Trainees need to learn not only about a range of different production methods and technologies but about markets competitiveness, standards and negotiation. Modern schooling provides insufficient instruction for learning a craft or profession, for the simple reason that it does not impart tacit skills in students
(Schuetze and Sweet, 2003).	Assess skills training methods	Survey	Employers complained that much of the knowledge and skills acquired in the education system was inadequate or irrelevant to the workplace	Curriculum should be developed based on industry requirement, so that skills that is being trained are in line with the current technology and job market

Table 2: Content analysis of technical papers reviewed(continued)

Author	Objective(s)	Methodology	Conclusions	Analysis / critique
Gowlland (2012)	Determine path of transmission of practical knowledge	Survey and case studies	Creation of the cooperative and factory helped opening up of knowledge when masters and a generation of new students were regrouped under the same roof	Apprenticeship system could absorb the significant demand shocks in the market to accommodate technological changes as was the case with many of the highly skilled trades
Muehlemann and Wolter (2014)	Assess training investment cost benefits in firms that offer apprenticeship	Case study and literature review	Apprenticeship training by firms largely depends on economic factors such as costs	Significant positive link between length of apprenticeship and requisite skills could be tested by using wage distribution as a proxy
IFPRI(2007)	Assess major factors that contributed to the formation of rural industrial clusters	Report survey	Apprenticeship plays a significant role in helping new industries overcome the growth constraints of capital and technology in the emerging stage of industrialization.	Clustered companies benefit from the supply of more specialized skilled labour that and contribute to any technological innovation. Though labour pooling provide additional dynamic gains, that need to enforce further apprenticeship training

Table 3: Data collected for ranking of apprenticeship training benefits

Identified critical apprenticeship training benefits	Calculated percentage response	Frequency index	Respondent's response and rating scale				
			100 -80%	80-60%	60-40%	40-20%	20-0%
			Strongly agree	Agree	Fairly agree	Not sure	Do not agree
Good attitude towards work	90%	0.90	6	3	1	0	0
Develop self confidence	88%	0.88	6	2	2	0	0
Learn work habits and responsibility	84%	0.84	6	3	0	1	
Understand culture of industry and company goals	76%	0.76	7	0	1	1	1
Productivity	68%	0.68	6	1	0	2	1
Quality Improvements	60%	0.60	6	0	0	2	2
Foster Innovation	56%	0.56	5	0	1	4	0
Lower youth unemployment	52%	0.52	4	0	2	1	3

3.1 Analysis of results

The results of apprenticeship benefits in Figure 1, can be interpreted that the most important outcome of apprenticeship learning, is good attitude towards work and self-confidence of workers. From the sequence of raking, a theory can be derived based on deductive reasoning. Vanderstopep and Johnston (2009) recounted that deductive reasoning, begins from accepted theories or theoretical framework, followed by data analysis. Neumann (1997) concluded that science in qualitative research tends to focus on subjective experience. Using both conceptual and theoretical frameworks, deductive reasoning was applied to analyse the benefits of apprenticeship training. According to (Wallimann, 2011) inductive reasoning derives a theory from observations. Using the argument by Wallimann, a theory was developed based on the ranked benefits of apprenticeship. Figure 1 presents the trend of benefits of apprenticeship training.

3.2 Derived theory

"*Apprenticeship teach good attitude towards work that helps employees develop self-confidence through learning good work habits and responsibilities. After employees have understood work culture of industry, productivity and quality improves that foster innovation which can lower youth unemployment"*

4. Conclusion

The theoretical statement of apprenticeship benefits was developed to describe and explain the phenomenon and to lay a ground work for hypothesis testing in future research. This paper has demonstrated that apprenticeship training benefits are many, this is the reason other countries are still using this type of training method. Apprenticeship basically is an educational training system alternative to formal classroom learning which can contribute to sustainable skills development. Innovations and technology, are the driving force for industrialisation. Therefore, human resource educators need to show curiosity in training critical skills needed for the industries.

Implementation of apprenticeship teaching at all levels of industry, will plays a big role in sharing knowledge, experiences, and best practices.

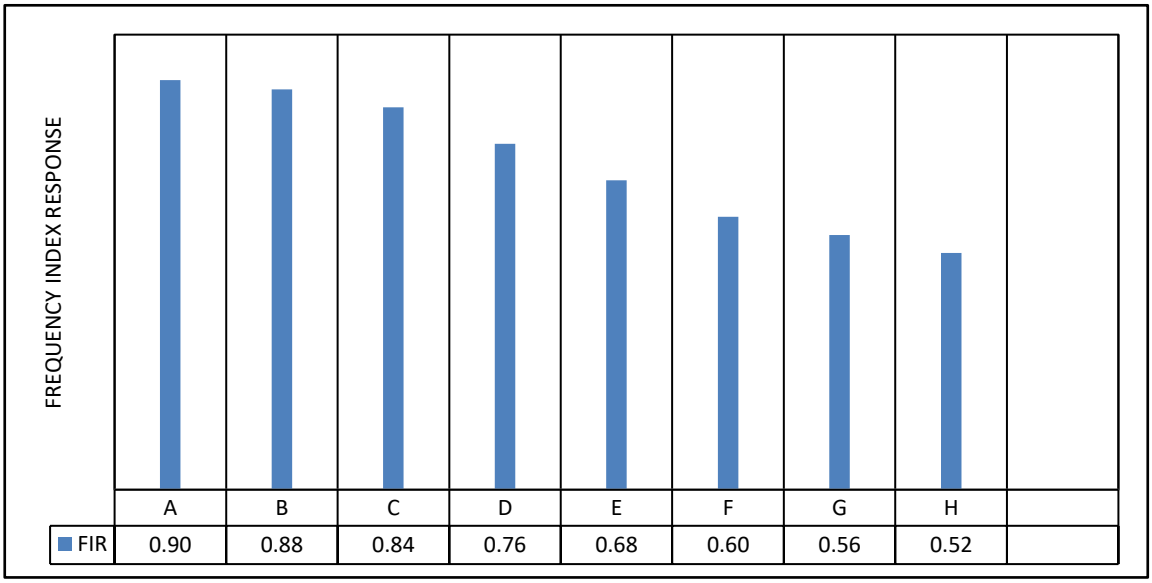

Fig 1: Ranked benefits of apprenticeship

A- Good attitude towards work
B- Self-confidence
C- Learn work habits and responsibility
D- Understand culture of the industry and goals
E- Productivity
F- Quality improvements
G-Foster Innovation
H- Lower youth unemployment

The identified lessons learned can be used to mitigate the skills gaps (Kaoma and Muya, 2016) that exist in the industry in Zambia. This paper may help policy makers to consider implementation of apprenticeship training in all sectors of the economy to achieve industrialisation benefits.

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Wood Waste Gasification for Power Generation in Mulobezi District

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Abstract

Power generation from biomass resource has gained popularity worldwide due to the many advantages it offers over the use of fossil fuels, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities. However, in Zambia this resource is either inefficiently utilized or not utilized at all. One of the sources of biomass resource in Zambia that is currently unutilized for energy generation is wood waste generated from saw mill plants. Zambezi Saw Mills Plant in Mulobezi district of Western province in Zambia generates wood waste that is inappropriately disposed. This paper seeks to determine the power generation potential from the wood waste generated at the Zambezi Saw Mills Plant. Using information from the plant's operations records and published journals in Zambia, the sub-Saharan Africa and other developing countries, the annual quantity of wood waste generated from sawn timber was first determined. Then, electricity production from this resource was estimated based on a gasification power based system that uses a downdraft gasifier and internal combustion engine. The annual wood waste generation was found to be 9, 503.12 m^3 or 1, 996 tonnes (on weight basis). From this wood waste, 1, 906 MWh of electricity could be potentially generated. Based on the annual average electricity consumption of 641.8 kWh per capita in Zambia, approximately 2, 969 people of Mulobezi district could be supplied with electricity generated from wood waste. The implications are an increase in Mulobezi district's electrification rate – from 4.4 to 16%. Clearly such an increase may positively influence socio-economic development in the district.

Key words: *Electricity generation, gasification, Mulobezi District, soci-economic development, wood waste*

1. INTRODUCTION

1.1 Wood waste in Mulobezi

Mulobezi district located in Western Province of Zambia has a typical low rural electrification rate of about 4.4% (GRZ, 2017). In part, it is the reason why the district has one of the lowest human development indexes of about 0.353 in the country (United Nations Development Programme, 2014). It is a well-known fact that access to modern energy such as electricity is a prerequisite to socio-economic development of any region (IIASA *et al.*, 2012). Hydro-based electricity is currently the only means of providing electricity to the district. With the current

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electricity generation deficit being faced in the country, electrification projects in Mulobezi district and other rural areas of Zambia have slowed down.

Fortunately, the district hosts a timber processing facility, Zambezi Sawmills Plant, which generates wood waste that could be converted to electricity using biomass gasification technology. The wood wastes generated mainly comprise saw dust, wood bark, slab and log-ends. Generation of power from this waste will increase the district's access to modern energy, thereby positively influencing its socio-economic development. In addition to this, it will provide an effective method of managing the waste. Currently, the common wood waste disposal methods being practiced at the plant include: heaping/abandonment at the mills, open air combustion, disposal along roadside and water bodies. Abandonment of wood waste such as saw dust at the saw mills causes aesthetic impacts while abandonment along the road side causes air quality impact as a result of wind which often blows and suspends the wood dusts into the atmosphere. This practice could cause respiratory problem in humans. According to Ohimain (2012), open air combustion of saw dust often causes air pollution with the release of CO_2, smoke, NOx etc. and loss of potentially useful energy into the environment.

1.2 Biomass gasification for power generation

Power generation from biomass has gained popularity worldwide due to the many advantages it offers over the use of fossil fuels, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities (IRENA, 2012). For example, the Government of India prefers the use of biomass based power systems over other renewable energy power based systems for decentralized electricity generation (Bocci *et al.*, 2014). As of 2014, the total installed capacity of biomass power in India was 1, 365.20 MW (Bocci *et al.*, 2014).

Lignocellulosic biomass such as wood waste can be converted into power through three thermal-chemical processes: combustion, gasification and pyrolysis (IRENA, 2012). The gasification route for biomass power generation is preferred to the other two routes because of the high electric efficiencies that the technology is capable of reaching (Veringa, 2004). As of 2011, Thailand had 14 biomass gasification power plants with a total capacity of 5.4 MW and 7 new plants each with a capacity range of 20 - 400 kW were being developed (Assanee and Boonwan, 2011).

Gasification is achieved by the partial combustion of the biomass in a low oxygen environment, leading to the release of a gaseous product (producer gas or syngas) (IRENA, 2012). To generate electricity, the syngas is burned in gas turbines or internal combustion engines. A biomass gasification based power generation system consists of pretreatment of biomass, gasification of biomass, gas cleaning and feeding of a combustible gas mixture in gas-turbine or gas- engine to generate electricity as shown in Fig. 1.

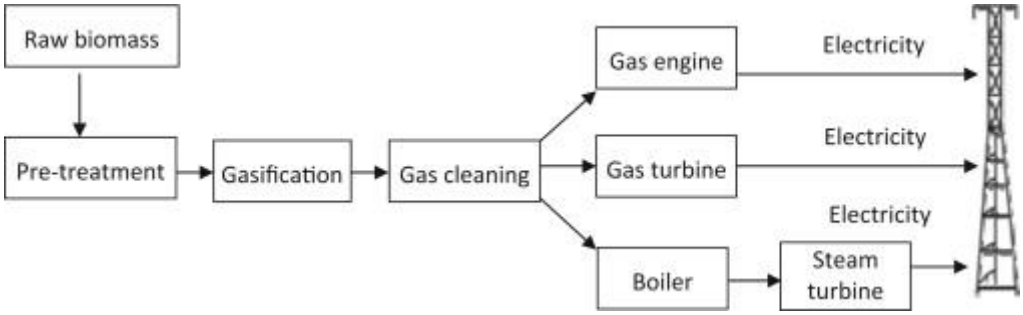

Figure 1: Flow sheet diagram for power generation using biomass gasification gas (Source: Asadullah (2014))

The flow of biomass from land to its end use for producing bionenergy such as syngas for electricity generation is called the biomass supply chain (Atashbar *et al*., 2016). The efficiency of this chain is critical for the economic variability of biorefinery: indeed as the biomass itself is rather cheap, the logistic costs represent an important fraction in the price of a ton of biomass delivered to the biorefinery (Atashbar *et al*., 2016). This supply chain includes different types of activities which can be classified into four main categories: harvesting and collecting biomass, storing, transporting and pre-processing (Gold and Securing, 2011). Therefore, in order to reduce the cost of energy produced from biomass such as wood waste and increase its competitiveness, it is necessary to improve its supply chain and optimise its design (Bowyer, 2012).

This paper seeks to estimate power production potential from wood waste generated from the Zambezi Sawmills plant and the number of households that can benefit from this electricity in Mulobezi District. The findings of this study will not only provide alternative means of increasing the district's accessibility to modern energy in form of electricity but also safer ways of managing the waste produced.

2. MATERIALS AND METHODS

Data and information required for the study was collected from relevant institutions, including Zambia's only electricity generation and supply company, ZESCO, and the Zambezi sawmills plant in Mulobezi where the study was conducted. The other source of data and information was from published journals in Zambia, the sub-Saharan Africa and other developing countries.

2.1 Availability of Wood Waste

Quantification of wood waste generated from Zambezi Sawmill Plant was based on the volume of logs sawn, density of the wood waste and sawmill conversion. The annual wood waste generated in tons per year was estimated using equation 1.

$$Q_{ww} = [(\eta_{sm} - 1) * V_{ts} * \rho_{ww} * 365] \dots\dots\dots\dots\dots\dots [1]$$

where V_{ts} is the volume of round log being sawn in m^3 and is calculated using the Smalian formula (Ofoegbu *et al*., 2014) shown in equation 2, η_{sm} is the sawmill conversion efficiency which is estimated to be 50% according to Ofoegbu *et al*. (2014) and ρ_{ww} is the density of wood waste. It is assumed that the wood waste being considered for electricity generation has been pretreated to a recommended density and moisture content of below 40% wt and 210 kg/m^3respectively (Asadullah, 2014).

$$V_{ts} = \frac{\pi L \times (D_b^2 + D_t^2)}{8} \dots\dots\dots\dots\dots\dots [2]$$

where D_b is the diameter at the base of the log (m), D_t is the diameter at the top of the log (m) and L is the length of the log (m).

2.2 Selection of gasification technology

The choice of gasifier was based on the capacity of the technology to produce good quality syngas for electricity production in a cost-effective and reliable manner. Four types of gasifiers were considered f this study, these included: updraft or countercurrent gasifiers, downdraft or concurrent gasifiers, cross-draft gasifiers, and fluidized-bed gasifiers. The quality of syngas produced from the selected gasifier dictated the type of engine required for electricity generation.

2.3 Electricity generation potential

Calculation of the potential power generation from wood waste generated at Zambezi sawmills plant in Mulobezi district was based on the selected gasification power generation technology, i.e. gasifier and engine type. Equation 3 was used for this estimation.

$$E_{ww(i)} = \frac{CV_{sg} * Y_{gd} * Q_{ww} * e_{dg(i)}}{3.6} \quad \text{..... [3]}$$

where E_{ww} is the electrical energy output in kWh based on engine type *i*, CV_{sg} is the lower heating value of the syngas (about 5.5 MJ/m^3(Elsner *et al.*, 2017)), Y_{sg} is the syngas production potential from wood based biomass products in m^3/kg (estimated as 2.5 m^3/kg according to Mustafa et al.(2017)) , Q_{ww} is the annual production of wood waste from Zambezi sawmills plant, $e_{dg(i)}$ is the electricity conversion efficiency of engine technology *i*.

3. RESULTS AND DISCUSSION

3.1 Gasification technology for power generation

Downdraft gasifier systems are not only simple in construction and cost competitive but also produce very small amount of tar which allows for a simpler design of the gas cleaning and tar removal systems. Also, the technologies of these systems are quite matured in the world, require minimum labour to operate them and are easy to maintain. Based on these advantages, a downdraft gasifier which is well suited for power generation from the wood waste produced at Zambezi sawmills plant was selected.

3.2 Electricity generation potential from wood waste

Currently, Zambezi sawmills plant has four milling machines; each processing an average of 30 round logs per day. According to the operations records of the plant, the average length, base diameter and top diameter of the logs sawn annually are 3.4, 0.45 and 0.35 meters respectively. The quantity of wood waste generated at Zambezi sawmills plant was estimated as shown in table 1 using sawmill a conversion efficiency of 50%.

Table 1: Quantity of wood waste generated at Zambezi Sawmills Plant

Logs sawn (annually)	Volume of round log (m^3)	Density of wood waste (kg/m^3)	Quantity of wood waste	
			Vol. (m^3)	Mass (tonnes)
43,800	19,006.24	210	9,503.12	1, 996

From the annual production of wood waste, the potential electricity generation was determined based on a downdraft gasifier coupled with an internal combustion engine system as shown in table 2. The average overall electrical efficiencies of such systems is 25% (Elsner *et al.*, 2017). It is assumed that the syngas produced from the gasification of the wood waste which is to be used for electricity generation has been cleaned up to meet the stringent requirement of the engine operation in terms of tar concentration (> 100mg Nm^{-3}) (Asadullah, 2014).

Table 2: Electricity generation potential at Zambezi Sawmills Plant

Quantity of Syngas (m^3)	Electrical conversion efficiency (%)	Annual Electricity generation potential	
		MJ	MWh
4,989,138	25	6, 862	1,906

Considering that the average annual electricity consumption in Zambia is 641.8 kWh per capita (according to BMI, (2015)), 2, 969 persons in Mulobezi could be supplied with electricity generated from the wood waste generated at Zambezi sawmills plant. As a result, the electrification rate in Mulobezi can potentially increase from 4.4 to 16%. This analysis is b

ased on the population of Mulobezi district and electrification rates of 27, 922 and 4.4% respectively (Central Statistical Office, 2011 and GRZ, 2017). Clearly, such an increment has potential to enhance socio-economic development and energy security of the district. In addition, the use of wood waste to generate modern energy (electricity in this case) contributes to the 2030 sustainable development agenda through: (i) increasing access to modern and reliable energy in the country (SDG 7) and (ii) reducing the use of traditional biomass for cooking purposes which results in the reduction of diseases related to indoor pollution (SDG 3).

3.3 Enabling Environment for biomass based power production

Recently, the Government of the Republic of Zambia (GRZ) developed the Renewable Energy Feed-in Tariff (REFiT) Strategy. The aim of this strategy is to accelerate private investments in small and medium sized renewable energy based power projects of up to 20 MW for increased access to clean energy services to supplement other government's power generation investment programs (GRZ, 2017). This strategy is envisaged to expand the renewable energy deployment by creating a platform to remove barriers and provide effective processes for licensing and technology based standardized Power Purchase Agreements (PPAs) in order to increase private sector involvement in power generation (GRZ, 2017). Ultimately, this will contribute to a diversified energy mix in order to enhance energy security.

One of the measures of the strategy is to provide a 3-year REFiT generation allocation of initially 200 MW, divided into 100 MW hydropower and 100 MW non-hydropower. One of the non-hydropower components is biomass based power generation. Therefore, projects involving power generation from biomass such as wood waste can now be supported by GRZ through the REFiT strategy. Apart from Zambezi sawmills, there are other plants in Zambia that generate sufficient wood waste for power generation. According to GRZ and UN (2014), there are more than 580 sawmilling micro, small, and medium enterprises (MSMEs) supplying plantation timber to the building sector of Zambia. As of 2014, the total demand for timber in Zambia was 600,000 m^3, 170, 000 m^3 more than the local annual supply of 430,000 m^3 (UN and GRZ, 2014). Since the ratio of processed timber to wood waste generated is 1:1(i.e. 50 % sawmill conversion efficiency used in this study), the total annual wood waste that could be generated from the MSMEs sawmills in 2014 in Zambia was 430, 000 m^3 or 90, 300 tonnes on weight basis. Therefore, the country had a potential of generating electricity from wood waste from MSMEs sawmills of 86, 224 MWh per annum. This can significantly enhance energy security and positively influence socio-economic development in the country.

4. CONCLUSION

The results of the study shows that Zambezi Sawmills Plant in Mulobezi district and the country as a whole has good potential of generating electricity from wood waste due to abundant wood waste produced from sawmills in Zambia. Due to the anticipated growth of the building sector in Zambia in which processed timber is a key component, the amount of wood waste generated is expected to increase. This implies that the potential of generating electricity from wood waste will also increase. Therefore, biomass based power generation is worth further exploring as it offers an opportunity to diversify the country's electricity generation mix.

Although the country has readily available wood waste, the development of any type of biomass based power generation facility requires a fuller understanding of their economic and financial benefits. This mainly requires designing and analyzing the biomass electricity generation supply chains. Such an investigation should be undertaken for the Zambian scenario using appropriate models that have been developed for optimizing biomass supply chains.

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A Prototype Fuzzy-Logic Based Airport Pavement Management System for Kenneth Kaunda International Airport

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Abstract

Proper record keeping, prioritisation and scheduling of Airport Pavement remedial activities are of great importance in facilitating the effective performance of airport infrastructure. Kenneth Kaunda International Airport's current maintenance plan is paper-based and would benefit from the integration of a computerised optimal timing system which would streamline operation, improve record keeping and reform spending in that regard. This study sought to create a server based software application called AeroPave centred on the aforementioned items, suitable for the Kenneth Kaunda International Airport (KKIA) airside pavements in Lusaka, Zambia.

The use of different predictive models developed using reliable scientific and engineering methods were considered to accurately plan for future maintenance and funding needs. The selection of the most suitable alternative model was governed by the resources and pavement historical data available. Ultimately a fuzzy-logic prioritisation model was used over analytical hierarchy systems owing to the lack of past standardised condition assessment records required to ensure the latter's reliability. The selected model utilised a Mamdani Inference Engine that accepts two input parameters; the Pavement Condition Index (PCI), the AGE of the Pavement within a 20 year design period and an output parameter; TREATMENT. The output is expressed as a percentage which is related to a treatment class legend that allow users to interpret the results in terms of actual maintenance activities. The AeroPave software was designed to also include a database to store pavement information and work history.

A PCI survey was carried out at KKIA with results showing an overall average PCI of 84 for the surveyed areas, namely; the runway, main taxiway and apron. These results were catalogued and added to the systems' database. It can be said from the trends observed from testing of the optimal timing model using sample data derived from the PCI ratings for KKIA that it is possible to use AeroPave at KKIA to recommend the optimal timing for treatment application. Further work needs to done to refine the fuzzy-logic prioritisation to make it more accurate.

Keywords: AeroPave, Airport, Fuzzy-logic, Maintenance, Prioritization

1. Introduction

1.1 Background

Historically, most airport sponsors have made decisions about pavement maintenance and rehabilitation (M&R) based on immediate need or experience rather than long-term planning or documented data. This approach did not allow the airport sponsors to evaluate the cost-effectiveness of alternative maintenance and repair strategies, and it led to an inefficient use of funds (U.S. Department of Transportation Federal Aviation Administration, 2006).

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A good management programme for pavement structures is a cornerstone of economic and sustainable use of pavements. These works need to be coordinated in a systematic and easy to interpret manner, one that is also oriented to save costs and ensure that areas in need of varying levels of attention are addressed accordingly. Therefore, many pavement management systems have been developed to create a collective source of information concerning the condition of the pavement (e.g. nature of the distresses present, sections experiencing similar distresses, etc.) in a network at any given time. This enables engineers to make informed decisions on the most economic course of action as well as predict future pavement treatment needs and optimised spending over the pavement life cycle.

Airport pavement structures must be kept at required levels of operational condition for use by aircrafts, all the while managing the cost of works. In the absence of pavement management systems, there is no systematic approach to selection of treatment methods, cost optimisation and planning/prediction of future pavement requirements. Resources are therefore, allocated to remedy a problem typically without investigating its cause and extent. In the long run this proves to be more costly than if the nature of the distress was known and adequately addressed to prevent reoccurrence within a short time period after works are done.

In Zambia, the Zambia Airports Corporation Limited (ZACL) is in charge of managing all the state owned Airports. The pavement structures are maintained and managed by the Department of Technical Services at ZACL. The department conducts maintenance actions such as patching, pothole mending and other related exercises on a reactive basis. Routine maintenance is restricted to grass cutting and repainting the pavement markings and is typically done in-house. When a major defect occurs that threatens to disrupt service, tenders are issued to external parties to investigate and apply necessary remedial actions. Regular condition inspections under the department are limited to simple visual surveys aimed at checking vegetation and the quality of signal paint markings and are done once every month. All records are kept using a paper based filing system. This (paper based filing system) offers little room for treatment optimisation and/or prioritisation.

1.2 Problem Statement

Kenneth Kaunda International Airport is currently undergoing rehabilitation and expansion works aimed at increasing its capacity. A maintenance programme, including preventive maintenance where appropriate, should be established at the Airport to maintain its pavement facilities to a condition which does not disrupt normal and safe operations. The Airport's current maintenance plan would benefit from the integration of a computerised optimal timing system in managing its airside pavement structures, resulting in lesser spending. Therefore, a Pavement Management System is required to help optimise the costs as well as to predict future distresses to aid management's resource allocation planning.

1.3 Objectives and Scope of the Study

The main objective of this study was to design a working prototype Pavement Management System custom suited for Kenneth Kaunda International Airport airside pavements able to optimise the maintenance costs and systematic scheduling of works. The following are the specific objectives of the study:

- To review pertinent historical, climatological and cost data as well as the design as-built drawings of the pavement.
- To conduct a Pavement Condition Assessment Survey including visual and intrusive tests on the pavement then compare the results with previous performance history.
- To determine maintenance needs and prescribe a framework for treatment selection and develop analysis procedures to determine most effective treatment, which includes a feedback mechanism.

- To develop a prediction model to establish optimal timing and treatment options for maintenance and rehabilitation works.

2. Pavement Management in Zambia

2.1 Design and Performance

Airport pavements, like highway pavements, are designed and constructed to support the loading imposed on them by the traffic they carry, which in this case are aircraft. They represent a key infrastructure sector in the economy of any nation as well as a large capital investment. The types of pavement common on an airfield are flexible and rigid pavements. Composite pavements are also present resulting from combinations of the two aforementioned types. This being said, it is the engineers' job to select the most economical design that provides satisfactory service.

There are a variety of methods used in flexible airport pavement design such as the

I. Corps of Engineers (CoE) method (Yoder & Witczak, 1975)
II. Federal Aviation Administration method (FAA) (Yoder & Witczak, 1975) and
III. The Asphalt Institute method (Yoder & Witczak, 1975)

In Zambia the design of pavement structures utilises the concept of the "design aircraft" incorporating the classification system developed by International Civil Aviation Organisation (ICAO) called the Aircraft Classification Number – Pavement Classification Number Method (ACN – PCN).

The period for which the pavement will be deemed serviceable is correlated to the pavements' performance. The parameters that determine the period of time for which a pavement is expected to perform optimally without requiring a major rehabilitation are;

i. The culmination of expected and/or predicted traffic loading over time and;
ii. The climatic conditions of the area.

This is often referred to as the design life of the Pavement. Effectively the same considerations made for highways remain the same for Airport Pavement structures.

The last major rehabilitation work conducted on the main taxiways at KKIA was done in 2005 (Zulu Burrow Limited, 2005). The intended design life was 20 years and the predicted loading equivalent to the Boeing 747-400 i.e. the design aircraft; for a total of 520 annual departures based of the detailed design report prepared by Africon Engineering International (Pty) Ltd, (2001).

2.2 Pavement Management Systems

Vitillo (2013) defines a Pavement Management System (PMS) as a set of defined procedures for collecting, analysing, maintaining, and reporting pavement data, to assist the decision makers in finding optimum strategies for maintaining pavements in serviceable condition over a given period of time for the least cost. Basically, this is a cost effective set of procedures that are used to coordinate the maintenance, preservation and rehabilitation of pavement structures. The PMSs were conceived in response to the shift from the design and build mode to repair and maintain mode (Kulkarni & Miller, 2003).

According to Vitillo (2013) a PMS can be divided into its core subsystems as follows;

PMS DATA

- Inventory
- Condition - Pavement Evaluation
- History – Initial Construction, Preventative Maintenance, Routnine Maintenance, Rehabilitation, Reconstruction
- Traffic
- Costs

MODELLING - ANALYSIS

- Serviceability Rating
- Performance Predictions
- Economic Analyses-Budgeting / Programming

DATA MANAGEMENT

- Relational Databases
- Report Generation

PMS should be considered as a tool for decision making, not a decision maker itself. These systems are not intended to replace engineering expertise and judgment, but rather to help in making cost-effective and timely decisions. The system should be flexible enough to incorporate user input in the decision making process (Bham, et al., 2007).

2.2.1 Airport Pavement Management Systems

This encompassing principle of sustainability of infrastructure in operation has been extended to airports as well. Airport Pavement Managements Systems (APMS) not only evaluate the present condition of a pavement, but also predicts its future condition through the use of a Pavement condition indicator (Fernandes, 2010). By projecting the rate of deterioration, a life-cycle cost analysis can be made for various alternatives. This analysis helps determine the optimal time for applying the best alternative (U.S. Department of Transportation Federal Aviation Administration, 2006).

2.2.2 Network level and Project level APMS

Airport pavement management can be applied at network and project level. The network level takes into consideration all the pavement assets being managed by the agency (NACL). The project level is specific to a given pavement area that has been identified for potential rehabilitation (National Academics of Sciences, Engineering and Medicine, 2008).

In the case of smaller airports, consisting of only one or two runways and few taxiways and aprons, the network-level pavement management may include only a handful of sections while larger airports may have hundreds of sections. Consequently, network-level management needs and procedures depend on airport size (Transportation Research Board , 2011).

At the project-level, management decisions are made regarding the most cost-effective maintenance and rehabilitation alternative for a given pavement, with a more detailed analysis for a given pavement section.

2.3 Application of Fuzzy logic in Pavement Management Systems

The objective of most Pavement Management Systems is to predict the optimal timing and cost of applying remedial or preventative actions to a pavement in response to its actual or anticipated deterioration over time. As such, most PMS incorporate a predictive model into their systems (George, 2000).

One of the most common types of models for multi-year pavement management analysis are Deterministic models. These models may be either empirical (based on data from in-service pavements) or mechanistic-empirical, calibrated using regression techniques that statistically develop relationships between two or more variables. Development of deterministic models requires a variety of data on factors that affect the rate of deterioration namely, traffic loads, pavement layer thicknesses, materials, subgrade strength, environmental factors, and construction techniques (Rajagopal, 2006). An example of such can been seen in the Micro PAVER system which has built-in algorithms to help the users develop performance prediction models using historic data of pavement condition for groups of pavements that exhibit similar attributes. Fourth degree polynomial constrained least squared regression models can then be developed to predict performance. A typical Prediction model is shown (Equation 1).

$$PCI = 0.1E3 - 0.86E1 * AGE + 0.79 * AGE^2 - 0.32 *(E\text{-}1) * AGE^3 + 0.43*(E\text{-}3) * AGE^4$$

(Rajagopal, 2006) (Eq. No.1)

Where:

- 'PCI'- The Pavement Condition Index on a 0 to 100 scale,;
- 'E' - Deterioration constant determined through graphical analysis of boundary conditions or derived from a graph of PCI vs AGE;
- 'AGE' - Number of years since construction or last major rehabilitation.

In PMS, the accuracy of deterministic models and analytical hierarchical systems in general is heavily dependent on the accuracy of information available to satisfy the first tab in Section 2.2.

In the case of KKIA however, this information is limited and some items could not be accurately verified owing to lost paper records in most cases. This prompted a re-evaluation of predictive models suitable for implementation at KKIA. Ultimately, this led to the adoption of soft computing techniques and in particular, fuzzy logic. According to Chen (2010) soft computing techniques are particularly appropriate to support these types of decisions where the information available carries with it a degree of uncertainty because these techniques are very efficient at handling imprecise, uncertain, ambiguous, incomplete, and subjective data.

Fuzzy logic systems are an extension of the traditional rule-based reasoning (expert systems), which incorporate imprecise, qualitative data in the decision-making process by combining descriptive linguistic rules through fuzzy logic (Zadeh, 1973). Fuzzy systems are convenient to model expert opinions because they handle linguistic rules efficiently and are fault-tolerant regarding small changes in the input or system parameters. One of the limitations of fuzzy systems is that they do not have formal algorithms to learn from existing data. The main advantage of this approach however, is the possibility of introducing and using rules from experience, intuition, and heuristics, and the fact that a model of the process is not required. Fuzzy systems also provide functional transparency (Chen, 2010).

3. Methodology

3.1 Study Area

The study area encompasses the sections of KKIA's flexible Pavements structures located in Lusaka, Zambia. The areas of interest are the taxiways, apron and runway shown in Figure 1.

Figure 1: Study Area (Image Courtesy of Google Maps)

3.2 Data Requirements and Sources

3.2.1 Data Requirements

An important step in building a working Fuzzy Inference PMS is developing the rules (set of commands derived from experience, intuition, ambiguous data, etc.) that govern the output of the fuzzy inference engine of the system. In this case the rules were the most likely defects to occur at a certain point during the pavement's design life and the most optimal treatments in terms of cost and effectiveness. These rules are cardinal to the reliable functioning of the predictive scheduling model.

The data required in this study was classified broadly into the following subgroups:

I. *Pavement network nomenclature*: To facilitate an easy to interpret referencing system that defines areas of interest and sections.
II. *Pavement inventory*: The Pavement inventory data required for the APMS analyses includes: information related to the geometry of the road sections (e.g., pavement width, number of lanes, etc.) and construction and maintenance history of the pavements.
III. *Traffic and Climatological data*: The Annual departures/arrivals and axle loading data collected and collated over the years.
IV. *Pavement condition data*: Pavement Condition Index chosen for its robustness in terms of usability in situations where other defect tests cannot be conducted.

3.2.2 Data Sources

Data sources are given in Table 1.

3.3 Developing the Airport Pavement Management System

3.3.1 Database Creation

Pavement Management Approach
As explained in section 2.2, there are two levels of Pavement Management Systems. The network level covers a much wider scope than the project level and is suitable for large airports. The project level on the other hand deals with individual sections within a network and is suitable for smaller airports i.e. airports with one runway.

This study adopted the project level approach as it was more suitable for KKIA. Kiema & Mwangi (2009) explain the approach as one that uses individual section data (e.g., traffic, ESALs, safety, inventory, pavement condition) to determine the optimum section maintenance and rehabilitation strategies and priority projects.

Sectioning of Pavement Data
Prior to conducting the field survey, a pavement network map was developed using available aerial photography and construction plans. The map was divided into facilities, features, and sample units. Features are divided into sample units as prescribed by ASTM (1998).

Table 1: Data used and their sources

Data Type	Characteristic of Data	Source
Pavement Inventory	The data for the Airport Pavement inventory relating to when the runway, taxiway and commercial apron were constructed, its maintenance history, the materials used and its initial design was scarce and only found in hardcopy paper form. The limited information available was collected from Zambia Airports Corporation Limited.	Zambia Airports Corporation Limited
Traffic Data	Number of departures/arrivals per year for the years 2015 and 2016. Gross loads for heaviest aircrafts serviced. Traffic data in the form of annual departure/arrivals figures and gross loads for aircrafts was available in digitized form and collected, however this information was ultimately discarded following the adoption of a fuzzy logic system.	Zambia Airports Corporation Limited
Climatological Data	Monthly Rainfall and Absolute Temperatures readings for a period of ten (10) years dating back from 2016	Zambia Meteorological Department
Pavement Condition Data	There has been no Pavement condition surveys conducted using a particular condition index prior to this study. Therefore, a visual inspection survey was conducted on the 2nd and 3rd of December 2016. . The inspections were conducted using the PCI survey procedure as described in the American Society for Testing and Materials (1998) ASTM 5340 D manual.	Zambia Airports Corporation Limited

Pavement Condition Assessment

There had been no pavement condition surveys conducted using a particular condition index prior to this study. Therefore, a visual inspection survey was conducted. The index chosen was the Pavement Condition Index (PCI). The inspections were conducted using the PCI survey procedure as described in the American Society for Testing and Materials ASTM 5340 D manual (1998). Classification of the condition pavements with regard to the PCI value is given in Table 2.

Table 2: PCI range and Pavement Classification *(Mahmood, et al., 2015)*

PCI range	**Pavement Classification**
10-0	Failed
25-11	Very Poor
40-26	Poor
55-41	Fair
70-56	Good
85-71	Very Good
100-86	Excellent

Development of Fuzzy Inference System (FIS) Model

The nature of the information to be analysed is complex by nature, i.e. there are many variables and parameters to be considered when looking at pavement deterioration. The fuzzy logic systems' operation is controlled by defining membership and rules that govern those functions. In the light of this challenge, the membership functions of inputs were established based on the k-means clustering (Naik, 2004) and the rules were generated by Wang and Mendel's (1992) method which basically requires precedence and experience to guide the development of the rules.

In this study a set of seven triangular membership functions were created with two input parameters namely; the different severity levels (low, medium, and high) for each input for corresponding pavement classifications under the Pavement Condition Index, "PCI" and the "Age" of pavement parameter. Another set of seven triangular membership functions were created to generate the final output based on the output of the first set. This set was governed by the parameters defined as "Treatment Class", and "PCI". The interactions of these functions is shown in Figure 2. Figure 3 shows a graphical representation of the Fuzzy Inference System.

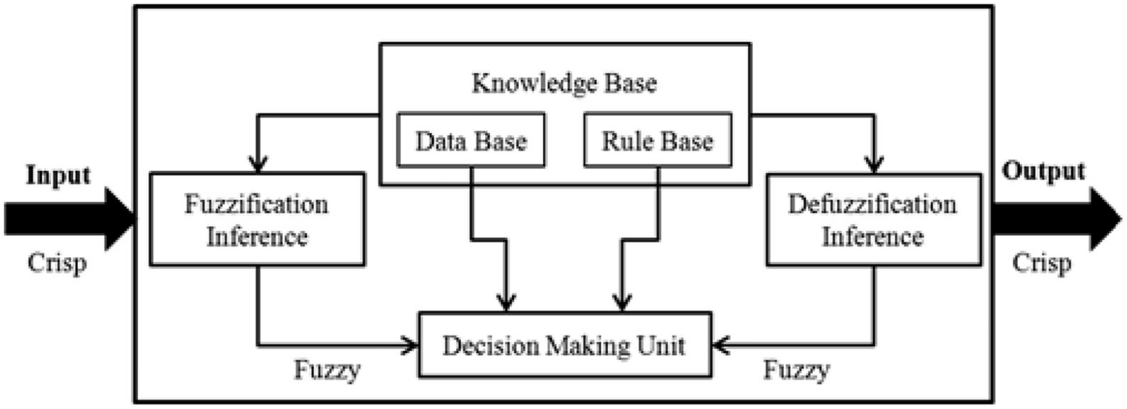


Figure 2: Fuzzy inference system structure *(Jang, 1993)*

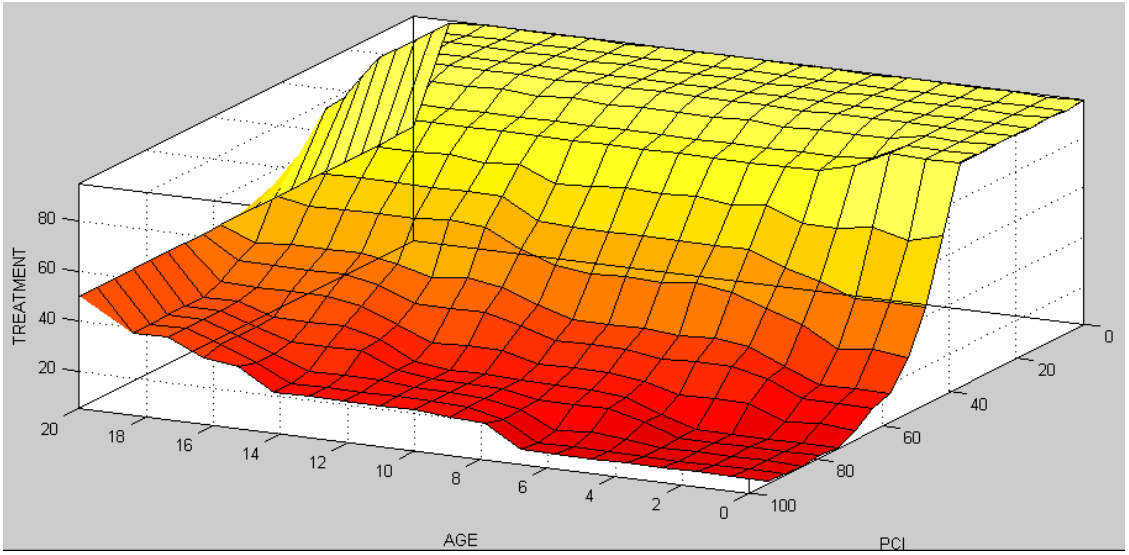


Figure 3: Graphical representation of Fuzzy Inference System (FIS)

Database Design Process

The database design followed six basic processes, there is no strict governing process to adhere to, but these describe a generally accepted approach:

1. *Requirement analysis*: To document the data requirements of the user. The following activities were carried out;
    a. Identification of application areas and user groups
    b. Analysis of existing documentation of application areas, e.g. policy documents, forms, reports, organisation charts
    c. Analysis of current operating environments and the planned use of the information, e.g. information flow, types of actions performed, frequency of action types
2. *Conceptual database design*: To produce a conceptual schema of the database. Basically an abstract representation of the database as it relates to information gathered in phase one.
3. *Choice of the Database Management System (DBMS)*: Non-relational versus Relational Database. In this study, a relational database was chosen for its performance and developed using PHP and MySQL.
4. *Data model mapping*: To transform the generic DBMS independent conceptual schema in the data model of the chosen DBMS
5. *Physical design*: to choose the specific storage structures and access paths for the database files
6. *Implementation*: Creating the database

Creation of Database Schema

The schema identified in step 4 was created and populated in phpMyAdmin. All the tables were linked through relationships.

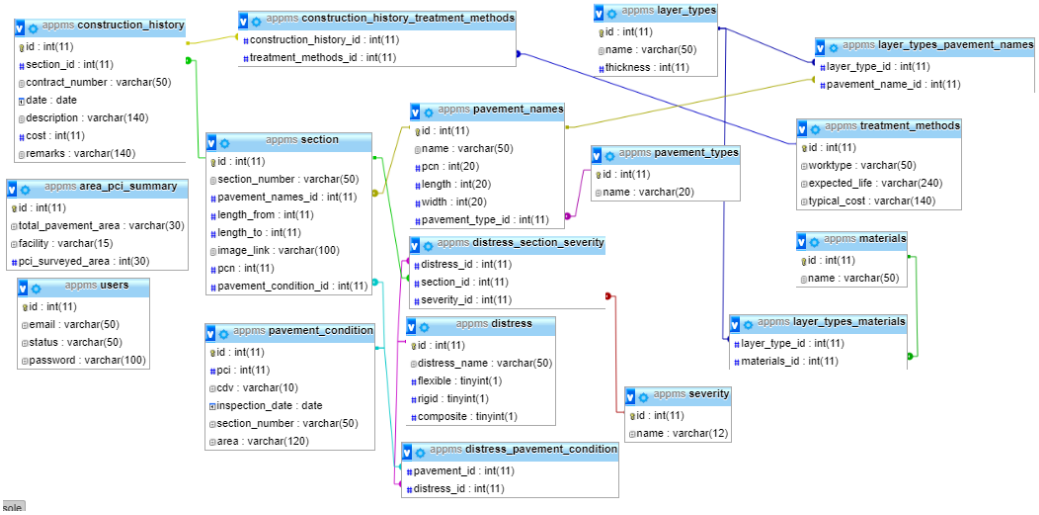


Figure 4: APMS database schema

As shown in Figure 4, the tables and their attributes were created. A number of relations were created in order to link all the related tables.

Figure 5 shows the flow chart of the stages through which the software application was developed.

4. Results and Discussion

The AeroPave (Version 1.0) Airport Pavement Management System was developed as a web application using the following programming languages and web technologies;

- PHP 5.6
- Bootstrap HTML
- CSS 3
- JavaScript
- MySQL

This was achieved by developing a database and implementing a Fuzzy inference engine using MySQL and PHP linked to a HTML and JavaScript generated user interface with the capability of being accessed online.

Figure 6 shows a screen shot of the AeroPave Software User Interface. The inputs into the system are the PCI and AGE and the output is a percentage related to a treatment class.

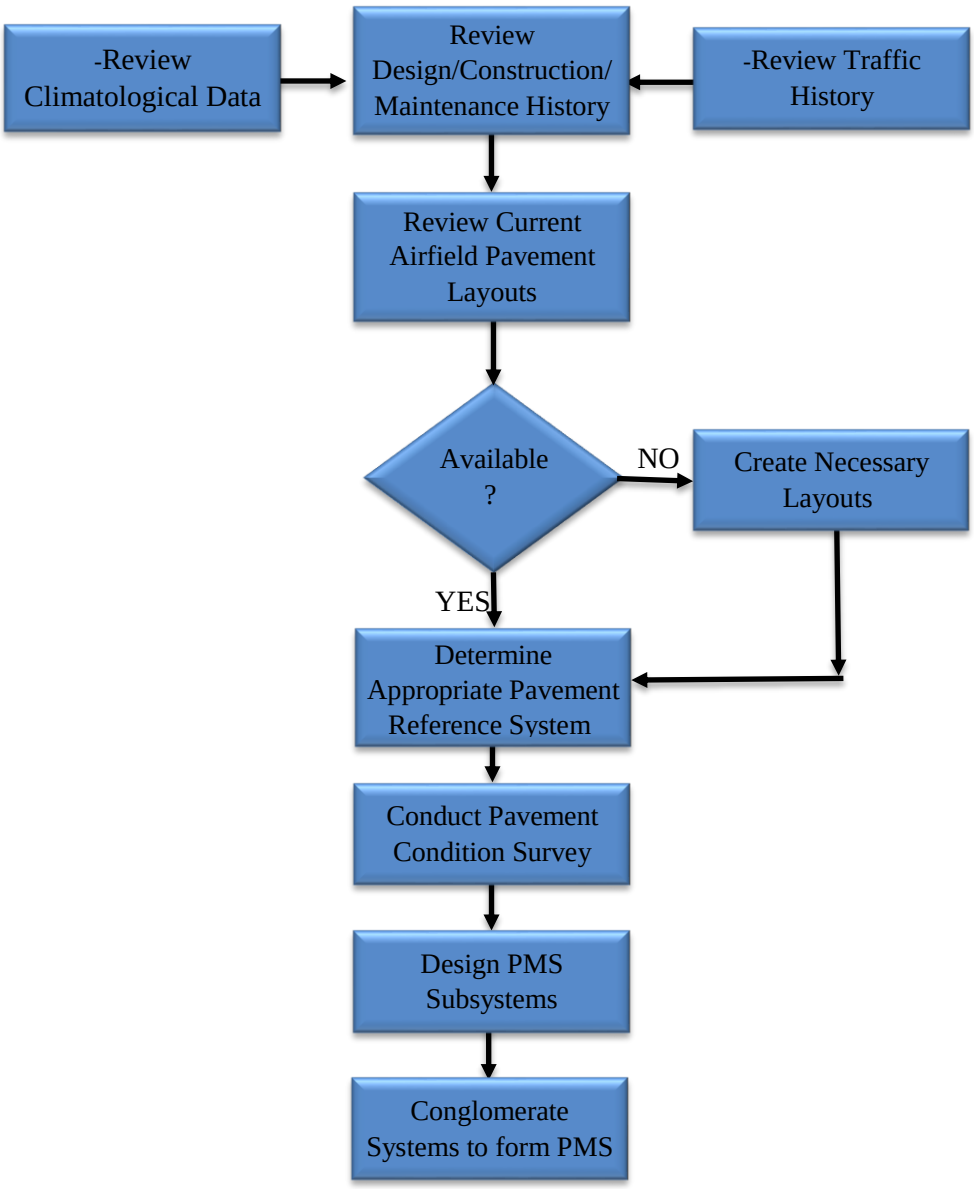
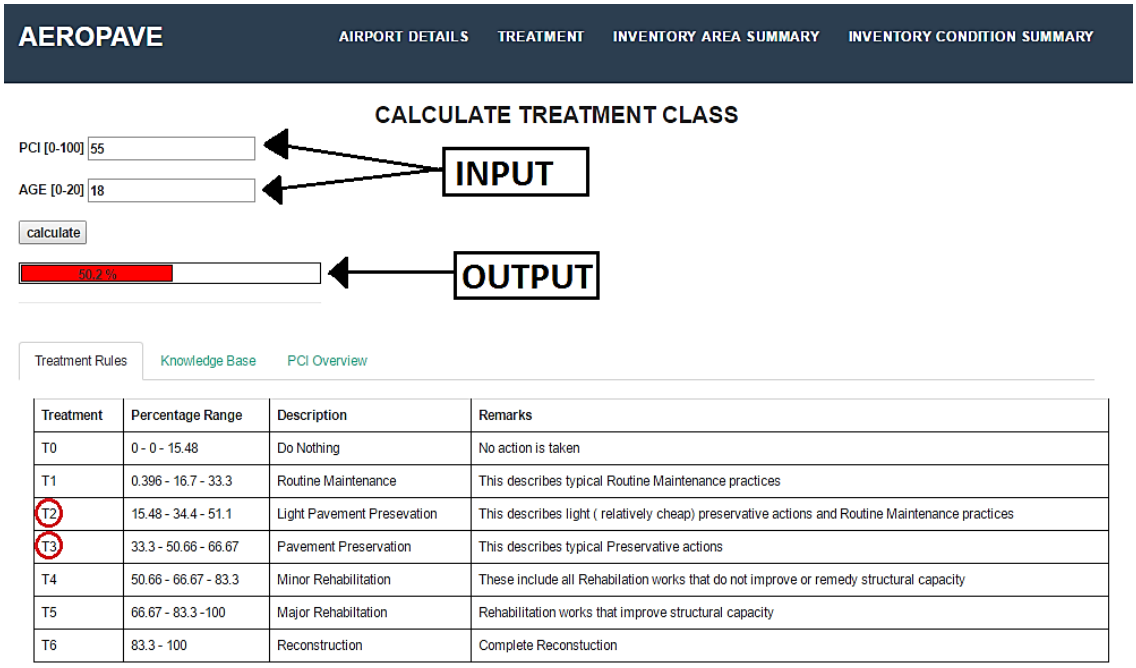


Figure 5: Development methodology flow chart



Treatment	Percentage Range	Description	Remarks
T0	0 - 0 - 15.48	Do Nothing	No action is taken
T1	0.396 - 16.7 - 33.3	Routine Maintenance	This describes typical Routine Maintenance practices
T2	15.48 - 34.4 - 51.1	Light Pavement Presevation	This describes light (relatively cheap) preservative actions and Routine Maintenance practices
T3	33.3 - 50.66 - 66.67	Pavement Preservation	This describes typical Preservative actions
T4	50.66 - 66.67 - 83.3	Minor Rehabilitation	These include all Rehabilation works that do not improve or remedy structural capacity
T5	66.67 - 83.3 -100	Major Rehabiltation	Rehabilitation works that improve structural capacity
T6	83.3 - 100	Reconstruction	Complete Reconstuction

Figure 6: AeroPave User Interface

The AeroPave Software offers two major functionalities:

1. A database for the Airport Pavement Management System; and,
2. Models for predicting future pavement conditions and optimal treatment timing using FIS

4.1 Predictive Model Validation

4.4.1 Data from Primary Source

The input data used in this example is from a primary source, i.e. it was taken from the PCI survey conducted and entered into the system; the PCI inspection carried out at KKIA on the days of 2nd and 3rd December, 2016 yielded the following overall PCIs for each section shown in Tables 3 and 4. Table 5 shows the treatment rules defined for the system, these rules are also displayed in the user interface of the treatment screen shown in figures 7, 8 and 9.

Example 1: The following example shows how the choice of treatment is arrived at for Runway section I-28 for the PCI survey conducted for this study (See table 3).

Facility: Runway

Section: I-28

PCI: 61

Age: 17 (since last major rehabilitation, see work history table 6)

Table 3: Section PCI Summary Runway

RUNWAY (03/12/2016)					
No.	**SAMPLE UNIT (Right Lane)**	**TOTAL DEDUCT VALUE**	**AREA SURVEYED (sqm)**	**PCI**	**RATING**
1	RUNWAY F-G	54	27943	46	FAIR
2	RUNWAY G-H	4.5	21407	95.5	EXCELLENT
3	RUNWAY H-I	3	21472	97	EXCELLENT
4	RUNWAY I-28	38.5	30815.73	61	GOOD
	TOTAL		101637.73	299.5	
	AVERAGE			74.875	**VERY GOOD**

Table 4: Section PCI Summary Apron

APRON (03/12/2016)					
No.	**SAMPLE UNIT**	**TOTAL DEDUCT VALUE**	**AREA SURVEYED (sqm)**	**PCI**	**RATING**
1	A	24	2250	76	VERY GOOD
2	B	8	1125	92	EXCELLENT
	TOTAL		3375	168	
	AVERAGE			84	**VERY GOOD**

Table 5: Treatment Rules for AeroPave

Treatment Legend		
Treatment	**Description**	**Remarks**
T0	Do Nothing	No action is taken
T1	Routine Maintenance	This describes typical Routine Maintenance practices
T2	Light Pavement Preservation	This describes light (relatively cheap) preservative actions and Routine Maintenance practices
T3	Pavement Preservation	This describes typical Preservative actions
T4	Minor Rehabilitation	These include all Rehabilitation works that do not improve or remedy structural capacity
T5	Major Rehabilitation	Rehabilitation works that improve structural capacity
T6	Reconstruction	Complete Reconstruction

Table 6: Work History

WORK HISTORY				
Section	Contract #	Date	Description	Total Cost (ZMW)
run_i_28	wc/zam/047/96	27/01/1997	Runway was strengthened by asphaltic overlay following settlement detected at the 28 end	4 679 131
twd_f_e	8acp/za/055	11/02/2005	Asphalt surfacing to new taxiway, overlays to existing taxiways a-f & 1-8	-
twd_f_e	nacl/cnp/r03/2013	28/05/2014	The repair of defects on the main taxiway and service taxiways	-
twd_g_a	nacl/cnp/r03/2013	28/05/2014	The repair of defects on the main taxiway and service taxiways	-

The inputs; PCI and Age were fed into the system and an output of 42.8% was generated shown in figure 6.

Interpretation

Output = 42.8%

The treatment percentage falls in classes T2 (Light Pavement perseveration) and T3 (Pavement preservation) respectively as shown in figure 7.

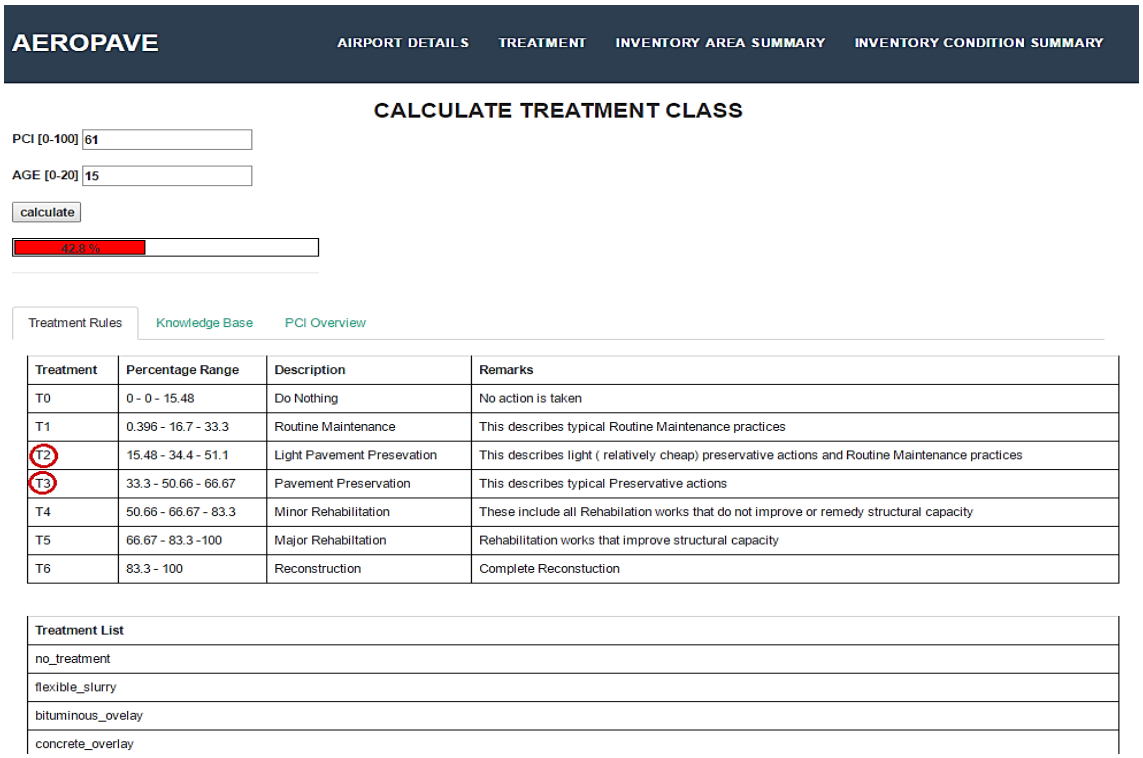


Figure 7: AeroPave Treatment page

4.4.2 Practical Considerations

- The cost of applying T2 activities is less than that of T3 activities
- The PCI of the section is 61 which is above the minimum level of service (MSL) 40
- However, the age of pavement is close to the 20 year period limit of the software.
- Therefore, select T3 for year 17.

4.4.3 Sample Data Sets

To predict treatment for scheduling purposes an anticipated PCI should be taken from a PCI deterioration model. The PCI of that particular year is fed into the system as well as the age. Table 6 highlights the treatment calculators' responses to sample data or dummy data to demonstrate its scheduling capabilities. The data was used to check if there are any errors in the application. The data sets used were chosen to simulate a case where a PCI deterioration model is available.

Table 7: Sample Data Sets

Trial No.	**Parameter**				
	Section	Year	PCI	AGE	Output(Treatment)
1.	Taxiway F-E	2016	76	12	16.8%
2.	Taxiway F-E	2019	61	15	42.8%
3.	Taxiway F-E	2022	55	18	50.2%

Example 2: The following example shows how scheduling can be achieved using the system for the Main Taxiway section F-E (See Table 7).

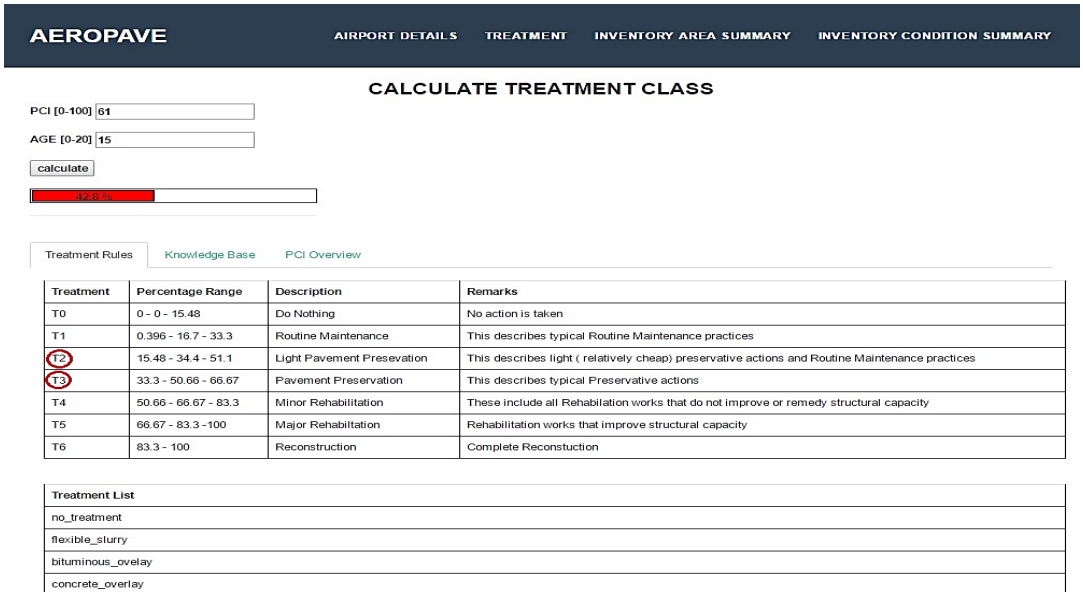
Interpretation

Output (2016) = 16.8%

Output (2019) = 42.8%

Output (2022) = 50.2%

The treatment percentage for 2019 falls in classes T2 (Light pavement perseveration) and T3 (pavement preservation) respectively as shown in figure 8. The treatment percentage for 2022 falls in classes T2 and T3 (Minor Rehabilitation) shown in figure 9.



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T5	66.67 - 83.3 -100	Major Rehabiltation	Rehabilitation works that improve structural capacity
T6	83.3 - 100	Reconstruction	Complete Reconstuction

Treatment List
no_treatment
flexible_slurry
bituminous_ovelay
concrete_overlay

Figure 8: Sample data tests 2019

Following the same procedure as in example 1, the recommended activities are T2 for 2019 and T3 for 2022. These can then be included in a work schedule to present to management.

4.4.4 Conclusion

Based on preliminary findings, subject to validation by actual future field data, the observed trends of the optimal timing model and supporting literature, it can be said that it is possible to use AeroPave at KKIA to recommend the optimal timing for treatment application. This can help in planning maintenance strategies by providing treatment guide for anticipated pavement conditions over time. Furthermore, it makes it easier to anticipate funding requirements based on the treatment required for a particular PCI thereby optimizing maintenance costs.

All associations of treatment to condition and age are based on experience and logic as defined by the treatment rules. Emphasis is therefore, put on the need to carry out condition inspections as frequently as recommended and monitor the performance of treatments applied in relation to spending to increase the accuracy of the system.

Looking at the current condition rating of the pavement and age since last rehabilitation, the system recommends routine maintenance actions to be applied. Doing so will help stay the need for expensive works in future and thus ultimately reduces overall cost.

Figure 9: Sample data tests 2022

4.4.5 Recommendations

To accurately predict the optimal timing of treatment activities there is need to have long term data and an accompanying PCI deterioration model that will show representative trends of the effectiveness of treatments for an analysis period.

There is need to establish a unique general maintenance policy that defines maintenance actions to be undertaken for particular distresses at varying severity to enable the engineer to make standard decisions when it comes to selecting a particular treatment.

There is need to conduct further research to implement a cost parameter in the system to allow all checks to be done by the system and simply reviewed (if necessary) by the engineer.

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Engineering Education: A framework for strategy and policy review of technical education vocational education training in Zambia

Daniel Noah Mwale[1]

Abstract

Engineering education in general and the engineering aspect of Technical Education and Vocational Education Training (TEVET) in particular, plays a key role in the economic development of any country. The current TEVET Policy was developed in 2009 it represents a TEVET system in Zambia, which is a mix of what was designed, and what evolved, and need a critical appraisal. This paper discusses and suggests a framework for the review of the TEVET policy and strategy in Zambia. The contribution of the TEVET sector in the industrialisation programme envisaged in the country's Seventh National Development Plan and Vision 2030 cannot be over-emphasised. The role of engineering education under TEVET with regard to skills development and training needs to be redefined and prioritised as an urgent national imperative hence, the need to review the TEVET policy and strategy to align it with the current industrialisation and future national development reality. A new strategy and policy are needed to take into account the role of engineering education through TEVET, the inescapable role of the private sector, the emerging technologies, the new modes of knowledge delivery in the engineering and technological environment, the role of Government, colleges and universities, the system of regulations and controls, the issues of globalisation, networking of engineering TEVET institutions, TEVET and research, innovation, the system of accreditation and its local and international interface and the promotion of excellence and its sustenance in TEVET. The country thus needs to intensify the development and application of science and technology in its socio-economic development.

Keywords: Engineering education, TEVET, Skills development and training, TEVET Strategy, TEVET Policy

Introduction and Background

Zambia has a vision of "…a prosperous middle income country by 2030…" (Vision 2030: 1996) In this vision Zambians, aspire to live in a strong and dynamic middle-income industrial nation that provides opportunities for improving the wellbeing of all, embodying values of socio-economic justice.

There is no doubt among policy makers in Zambia of the critical role that Engineering Education (EE) and Technical Education and Vocational Training (TEVET) can play in industrialisation and national development (UNESCO:2005). The increasing importance that the

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Zambian government attaches to TEVET is reflected in the Seventh National Development Plan (Republic of Zambia: 2017)

In the context of this paper, engineering education encompasses the engineering aspect of TEVET and that in this paper, TEVET refers to the engineering aspects of TEVET which forms part of engineering education. The Zambia Qualifications Framework (ZQF) determines and places the engineering technologist at ZQF Level 6, the technician at ZQF Level 5, the craft at ZQF Level 4, and trade test/skills at ZQF Level 3. The engineering graduate with a first degree in an engineering field from a recognised university is placed at ZQF level 7, Post graduate Diploma at Level 8, Masters at Level 9, and Doctorate at Level 10.

In line with the Vision 2030 and the Seventh National Development Plan (2017-2021), the government recognises that there exists skilled worker gap across the all the productive sectors of the economy and serious mismatch of skills offered by training institutions against the skills required by industry. The target of one million jobs require skills delivered in the universities and colleges. It is important to understand the actual trends in numbers, placements, salaries, employability, research output and compare and benchmark performance. An understanding of the reality should form the basis of policy changes that ensure that the engineering education system and the TEVET system both meet the changing needs of the Zambian industry and society (Vision 2030, SNDP:2017-2021).

The Zambian government recognises the importance of TEVET as an important sector in engineering education in the provision of skills for empowering individuals to make a meaningful contribution to the creation of wealth. The Zambian government also recognises the fact that vast numbers of young people are outside the formal school system and the urgent need to integrate non- formal learning methodologies and literacy programmes into national TEVET programmes and the integration of vocational training (Vocational pathway) into the general education system (SNDP:2017-2021). Zambia urgently needs a coordinated blueprint for TEVET, research and development encompassing government, private sectors, and research and academic institutions, consistent with the industrial, technological and economic future of the country (SNDP:2017-2021).

Questions arise about the ability and capacity of the current TEVET delivery systems to train the skilled and entrepreneurial human capital that Zambia needs to create wealth to support the efforts in industrialisation and poverty reduction. Another important question is whether the TEVET system in Zambia is delivered at different levels of sophistication in tandem with the technological advances dictates of the times. Is the TEVET system responding to the different training needs of learners from different socio-economic and academic backgrounds, and prepare them for gainful self-employment and sustainable livelihoods. Are the youth, the poor, and the vulnerable of society benefitting from TEVET?

Many studies and reports have been made with regard to the challenges facing engineering education in Sub-Sahara Africa, Zambia included. The studies are in agreement that there is a severe shortage of skilled and experienced engineers in region, and that this lack of capacity at every level of the profession is a substantive obstacle to achieving almost all the development goals, from the provision of basic sanitation to the reduction of rural poverty (Onyancha et al: 2016). In most countries, they add, studies find notable levels of unemployment among engineering graduates, mostly because engineers were graduating without the essential skills and experience to be employable, but also due to the huge presence of foreign engineering firms who prefer to import their own skilled labour, or the reluctance of the graduates to take up poorly paid positions in rural areas.

Low capacity at all levels of engineering has been identified as one of the burning issues in TEVET in Zambia. Although there is legislation to regulate the practice of engineering, there have been no meaningful steps to ensure compliance and enforcement. Foreign companies doing nearly all the huge infrastructural developments are not compelled to execute knowledge and technology transfer

to the indigenous engineer. Inspite of the current unprecedented infrastructure and other developments, which are mainly engineering in nature, significant numbers of engineering professionals are still unemployed. Mainly because engineering professionals are graduating without the necessary skills and experience to be employable, but also partly due to the local presence of foreign engineering firms who prefer to import their own skilled labour, or the reluctance of the graduates to take up poorly paid positions in rural areas.

Inadequate resources to support engineering training in public TEVET institutions has resulted in the poor quality of engineering education, which continues to be based on outdated curricula and teaching methods not relevant to local needs, and being too theoretical as the tertiary education institutions lack resources for adequate laboratory experiments and capacity to conduct research.

There are serious gaps between industry and TEVET institutions. There need for clear policy on how these linkages would be formed in order to build and build stronger links with industry. Industry should be compelled to support higher education institutions by providing industrial placements for academic staff and work placements for undergraduates; provide continuous professional development.

There is need for the Government to adopt sound industrial policies so as to create jobs, promote enterprise development and improve skills training. The government must increase its current investment in higher education in general and engineering education in particular. The current levels of investment in TEVET cannot result in training of high skilled human capital.

According to UNESCO (2012:14), 'successful TVET policy and reform entail engaging with quite a complex mix of policy areas. TVET policies can be understood in terms of their potential and actual contributions to addressing interconnected concerns'. It has been observed that the current analytical tools and policy approaches to TEVET are not sufficient to address the present and future challenges to shape and review the policy areas in a comprehensive way, this paper suggests examining the efficiency and effectiveness of TEVET and the extent to which it is accountable, responsive, and attractive, considering the extent to which TEVET promotes access, equity, and inclusion, and for understanding the implications of developing TEVET for all and the possibilities of a transformed TEVET in a lifelong learning perspective that is context sensitive and more focused on innovation, self-reliance and sustainable development (UNESCO 2012:14).

It is within this framework that a fundamental review of engineering education and TEVET strategy and policy in Zambia need to be undertaken as a matter of urgency. The review should, therefore, position the Zambian engineering education and the TEVET system as drivers for the Zambian industrialisation programme, invigorate, remodel and harmonise the TEVET system in Zambia in order to transform it into a mainstream programme for youth development, youth employment, youth empowerment and human capital capacity development in Zambia; to position TEVET programmes and TEVET institutions in Zambia as vehicles for multi layered and sectoral integration as well as socio-economic development as it relates to improvements in infrastructure, technological progress, energy, trade, tourism, agriculture, good governance and create synergies and shared responsibilities for the rejuvenation and coordination of engineering education and TEVET policies, programmes and strategies in Zambia.

A credible TEVET strategy must necessarily fit into the country's socio-economic context. The purpose here, therefore, is to present a policy framework and a set of practical recommendations to inform national policies, promote national discussion and action aimed at promoting quality and relevant engineering education through TEVET.

Current Status of TEVET in Zambia

TEVET systems in Zambia are delivered at different levels in different types of institutions, including technical and vocational schools (both public and private), colleges, trades training institutions, and apprenticeship training centres. In Zambia, traditional apprenticeship offers the largest opportunity for the acquisition of employable skills in the informal sector. In Zambia, the informal sector accounts for more than 89.3 percent of the workforce (CSO: 2017). In Zambia, formal TEVET programmes are institutional-based.

In general, however, students enter the vocational education pathway at grade 8. Oversight responsibility for TEVET is shared in general between the Ministries of Education and Ministry of Higher Education through TEVETA or technical specialised supervision of the sector ministries.

With a few exceptions, the socio-economic environment and the contextual framework in which engineering education and TEVET delivery systems currently operate in Zambia is characterised, by:

- A fragile national economy, high population growth, and a growing (unskilled) labour force;
- Shrinking or stagnant wage employment opportunities especially in the industrial sector;
- Huge numbers of poorly educated, unskilled and unemployed youth;
- Uncoordinated, unregulated and fragmented delivery systems;
- Low quality of training delivery;
- Poor institutional response to technological advancement
- Gender and economic inequities;
- Poor public perception of TEVET;
- Outdated and fragmented curricular;
- Lack of cooperation and support from industry;
- Lack of base-line data about skills availability, employability and skills gaps
- Weak monitoring and evaluation mechanisms, and
- Inadequate financing, poor institutional management systems, and ill-adapted organisational structures.

TEVET in Zambia is delivered by both government and private providers, which include for-profit institutions and non-profit, NGO and Church-based institutions. In recent years, Zambia has observed the growing contribution of the non-government provision of TEVET both in terms of a number of institutions and student numbers. This trend is linked to the fact that private providers train for the informal sector (which is an expanding job market all over Zambia) while public institutions train mostly for the more or less stagnant industrial sector. Private providers also target business and service sector skills like secretarial practice, management studies that do not require huge capital outlays to deliver. A limited amount of in-company or enterprise-based training also takes place in some organisations. (E.g. the mining sector); however, this type of training is often dedicated to the sharpening of specific skills of company employees.

National Qualifications Framework

The Zambia Qualifications Authority was established by an Act of parliament. The Act seeks to "provide for the development and implementation of a national qualifications framework; establish the Zambia Qualifications Authority; provide for the registration and accreditation of qualifications; provide measures to ensure that standards and registered qualifications are internationally comparable; and provide for matters connected with, or incidental to, the foregoing" (ZAQA Act 13 of 2013).

This was an important step in the TEVET system. It is a necessary tool for bringing coherence into the TEVET system. The ZQF prescribes proficiency requirements, qualification levels, qualification descriptors, and certification standards and increases the portability of TEVET qualifications across national frontiers when linked to other national qualification frameworks. TEVET then becomes a factor of regional integration.

Open Distance Education (ODL) in Engineering TEVET

There are difficult issues in accreditation of distance education programmes in engineering. The introduction of national curriculum standards for engineering professionals, however, created an objective reference point against which the outcomes of both face-to-face and distance education programmes can be compared. Until recently, the overall strengths and weaknesses of distance education programs are reasonably well understood, and, in determining an approach to accreditation, and considered sufficient to focus on specific competencies defined in the national curriculum standards where distance education programs might arguably offer less scope for development and demonstration than the otherwise equivalent face-to- face programs.

National curriculum standards, developed by TEVETA, are competencies that required demonstration and assessment in parallel and in context. The review of engineering education and TEVET training should, therefore, place particular emphasis on the need to foster leadership, innovations self-employment, teamwork, and communication. A reasonable conclusion would be that collaborative and effectively supervised work over an extended period should be an integral part of any undergraduate engineering course and TEVET engineering course, whether delivered by distance education or otherwise. Accreditation for distance education programmes should be available only where entry is restricted to mature students already working in an engineering environment and where, at least during the final year, the programmes make extensive provision for residential schools.

Careful consideration must be to implement rigorous quality assurance systems to ensure that the claimed equivalence of internal and external programmes matched the actual learning experiences of the individual students. For example, distance education students may be required to complete log books or a course portfolio of evidence, in much the same way as graduates, record the engineering activities in which they are engaged, and to have the accuracy of the log books verified by a professional engineer approved as a professional supervisor by the Engineering Institution of Zambia and the university. Residential schools in the final year should place special emphasis on developing key competencies in planning, collaboration, and communication, and ensure that opportunities are provided for effective and broadly based contact between staff and students, particularly when major projects were initiated and evaluated. In face-to-face programs, the interaction between students take place in formal and informal environments and widely regarded as an essential element in developing the key competencies identified above. Such interaction appear to be most effective in the later years of a course, and provision must be made in distance education programmes for student-to-student communication beyond that possible in the often high pressure environment of residential schools. Well-designed and readily accessible Internet facilities are a useful tool in fostering such communication.

The success of the distance learning approach for engineering at all levels largely depends on the critical role the Engineering Institution of Zambia must play by legislative flexibility to engage engineering units and organisations to embrace the ODL approach by empowering practicing engineering professionals to provide workplace assessment and supervision for students.

International and Zambian best practices

The current status of TEVET in Zambia is not all about weaknesses. In 1996 and 2009, the TEVET system in Zambia experienced promising reforms to build on the critical aspects of the system. The major reforms concern the setting up of TEVETA, and the enactment of laws to strengthen national vocational training programmes, the establishment of the national qualifications framework and the need to link training to employment (either formal or non-formal) which is best practice world-wide.

TEVETA was setup by an Act of Parliament that established the authority with the overall responsibility for TEVET skills development in the country. In order to achieve greater coherence within the diverse TEVET system, the government established the Zambia Qualifications Authority to provide a mechanism for awarding qualifications based on the achievement of specified learning outcomes prescribed by industry. The framework allows for the accumulation of credits and recognition of prior learning, which promotes the culture of life-long learning. Employers and industry as a whole should offer more support to vocational and technical training financially.

The globalisation challenge

In Zambia, globalisation has created a tension between developing skills for poverty eradication and skills for global economic competitiveness. Although the primary objective of technical and vocational training in Zambia is to help alleviate poverty through the acquisition of employable skills, a strategic approach to skills development in the country cannot ignore the effects of globalisation. In a globalising world economy, the acquisition of "industrial" skills is also important. However, the sheer lack of skills of all sorts in Zambia and the demands of poverty alleviation mean that Zambian must pursue the development of skills at all levels of the spectrum (basic, secondary, tertiary levels), with each level emphasising the skill levels that correspond best to their stage in economic development and the needs of the local labour market and the future. ICT education at all levels is also important for survival in a globalising labour market.

Another dimension of the implications of globalisation for vocational training in Zambia is the flooding of markets in Zambia with all manner of cheap goods and technology products from foreign countries. The question arises as to how competitive locally produced goods are against the cheaper imported versions? National policies should, therefore, take into account these and other globalisation-induced factors in designing TEVET programmes and courses.

Priority TEVET areas

A recent survey conducted by the African Union on the state of TEVET in 18 African (Onyancha, Muwina, Siame, and Nkonde: 2016), countries points to a number of priority areas for vocational training in Africa. The agricultural sector receives the highest priority, followed by public health and water resources, energy and environmental management, information and communication technologies, construction and maintenance, and good governance. According to the Zambia Statistical Office (The Statistician: 2017), the agricultural sector employs the highest number of people at 48.9% of the total workforce in Zambia, Manufacturing and construction at 3.8% and 3.1% respectively. These statistics point to where the priorities for skills should be.

Strategic Policy Framework

Key strategic and policy issues: The other key issues that the review ought to seek to address are the following:

Poor Perception of TEVET

The public and even parents consider the vocational education track as fit for only the academically less endowed. Students entering the vocational education stream find it difficult, if not impossible, to proceed to higher education. There is the need to make TEVET less dead-ended.

Gender

The need to deal with gender stereotypes in TEVET and increase access to engineering education by females.

Lecturer training

The delivery of quality TEVET is highly dependent on the competence of the teacher; competence measured in terms of theoretical knowledge, technical and pedagogical skills as well as being abreast with new technologies in the workplace.

Strengthening the Linkage between vocational and general education

In general, vocational education and training forms a separate parallel system within the education system with its own institutions, programmes, and teachers. This situation tends to reinforce the perception of inferiority of the vocational path. It is therefore important to enhance articulation pathways between vocational education and general education. To achieve success in vocationalisation, the quality and relevance of the courses ought to improve as well as placement of more emphasis on soft/employability skills development.

Linkage between formal and non-formal TEVET

It should be possible for students who drop out of the school system to learn a trade to re-enter the formal vocational school system to upgrade their skills, either on part-time or full-time basis. Similarly, regular vocational school students should be able to acquire relevant practical skills in the non-formal sector.

Linkage of TEVET to the labour market

The ultimate aim of vocational training is formal employment and self-employment. TEVET programmes therefore are linked to the job market. In this way, the socio-economic relevance of TEVET can be enhanced.

Traditional skills, business management, and entrepreneurial training

TEVET programmes in Zambia should help develop indigenous skills associated with the manufacture of traditional artefacts and crafts for value addition. As employment opportunities in the formal sector shrink, the acquisition of business management and entrepreneurial skills for self-employment becomes a major imperative in the design of vocational training programmes.

Harmonization of TEVET programmes

Harmonisation of TEVET programmes and qualifications in TEVET can contribute to uniting the people of Zambia. This is possible if training programmes and qualifications

can be harmonised into a coherent system of mutual recognition of competencies. Portability of TEVET qualifications enhances the value and perception of TEVET.

Partnerships with industry

Partnerships with industry, represent one potent weapon that could be brought to bear on the otherwise intractable problem of meeting the increasing costs of high quality TEVET training.

Technology and innovation

The need to bridge the technology gap between TEVET institutions and industry to enhance innovation. The need to review the ICT curricular to make it relevant to the current and future ICT demands. There is currently duplication of effort and content across the entire ICT curricular. The TEVET content was developed before the new secondary school curriculum. The same apply to engineering drawing.

Guiding Principles

The guiding principles that are considered the major drivers of any TEVET strategy or policy include access and equity, quality, proficiency, and relevance. The others are employability, entrepreneurship, efficiency, and sustainability. The strategy should also promote linkages and partnerships, responsible citizenship, conservation of resources and respect for the environment, and articulation pathways throughout the system.

Main Goal and Vision of the Policy and Strategy Review

Taking into account the key strategic policy issues and guiding principles, the main goals of the strategy and policy should ensure the promotion of skills training delivery, effective assessment of skills for awards, and responsible productive citizenship. The ultimate vision of the strategy and policy should position the Zambian TEVET system as a tool for empowering the people of Zambia, especially the youth, for sustainable socio- economic development.

Strategic and Policy Objectives

The broad outcomes of the envisaged review of the TEVET system include development through a comprehensive consultative process a strategy and policy to deliver quality TEVET, assure employability of trainees, improve management of training provision, promote life-long learning, enhance collaboration among all stakeholders (government, industry, and community), and enhance status and attractiveness of TEVET.

(i) Access and Quality Delivery of TEVET

Training for high-quality skills requires appropriate training equipment and tools, adequate supply of training materials, and practice. Other requirements include relevant textbooks and training manuals and qualified instructors with experience in industry. The delivery of quality TEVET is also closely linked to the building of strong, professional management and leadership capacity as well as a suitable qualifications framework and monitoring mechanism to drive the entire system.

(ii) Employability and relevance of skills

Assuring the employability of trainees begins with effective student support systems for potential trainees in the choice of training programmes in relation to their aptitude and

academic background. Employability presupposes the acquisition of employable skills that are related to the demands of the labour market. Tracer studies which track the destination of graduates in the job market can provide useful feedback for the revision of training programmes so as to enhance the employability of trainees.

(iii) Improve coherence and management of training provision

In order to ensure coherence and management of training provision, it is necessary to strengthen TEVETA to coordinate and drive the entire TEVET system. The operations of TEVETA should be decentralized to local government level to ensure compliance, quality assurance, and ensure compliance to standards throughout the TEVET by institutions throughout in the country.

(iv) Life-long learning

Life-long learning has a beneficial effect on the development of a high quality TEVET system. The skills of the workforce can be continually upgraded through a life-long learning approach. This also means that learners who have had limited access to training in the past can have a second chance to build on their skills and competencies.

(v) Improve Perception of TEVET

TEVET should be promoted as a tool for economic empowerment in Zambia. For this, the use of role models in TEVET and the involvement of successful entrepreneurs in motivation campaigns will be necessary. The engagement of professional bodies could play a significant role.

Strategy and Policy Implementation

The diverse nature of TEVET with its longitudinal and transversal dimensions suggests that the implementation of any strategy to revitalise the sector is more likely to be successful within a national policy framework with clear implementation guidelines and policy roles for the various actors as well as action plans for resource mobilization and allocation. Above all, political commitment to the revitalisation effort can make the difference between success and failure.

Implementation structures

There are requirements for review and development of a national TEVET strategy and policy that sets out the government's vision for skills development. The national strategy and policy should make provision to oversee the implementation of the policy and most importantly the coordination across the legislative mandate of organisations statutory bodies and agencies.

Strategy for non-formal TEVET and projects in rural areas

Non-formal TEVET

Non-formal TEVET has the advantage of shorter duration, is occupation-specific, flexible and may or may not follow the standard curriculum prescribed by national educational authorities. The emphasis is on acquisition of practical skills for direct employment. For this reason, skilled craftsmen with some pedagogical training may be engaged as instructors. However, the strategies and structures for formal and non-formal TEVET delivery are similar in many respects. In particular, it is important that the two TEVET systems are coordinated by a national coordinating body (incorporating all line ministries) in order to facilitate articulation between the two systems and enhance consistency and better administration of the whole TEVET system.

Experimental projects in rural areas

The difficult conditions in rural areas, which include dilapidated educational infrastructure at all levels and the shortage of teachers and skilled instructors, demand a training approach that takes into account these special circumstances. Since a good basic education enhances effective technical vocational training, combining literacy programmes with employment skills training presents a sustainable approach to skills development in rural areas. Technical and vocational training in rural areas should therefore be delivered concurrently with the teaching of basic skills such as:

- Entrepreneurship and value addition
- Business entrepreneurial skills
- Literacy and numeracy
- Family life skills (parental care and domestic skills)
- Human relations and inter-personal skills (interaction with others from different ethnic backgrounds)
- Emphasis should be on TEVET programmes such as: Building skills; production skills; Agriculture skills (crop production, aqua-culture and animal husbandry) electrical installation and electronic equipment repair; Car repair and maintenance
- Water supply conservation and sanitation
- Appropriate ICT skills
- Tourism and hospitality skills
- Communication and language skills (learning of a second language in multi-lingual societies)
- Good governance and citizenship

Given the scale of human resource development needs in Zambia, it will be essential for the government to foster collaboration and partnerships with private sector training providers, including NGOs, CBOs, civic authorities, and traditional leaders.

Key strategy and policy issues

A number of policy issues are critical to the successful implementation of the strategy or policy. These include:

(i) The need to conduct a comprehensive assessment of the capacity of the national TEVET System capacity
(ii) Linkage of the TEVET strategy and Policy with other national policies and strategies
(iii) Linkage with relevant regional and international policies
(iv) Linkage with the current and future world of work
(v) Enhanced instructor training and professionalisation of TEVET staff
(vi) Funding and equipping of TEVET institutions
(vii) Enhance promotion of female participation in TEVET especially in engineering education
(viii) Enhanced and effective professional participation of relevant stakeholders in the TEVET sector including statutory bodies.

Policy roles and recommendations

The policy implementation roles of the various stakeholders may be summarised as follows:

The Government

- Give legislative backing to national TEVET policies;
- Improve coherence of governance and management of TEVET;
- Introduce policies and incentives that support increased private sector participation in TEVET delivery
- Initiate cooperating and development partners investment in TEVET
- Partner with informal TEVET trainers to incorporate literacy and numeracy skills into their training programmes;
- Invest in training materials and equipment;
- Invest in TEVET instructor training and enhance status of instructors;
- Institute measures to reduce gender, economic, and geographical inequities in TEVET provision;
- Introduce sustainable financing schemes for TEVET;
- Increase funding support to the sector;
- Set up venture capital to support TEVET graduates;
- Build leadership and management capacity to drive TEVET system;
- Strengthen vocational education pathway into the general education system, so that the vocational track is less dead-end;
- Support the enhancement and advancement of ICT into TEVET;
- Monitor and periodically evaluate the performance of the TEVET system and apply corrective measures in collaboration with all stakeholders accordingly;
- Support development of national TEVET policies and strategies;
- Fund TEVET research and advocacy;
- Support capacity building in TEVET sector;
- Help in identifying and disseminating best practices in TEVET;
- Support TEVET technology advancement;

TEVET Stakeholders

- Disseminate TEVET strategy document widely among members;
- Encourage cooperation in the field of education and training;
- Reach out to support TEVET in Zambia;
- Identify, document and disseminate best practices to institutions;
- Sensitize the role of TEVET for socio-economic development as well as the need to increase funding for TEVET;
- Actively play TEVET advocacy;
- Offer technical assistance to TEVET institutions;
- Project TEVET as a vehicle for national development;
- Monitor implementation of strategy and policy at professional category

Training Institutions

- Provide relevant quality training within national qualifications framework;
- Develop business plans to support and sustain skill training activities;
- Create strong linkages and collaboration with employers and industry;
- Mainstream gender and other emerging themes into training activities and programmes (governance, the environment, gender);
- Develop robust and sustainable institute bursary schemes for trainees from poor families;

- Strengthen student support services to trainees;
- Network and bench-mark with other T E V E T providers;

Parents, Guardians, Schools, and Sponsors

- Support potential students to choose the vocational education stream
- Enhance the perception that in communities
- Advocate for more funding from government in favour of TEVET
- Support activities of training providers

Industry

- Contribute financially to national training;
- Provide opportunities for TEVET facilitators/trainers to regularly update their workplace and professional experience;
- Provide opportunities for industrial attachment and placement for trainees;
- Contribute to the development of national skills standards;
- Support and deliver workplace training to employees as part of continuous professional development;
- Provide support through professional bodies towards technology and innovation advancement

Policy evaluation

The evaluation benchmarks of the TEVET strategy and policy over a period of time depending on the situation, including the following principles:

(i) Training outcomes
(ii) Employment
(iii) Citizenship development

The training-related criteria may include, access and equity, system efficiency, trainee satisfaction, effective industry participation in the development of training packages, and the availability of vocational pathways within the system and creation of baseline data for TEVET system activities. The employment-related criteria may include the percentage of trainees in gainful formal employment and self-employment after training, and how long after training it takes to be employed, wage and salary levels, employers' satisfaction with the performance of graduates, and the relevance of training to actual employment. The citizenship- related criteria would measure indicators such as public perception of TEVET.

Conclusion

This paper has made an attempt to form a framework for the review of national TEVET strategy and policy to address the current challenges of technical and vocational training to support industrialisation, economic development and the creation of national wealth and contribute to poverty eradication as envisaged in the Vision 2030. The paper acknowledges that technical education vocational and training alone does not provide jobs or eradicate poverty. Good government policies are pivotal. The paper therefore urges government and stakeholders to create an economic environment that

stimulates the growth of enterprises and generally stimulates the economy. When businesses develop and expand, additional labour-market demands for technical and vocational training emerge, new job opportunities are created, more people get employed, and the incidence of poverty reduces. For this to happen on a sustainable basis, however, the TEVET system must be labour-market relevant, equitable, efficient, and of high quality. This paper provides the framework for further discussion and the design and implementation of a formidable national TEVET system.

It is important for our engineering community to contribute more meaningfully to the nation's development. The choice of research problems that are relevant in the Zambian context is important to realise this. The Zambian engineering community through the Engineering Institution of Zambia and other key players also has a key responsibility in guiding the nation's technology choices and providing directions to science and technology policy. TEVET policies are more effective when they are underpinned by sound research results and research can play a critical role in evaluating policy effectiveness. Designing and implementing long-term development policies without backing them up with sound evidence can be negative, as measures taken can have unwanted, and even opposite, effects.

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Improving blast advance: A study of Mopani Copper Mines Mufulira deeps section, Zambia

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Abstract

Drilling and blasting of development ends at Mufulira mine site are carried out by contractors. The average monthly development target rate is normally 3 m. However, this advance rate is not or is rarely achieved by the contractors when compared to the average actual monthly advance of 2.7 m thus, leading to poor development performance. The objective of this research was to investigate and evaluate the development operations at Mopani Copper Mine Plc, Deeps Section with a view to improving the advance rates per blast from an average of 2.7 m to 3 m. During the study, each development operation were studied in order to determine the time it would take to complete each operation cycle. This was done in order to determine the major causes of low advance rates hence poor development performance. The detailed study established that the contractors are not able to achieve their targets because they do not adhere to the set standards. Advance rates are also adversely affected due to frequent breakdown of the drilling equipment. In this paper, suggestions on how to improve development advance per blast to 3 m are suggested.

Keywords: Development, drilling, blasting, advance rates, performance

1. Introduction

Mopani Copper Mines (MCM) Plc is a Zambian registered company owned by Carlisa Investments Corporation and Zambia Consolidated Copper Mines Investments Holding (ZCCM-IH) Plc. Carlisa Investments Corporation is a joint venture comprising Glencore International AG and First Quantum Minerals Ltd. Mopani Copper Mines Plc has two mine sites namely Nkana and Mufulira. Mufulira mine site is located in the town of Mufulira on the Copperbelt Province of Zambian (Figure 1). This is an underground mine which comprises of nine (09) Sections namely West Portal, East portal/Insitu Leach, Pillar, 14 Shaft, 52 Block, Upper 1, Upper 2, Central and Deeps section. Underground development is currently at 1507m level. Development is planned to carry on up to a depth of 2020m level. Production is currently taking place from 1390m to 1473m levels.

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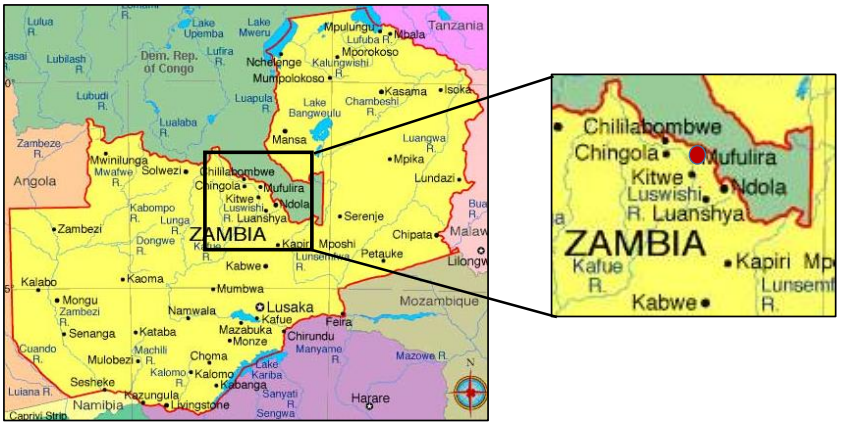


Fig 1: Location of Mopani Copper Mine Mufulira mine site

All development drilling and blasting works at Mufulira mine site are carried out by contractors i.e. Redpath, AAC, Reliant and Murray and Roberts. Development ends range from 4 m x 4 m to 4.8 m x 4.8 m. Figure 2 shows a 4 m x 4 m development which is one of the development ends at MCP.

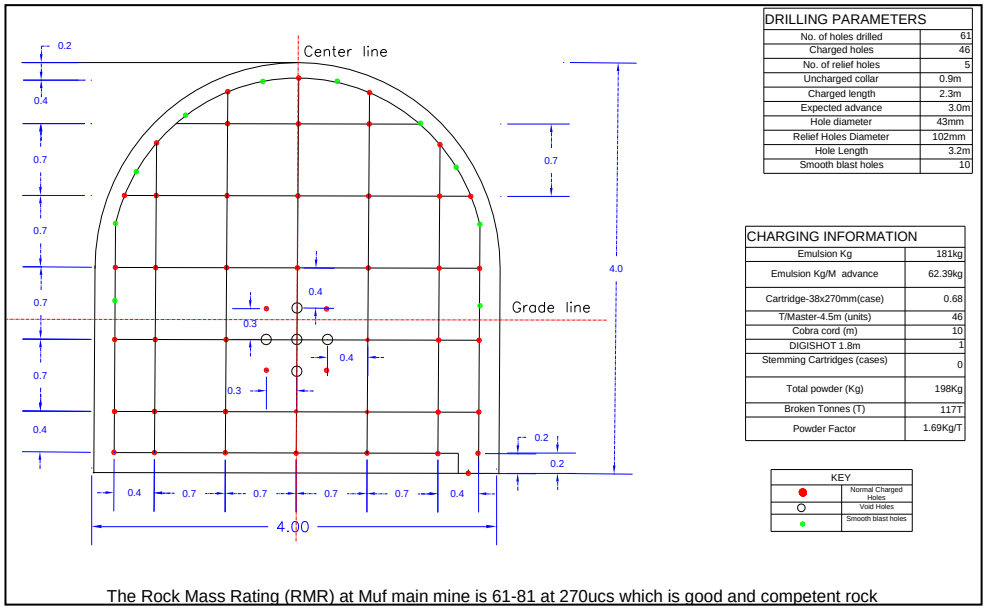


Fig 2: Development end (4m x 4m) drilled and blasted at Mufulira mine site

The standard advance rate to be achieved for this development end is 3 m. However, this target advance rate is not or is rarely achieved by the contractors. The average actual monthly advance rate is normally 2.7 m while the average development performance efficiency is 71% (Figures 3 and 4). Therefore, with this efficiency, the performance by contractors needs to be improved. In this paper therefore, causes of poor performance are highlighted and suggestions on how to improve development advance per blast to 3m have been suggested.

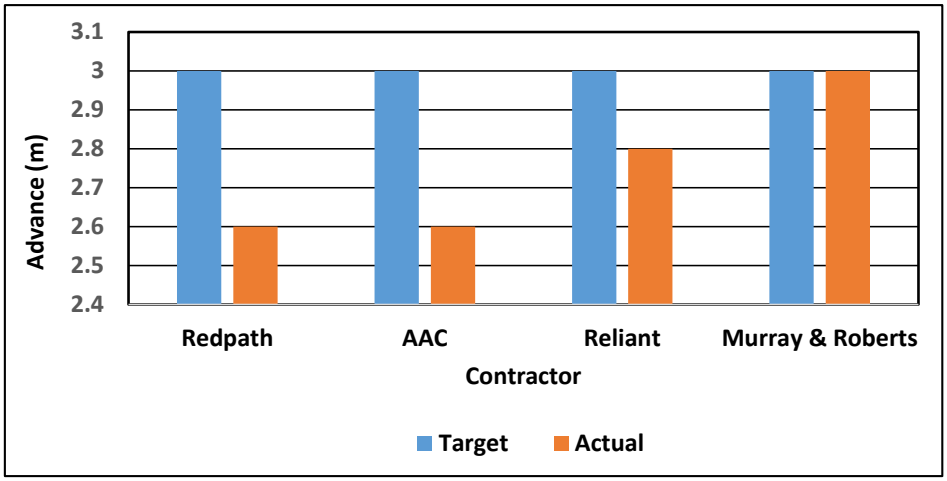


Fig 3: Contractor's development average advance from January 2016 to August 2016

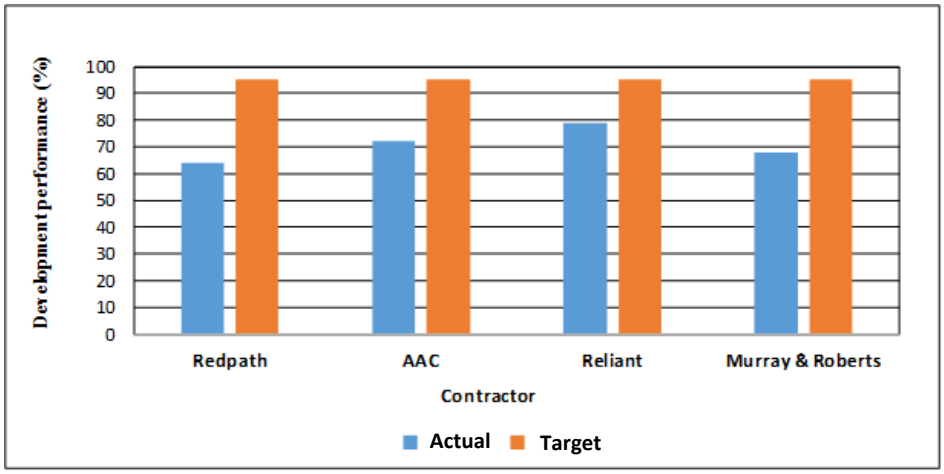


Fig 4: Contractor's development performance from January 2016 to August 2016

1.1 Research objectives

1.1.1 Main Objectives

The main objective of this study was to investigate why the mine is achieving less than the targeted advance rate.

1.1.2 Sub objectives include

(i) Investigation the delays in the development cycle i.e. drilling, charging and blasting;

(ii) Determine development cycle time (i.e. drilling, charging and blasting cycle times);

(iii) Determine the drilling cost per metre; and

(iv) Suggestion on ways of improving advance rates.

1.2 Research methodology

To achieve the stated objectives during the investigations, site visits to underground development operations were conducted. To investigate the delays in the development cycle time, measurements of duration each development operation (drilling, charging and blasting) was taking to be completed was carried out using a stop watch. The duration of each operation from the start to until the end i.e. drilling, charging and blasting (re-entry time after blasting) was recorded. The length of the drilled holes were measure using a tape.

2. Rock mass characteristics

The approximate uniaxial compressive strengths (UCS) of rocks at Mufulira mine site are given in Table 1. They were derived from point load tests according to the classification system used by the International Society for Rock Mechanics, 1986;

Table 1: General stratigraphy and geotechnical domain for Mufulira Deeps section (Geo-Hydro Consultants, 1991)

Geological Unit	Thick (m)	UCS (MPa)	RMR	General Geotechnical Description
Lower argillaceous quartzite	40m	320	–	Good quality, massive, bedded, partings infilled with calcite
A' orebody quartzite	8m	220	81	Good quality but bedded with weak graphic partings in lower, greywacke part of orebody. Upper part shows calcite infilled bedding partings with beds 10 to 50m thick
Inter A/B quartzite	10-30m	320	68	Average quality, Bedded
Banded shales, quartzite and dolomite		160-250		
Lower dolomite		50	49	Weak and friable
B' orebody quartzite	7m	320	81	Very good quality, bedded
Inter B/C quartzite	4-18m	310	64	Good quality, bedded
Banded shales and dolomites		211		Moderate quality. Mud seam at base may be weak in places.
C' orebody quartzite	9m	310	81	Very good quality
Footwall quartzite	0-150m	270	61	Shear zone at basement contact
Basement Schist	–	300	–	Strong, competent
Basement Quartzite	–	300	80	Very strong, competent

From Table 1 it can be seen that the orebody quartzite's are described as extremely strong while the footwall and the hanging wall rocks are strong to very strong (Geo-Hydro Consultants, 1991)). The exception is the lower dolomite unit which forms the immediate hanging wall of the B orebody and is classified as Medium strong to strong. The Rock Mass Rating (RMR) system was incorporated in the characterization process, particularly in determining the minimum ground reinforcement/support for each domain (Laubscher, 1990).

3. Lost-Blast Analysis

The Lost-Blast analysis simply assigns a reason to the number of blasts lost. This helps the mine to understand why the contractors are not able to meet their targets. After the analysis, Figure 5 shows the Lost-Blast Analysis charts indicating the main contribution to low development rates while Tables 2 and 3 shows Lost-Blast analysis broken down into production and mechanical related loses. Figure 6 shows a comparison of production and mechanical related delays.

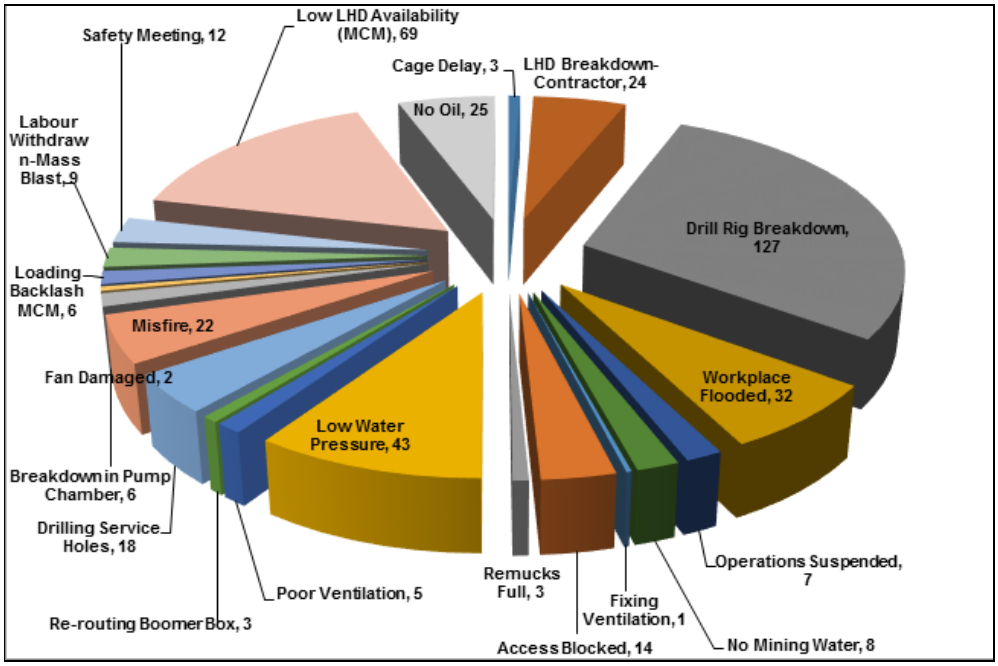


Fig 5: Lost-Blast Analysis Pie Chart for March to August 2016 (Mwila, 2016)

Table 2: Production related delays

Item No.	Activity	No. of Times
1	Safety Meetings	12
2	Labour withdrawn - mass blast	9
3	Loading backlash	6
4	Misfires	22
5	Fan Damage	2
6	Drill service holes	18
7	Poor ventilation	5
8	Remucks	3
9	Operations suspended	7
10	workplace flooded	32
11	Access blocked	14
12	No mining water	8
	Total	**138**

Table 3: Mechanical related delays

Item No.	Activity	No. of Times
1	Breakdown in pump chamber	6
2	Re-routing boomer box	3
3	Lower water pressure	43
4	Fixing ventilation	1
5	Drill Rig Breakdown	127
6	LHD Breakdown - contractor	24
7	No oil	25
8	Cage delay	3
9	Low LHD Availability	69
	Total	**301**

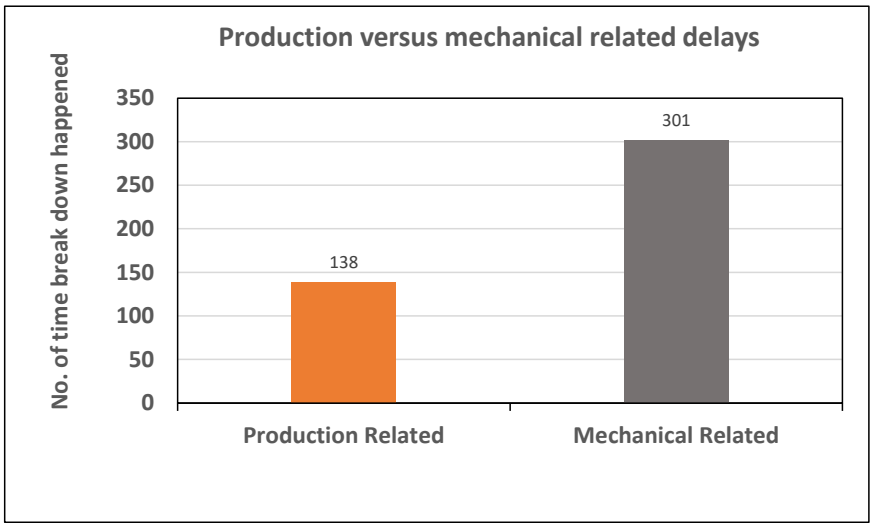


Fig 6: Production versus mechanical related delays

4. Development cycle time

The mine has two working shifts i.e. day and night. Each shift work is for 12 hours in which all development operations should be completed and blasting undertaken. The day shift begins at 06:00 hours and ends at 18:00 hours. Table 4 and Figures 7 and 8 shows the monitored time it took for each operation in comparison to the planned time during the day shift as well as the total development cycle time.

Table 4: Development cycle time

DEVELOPMENT SHIFT REPORT				
Activity	**Plan**	**From**	**To**	**Actual**
Shift on shaft bank (min)	0:05		7:00	
Shift to Sub-Vertical Shaft	0:10	7:00	7:10	0:10
Shift down at Sub-Vertical	0:05	7:10	7:15	0:05
Shift arrive in section	0:15	8:45	9:00	0:15
Safety talk	0:10	9:00	9:30	0:30
Ventilation installation and services	0:30	9:55	10:45	0:45
Barring end	0:45	10:45	11:10	0:40
Drill support	4:30	11:10	13:05	1:55
Remove rig	0:15	13:05	13:10	0:05
Lash barred ground	0:20	13:10	13:20	0:10
Prepare face & establishing survey lines	0:15	12:00	12:12	0:12
Move rig in for drilling	0:15	13:20	13:25	0:05
Prepare face	0:20	13:25	13:35	0:10
Drill round	2:45	13:35	16:15	2:40
Charge up round	0:45	16:15	17:05	0:50
Connecting up round to Digi shot & tagging	0:15	17:05	17:20	0:15
Blast	0:05	17:50	18:00	0:10
Total	**11.40**			**8:57**

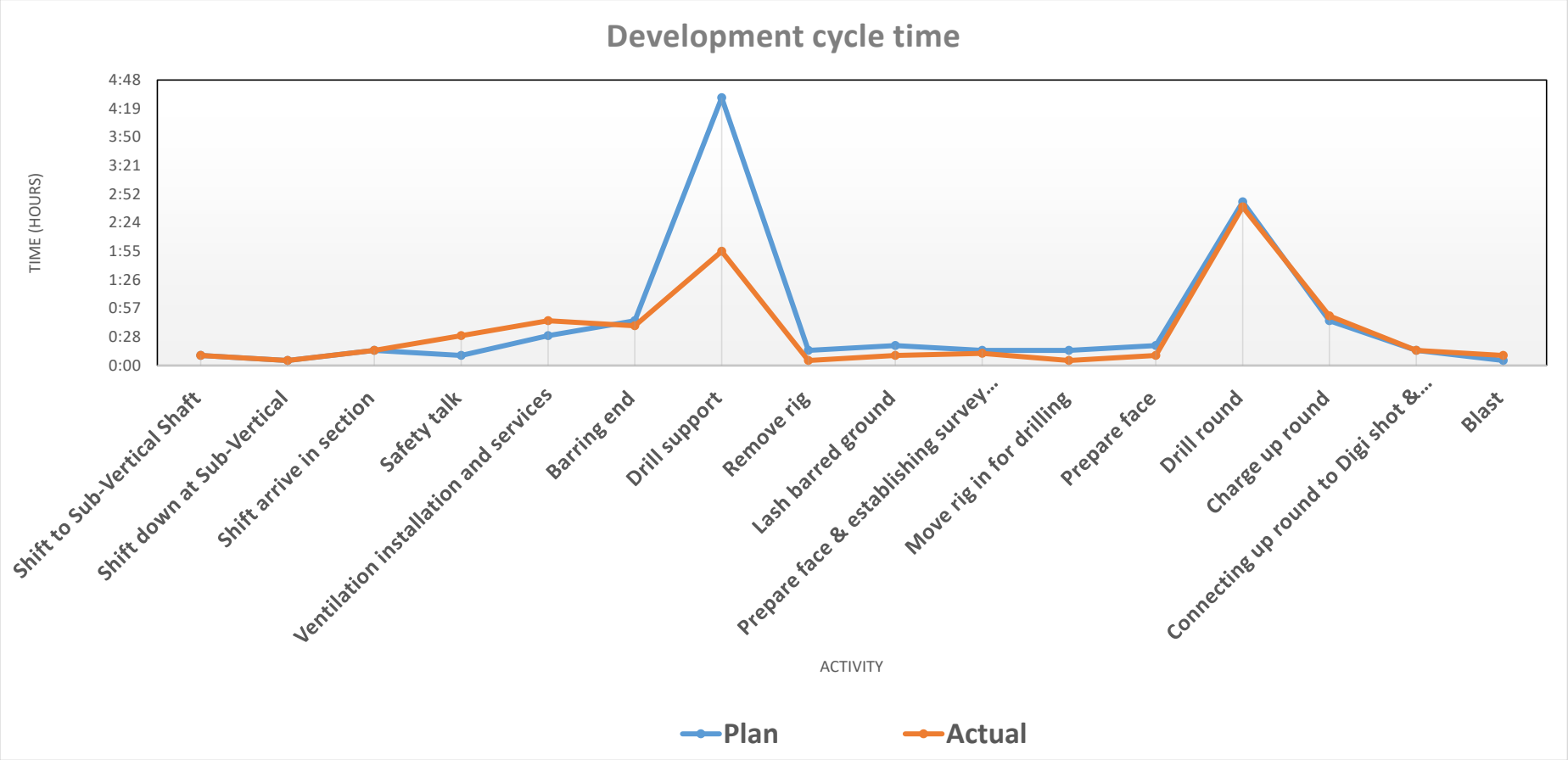


Fig 7: Development cycle time

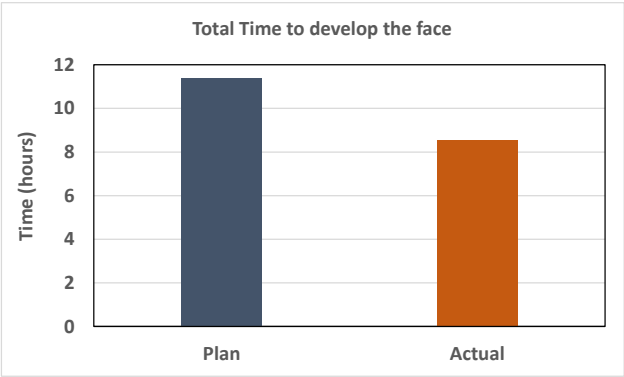


Fig 8: Total planned versus actual development cycle time

According to Figure 8, it was observed that the planned cycle time to develop the face is more than the actual time which is a good situation. However, following underground visits, it was observed that for most of the contractors, the shift boss who is in charge of giving instructions for the shift would arrive in the section as late as 09:00 hours instead of 06:00 hours meaning 3 hours is lost in the process. Therefore, when work starts late, the workers will also finish late or will rush some activities since they will have insufficient time to drill the total number of required drill holes and ream the required number relief holes as well as cleaning the holes before charging and blasting. As can be seen from Table 4 and Figure 7, the contractor finished drilling support holes 2:35 hours earlier than the required time. This would compromised the quality of support hole drilling. The set time for blasting (according to the blasting schedule for the mine) is between 17:00 hours and 17:30 hours so that 30 minutes is allowed for the fumes to leave the section after blasting before the night shift arrives at 18:00 hours. However, from Table 4 above it can be seen that the blast was undertaken as late as 18:00 hours.

4.1 Development Drilling

Tables 5 and 6 show the development drilling and charging parameters for a 4 m x 4 m development end. Figure 9 shows planned and actual underground drilling layout for different development ends.

Table 5: Drilling Parameters for a 4 by 4m face, comparing theoretical and actual findings

Drilling Parameters	**Planned**	**Actual**
No of holes drilled	61	48
Charged holes	46	46
No of relief holes	5	2
Uncharged collar	0.9m	0m
Charged length	2.3m	2.5m
Achieved advance	3.0m	2.4m
Hole length	3.2m	2.5m
Smooth blast holes	10	0

Table 6: Drilling Parameters for a 4 m by 4 m face, comparing theoretical and actual findings

Charging Parameters		
Theoretical Standards (4.5m×4.5m face)		**Actual Findings**
Emulsion (kg)	185kg	190kg
Cartridges (38×270mm)	17kg	17kg
T-master 4.5m (units)	47	47
Total powder	202kg	207kg
Ventilation		
Theoretical Standards (4.5m×4.5m face)		**Actual Findings**
Wet bulb temperature	32.5	34

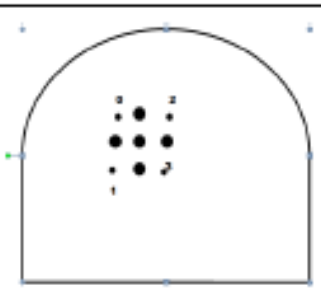
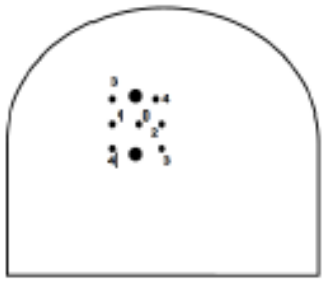
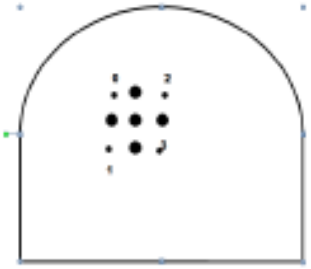
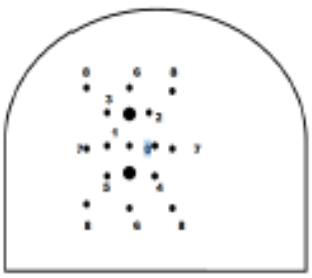
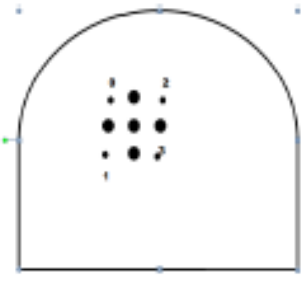
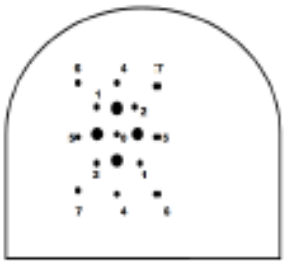
	Drilled Cut on Face	
	standard	**Actual**
4m×4m face		
4.5m×4.5m face		
5.5m×4.8m face		

Fig 9: Planned and actual underground drilling layout for different faces

5.0 Results

The Following are the results of this study.

5.1 Reasons for poor advances

It has been observed that contractors are not achieving the 3 meters advance per blast due the fact that they are not adhering to the preset standards. The reasons are outlined below for specific development operations:

5.1.1 Drilling

As a standard, the required drill hole length of 3.2 metres is not drilled (see Table 5). However, from the measurements, it was noted the average hole length of 2.5 metres is drilled. This reduces the possibility of achieving the 3 metres advance because the required hole length to be drilled for each specific end is not adhered to. Additionally, the standard 61 required drill holes were not drilled at the face as only 48 holes were drilled. This increased the burden at the face and hence blasting is affected as much explosive energy will be lost in trying to overcome the strength of the rock. Furthermore, the required number of relief holes are not drilled (Table 5 and Figure 10). Instead of drilling five (05) relief holes only two (02) holes were drilled. With five relief holes, enough initial breaking face is created when blasting begins. However, as only two (02) relief holes are drilled in most cases, this reduces the amount of breaking face which leads to poor advances. Of the two holes reamed, the centre hole is not reamed which is very critical for providing the initial breaking face.

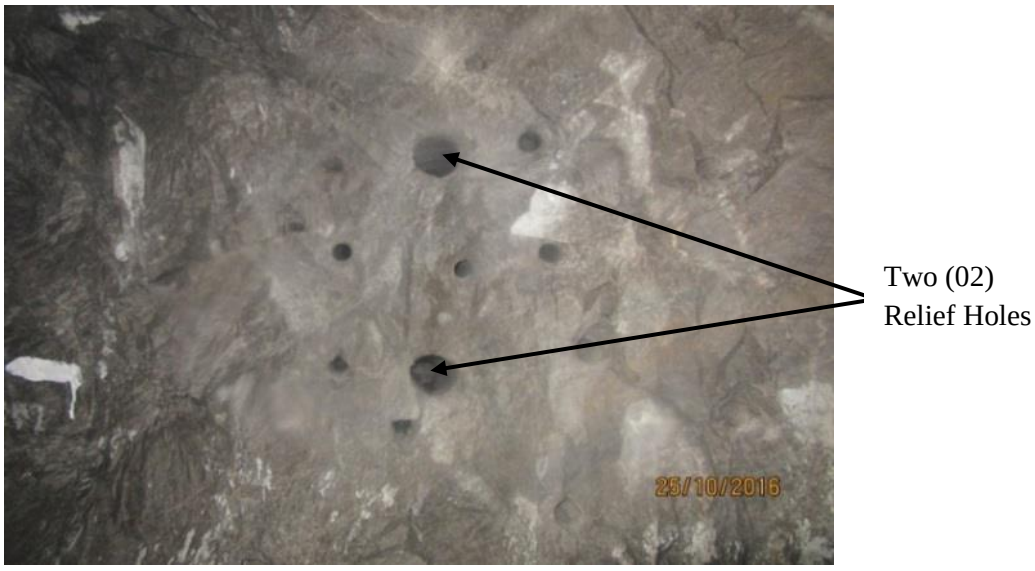


Fig 10: Showing two (02) drilled relief holes instead of 5

5.1.2 Workers starting drilling late

As a result of drilling beginning as late as 13:00hours as observed during the field visit, there is no enough time to drill and ream the required number of holes for the face before blasting time. Hence, workers will be in a hurry to complete drilling and charging the face thereby, drilling shorter and fewer holes as well as reaming less relief holes in order to be able to blast at the appointed time stipulated on blasting schedule.

5.1.3 Charging

During field visit, it was found that drilled holes are not cleaned before charging and charged holes were not stemmed. It was very important that holes are flushed before charging with emulsion because the presence of rock particles within drilled holes will affect the effectiveness and strength of the emulsion when blasting. Stemming of the charged holes compresses the charge and increases pressure which in turn helps to have a good blast.

5.1.4 Ventilation

It was also noted that there was poor working conditions with an average wet bulb temperature of 33.5^0C (Table 6). This makes working places very hot, hence, workers would want to leave the drilling sites early consequently leading to drilling and reaming fewer holes as well as drilling shorter holes. Additionally, high temperatures in the working areas will lead to low concentration on the part of workers because working conditions are not favorable for them.

5.2 Other observed reasons for poor development performance

Other observed reasons for poor advance rates and thus poor development performance are outlined below.

5.2.1 Workers arriving

If development operations begin late, this would mean there is a high possibility that the development ends will not be blasted on time because drillers will not have enough time to drill, charge and blast the development face. Therefore, if this continues to recur, contractors will not be able to meet their development targets in terms of metres which will eventually lead to poor drilling performance.

5.2.2 No underground buffer stores

Underground buffer stores facilitate the storage of necessary machine spares that easily wear out or break. Therefore, if these are not readily available within the section when there is need for them, it will cause delays. Hence, the end will not be blasted which affects the overall development performance of contractors.

5.2.3 Consistent drill rig breakdown

Consistent breakdown of the drill rig was the largest contributor to low development performance (Figure 5 and Table 3). This is because each time the drill rig breaks down, time has to be spent fixing the machine which reduces the time required to do intended operations within the shift.

6. Cost Analysis

Tables 7 and 8 show the cost analysis of drilling, charging and blasting a 4 m x 4 m face. The parameters in these tables are used to determine the cost per metre of the development end.

Table 7: Cost of drilling, charging and blasting a 4 m×4 m face when the blast holes are collared

Item	Amount used	Unit Price	Cost
Emulsion	181kg	$1.32/kg	$238.92
Cartridges (38×270mm)	17kg	$2.05/kg	$34.85
Tunnel master-4.5m per pre pack	46 detonators	$2.12/ detonators	$97.52
Cobra Cord	3m	$0.38924/m	$1.168
Digishot 1.8m (detonator used as initiator)	1 detonator	$11.55/detonator	$11.55
Drilling Cost per meter	46 blast holes of 3.2m per blast hole	$2.853/m	$420.0
Total Cost			**$804.01**

$$Cost\ per\ metre = \frac{Total\ Drilling\ Cost}{Drill\ hole\ length}$$

$$Cost\ per\ metre = \frac{804.01}{2.7} = \$297.80/m$$

Table 8: Cost of drilling, charging and blasting a 4 m x 4 m face when the blast holes are not collared

Item	Amount used	Unit Price	Cost
Emulsion	190kg	$1.32/kg	$250.80
Cartridges (38×270mm)	17kg	$2.05/kg	$34.85
Tunnel master-4.5m per pre pack	46 detonators	$2.12/ detonators	$97.52
Cobra Cord	3m	$0.38924/m	$1.168
Digishot 1.8m (detonator used as initiator)	1 detonator	$11.55/detonator	$11.55
Drilling Cost per meter	46 blast holes of 3.2m per blast hole	$2.85/m	$420.0
Total Cost			**$815.89**

$$Cost\ per\ metre = \frac{Total\ Drilling\ Cost}{Drill\ hole\ length}$$

$$Cost\ per\ metre = \frac{815.89}{2.7} = \$302.18/m$$

According to Tables 7 and 8, it can be seen that if the blast holes are not collared, the cost per meter is more than when the hole is collared i.e. there is an additional $11.88 to the total cost of charging a face. Therefore, the total cost increases by approximately 1.5%. This may seem small but considering that the face may be blasted every day and when computed annually, the company will spend an additional cost of $4336.2/year which can be saved if the blast holes are properly collared.

7. Conclusion

Results of this study indicate that the major causes of poor advances and development performance are:

- Consistent drill rig breakdown.
- Drilling of incorrect hole length i.e. shorter holes were drilled;
- Drilling of less number of holes compared to required number of holes as per drilling patterns;
- Reaming of only two (02) relief holes instead of five (05) holes as per drilling pattern;
- Poor working conditions with average wet bulb temperature being 33.5^0C;
- Workers arriving late in the section and starting development operations late;
- Drilled holes not being cleaned before charging up ends with emulsion; and
- Unavailability of buffer stores in the working places.

8 Recommendations

In order to improve and maintain development efficiency to 95% advance rate the following are recommended.

- Consistent break down of the drill rig should be looked into. A robust maintenance schedule of the drill rig should be put in place to improve the availability of the rig.
- Drillers should adhere to drilling 3.2 m development holes at the face than the current 2.5m;
- Drillers should always ream five (05) relief holes to provide sufficient initial breaking face as the center reamed hole is very critical.
- The planned total number of holes should be drilled according to the drilling pattern and to the required burden for easy breaking of rock at the face.
- To improve development performance workers should arrive at the shaft by 05:30 hours and be in the section by 06:30 hours for day shift and 17:30 hours and be in the section by 18:30 hours for night shift. This will ensure that all development operations take place within the shift and the targeted metres shall be achieved
- Buffer stores should be created underground for storing essential and critical spares of the drill rig. This will reduce on the time required to replace the machine part that has worn out or broken. Hence, development operations will be carried on as planned with minimum delay.

Acknowledgement

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Determination of total heat load and air quantity requirement for Deep Mining at Mufulira Copper Mine Plc, Zambia

Francis Chewe[1], Victor Mutambo [2]

Abstract

Currently, Mufulira mine in Zambia has a proven and probable ore reserve of 19 million Tonnes and an estimated mine life of 25 years at the prevailing average commodity prices. The Orebody comprises of three superimposed ore bodies with an average dip of 45°. Mining operations are currently taking place at the depth of 1457 mL while the target level of operation is 2020 mL which is the toe of the orebody. The mining methods in use are variants of Sub level Open Stopping locally referred to as Mechanized Continuous Retreat (M.C.R 1 and M.C.R 2).

In the year 2004, Mufulira mine embarked on an expansion program which saw the extension of mine life to the current 25 years. This involved the mining of the lower echelon from 1340 mL to 2020 mL here in referred to as "Mufulira Mine Deeps Sections". However, since the commencement of the expansion program, Deeps Sections have been experiencing very high temperatures ranging from **30°C to 33° C** wet-bulb and **35° C to 37° C** dry-bulb temperatures. These high temperatures are mostly attributed to excessive heat build-up in the deeps Sections and they have negatively impacted on the general productivity of the mine.

Therefore, this study focused on determining the total heat load in the deeps Sections of Mufulira Mine and the study has established a total heat load of **52 400 kW.** Furthermore, Air quantities were determined based on two sets of parameters which are Psychrometric properties of the underground atmosphere and the Production Air-tonnage ratios. The worst case scenario gave a quantity of **1798 m^3/s** determined from Production Air-tonnage ratios while Psychrometric properties gave **1 722 m^3/s**.

Results of the study have established the need to set up a refrigeration system using either spot coolers with individual cooling capacities of **1200 kW** installed underground, or using a Bulk Air Cooler System with a minimum cooling capacity of **12 MW_R** constructed on the surface.

Keywords: Deeps Section, Heat Load, Air Quantity, refrigeration.

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1. Introduction

Mufulira mine is an underground copper producing mine which lies on the north-eastern side of the Kafue Anticline on latitude 12° 32' south of the equator. The elevation of the mine is about 1250 meters above sea level. The mine is approximately 50 km north of Kitwe town of the Copperbelt province of Zambia and 10km south of the Mukambo border post between Zambia and the Democratic Republic of Congo (DRC). (Figure 1).

Figure 1: Location of Mufulira mine on map of Zambia

In 2004, Mufulira mine embarked on an expansion program which saw the extension of mine life to 25 years. The expansion programme involved mining of the lower echelon from 1340 mL to 2020 mL here in referred to as "Mufulira Mine Deeps Sections". However, since the commencement of the expansion program, the Deeps Sections have been experiencing very high temperatures ranging from 30°C to 33°C wet-bulb and 35°C to 37°C dry-bulb temperatures respectively which is against the mine Safety regulations (Zambian Mine regulations,1974). These high temperatures are mostly attributed to excessive heat build-up in the deeps Sections and have negatively impacted on productivity of the mine by not reaching the set production targets.

Therefore, this study was aimed at determining the total heat load in the deeps Sections below 1457mL. In order to predict the future air requirements, the heat load was then projected to the undeveloped lower levels down to 2020 mL which forms the toe of the Mufulira ore body. The study also sought to establish possibility of establishing a refrigeration system for the mine to meet the ventilation requirements for deeps Sections.

1.1 Heat sources in Underground Mines

According to Hartman et al. (Hartman H. L., Murmansk, Ramani, & Wang, 1997) potential sources of heat in underground mines include Auto-compression, virgin rock, underground water, machinery and lights, human metabolism, oxidation, blasting activities, rock movement and pipelines. It has been observed that the virgin rock, auto-compression, underground water and mine equipment are the highly rated contributing sources to the total heat load in deeps mining (Chambers of Mines of South Africa, 1982*)*.

1.2 Mufulira Mine Ventilation Systems

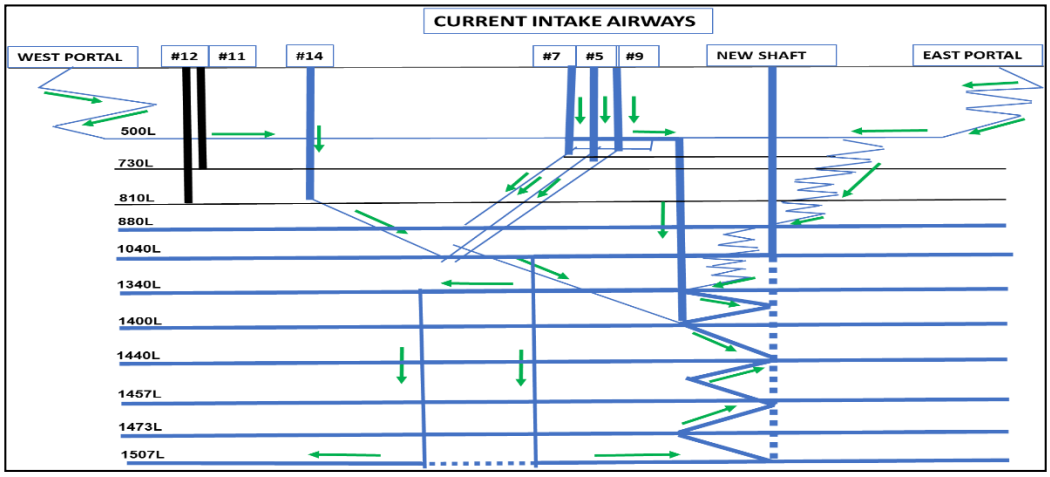
1.2.1 Downcast Airways

Mufulira mine is ventilated by eight (08) main downcast shafts namely number 11, 12 and 14 shafts on the western side of the mine and number 5, 7 and 9 shafts on the central and eastern sides. In addition to these eight shafts, the mine has two (02) main adits namely; the Western and Eastern portals which also act as intake airways.

On the western side, An air volume of 704m³/s enters through number 11 and 12 shafts of 6.7 diameter and then splits into 5 haulages namely 500 mL, 580 mL, 660 mL, 730 mL and 810 mL and flows eastward to number 1, 2, and 3 shafts and then down to 1040mL. A quantity of 237m³/s off the 14 shaft measuring 5.5 diameter from surface flows through the 14 x 3 to 1040mL. On the eastern side of the mine, air volume of 636.0m³/s enters through 5, 7 and 9 shafts on the eastern side measuring 10.3m², 25.2m² and 35.3m² respectively. towards 500 mL and finally linking to sub vertical shaft and 56 Ramp and flows through to 1340 mL which acts as the main intake air feeding the Mufulira deeps.

Below 1340 mL, the existing 30m² decline ramp with carrying capacity of 225 m³/s conveys the fresh air to the Deeps. Figure 2 shows the layout of the main Intake airways at the mine.

Figure 2: Main Intake Airways.



1.2.2 Up cast shafts

Mufulira division has two designated main up-cast shafts namely, the number 8 and 10 shafts which were initially designed to carry return air from the east and western blocks respectively. The total density was at 1.2 kg/m³. Therefore, the total mass flow rate is 1236.96 kg/s at static pressure of 7.75kPa. Upcast quantity as at 5th August, 2016 was measured to be 1030.8 m³/s (one fan is off at 10# shaft). Figure 3 shows the outline of the Main Exhaust Airways.

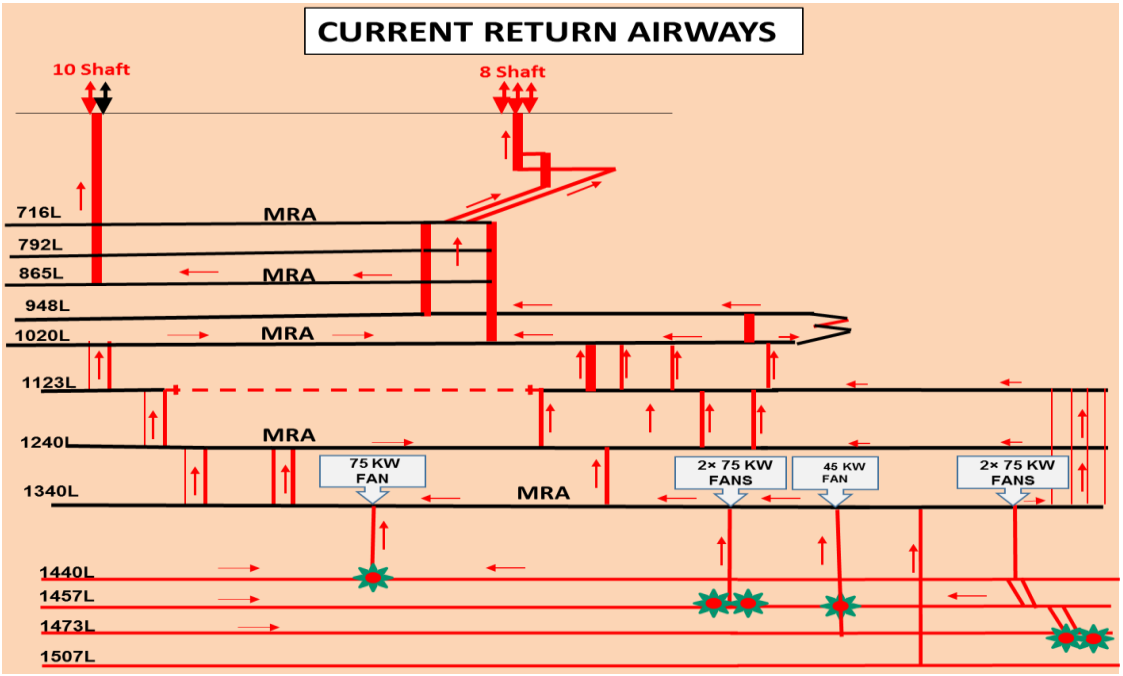


Figure 3: Mufulira mine main exhaust airways.

2. Methodology and materials

The methodology used involved the following;

i. General literature review about sources of heat and its determination

ii. Comprehensive literature review of relevant information from various departments of the mine such as Mine Technical, Mine Planning and Ventilation departments. The mine design layouts were also reviewed

iii. Ventilation surveys and investigations- These were aimed at taking measurements of all the psychrometric variables: temperature, cross sectional areas, relative humidity, pressure and air quantities in the working areas. Furthermore, field work involved analysing the primary and secondary ventilation systems in terms of the type of the fans installed.

2.1 Instrumentation.

2.1.1 Vane anemometer

Vane anemometer was used for the measurement of air velocities. This instrument is fitted with a clutch mechanism for disconnecting the dials from the spindle (Figure 4)

Figure 4: Vane Anemometer

The anemometer was traversed across the airway at a speed of approximately 0.2m/s, in perpendicular to the direction of airflow. At half way across the airway, the operator turned facing the opposite sidewall by making sure that the vanes of the anemometer were still facing the air stream. The traverse was completed and terminated in the other bottom corner. In this investigation, the traversing period was taken to be 50 seconds and hence, after this period the instrument and the stopwatch were stopped by stopped by pressing the clutch so that further revolutions of vanes were not recorded.

2.1.2 Distometer

A distometer shown in Figure 5 was used for the measurements of length, area and volume. The instrument is pointed at the apex of the excavation from the ground level then it electronically reports the cross sectional area of the airway. This area is then multiplied by the velocity of the air to get the flow rates.

2.1.3 Whirling Hygrometer and Infra-Red Thermometer

Whirling hygrometer consists of two thermometers for measuring the wet bulb and dry bulb temperatures.

3. Data Collection

A series of ventilation surveys were conducted with particular attention paid to variables that contribute to heat load. These included temperature, air velocities, barometric pressure and other psychrometric variables. Table1 highlights the dry-bulb and wet-bulb temperatures for various working areas.

Figure 5: Distometer

Heat from the following sources was determined: mobile equipment; virgin rock; auto-compression; blasting activities; electrical installations; Hydro-geological (hot fissures); and human beings (metabolism).

3.2 Virgin rock temperatures in Mufulira Mine (VRT)

Estimation of heat load from both the virgin and broken rock is based on the virgin rock temperatures (VRTs) as shown in Table 2.

Table 1: Sample of the ventilation surveys Conducted

Meter level	Location	Wet-bulb (°c)	Dry-bulb (°c)	Standard Wet-bulb (°c)
1340 ml	Loader Workshop	30	32	31
Decline	Below 1457ml	33	35	31
	Footwall drive	32	35	31
	Mining drive	33	35.5	31
1457ml,	Entrance	29	34	31
	Footwall drive	33	35	31
	Mining drive	33.5	37	31
1473ml	Footwall drive	30.5	35	31
	AAC decline	34	34	31
1507ml	Decline to New Shaft	32	35	31
	Decline to Crusher	31	35.5	31

3.1 Heat sources in Mufulira Deeps Sections

Table2: Mufulira Mine virgin rock temperatures

LOCATION	HOLE LENGTH(m)	MAX. TEMPERATURE(°C)	AVERAGE TEMP(°C)
1340ml	102	36	35.4
1340ml	330	40	38.2
1340ml	280	38	35.5
1340ml	152	36	35.5
1423ml	150	36	35
1423ml	60	36	35
1423ml	496	43	38.4
1423ml	300	38	38.4
1440ml	131	37	35.6
1440ml	559	43	39.5
1440ml	450	42	38.4

3.3 Mobile Equipment

Total fleets and their rated powers in kilowatts are shown in Table 3.

Table 3: Total fleet with rated power for Mufulira mine

COMPANY	EQUIPMENT CATEGORY	EQUIPMENT TYPE	NO. OF UNITS	RATED POWER (kW)	TOTAL POWER (kW)
MOPANI FLEET	LOADERS	CAT1600G	10	201	1,206
	DUMP TRUCKS	AD 30	1	298	298
		AD45B	4	380	1,520
REDPATH RIG RESOURCE	CATR1600G	CAT1600G	2	208	416
		ST1030	1	186	186
		LH 400T TORO	1	158	158
	DRILL RIGS	BOOMERS	2	55	110
		SIMBA	2	55	110
		TROIDON XP 66	1	55	55
		RAPTOR XP 55	1	55	55
	UTILITY VEHICLES	UV100	3	71	213
RELIANT	DRILL RIGS	BOOMER	2	65	130

		TRAIDON DOUBLE	1	75	75
	LOADER	ST 1530	1	186	186
AAC MINING EXECUTORS	ST1030	ST1030	3	224	672
		MT 436-B	2	299	598
	S1D BOOMER	S1D BOOMER	4	55	220
		LANDCRUISER	1	95	95
MURRAY & ROBERTS CEMENTATION	L.H.D 514	L.H.D 514	2	280	560
	TH540	TH540	3	355	1,065
		MANITOU	2	120	240
		GETMAN	2	120	240
		LANDCRUISER	3	71	213

3.4 Thermal properties of the Mufulira rock

Since heat is a formal of energy that needs a medium to be transferred from one point to another, it's important to note and understand the local thermal properties of the rock and mine environment which affect the local flow of heat in the mine. Table 4 summarises the rock thermal properties for Mufulira mine.

Table 4: Rock thermal properties for Mufulira Mine

Locality	Thermal Conductivity (W/m k)	Density (Kg/m3)	Diffusivity (m2/s)	Specific Heat (kJ/kg K)
Shafts	4	2 560	1.9 x 10-6	0.84
Development Roadways	4.4	2 560	1.9 x 10-6	0.8
Stopes	2.9	2 560	1.4 x 10-6	0.78

4. Data analysis

4.1 Heat from the rock strata

Analysis of heat generated from the rock is based on the average virgin rock temperatures of the rock in the local area of the mine. This analysis is subsequently coupled with the determination of thermal gradient for the entire mine.

4.2 Determination of geothermal gradient;

$$\text{Geothermal Gradient } (\Delta G) = \frac{(Change\ in\ temperature)}{(Change\ in\ depth)} \quad [1]$$

$$\Delta G = \frac{39.5-38.2}{1440-1340}$$

$$\Delta G = 0.013\ ^\circ C/m$$

$$\Delta G = 0.013\ \frac{^{\circ}C}{m} * 100m$$

$$\Delta G = 1.3\ ^{\circ}C \text{ Every } 100m$$

4.3 Projection of the Virgin Rock Temperatures

After estimating the average virgin rock temperatures for various meter levels, a graph of virgin rock temperatures is produced which projects the thermal behaviour of the rock down to 2020 mL (Figure 6).

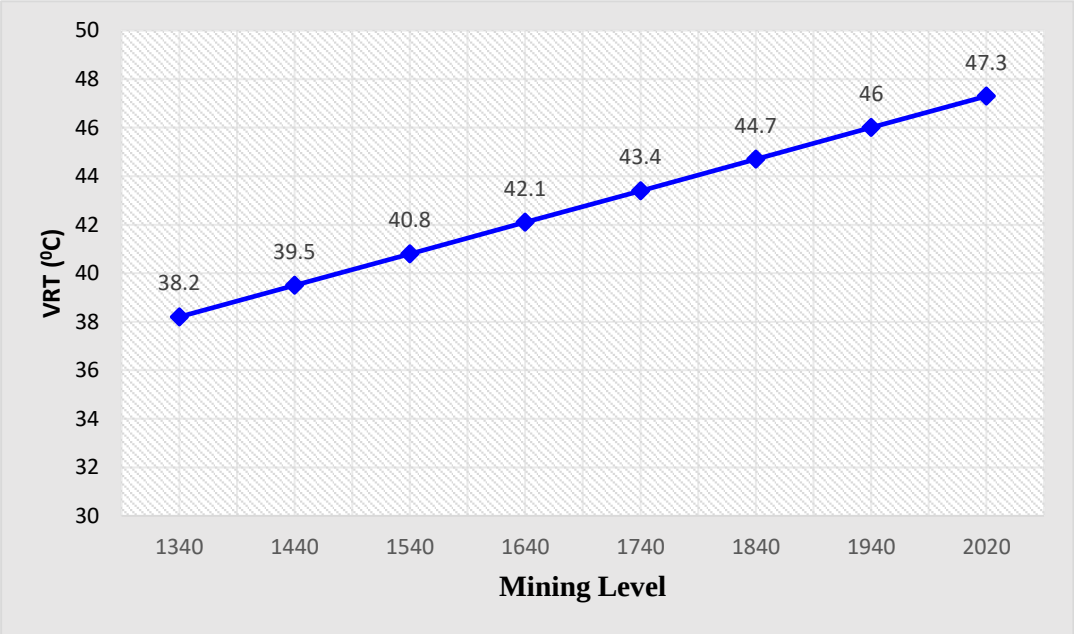


Figure 6: Virgin Rock Temperatures projection

4.4 Heat from Mobile Equipment

In the combustion of fuel, the heat produced is a function of the calorific value of the fuel which is approximated as 42565.8 kJ/kg for diesel fuel (Howard, etal, 1982). Using this value and the rate of burning for various machineries, the amount of heat based on rated powers produced from each machine can be estimated as indicated below;

Sample Calculation for CAT1600 LHD;

Heat produced = burning rate × calorific value [2]

= 0.5kg/min×42565.8 kJ/kg

= 354.72 kW

Sample Calculation for CAT1700 LHD;

Heat produced = burning rate × calorific value [3]
= 0.227kg/min×42565.8 kJ/kg

= 161 kW

4.5 Total Heat load from fleets;

Since Mufulira is a 100% mechanized mine, a fleet availability of about 90% was used.

Heat load from fleets = 90% × total rated power (kW) [4]

= 90% × 11,279kW

= **10151.1 kW**

Therefore, a total of 10151.10 kW of heat is expected from all the mobile equipment operating in the Mufulira Mine.

4.6 Heat transfer from auto compression

Equation 4 is used in determining heat from auto compression;

$H = dT \times Cp \times M_a$ [5]

Where,

H = heat due to auto compression (kJ/s)

dT = change in dry bulb temperature (°C) = 0.9 °C

Cp = thermal Heat capacity (kJ/kg) = 1.005 kJ/kg

M_a = mass flow rate of air (kg/s)

Applying **Equation 5** for the various vertical shafts at Mufulira mine, the effects of auto compression can be approximated as follows;

Shaft # 5

H= 0.9(500/100) x 1.005 x 92.79 (70% utilisation)

= 419.64 kW

Shaft # 7

H= 0.9(500/100) x 1.005 x 227.03 (70% utilisation)

= 1026.74

Shaft # 9

H= 0.9(500/100) x 1.005 x 318.12 (70% utilisation)

= 1438.24

Shaft # 14

H= 0.9(800/100) x 1.005 x 216.22 (70% utilisation)

= 1564.54

***Shaft #* 15 (New Shaft)**

H= 0.9(2020/100) x 1.005 x 270.27 (70% utilisation)

= 4938.08

Therefore the total heat due to Auto compression (H) **= 9387.24**

4.7 Heat from blasting

Considering the type of explosives being used in Mufulira deeps and the average daily consumption shown in Table 5, total heat energy liberated from blasting activities can be estimated as follows;

Table 5: Properties of explosives used at Mufulira Mine

Explosive type	**Calorific value (KJ/Kg)**	**Quantity per day (Kg/day)**
Emulsion (high explosive)	86 000	2500
Magnum buster (primer)	92 000	500

$$\boldsymbol{Qe} = \frac{\mathbf{Ee.qe}}{\mathbf{86400}} \qquad [5]$$

Where; $\boldsymbol{Qe}$ = Energy from blasting

$\boldsymbol{Ee}$ = relative effective energy

$\boldsymbol{qe}$ = explosive daily quantity

Therefore; $Qe = \frac{\mathrm{Ee.qe}}{86400}$

$$Qe = \frac{(86000 * 2500)}{86400}$$

$$Qe = \mathbf{2488.4\ Kw}$$

4.8 Heat Load from Humans

According to *Wyndham (1971),* it was established that the amount of heat produced by the human body varies depending on the amount of work performed. Mining operations range from simple

to relatively hard work as shown in Table 6. The total number of people entering the Mufulira deeps on average is 600 (Table 7).

Table 6: Metabolic heat

State of work	Heat produced (W)
At rest	90
Light rate of work	200
Moderate rate of work	275
Hard rate of work	470

Table 7: Average number of workers entering Mufulira Deeps

Mopani employees	Contracting employees	Total
100	500	600

Assuming underground work is between moderate and hard rate of work, then;

$$q_{human} = (275 + 470)/2w \quad [6]$$

$$= 372.5w$$

Where q_{human} is the quantity of heat expected from metabolism

Total $q_{human} = 600 \times 372.5$ w

= **223.5 kW**

4.9 Total heat load for the Mine

The total heat load for the mine is the sum of all the heat transfers that take place in the ventilating air streams. This means that all the individual analyses done for various heat sources have to be summed up to get the total mine heat load. The load established was **52 377.23 kW**.

4.10 Determination of Air Quantities required to dilute the heat load.

Air quantity required to dilute the heat load was estimated after comparing two methods based on the overall psychrometric properties of the mine and the Air-tonnage Ratios for the Mine.

4.11 Air Quantities Based on Psychrometric Properties.

Psychrometric variables such as temperatures (wet and dry bulb), pressure, air densities and Sigma heat of the underground atmosphere are taken and compared with the standard values of the psychrometric variables for the mine. These values are presented in Table 8**.** Total air quantity required to dilute the total heat load established based on the psychrometric properties was determined using Equation [7].

Table 8: Current and standard psychrometric properties

Current working conditions	Target working conditions
Temperature = 33.5/37 ° C	Temperature = 28/32 ° C
Pressure = 120kPa	Pressure = 120kPa
Density = 1.17 kg/m³	Density = 1.17kg/m³
Sigma heat = 103.0 kJ/kg	Sigma heat = 77.0 kJ/kg

Applying Equation (7) with the psychrometric data from in Table 8, we evaluate the required air quantities to dilute the heat in the lower deeps Sections of Mufulira mine as follows;

$$Q_{required} = \frac{(\textbf{Total Heat Load Discharged Into The AirStream})}{(\textbf{Average Air Density} * \textbf{Change in Sigma Heat})} \quad \textbf{[7]}$$

$$\boldsymbol{Qrequired} = \frac{\mathbf{52377.23}}{\mathbf{1.17} * (\mathbf{103} - \mathbf{77})} = \mathbf{1721.80\ m^3/s}$$

Therefore, based on Psychrometric properties of the mine, a total of $\mathbf{1721.80\ m^3/s}$ is required to dilute the heat load of $\mathbf{52377.23\ kW.}$

4.12Air quantities based on Air-tonnage Ratios and Mobile Equipment for the Mine

According to *Burrows, (1982),* it was stated that for the purpose of ventilation planning, the factor of air quantity per ton of broken rock has considerable significance. This factor represents the Air-tonnage ratio which relates the production rate to the air requirements. Figure 6 shows Standard graph of Air-tonnage ratio.

Therefore, Figure 6 has been used to estimate the amount of air quantities expected to dilute heat from a broken tonnage of rock per main level interval of 100m. This is made possible by relating the Virgin rock temperatures that have been recorded on different meter levels of operations in the mine against the underground m³/s per 100 tons broken rock per month. Air-tonnage ratios established a total quantity of 1798 kW.

Table 9 shows a summary of air quantities required per sub-level for a particular production rate. The dilution factor for mobile equipment was taken to be 0.08 as applied at the mine.

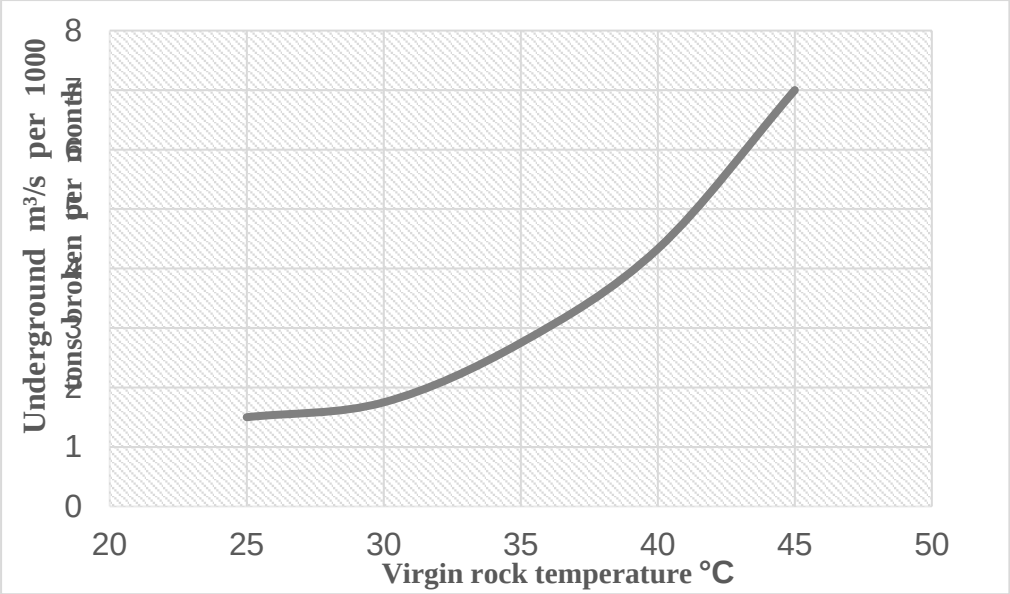


Figure 6. Graph of Air-tonnage ratio.

Table 9: Air quantities required per sub-level at a given production rate

Meter Level	Monthly Production (tonne)	Air Volume per 1000 tonnes (m³/s)/1000	required quantity (m³/s)	Mobile Equip. power (kW)	required quantity (m³/s)	Total required quantity (m³/s)	Available Exhaust quantity (m³/s)
1440ml	220000	4.2/1000	924	200	16	940	1,210
1540ml	220000	4.8/1000	1056	200	16	1072	1,210
1640ml	220000	4.9/1000	1078	200	16	1094	1,210
1740ml	220000	5/1000	1100	200	16	1116	1,210
1840ml	220000	5.6/1000	1232	200	16	1248	1,210
1940ml	220000	7.2/1000	1584	200	16	1600	1,210
2020ml	220000	8.1/1000	1782	200	16	**1 798**	1,210

At this point it's important to note that ventilation planning is done based on waste case scenario values. Therefore, for the accuracy of this paper, Air quantities determined based on Air- tonnage ratios are used because it represents the waste case scenario compared to the Air quantities determined based on Psychrometric properties which are $\mathbf{1\,721.80\ m^3/s}$**.** This means that a total of **1 798 m³/s** air quantity is required to dilute the total heat load of $\mathbf{52\,377.23Kw}$**.**

It is also important to note that **1 798 m³/s** represents the air quantity required to be admitted into the deeps Sections in order to completely dilute a total heat load of $\mathbf{52\,377.23Kw}$ without any artificial aids such as refrigeration systems. However, considering the Upcast Capacity of the system which can only upcast a maximum of $\mathbf{1210\ m^3/s}$, it means that the current ventilation system cannot manage to circulate the whole **1 798 m³/s** throughout the mine.

Therefore, the deficit air quantity $\boldsymbol{Qdeficit}$ that is required to be sourced for within the ventilation system is the difference between $\boldsymbol{Qrequired}$ and the available upcast capacity of the Main surface exhaust fans $\boldsymbol{Qavailable}$ and its computed as follows;

$$Qdeficit = Qrequired - Qavailabl$$

$$Qdeficit = 1798 \quad - 1210$$

$$\boldsymbol{Qdeficit = 588\ m^3/s}$$

4. Discussion

4.1 Balancing of Intake circuit with exhaust circuit for deeps Sections

The current and proposed intake airways in Mufulira Deeps Sections can only handle a nominal intake quantity of **1348.30 m³/s** when all the standard parameters are considered. However, the total quantity required to dilute the heat load is found to be **1 798 m³/s.** This means that more intake air is required in the lower Sections. However, the current up cast fans cannot develop enough suction pressure to exhaust such quantities of air. The fans can only handle a maximum of **1210.00 m³/s**. This means that a deficit of **588 m³/s** of air still needs to be sourced for. Therefore, any design to be recommended must be able to account for this deficit of air. Among other options that can be implemented to cater for the **588 m³/s** is the installation of a new exhaust fan. However, it's important to consider other options such as the introduction of a refrigeration system.

5. Conclusion

After reviewing the ventilation system for Mufulira mine, it has been established that the current system cannot provide adequate ventilation for the Deeps Sections due to its limitations in both the design and operations.

The total heat load for the deeps Sections has been found to be **52 377.23 kW**, while the total air quantities required has been determined to be **1 798 m³/**s against the current air quantity of **1210.00 m³/s** being supplied**.** This leaves a deficit quantity of **588 m³/s.**

6. Recommendations

7.1 Intake airways

- Main access ramp (56 ramp) should be extended from 1340ml to 2020ml
- Main ramp (62/63) ramp should be extended from 1340ml to 2020ml
- Three ventilation raises (3 × 3m diameter) should be developed from 1340ml to 2020ml.

7.2 Return airways

- Development of ventilation raises should be treated as priority because most of the time development of raises is behind schedule.
- Surge arrestors should be installed on the main surface fans to avoid electrical failure of fans.

- Main return airways (MRAs) should be developed every 100m depth because the mining method demands that MRAs are placed at every main level interval. Therefore, 1440ml, 1540ml and others proceeding main levels should be turned into MRAs.
- Installation of booster fans at 1340ml to assist main fans to overcome system resistance.
- Old stoping areas should be sealed off to prevent major air leakage in the mine.

7. Acknowledgements

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Construction and Demolition Waste Management for Sustainable Construction

Michael N. Mulenga[1]

Abstract

Zambian construction is one of the fastest growing sectors in Zambia increasing at 15.3% pa in 2012, arising from increased residential, commercial developments and mining infrastructure. The industry in Zambia, like elsewhere, is composed of many players including designers, contractors, regulators, manufacturers and suppliers of construction materials. However, opportunities for utilizing construction and demolition waste (CDW) for sustainable construction and management have been minimal.

Most research in developing countries has been targeted on Municipal Waste (MW) rather than CDW. However, quantities of CDW may be estimated from MW data. CDW is generally in form of masonry units, mortar, timber, glass, steel and plastic and most generation arises from masonry units and mortar. In developed countries, guidelines on Construction and Demolition Waste Management (CDWM) exist, supported by regulation and legislation. In Zambia little has been done to address CDWM, for a sustainable construction.

This paper addresses the status on CDWM in Zambia when compared to the rest of the world, mainly through literature review, with a view to recommending strategies for sustainable CDWM. As highlighted by several researchers and institutions, worldwide, CDWM requires partnerships of strategies, which covers processes over the entire life cycle of construction infrastructure. The paper highlights some of best practices towards sustainable CDWM around the world. Finally, it makes recommendations on achieving best practice in Zambia, sub-region and beyond.

Keywords: Municipal Waste, Construction and Demolition Waste, design and construction practices

1 Introduction

There are many definitions of construction and demolition waste. As highlighted by Osmani et al. (2005), the European Council Directive 91/156/EEC, defines waste as "any substance or object which the holder discards or intends or is required to discard" (Directive 91/156/EEC [2], Article 1, Letter

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a).This definition was further expanded as a "material which needed to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process".

Waste is a human concept defining a material with no intrinsic worth or value, or a material discarded despite its inherent worth or value. The Environmental Protection Agency (EPA)-Ireland definition of Construction and Demolition Waste as outlined in their annual National Waste Reports is: *"...all waste that arises from construction and demolition activities including excavated soil from contaminated sites. Those wastes are listed in Chapter 17 of the European Waste Catalogue (EWC)."*

Osman et al. (2005) identified seven different types of waste: bricks, blocks and mortar (33%);

timber (27%); packaging (18%), dry lining (10%); metals (3%); special waste (1%); and other waste 10%. It can be observed that most of the Construction and Demolition Waste (CDW) results from masonry units and mortar, possibly due to the high level of manual handling.

Yakkaluru and Naik (2016) categorized CDW as follows; *Process Waste*: The waste generated in the process of construction activities, such steel off-cuts, masonry units, concrete and timber; *Demolition Waste*: The waste generated in the demolition activity. They further categorized process waste into *Natural Waste*: Acceptable level of waste from a construction activity; *Direct Waste*: This is the waste which can be prevented and involves the actual loss, *Indirect Waste*: This is cost waste, distinguished from direct waste by no physical loss of material, and *Consequential Waste*: Cost of wasted materials is greater than its value and this additional cost is usually hidden.

Several studies have been undertaken on analysing CDW, such as those based on efficiency of manufacturing, sources or as a result of flaws in the design and/or procurement/project management and materials handling in the more countries. Other studies have focussed on assessing opportunities and barriers to sustainable Construction and Demolition Waste Management (CDWM).

In developing countries, such as Zambia, limited studies have been conducted and emphasis has mainly been on Municipal Waste (MW) rather than CDW. World Bank (2012) through the International Financing Corporation (IFC) 2012 fact sheets, indicate Municipal Waste (MW) generation and collection rates, by region, per capita by region, per capita by income levels around the world and give projections for 2025. Figures 1 shows the world population figures, which have a bearing on the MW generation levels, and hence CDW.

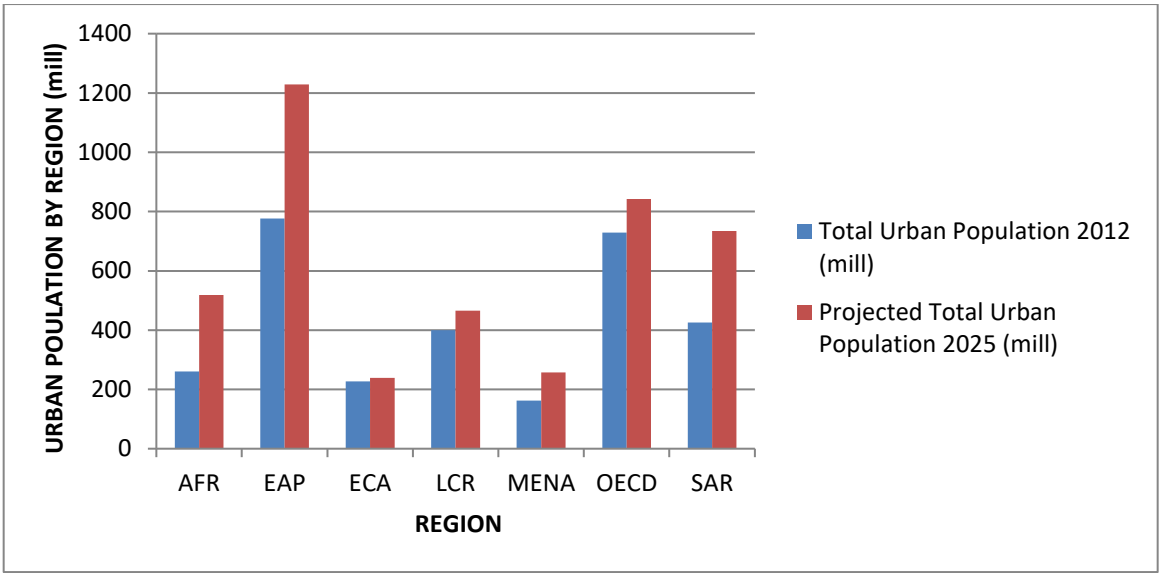

Figure 1 Total Urban Population by Region (World Bank 2012)

AFR=Africa, EAP=East Asia and Pacific, ECA=Europe and Central Asia, LCR= Latin America and the Caribbean, MENA= Middle East and North Africa, OECD = Organisation for Economic Cooperation and Development, SAR= South Asia Region

Figure 2 gives the total MW generation rates per day, by region. It will be noted that the Middle East and North Africa (MENA) and the Organisation for Economic Cooperation and Development (OECD) have the highest waste generation rates. Africa has the lowest generation rate, depicting the lower levels of construction activities.

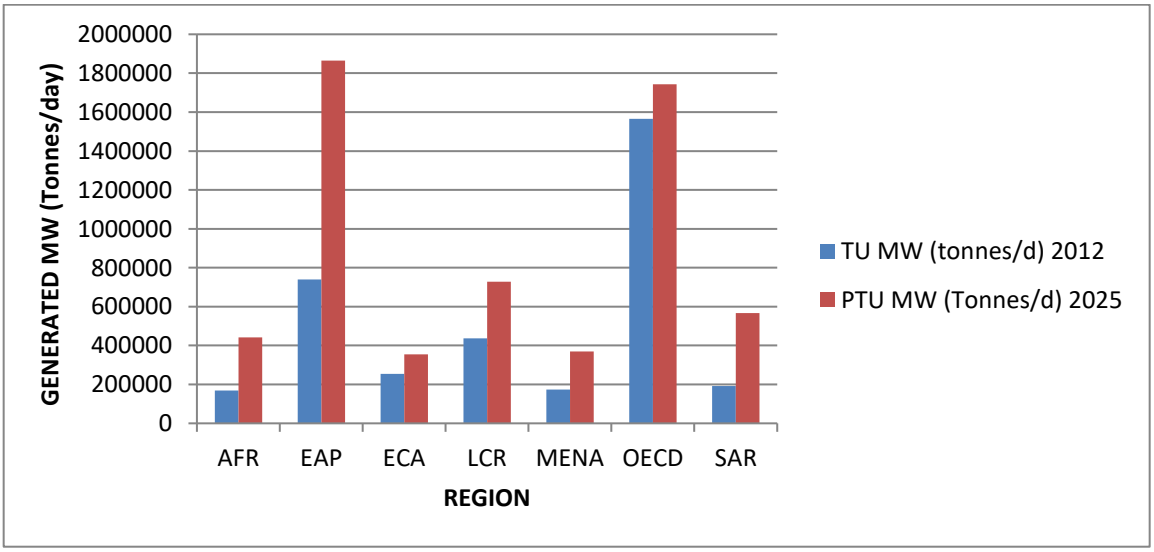

Figure 2 World Municipal Waste Generation Figures (World Bank 2012)

Figure 3 shows urban world MW generation rates, per capita, and by region. It may be observed that SAR and SFR show lower per capita generations, by region.

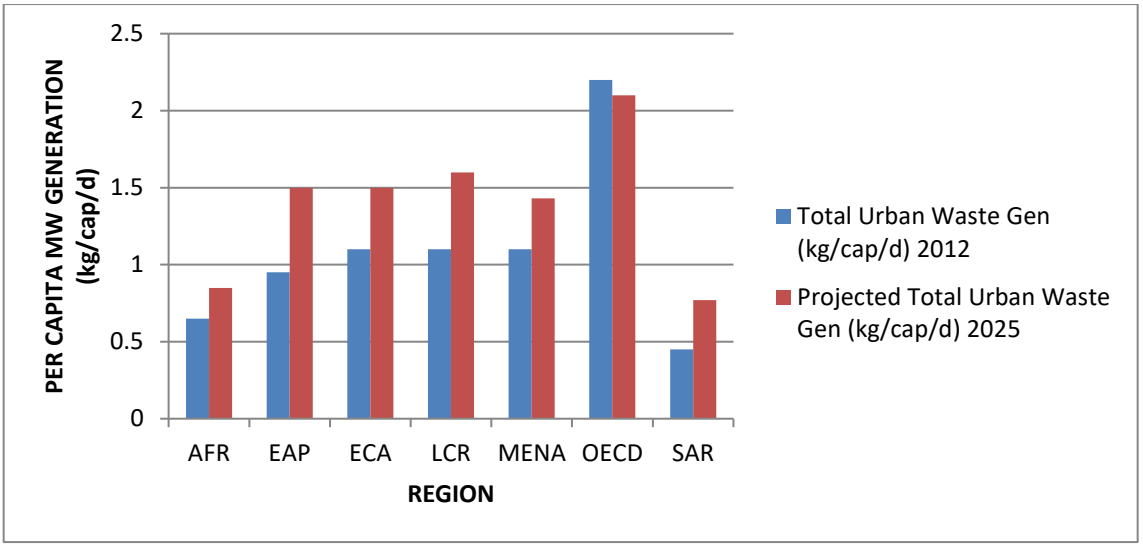

Figure 3 World Municipal Waste Per Capita Generation Rates, by Region (World Bank, 2012)

Figure 4 gives per capita MW generation for selected countries. The generation rates are highest for the HI countries (UAE, UK, USA). For Africa, it will be observed that the per capita generations are less than 1.0 kg/cap/d except for South Africa where the generation rate is 2.0 1.0 kg/cap/d.

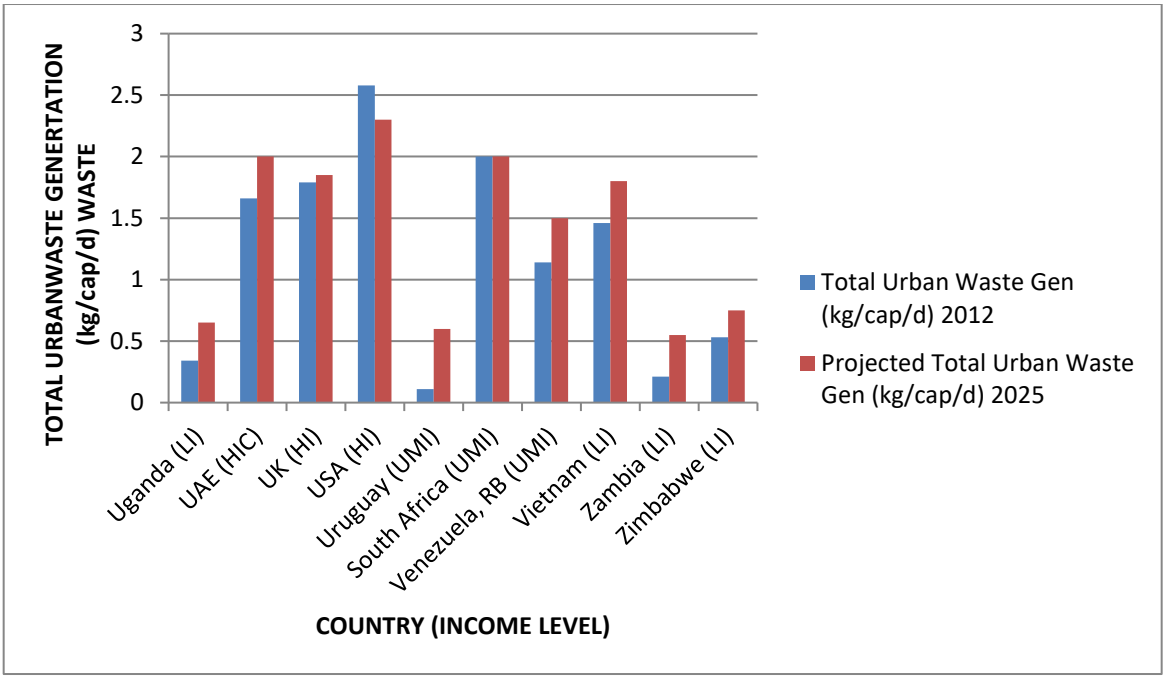

Figure 4 Per capita Municipal Waste Generation Rates, by Country (World Bank, 2012)

LI=Low Income, HIC=High Income, UMI=Upper Middle Income, LMI=Lower Middle Income

CDW may be estimated in terms MW amounts. Table 1 gives an example of CDW generation rates based on total MW generation rates. In general, CDW generation may be estimated either in terms of the total cost of a construction, or in term of the floor area for the building. If the later is used, the cost will depend on the type of structural and non-structural members. For example, reinforced concrete frame buildings are likely to have different factors than those which could be used for a steel frame building.

Table 1 Construction and Demolition Waste as Percentage of Total Municipal Waste

Country (Year)	**Total Annual Municipal Waste (Tonnes)**	**Construction Waste as % Total Annual Municipal Waste**
Hong Kong (2012)	5,050,000	25
Mainland China (2011)	190,000,00	30-40
Australia (2008-2009)	19,000,000	55

Source: Wing-Yan Tam and Weisheng Lu (2016)

Wing-Yan Tam and Lu (2016) conducted an ex post facto research is to compare CWM profiles, practices, and performance in Australia, Europe (EU-27 member countries in the European Union), Hong Kong, and the United Kingdom. They argued that there are two generic practices for dealing with CDW. From a technical point of view, environmental engineers investigate how "hard" technologies can help manage CDW, through construction practices such as prefabrication, using metal formwork, and using recycled aggregate for different concrete applications. They further argued that by appreciating the levels of CDW, the social issues, "soft" economical or managerial measures can be promoted. The research indicated that CDW generation per construction GDP (CDW/CGDP) (mt/mUS$) was a universal benchmark that can be used to compare C&D WM practices across different jurisdictions. The research established that Australia has a range 28.48 - 44.04 (t/mUS$); Europe between 47.00 and 58.89 (t/mUS$); Hong Kong has 39.85 - 120.86 (t/mUS$); and the United Kingdom 34.29 - 51.53 (t/mUS$). The research concluded that generally, most countries witnessed a declining trend in terms of waste generation due to promotion a "greener" construction industry around the developed world.

Abarca Guerrero (2014), collected some waste generation rates, and developed a construction waste generation model for developing countries, with a case study on Costa Rica. The construction sector in Costa Rica is labour intensive, relying mainly on unskilled workers, trained on site and moving rapidly among construction projects. The construction waste generation model shows that the construction industry in developing countries faces many challenges in order to improve the performance and efficiency of the building process. These challenges are not only as a result of technological aspects, but financial, environmental, socio-cultural and legal aspects also hinder the industry to modernize their practices.

In Zambia very limited studies have been conducted on CDW. However , Muleya and Kamalondo (2017) in their research on Waste Management Practices in the Zambian Construction Industry (ZCI), concluded that waste management practices in the ZCI do not fully conform to the waste management hierarchy. Further, the study clearly indicated that there is unsustainable construction waste management practice in the Zambian Construction Industry. Chishimba (2017) conducted a study in Lusaka which established some monthly waste generation rates based on the stage of building

construction and floor area. The study involved literature review, questionnaires, interviews and a case study. Table 2 summarises estimated CDW generation rates based on floor areas.

Table 2 Monthly Construction Waste Generation rates per floor space

Construction Stage	**Average Waste Generation Rate (kg/m^2/month)**
Sub-structure	5.1
Super-structure	16.4
Finishing-works	14.1

Source: Chishimba (2017)

2 Strategies for Sustainable CDWM and Barriers

Good Construction and Demolition Waste Management (CDWM) strategies have been developed especially in the more developed countries, however barriers do exist. Good practices and the barriers encountered are discussed in the following sections.

2.1 Examples of Good CDWM Practices

According to European Commission on Environment CDW accounts for approximately 25% - 30% of all waste generated in the European Union (EU) and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled

.CDW has been identified as a priority waste stream by the EU and high potential for re-use and recycling exist, particularly for derived aggregates from roads, drainage and other construction projects. Technology for the separation and recovery of construction and demolition waste is well established, readily accessible and in general inexpensive.

The Waste Framework Directive (2008/98/EC) provides a framework for moving towards a European recycling society with a high level of resource efficiency. Article 11.2 stipulates that "Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the List of Wastes shall be prepared for re-use, recycled or undergo other material recovery" (including backfilling operations using waste to substitute other materials).

Despite this effort, the level of recycling and material recovery CDW varies in the range <10% to > 90%, across the Union. Separation at source ensures CDW does contain amounts of hazardous wastes, which could pose particular risk to the environment and hamper the recycling effort.

A number of countries have come up with guidelines on waste minimization and management (WMM) to address effects of CDW.The Environmental Protection Agency (EPA) has estimated that CDW production rose from 3.7 million tonnes (Mt) in 2001 (EPA, 2003) to a peak of 17.8 Mt in 2007, (EPA, 2009a), with a subsequent decline to just over 3 Mt in 2011 (EPA, 2013).

The UK Waste and Resources Action Programme (WRAP) have identified five key principles that design teams can use during the design process to reduce waste:

1. Design for Waste Efficient Procurement;

2. Design for Materials Optimisation;
3. Design for Off-Site Construction;
4. Design for Reuse and Recycling; and
5. Design for Deconstruction.

The European Community has developed a *Design out Waste* management hierarchy, which involves five steps; Prevention, Preparing for re-use, Recycling, Recovery and Disposal.Sustainable management of construction waste can only be tackled by a partnership of interventions from all stakeholders.

Good practice WMM can be applied to all forms of construction projects, regardless of the procurement route adopted. It entails adopting WMM principles at the earliest possible stage, as mandated by the client through procurement provision. The principles should be communicated to all stakeholders by the design team, contractor, sub-contractors and waste management contractors throughout all project phases – from outline design to project completion, operation, maintenance, and decommissioning.

The NSGH project in Glasgow, for example, was £575 million capital project and the largest NHS construction project in Scotland.Use of a NetWaste Tool, resulted in:

- a 6,500-tonne reduction in construction waste generated throughout the project compared with standard industry practice if all identified actions were to be implemented

- An identified potential cost saving in the avoided cost of wasted materials when compared with standard industry practice.

- A landfill diversion rate of over 90%.

Based on a Sustainability study, for £575 million=US$875.09million (US$ 1.5219 to 1 UK £ (www.gov.uk, spot rates, HM Revenue and Customs) and average 52.945t /million US$ (Tan et al), the expected waste generation rate was 52. 945x875.09=46, 332t. Thus, the reduction in construction waste (6500t) may be estimated to be 14% was generated, compared to industry average in the UK.

Seneviratne et al. (2015) demonstrated that contractor capacity in Malaysia has a bearing on the waste generation, by determining cement wastage. The study established that upper grade contractors generated less waste compared to their lower grade counterparts. The corresponding cement wastage; for grade M1 (highest) to M5 (lowest) contractors were 5.35%, 6.01%, 5.97%, 13.35% and 24.18%, respectively. This confirmed the research hypothesis that "Construction waste generation is inversely proportional to the capacity of a contractor".

According to the Resource Efficiency in the Building and Related Industries (REBRI) Guide (2014) in New Zealand, CDW may represent up to 50% of all waste to landfills in New Zealand and the majority of waste to clean fills or CDW dumps. This implies up to 1.7 million tonnes of CDW is sent to landfills every year and similar amounts to clean fills. The guidelines cover:

1. pre-design and planning;

2. concept design;

3. detailed design;

4. building material and product selection;

5. project management; and

6. after the project is finished.

Peddavenkatesu and Naik (2016), through their study, established causes of CDW generation as; improper storage of cement, construction flaws, improper handling of materials and products (cement, masonry units), unrequired extra works such as extra slab thickness, extra filing of columns and improper planning and procurement.

Ajayi (2016) investigated the interrelation of design, procurement and construction strategies for waste minimisation, using a dynamic approach, on construction waste mitigation. The study identified the design stage had the most decisive impacts on construction waste minimisation. Materials procurement process was a factor in enhancing waste minimisation. The study suggested that during the construction stage, waste reduction could be achieved through interventions such as prefabrication and offsite technology, contractual requirements, maximisation of materials reuse and improved collaboration. The study identified the dynamic interplay between various stake holders suggested that designers could effectively minimize waste through dimensional coordination and standardisation of design in line with standard materials supplies.

Mulenga (2011) highlighted that several materials of construction from different sources are available on the Southern African market, and there was need for harmonization of standards in Southern Africa. Standardization is a means by which regional and international agreements, trade and collaboration can be boosted to achieve a sustainable built-environment. 'Green' practices and innovation must be encouraged through intelligent standards, codes of practice and specifications, as well as advocacy.

In 2011, the United Nations Environment Programme (UNEP) supported the Government of Zambia in developing a National Sustainable Consumption and Production (SCP) Programme that recognizes the contribution of green building and green jobs to the sustainable development of the country. The SCP Programme is being implemented by Zambia Environmental Management Agency (ZEMA). Interventions at policy level for the Green Jobs Programme (2012-2017) in the building construction sector in Zambia will build on the UNEP's evidence-based policy measures arising from the inception phase of international best practice research in green building, which support CDWM.

The Zambia Green Building Association (ZGBA) is an independent, not-for-profit, member-based organisation with the mission to drive the sustainable transformation of the built environment was launched on February 26, 2015. It serves as a platform for the whole of the Zambian property and building construction industry to collectively create a community that champions the sustainable transformation of the built environment in Zambia.

2.2 Addressing barriers to Achieving Good Practice in CDWM

Zou et al. (2015) conducted a study on barriers to building and construction waste reduction, re-use and recycling focusing on the Australian capital region. The top six barriers identified from the research included the following:

Policy and governance: Government policy is not driving recycling;

Quality: contamination of recyclables due to lack of separation or lack of space for separation;

Cost: Alternatives to recycling are cheaper – landfill gate prices are too low;

Information: Lack of information re industry infrastructure;

Knowledge and education: Lack of knowledge across industry and requirement for training; and

Perception and culture: C&D material is not considered as a potential resource (except metal).

WRAP (UK) has also highlighted the barriers and how to achieve good practice during the construction stage, as presented in Table 3.

Table 3 Key constraints to achieving good practice

Key Constraint	Implication	Achieving Good Practice
Lack of a client requirement for Good Practice	No contractual obligation by the Contractor	Client and design team to make contractor realize benefits of Good Practice (cost savings, efficient operations)
Site location	No collection and recycling facilities	Ensure the waste management contractor provides a cost effective collection and recycling facilities
Project type	Fit-out projects offer less opportunities for waste recovery	Identify and focus on those material streams that offer Quick Wins
Space on site	Limit space for waste segregation	Target key waste streams and segregate offsite
Project time scales	Tight schedules tend to overlook good practice	Identify and plan the key material streams offering Quick Wins Implement the good practice based on experience Establish partnerships with waste management contractors
Contract variations	Loose Procurement methods lead to increase levels of unplanned wastage.	Set up a dialogue with the client and designers at an early stage Identify areas in the design that are not sufficiently developed and suggest possible Waste implications.

Source: Adapted from WRAP (UK), Achieving Good Practice Waste Minimization and Management (WMM), Guidance for Construction Clients, Design Teams and Contractors Practice Waste

3 Conclusion and Recommendation

3.1 Conclusions

Sustainable CDWM is only achievable if CDW is addressed at all stages of the construction cycle, and this is essential regardless of degree of mechanization (Labour-based, Intermediate or Machine-based). In Zambia there are unsustainable CDWM activities and little research is being conducted in this area. However the intervention at policy level, through the Green Jobs Programme (2012-2017) in the building construction, and the creation Zambia Green Building Association are steps in the right direction.

To benchmark good practice, there is need to conduct studies on CDW generation, and disposal. It is said, "**If you can't measure it, you can't improve it.** *Peter Drucker"*. The majority of studies have been conducted in the developed world, and have tended to target Municipal Waste, rather than CDW, hence the need to develop models that can address the developing world. The CDW generation model quantities are based on either the total cost of the construction projects, or the floor space, depending on the type of building.

It has been shown that to address sustainable CDWM requires concerted efforts from all stakeholders, supported by appropriate policies, regulation and enforcement. The developed countries are advanced in this area but Zambia and regional groupings need to develop appropriate standards and codes of practice, to promote trade and regional integration.

3.2 Recommendations

Zambia and the sub-region need to develop appropriate standards and codes of practice and specifications that will ensure sustainable CDWM, taking into account topical issues such as Climate Change and "Green" construction and maintenance principles. Research targeted at CDW is urgently required. Therefore, country and regional regulatory, professional and economic bodies, such as SADC, SATTC and ASANRA should spearhead funding such efforts.

More concerted efforts are required towards sustainable CDWM through strong partnerships between education, training, Research & Development institutions, and the construction industry.

Pro-active efforts and dedicated funding are required to promote best practices in the construction industry, through policies, legislation, regulation and enforcement, which should also address regional requirements.

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Determination of Inter-Dependencies of Pestle Factors Affecting the Potential of Mining Zambia's Low Grade Copper Ore Deposits

Sam Kangwa[1] and Victor Mutambo[2]

Abstract

The Zambian economy has been based on the copper mining industry, which accounts for 12% of the country's GDP and 75% of total export value. The sector is also a significant source of formal employment, accounting for 1.4% of the employed population. Owing to the importance of copper mining, it is vital that the industry be sustained. Since copper is a depletable resource, there is need to analyse the potential of mining low-grade deposits. PESTLE factors are among other factors which impede mining of low-grade copper deposits in Zambia. PESTLE factors are well analysed and documented. However, analysing of the PESTLE factors is not sufficient as factors may interrelate and impact on each other. Interdependencies among factors present a complex environment when finding solutions for low rated factors. Therefore, determination of their interdependencies contributes to providing a better understanding of how to improve on the macro-environmental factors identified by the PESTLE factors. This paper therefore, focuses at determining and mapping the potential inter-dependencies among the PASTLE factors. DEMATEL method was applied to determine the inter-dependencies. The results of the analysis indicate that there are positive and negative relationships among the PESTLE factors. It was concluded therefore that favourable macro-environmental factors for mining low-grade copper deposits can be achieved by addressing interrelated factors together rather than individually.

Keywords: PESTLE factors, interdependencies, copper, low-grade, DEMATEL

1. Introduction

Copper mining in Zambia has been an important activity since 1902 and has been a principal catalyser of industrial, social, and infrastructure development (Zambia Development Agency, 2016). Copper accounts for 12% of the country's gross domestic product (GDP) and 75% of total export value. The sector is also a significant source of formal employment, accounting for 1.4% of the employed population (Central Statistical Office, 2016). All industries create spillover effects, known as multipliers, but the mining sector in Zambia generally creates a higher multiplier effect than other sectors. For example, the formal mining industry in Zambia not only creates mining jobs but also

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generates indirect and induced employment by stimulating demand for goods and services and by fostering businesses which exist because of the presence of the mines.

The economic report on Africa (World Bank, 2017) revealed that Zambia's copper mining sector could continue to operate at current average rate of 700 kt/a for the next 60 years, even without new discoveries. The resources available to existing mines in Zambia are estimated at 2.8 Gt of ore ranging between 0.6 and 4% copper. In additional, Zambia has potentially recoverable ores estimated at 1.6 Gt ranging between 0.4 and 0.6% copper. The additional resources would prolong mining for approximately 30 years.

Zambia is the second to the Democratic Republic of the Congo, the largest producer of copper in Africa. Zambia produces 5% of the world's copper production (World Bank, 2017). Although copper production was affected by low copper prices and privatisation of the mines in the 1990s, production has been increasing since 2000, as shown in Figure 1. Owing to the increase in copper production, the projected lifespan of the industry will be shortened from 60 years, as reported by the World Bank (2017).

Copper reserves are depletable resources, and hence with time, the mining industry in Zambia would cease due to recoverable copper reserves becoming exhausted. It is therefore imperative for Zambia to unlock more reserves and prolong the copper mining industry; and continue maintaining its position in copper production.

In Zambia, economically recoverable copper deposits are those with grades more than 0.5% for surface mining and more than 1.5% for underground mining (Kangwa and Mutambo. 2018). In countries like Chile, Australia, and Canada, deposits at 0.4% and 1.0% are economically extracted by surface and underground mining respectively.

Since copper is a depletable resource, there is need to analyse the potential of mining low-grade copper deposits. Political, Economic, Social, Technological, Legal and Environmental (PESTLE) factors are among other factors which impede mining of low-grade deposits. PESTLE factors are well analysed and documented (Chibesakunda, 2015; Kangwa and Mutambo, 2018). However, analysing of the PESTLE factors is not sufficient as factors may interrelate and impact on each other. Interdependencies among factors present a complex environment when finding solutions for challenges related to mining sector. Therefore, determination of their interdependencies contributes to providing a better understanding of how to improve on the macro-environmental factors identified by the PESTLE factors. This paper therefore, focuses at determining and mapping the potential inter-dependencies among the PASTLE factors.

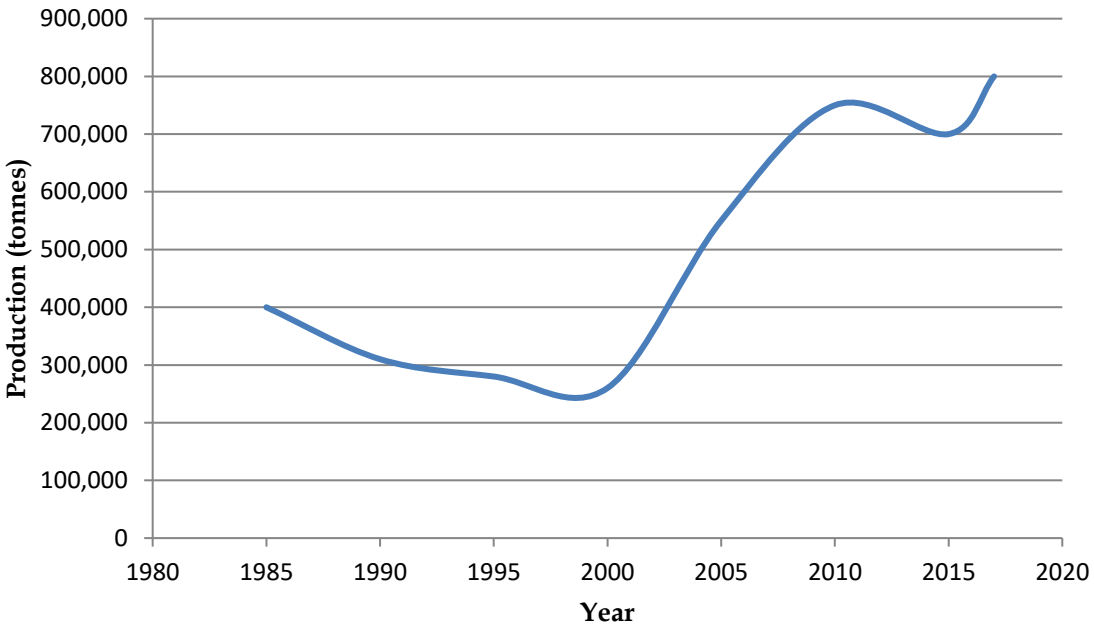

Figure 1: Zambia's copper production from 1990 to 2017

Studies on interdependencies on various aspects exist in different research disciplines and fields of study. The main aims of investigating the interdependencies among the elements under investigation are to explore the complex network of interdependencies between the elements and to analyse and evaluate the direct and indirect relationship between the elements and their impact in decision making (Mkude and Wimmer, 2015; Tzeng et al., 2007). Furthermore in his work of analysing a macro-environment of a company using PESTLE, Yüksel (2012) argues that it is crucial to consider the interdependencies and relations between the PESTEL factors to achieve a holistic perspective. The aims are of great significance in strategic planning because it is impossible to consider economic conditions in isolation from political conditions.

The aim of this paper is to investigate and determine the existing interdependencies among PESTLE factors as related to Zambia's potential of mining low-grade copper deposits. A review of the literature reveals that different approaches and techniques are used for determination of interdependence (Lynch, 2009). The techniques such as Decision Making Trial and Evaluation Laboratory (DEMATEL), Matrix Laboratory (Matlab), Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are applied. In this paper, DEMATEL model is used to determine inter-dependencies for PESTLE factors. DEMATEL technique was used because it is widely applied in analysing complex decision making in industrial planning including mine planning and it used in research and solving intertwined criteria and alternatives. The DEMATEL software was also available for immediate use.

2. DEMATEL technique

DEMATEL technique was proposed by Fontela and Gabus (1976) to overcome many global complex problems in scientific, political, and economic. The technique includes structuring, graphical representations and analysing causal influences. There are multi-paradigm numerical computing environment and are proprietary programming languages which allow matrix manipulations, plotting of functions and data implementation. In practice, DEMATEL technique has been applied to demonstrate the interrelations among criteria and to find aspects/criteria which play central roles in system to represent the effectiveness of them. DEMATEL is not only used to obtain the influence levels of each element over others but also has been applied to detect complex relationships and build an impact-relation map (IRM) of the criteria

In general, DEMATEL technique is able to determine direct, indirect, and interdependencies among the unpredictable features or attributes. In addition, DEMATEL helps to identify practical solutions for particular problems and cluster of complicated problems (Chen, Tzeng and Huang, 2014). In DEMATEL structure, each factor or part may exert on and obtain from other higher or lower level factors. One of excellence of this technique rather than other decision making methods is feedback application. The entire factors establish worth and importance of factors instead of considering only specific factors.

DEMATEL is based on graph theory. It enables the researchers to have an enhanced realisation of causal relationships by dividing important and related issues to cause and effect. DEMATEL therefore, makes it possible to visualise the causal relationships of sub-criteria and systems in the course of causal diagram that it may demonstrate communication network or a little control relationships between individuals (Chen, Tzeng and Huang, 2014). The most important property of the DEMATEL method used in the multi-criteria decision making (MCDM) field is to construct interrelations between criteria. In order to obtain a suitable impact-relations map, an appropriate threshold value is needed to obtain adequate information for further analysis and decision-making.

3. Application of DEMATE technique

There are four steps in the DEMATEL technique (Liou et al., 2007).

1. Calculation of the average matrix,
2. Calculation of the normalised initial direct-influence matrix,
3. Derive the total relation matrix, and
4. Set a threshold value and obtain the impact-relations map.

Stage 1: Compute the average matrix to find direct relation.

Each respondent is asked to evaluate the direct influence between any two factors on an integer scale ranging from 0 to 4, where higher value indicates greater influence. Xij represents the degree to which the respondent thinks factor i affects factor j. For I= j the diagonal elements are set to zero. For each

respondent, an n x n non-negative matrix can be stated as Xk = [Xij k], where, k is the number of respondents with $1 \leq k \leq H$, and n is the number of factors. Thus, X1, X2, X3,……XH are the matrices from H respondents (Yüksel, 2012). To take into account all opinions from H respondents, the average matrix A = [aij] is as follows:

$$a_{ij} = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^{k} \quad (1)$$

Stage 2: Normalize the initial direct matrix

Normalise the initial direct-relation matrix (A) to get matrix D by dividing matrices with S, where,

$$S = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{J=1}^{n} a_{ij}} \quad (2)$$

Each element in matrix D falls between zero and one

Stage 3: Calculate the total relation matrix

Calculate the total relation matrix T by T = D (I - D)-1, where I is the identity matrix. Define r and c can be nx1 and 1xn vectors representing the sum of rows and sum of columns of matrix T, respectively. Suppose ri be the sum of the ith row in matrix T, then ri summarises both the direct and indirect effects of factor to the other factors. If ci denotes the sum of the jth column in matrix T, then cj shows both direct and indirect effects on factor j from the other factors. When j = i the sum (ri + cj) shows the total effects given and received by the factor. Thus (ri + cj) indicates the degree of importance that factor i plays in the entire system. In contrast, the reciprocal (ri - cj) depicts the net effect that factor i contributes to the system. Moreover, if (ri - cj) is positive, the factor is a net cause; if (ri - cj) is negative, the factor i is a net receiver or result (Liou et al., 2007).

The total influence or total relation can be summed up as:

$D^2, D^3, \ldots, D^{\infty},$

$\lim_{m \to \infty} D^m = [0]_{nxn}$

$[\mathbf{0}]_{nxn}$ is a n x n null matrix

$$\sum_{m=1}^{\infty} D^i = D + D^2 + D^3 \ldots D^m$$

$$= D (I + D + D^2 + \ldots + D^{m-1})$$

$$= D (I - D)^{-1} (I - D) (I + D + + D^2 + \ldots + D^{m-1})$$

$$= D\,(1 - D)^{-1}\,(I - D^{m}) = D\,(I - D)^{-1} \quad (3)$$

I is identity matrix, T is total relation matrix ([T]nxn).

The sum of rows and sum of columns of the total relation T are computed as r and c n x 1 vectors

$$[r_i]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} \quad (4)$$

$$[C_j]_{1xn} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn} \quad (5)$$

The sum of the ith row of the matrix T is [ri]nx1 and indicates the total effects, both direct and indirect, given by the factor I to other factors. Likewise, [Cj]1xn is the sum of the jth column of the matrix T and donates the total effects, both direct and indirect, received by the factor j from other factors. Consequently, when j = I, the sum (cj + ri) which is called "prominence" gives us an an index representing the total effects both given and received by the factor i. in other words, (cj + ri) demonstrates the degree of the importance (total sum of the effects given and received) that the factor I plays in the system. In additional, the difference (cj - ri) which is called "relation" shows the net effect that the factor I contributes to in the system. When (cj - ri) is positive, the factor I is net causer and when (cj - ri) is negative the factor I is a net receiver (Tzeng et al., 2007).

Stage 4: Set a threshold value (where necessary)

Set a threshold value to obtain the digraph. Because matrix T provides information on how one factor affects another, it is necessary for a decision maker to set up a threshold value to filter out some negligible effects. Only the effects greater than the threshold value are chosen and shown in the digraph. The digraph can be acquired by mapping the dataset of (r+c, r-c).

4. PESTLE analysis

The main factors do not enable detailed analysis of the macro environment; therefore the initial stage which was carried out in determination of inter dependence of PESTLE factors affecting Zambia's potential of mining low grade copper ore deposits was identification of relevant sub-factors. The sub-factors assisted in the rating of the main factors. A cluster of sub factors per factor was identified as indicated in Table 1.

Table 1: Identified PESTLE sub-factors

PESTLE Factor	Identified sub-factors	PESTLE Factor	Identified sub-factors
Political (P)	P1: Political stability	Economical (E)	E1: Taxes and duties
	P2: Nationalisation of mines		E2: Investment policies
	P3: Political interference		E3: Inflation and exchange rates
	P4: Transparency and control of corruption		E4: Wage pattern
	P5: Bureaucracy issues		E5: Cost of living
	P6: Governance issues		E6: Trading practices
	P7:Trade restriction and reforms		
Social (S)	S1: Attitude towards work	Technology (T)	T1: Infrastructure
	S2: Employment levels		T2: Geological mapping & survey
	S3: Income statistics		T3: Mining machinery/software
	S4: Access to essential services		T4: Energy/auxiliary services
	S5: Cross-cultural comm.		T5: Technology transfer
	S6: Ethics & religion issues		T6: Research & Development
	S7: Communities demands		T7: Skilled labour force
Legal (L)	L1: Mining Act and policies	Environmental (En)	En1: Environmental protection
	L2: Employment laws		En2: Waste disposal
	L3: Taxation		En3: Contamination levels
	L4: Regulatory bodies and compliance systems		En4: Reclamation policies
	L5: Import and export policies		En6: Geographical location
	L6: Human rights		En6: Climate and cyclical weather
			En7: Water treatment

Secondly, the hierarchical structure of factors and sub-factors was formed, as seen in Figure 2. The hierarchy consists of three levels; the first level includes the objective function that is to "determine Zambia's potential of mining low-grade copper ore deposits". The second level contains the six main factors of the PESTLE analysis. The second level also displays potential relationships between PESTLE factors. The third level consists of 40 su-factors clustered within the main factors.

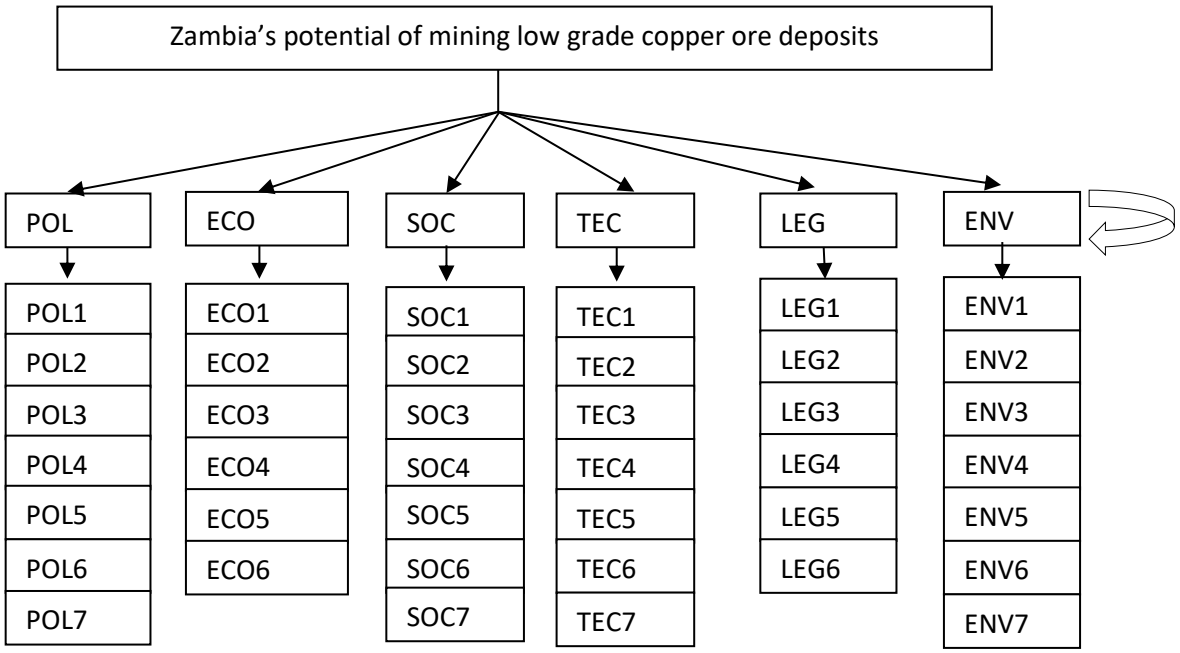

Figure 2: The hierarchical model of identified PESTLE sub-factors

5. Rating of PESTLE Sub-factors

A questionnaire was developed and conducted to six mining engineering experts. The respondents were asked to evaluate the direct influence between any two factors on an integer scale ranging from 0 to 4, where higher value indicated greater influence. Xij represented the degree to which the respondent considered how factor i affects factor j. The average matrix to find direct relation was computed as indicated in step 1 and equation 1.

The computed initial direct-relation matrix (A) was formed as:

A = [0,1,3,1,2,1;4,0,2,3,3,2;3,4,0,4,2,3;3,3,1,0,1,1;3,1,2,1,0,1;3,2,2,3,2,0]

Matrix A =

$$\begin{bmatrix} 0 & 1 & 3 & 1 & 2 & 1 \\ 4 & 0 & 2 & 3 & 3 & 2 \\ 3 & 4 & 0 & 4 & 2 & 3 \\ 3 & 3 & 1 & 0 & 1 & 1 \\ 3 & 1 & 2 & 1 & 0 & 1 \\ 3 & 2 & 2 & 3 & 2 & 0 \end{bmatrix}$$

Before normalising the initial matrix, the identity matrix (I) was developed. This is a square matrix in which all the elements of the principal diagonal are ones and all other elements are zeros. The effect of multiplying a given matrix by an identity matrix is to leave the given matrix unchanged. n×n matrices were used to represent linear transformations from an n-dimensional vector space to itself, In represents the identity function, regardless of the basis. The ith column of an identity matrix is the unit vector e_i. It follows that the determinant of the identity matrix is 1 and the trace is n. Therefore I = [1,0,0,0,0,0;0,1,0,0,0,0;0,0,1,0,0,0;0,0,0,1,0,0;0,0,0,0,1,0;0,0,0,0,0,1], thus:

Matrix I =

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Based on developed initial direct relation matrix A, the data was normalised to determine matrix D. The matrix was developed by D = A / S and applying equation 2.

Matrix D = A / S

$$\begin{bmatrix} 0 & 0.0625 & 0.1875 & 0.0625 & 0.125 & 0.0625 \\ 0.25 & 0 & 0.125 & 0.1875 & 0.1875 & 0.125 \\ 0.1875 & 0.25 & 0 & 0.25 & 0.125 & 0.1875 \\ 0.1875 & 0.1875 & 0.0625 & 0 & 0.0625 & 0.0625 \\ 0.1875 & 0.0625 & 0.125 & 0.0625 & 0 & 0.0625 \\ 0.1875 & 0.125 & 0.125 & 0.1875 & 0.125 & 0 \end{bmatrix}$$

The total relation matrix T was computed by T = D (l – D)-1 and applying equations 3, 4 and 5. DEMATEL software was used to compute matrix T.

Matrix T =

$$\begin{bmatrix} 4.4953 & 4.2285 & 5.6766 & 4.4381 & 4.7729 & 3.4496 \\ 10.1961 & 4.7656 & 6.5488 & 7.6234 & 7.1360 & 5.3833 \\ 10.7002 & 9.0520 & 5.4849 & 9.4733 & 7.1711 & 6.8689 \\ 7.3919 & 5.8802 & 4.3079 & 3.5601 & 4.2239 & 3.4913 \\ 6.8173 & 3.9605 & 4.7984 & 4.1583 & 2.8619 & 3.2596 \\ 8.6787 & 6.0884 & 5.9669 & 7.1458 & 5.8230 & 3.2328 \end{bmatrix}$$

Computation of influences of PESTLE factors by summing up of rows and columns of matrix T to define r and c as shown in Table 1.

Table 1: Summation of rows and columns of matrix T

	Matrix T						Sum (r)
T = D (I –D)-1	4.4953	4.2285	5.6766	4.438	4.7729	3.4496	27.0609
	10.1961	4.7656	6.5488	7.6234	7.1360	5.3833	41.6532
	10.7002	9.0520	5.4849	9.4733	7.1711	6.8689	68.7141
	7.3919	5.8802	4.3079	3.5601	4.2239	3.4913	28.8553
	6.8173	3.9605	4.7984	4.1583	2.8619	3.2596	25.856
	8.6787	6.0884	5.9669	7.1458	5.8230	3.2328	36.9356
Sum (c)	48.2795	33.9752	32.7835	36.3989	31.9888	25.6855	

The sum of influence given and received among PESTLE factors is indicated in Table 2.

Table 2: Summation of influence among PESTLE factors

	c	r	c + r	c - r
Political	48.2795	27.0609	75.3404	21.2186
Economic	33.9752	41.6532	75.6284	-7.678
Social	32.7835	68.7141	101.4976	-35.9306
Technology	36.3989	28.8553	65.2542	7.5436
Environmental	31.9888	25.856	57.8448	6.1328
Legal	25.6855	36.9356	62.6211	-11.2501

The digraph was developed by mapping the dataset of (r+c, r-c) as shown in Figure 3.

Finally, the inter dependencies matrix of PESTLE factors based on the DEMATEL digraph was determined. The digraph was used for better capturing the causal relationship visibly between PESTLE factors.

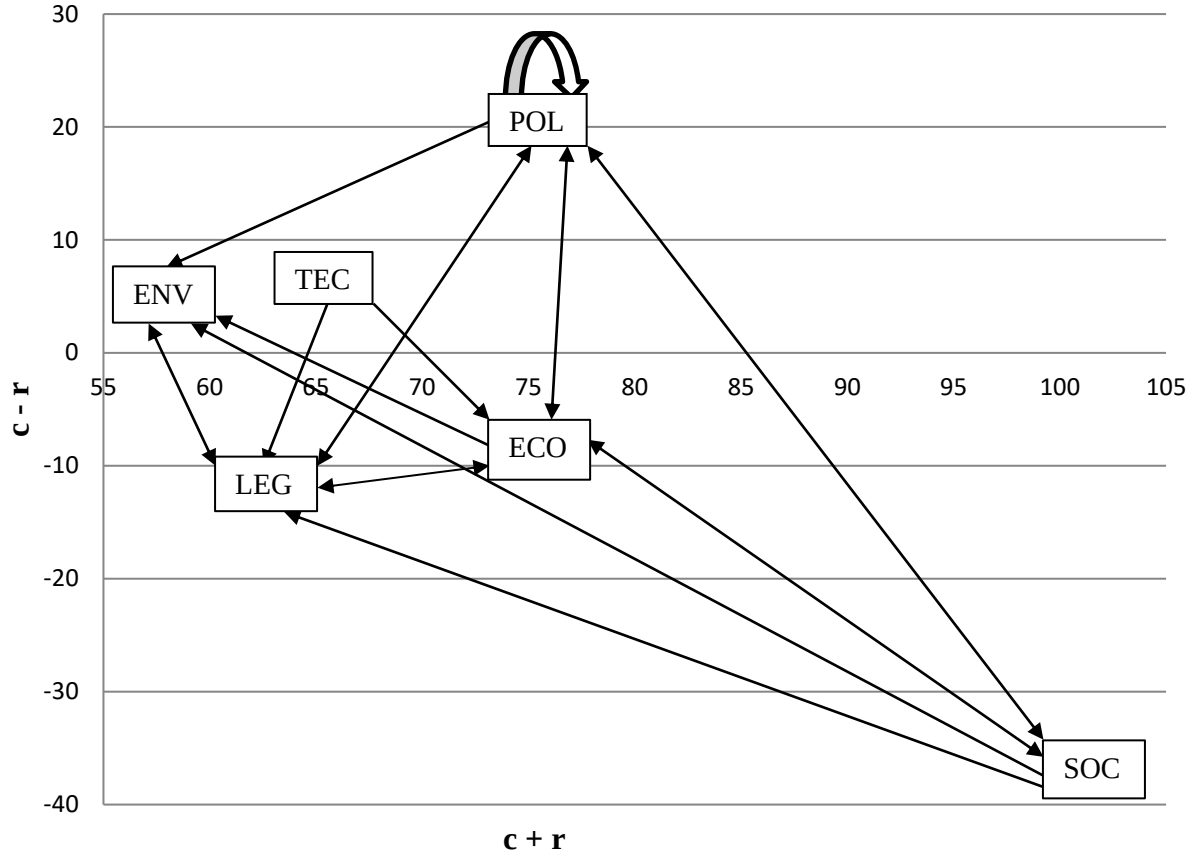

Figure 3: The digraph showing relations among PESTLE factors

6. DEMATEL results

Table 2 indicates the sum of influence (c + r) which gives us an index representing the total effects both given and received by other factors. In additional, the difference (c - r) which is called "relation" shows the net effect that other factors contribute to in the system. When (c - r) is positive, that factor is net causer and when (c - r) is negative that factor is a net receiver. The results showed that currently in Zambia, social factors have high effect on the other PESTLE factors meaning that social factors have high influence on the other domains. Social factors are followed by economic and legal factors, while political factors are prominently affected by other factors. That means political factors are highly influenced by other PESTLE factors. The results also indicate that social factors play high degree of importance in the entire system and are sensitive to change by other factors. The matrix T indicates that environmental factors are least influential in the entire systems. Figure 3 shows the direction of relations among PESTLE factors.

7. Conclusion

It can be concluded that to determine the Zambia's potential of mining low grade copper deposits; all PESTLE factors should be addressed simultaneously with emphasis on social and economic factors. Environmental and technological factors which are least independent of the other PESTLE factors, can be considered during the operation phase

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Application of Gray Markov SCGM(1,1)c Model to Predicting Fatal Accidents in the Zambian Copper Mines

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Abstract

Most mine accidents are caused by human error. The effects of accidents either fatal or not are adverse and range from economical to social. Predicting fatal accidents will provide the basis of safety assessment and decision making and also help to plan for possible economic and social imparts generated by the fatal accidents. In this paper, the amended Grey Markov model with double exponential smoothing has been proposed to predict fatal accidents in Zambian copper mines. The amended Grey Markov combines the advantages of the grey prediction model and the Markov chains and can therefore be used on data that is limited and has stochastic fluctuations. The second Amended Gray SCGM(1,1)c model, with low average relative and excellent precision, was applied to imitate the development tendency of the mine fatal accident 2001 and 2015. Markov prediction was used to predict the fluctuation along the tendency beyond 2015. Finally, the Amended Gray Markov was used to predict the total of fatal accidents in Zambian Copper and predicted the Value of 17 compared to actual value of 19. The model predicted will low relative error of 0.1 and therefore possesses stronger engineering application.

Key words: Amended Grey-Markov, fatal accidents, Prediction

1.0 Introduction

The copper mining industry is one of the largest industries in Zambia. It accounts for about 15% percent in formal employment, 8 percent in gross domestic products (GDP) and 84% percent in export earnings (Miller HB et al, 2006). However, due to the complexity of copper mining industry, accident (fatal and non fatal) cannot be well controlled and this somehow, restricts the copper production capacity in Zambia. Recent studies have shown that high occupational accidents are found in the Zambian mining industry as well as the rest of the world. (Prudence M et al, 2009, Leigh JP et al, 2004 and Kucuker H, 2006). The adversity of these mine accidents can be very bad leading to suspension of production and poor corporate image for the company or companies involved. Other major consequences of mine accidents include economical and social impacts. The most common economical consequences of mine accidents include cost to the employer such as lost wages, health costs and other indirect costs. Indirect costs to employer include cost associated with additional hiring and training, time delays due to disruption of the work process and effects etc. Costs to family such as reduced income, depletion of reserves and loss of assets; and cost to community such as increased use of social services of the affected family members are also the most common economic effects of mine accidents (Camm T et al, 2000). Among the mine accidents, fatal accidents are the ones with most adverse consequences on the employers, families and the communities. Accurately predicting fatal accidents will not

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only provide the basis of safety assessment and decision making but will also help to plan for possible economic and social imparts generated by the fatal accidents.

Copper mining production system is very complex and combined effects on various factors lead to mine accidents. Many scholars and experts consider that human error or people's unsafe behavior is the main reason for mine safety accidents (Tain SC et al, 2006, Chen H et al, 2007 & Hong C et al, 2006). Furthermore, studies have shown that human factors are relatively complex and unchangeable(Patterson et al, 2010), therefore, more affecting data is unknown. Mine accident causation by human error meets the criteria of been classified as a grey system.In recent past, Jain-Yi lan et al, (2014) observed that the main methods for predicting safety accident include experience model, regression model, and the gray prediction method. These models are not suitable to predict mine fatal accidents because most mine accidents are caused by human error. The Gray Markov SCGM $(1,1)_c$ is the most appropriate tool to for predicting fatal mining accidents in Zambian copper mines because they are mostly caused by human error. Furthermore, the Gray Markov SCGM $(1,1)_c$is the most suitable tool for predicting fatal accidents because of lack of sufficient historical data of fatal accidents in the Zambian Copper Mines. The Gray Markov combines the advantages of the grey and Markov prediction models. According to the copper mining industry fatal accidents statistics provided by Mine Safety Department and the reports of the auditor general on the management ofoccupational safety and health for national assembly,an amended Gray Markov *SCGM(1,1)c* model is proposed. The gray *SCGM(1,1)c* model is applied to imitate the development tendency of the mine fatal accidents, and the amended model is used to improve prediction accuracy. The Markov prediction is used to predict the fluctuation along the tendency to further improve the prediction accuracy on random volatile accident data.

2.0 Methodology

2.1. Gray SCGM(1,1)c Model Establishing

2.1.1 Model Selection.

According to the actual accidents situation in Zambian mines, human error of the miner is not regular; it posses characteristics of being randomly scattered, lack of raw certain data and imperfect and uncertain information of what causes it. Modeling of such data is very difficult using probabilistic statistics and mathematical statistics methods. Gray Markov *SCGM(1,1)c* prediction model is the most suitable for model accident information as it possesses characteristic of requiring less information, easy calculation,high accuracy, and so on. The model does not list factors affecting data research object but finds useful information and explores the inherent laws from their own time data sequence establishing model to predict.

2.1.2 Data Processing

Taking account of randomness of fatal accidents data, caused by human error, in the Zambian Copper mines, the original time series $^{(0)}$ of the mine fatal accident can be expressed:

$$x^{(0)} = \{x^0(1), x^{(0)}(2), \cdots, x^{(0)}(n)\} \quad [1]$$

First, $x^{(0)}$is integrated as follows;

$$\bar{x}^{(1)} = \{\bar{x}^{(1)}(2), \bar{x}^{(1)}(3), \dots, \bar{x}^{(1)}(n)\} \quad [2]$$

Where;

$$\bar{x}^{(1)}(k) = \sum_{m=2}^{k} \bar{x}^{(1)}(m), \;\; k = 2,3,\dots,n$$

$\bar{x}^{(0)}$is a close mean value generated sequence for $\bar{x}^{(0)}$:

$$\bar{x}^{(0)} = \{\bar{x}^{(0)}(2), \bar{x}^{(0)}(3), \dots, \bar{x}^{(0)}(n)\} \quad [3]$$

Where

$$\bar{x}^{(1)}(k+1) = \frac{x^{(0)}(k+1) + x^{(0)}(k)}{2}$$

2.1.3 Response Function

Human error, which is random, leads to accidents (fatal) in Zambian copper mines. Therefore, the majority of accidents are assumed to be dynamic in nature. Given that integral sequence of mine fatal accidents time series is expressed as $\{\bar{x}^{(0)}(k)\}$ that is associated with satisfaction trend of non-homogeneous index discrete function expressed as $f_r(k) = be^{a(k-1)} - c$, thus the data of $\bar{x}^{(1)}(k)$ is fit to $f_r(k)$. According to gray system cloud forecast method, the system gray *SCGM(1,1)$_c$* prediction model can be expressed as;

$$\frac{d\,\bar{x}^{(1)}(k)}{dk} = a\bar{x}^{(1)}(k) + u, k \geq 2 \quad [4]$$

Its time response function can be expressed as follows;

$$\bar{x}^{(1)}(k) = \left[\bar{x}^{(1)}(1) + \frac{\mathrm{U}}{\mathrm{a}}\right].e^{ak} - \frac{U}{a} \quad [5]$$

Where;

$$a = \frac{\ln \sum_{k=3}^{n} \bar{x}^{(0)}(k-1)\bar{x}^{(0)}(k)}{\sum_{k=3}^{n}\left(\bar{x}^{(0)}(k-1)\right)^2} \quad [6]$$

$$b = \frac{(n-1)\sum_{k=2}^{n} e^{a(k-1)}\bar{x}^{(1)}(k) - \left(\sum_{k=2}^{n} e^{a(k-1)}\right)\left(\sum_{k=2}^{n} \bar{x}^{(1)}(k)\right)}{(n-1)\sum_{k=2}^{n} e^{2a(k-1)} - \left(\sum_{k=2}^{n} e^{a(k-1)}\right)^2} \quad [7]$$

$$c = \frac{1}{n-1}\left[\left(\sum_{k=2}^{n} e^{a(k)}\right)b - \sum_{k=2}^{n} \bar{x}^{(1)}(k)\right] \quad [8]$$

Given $\bar{x}^{(1)}(1)$=*b-c*, *U=ac*, $\bar{x}^{(1)}(k)$ is reverted, the system gray *SCGM(1,1)$_c$* prediction model of original data will be expressed as;

$$\hat{x}^{(0)}(k) = \frac{2b(1-e^{-a})}{1+e^{-a}}.e^{a(k-1)} \quad [9]$$

The Grey precision index ($Y(k)$), residual error ($\varepsilon(k)$) and the relative error (Δk) are calculated as follows

$$Y(k) = \frac{x^0(k)}{\hat{x}^{(0)}(k)} \quad [10]$$

$$\varepsilon(k) = \hat{x}^{(0)}(k) - x^0(k) \quad [11]$$

$$\Delta k = \frac{|\varepsilon(k)|}{x^0(k)} \quad [12]$$

Indicators in equation 10, 11 and 12 are gray fitting accuracy indicators, which reflect the degree of deviation of the predicted values to original data set.

2.2 Establishment of the Residual Amended SCGM(1,1)c Model

Statistics data fluctuations of Zambian copper mining fatal accidents are not larger, and the regularity is not very strong as uncertainty of the person's behavior. Therefore, the prediction accuracy should not be too good if the *SCGM(1,1)c* model is solely applied to predict accident deaths of Zambian copper mines. In orderto improve the prediction rate and better meet the actual situation,the prediction model should be corrected to improve the accuracy. Amended principles and steps are as follows.

(1) The first time residuals data sequence is obtained in accordance with the predicted value and actual value:

$$\varepsilon^{(0)}(k) = \hat{x}^{(0)}(k) - x^0(k),\ k = 1,2,3,\dots,n \quad [13]$$

$$\varepsilon^{(0)}(k) = \{\varepsilon^0(1), \varepsilon^0(2), \dots, \varepsilon^0(n)\} \quad [14]$$

(2) Processing residuals correction sequence.
Given that $M = (1 + e^{-a})^{-1}(1 - e^{-a})^b$, the *SCGM(1,1)c* prediction will be expressed as $\hat{x}^{(0)}(k) = 2e^{a(k-1)}M$. If $\varepsilon^{(0)}(k) \geq 0, (k = 1,2,3,\dots,n)$ the residual amended SCGM(1,1)c model will be expressed as $\hat{\varepsilon}^{(0)}(k) = 2e^{a_1(k-1)}M_1$. a_1,M_1, and b_1 can be obtained in accordance with a,M, and b used method. The first time residuals corrected *SCGM(1,1)c* model can be expressed as follows:

$$\hat{x}_{\varepsilon_1}{}^{(0)}(k) = 2\left(e^{a(k-1)}M - e^{a_1(k-1)}M_1\right) \quad [15]$$

If $\varepsilon^{(0)}(k) < 0, (k = 1,2,3,\dots,n)$, the first time residuals corrected *SCGM(1,1)c* model can be expressed as follows:

$$\hat{x}_{\varepsilon_1}{}^{(0)}(k) = 2\left(e^{a(k-1)}M + e^{a_1(k-1)}M_1\right) \quad [16]$$

The first time residuals amendment did not meet the forecast accuracy required. Therefore, a second residual correction according to the principals in section 2.2 was carried out the data set until required accuracy requirements were met. The residual correction generic model can be expressed as follows:

$$\hat{x}_{\varepsilon_2}{}^{(0)}(k) = \hat{x}_{\varepsilon_1}{}^{(0)}(k) - 2e^{a_2(k-1)}M_2 \quad [17]$$

Where; ${\varepsilon_1}^{(0)}(k) \geq 0, (k = 1,2,3,\dots,n)$, and;

$$\hat{x}_{\varepsilon_2}{}^{(0)}(k) = \hat{x}_{\varepsilon_1}{}^{(0)}(k) + 2e^{a_2(k-1)}M_2 \quad [18]$$

Where; ${\varepsilon_1}^{(0)}(k) \leq 0, (k = 1,2,3,\dots,n)$

2.3 Error Analysis

To examine the precision of the proposed model, further tests are required to determine the error between the forecast value and actual value. In this study, the relative error (RPE) analysis was adopted to assess the model precision.

2.3.1 Relative error analysis

Relative percentage error (RPE) compares the real and forecast values at specific time k. RPE is defined as Equation 12. The total model precision can be defined by average relative percentage error (ARPE) as follows

$$ARPE = \frac{1}{n}\sum_{k=1}^{n} RPE, \text{ where k = 2, 3, 4, ..} \quad [19]$$

2.3.2 Model Precision Test

Table 1 after Qiao T(2016) was used to assess the precision level of the results generated by a model.

Table 1: Classification of prediction results

Prediction Precision Grade	P	C
Excellent	>0.95	<0.35
Good	>0.8	<0.5
Fair	>0.7	<0.55
Poor	<0.7	>0.65

$$C = \frac{S_2}{S_1} \quad [20]$$

Where;$S_1^2 = \frac{1}{n-1}\sum_{k=1}^{n}[x^0(k) - \bar{x}]^2$, $S_1^2 = \frac{1}{n-1}\sum_{k=1}^{n}[\varepsilon^0(k) - \bar{\varepsilon}]^2$, $\bar{\varepsilon}=\frac{1}{n}\sum_{k=1}^{n}\varepsilon^0(k)$, $\bar{x}=\frac{1}{n}\sum_{k=1}^{n}x^0(k)$,

$$P = p\{|\varepsilon_i^0(i) - \bar{\varepsilon}_i^0(i)| < 0.6675S_1\} \quad [21]$$

2.4 Establishment of Amended Markov SCGM(1,1)c Model.

The *SCGM(1,1)*$_c$prediction fitting curve is essentially an exponential curve, and the prediction result is a relatively smooth curve. Because human error accidents are main part of mine accidents, the *SCGM(1,1)*$_c$model solely applied cannot meet forecast accuracy requirements. Markov theory has no aftereffect, that is to say, "the future state of the system is only related to the current state, and has nothing to do with the past state." Meanwhile, Markov model is adopted to predict states trends through probability transfers, it can adapt to the randomness and variability of state. Applying Markov theory to correct the SCGM(1,1)$_c$prediction model of Zambian copper mine fatal accidents can better solve the variability and randomness of accidents caused by human errors to improve the prediction accuracy.

2.4.1 State Divided.

The annual change of the number of deaths incopper mine accidents Zambia is a dynamic non stationary random process, and thus the prediction fitting precision indicators also are variable and random. Because boundary and connotation of the different annual state are changeable, an adaptive state divided criterion needs to be determined, and the criterion should be consistent with

basic timing trend of the Zambia Copper Mines fatal accidents. Thus, (k) was divided into m states, and each state can be expressed as:

$$E_i \in [\otimes_{1i}, \otimes_{2i}], i = 1,2, \dots, m. \quad [22]$$

Where; $\otimes_{1i} = Y(k) + A_i$, $\otimes_{2i} = Y(k) + B_i$

In the formula, E_i is expressed as i state, $\otimes_{1i}$ and $\otimes_{2i}$are, respectively, expressed as the upper and lower bounds of the i state, and A_i and B_i are constants determined according to prediction data. Because (k) is a time function, $\otimes_{1i}$ and $\otimes_{2i}$ will be changed with time, so the state possesses variability.

When the state is divided, the numbers of different intervals are reasonably divided according to the actual situation. If raw data are less, the interval division should be less so as to increase the number of transfers between the various states, and thus the transfer law can be more objectively reflected between states. Conversely, if raw data are more, the interval division should be less in order to excavate more information from a large number of data to improve the prediction accuracy. It is suitable to adapt clustering classification method to determine class number and classification intervals due to less data and uncertain status of human error accidents in the copper mines.

2.4.2 Construction of State Transition Rate Matrix

The original number of samples is expressed as $M_{ij}(k)$from the state E_i transiting to the sate E_j by k step, and the number of occurrences of the state $E_i$is expressed as M_i, so statetransition probability is expressed as follows:

$$P_{ij}(k) = \frac{M_{ij}(k)}{M_i}., i, j = 1,2, \dots, M. \quad [23]$$

M × M state transition probability matrix can be obtained as follows;

$$P(k) = \begin{bmatrix} P_{11}(k) & P_{12}(k) \cdots & P_{13}(k) \\ P_{21}(k) & P_{22}(k) & P_{23}(k) \\ \vdots & \vdots & \vdots \\ P_{m1}(k) P_{m2}(k) & & P_{m3}(k) \end{bmatrix} \quad [24]$$

2.4.3 The Predictive Value Determined

The state transition probability matrix (k) reflects all statistical regularities of state transition, and the future system state steering can be predicted by investigating the matrix. In the actual analysis of the process, one step transition probability matrix (1) is generally only examined. Given that predicted moment object is in the state $E_{k,}$ investigating the k row of (1) can get the following.

(1) If max $P_{ij} = P_{kl}$, the next time system should most likely shift from the state E_k to the state E_l.
(2) If there are two or more probability values identical or similar to k row in the matrix $P(1)$, the future state steering will be difficult to determine; it needs to consider probability transition matrix $P(2)$ or $P(n)$ $(n \geq 3)$.

The system's future state will be determined by investigating state transition probability matrix, and gray change interval of relative prediction value in the future moments also will be determined; it can be expressed as $[\otimes_{1i}, \otimes_{2i}]$. Predicted value of the future moment can be expressed as the interval median as $Y'(k)$.

$$Y'(k) = \frac{x^0(k)}{\hat{x}^{(0)}(k)} = \frac{1}{2}(\otimes_{1i}+\otimes_{2i}) = Y(k) \times \frac{1}{2}(A_i + B_i) \quad [25]$$

3.0 Application

The original data sequence of mine fatal accidents from 2001 to 2015 in the Zambian Mining industry are shown in Table 2, and then we are applying Grey-Markov forecasting model to forecast the mine fatal accidents, according to the methodology proposed in section 2, the forecasting steps are as follows.

3.1. Building GM(1,1) forecasting model

Based on the original data of fatal mine accidents from 2001 to 2015, the value (*a*=-0.0408, *b*=-596.85) can be obtained can be obtained after calculating, then the grey forecasting mode can be established;

$$\hat{x}^{(0)}(k) = 24.36e^{-0.0408(k-1)} \quad [26]$$

The forecast value is calculated out by Equation 26, see Table 2

Table 2: Real Value and Forecast Value of Fatal Copper Mine Accidents from 2001 to 2015

Year	Real Value	Forecast Value	Relative Error	Grey Precision Index (%)
2001	23	24.36	0.06	94
2002	17	23.39	0.38	73
2003	21	22.45	0.07	94
2004	19	21.55	0.13	88
2005	34	20.69	0.39	164
2006	18	19.86	0.10	91
2007	15	19.07	0.27	79
2008	21	18.31	0.13	115
2009	17	17.57	0.03	97
2010	14	16.87	0.21	83
2011	20	16.20	0.19	123
2012	12	15.55	0.30	77
2013	12	14.93	0.24	80
2014	13	14.33	0.10	91
2015	16	13.76	0.14	116

3.2. Building of the Residual Amended SCGM (1,1)c Model

Based on the relative error between the real and forecasted data between of fatal mine accidents between 2001 to 2015, the residual Amended $SCGM(1,1)_C$ was developed with a value of a_1=-0.1984 and b_1=-61.3129. The first time residuals corrected *SCGM(1,1)c* model can be expressed as follows:

$$\hat{x}_{\varepsilon_1}{}^{(0)}(k) = 2\left(e^{-0.0408(k-1)}12.18 \pm e^{-0.2107(k-1)}6.06\right) \quad [27]$$

For $\varepsilon_1{}^{(0)}(k) \leq 0$, + is used and $\varepsilon_1{}^{(0)}(k) \geq 0$, - is used.

The forecast values as calculated out from Equation 27 are shown in Table 3.

Table 3: Forecast Value of Fatal Mine Accidents from 2001 to 2015 using the residual SCGM (1,1)c

Year	Real Value	Forecast Value	Relative Error	Grey Precision Index (%)
2001	**23**	12	0.47	187.98
2002	**17**	13	0.21	126.42
2003	**21**	14	0.32	146.89
2004	**19**	15	0.22	127.83
2005	**34**	26	0.23	129.90
2006	**18**	15	0.15	117.16
2007	**15**	15	0.00	97.51
2008	**21**	21	0.00	98.44
2009	**17**	15	0.11	112.65
2010	**14**	15	0.07	94.36
2011	**20**	18	0.10	111.94
2012	**12**	14	0.17	84.61
2013	**12**	14	0.17	86.90
2014	**13**	13	0.00	96.94
2015	**16**	15	0.06	110.24

3.2. Building of the second Residual Amended SCGM (1,1)c Model

Based on the relative error between the real and forecasted data between of fatal mine accidents between 2001 to 2015, the second residual Amended $SCGM(1,1)_C$ was developed with a value of a_2=-0.2107 and b_2=-43.273. The second time residuals corrected *SCGM(1,1)c* model can be expressed as follows:

$$\hat{x}_{\varepsilon_2}{}^{(0)}(k) = \hat{x}_{\varepsilon_1}{}^{(0)}(k) \pm 9.08e^{-0.2107(k-1)} \quad [28]$$

For $\varepsilon_2{}^{(0)}(k) \leq 0$, + is used and $\varepsilon_2{}^{(0)}(k) \geq 0$, - is used.

The forecast values as calculated out from Equation 28 are shown in Table 4.

3.3. Error Analysis for the prediction models

The average relative error calculated using equation 23 for GM (1,1), Residual Amended SCGM (1,1)c Model and the second Residual Amended $SCGM(1,1)_c$ were 0.18, 0.25 and 0.07 respectively. Furthermore, the precision test for the second Residual Amended $SCGM(1,1)_c$(lowest ARE) classified the model as excellent i.e C=0.046 which is less than 0.35 and the Value of P is equal 1 which is greater than 0.95. Therefore, the second residual amended $SCGM(1,1)_c$ model was selected to be used to predicted fatal mining accidents in the copper mines beyond 2015.The fitting of the predicted values by the models Versus the actual are shown in Figure 1.

Table 4: Forecast Results for second Residual Amended SCGM (1,1)c Model

Year	Real Value	Forecast Value	Relative Error	Grey Precision Index (%)
2001	**23**	21	0.083	109
2002	**17**	20	0.198	84
2003	**21**	20	0.050	105
2004	**19**	20	0.044	96
2005	**34**	30	0.120	114
2006	**18**	18	0.009	99
2007	**15**	13	0.146	117
2008	**21**	19	0.083	109
2009	**17**	17	0.019	102
2010	**14**	14	0.026	103
2011	**20**	19	0.045	105
2012	**12**	13	0.092	92
2013	**12**	13	0.106	90
2014	**13**	12	0.045	105
2015	**16**	15	0.033	103

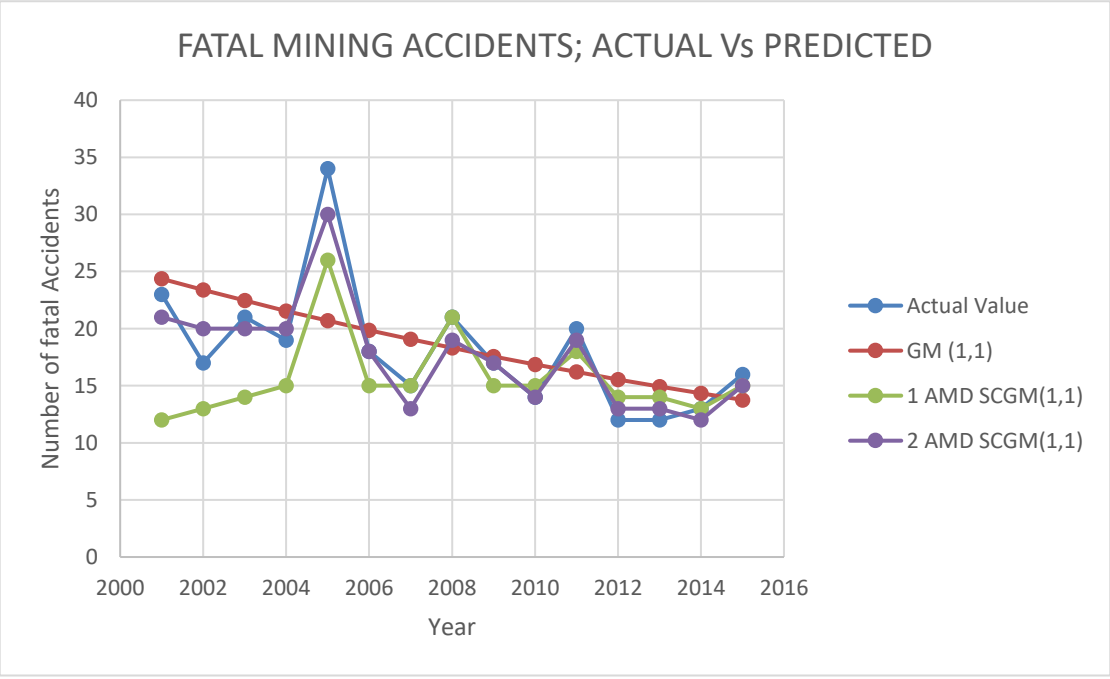

Figure 1: Curve fitting of mine fatal accidents with results from different prediction models

3.4 Dividing states for Markov forecasting

According to grey precision index (see Table 4) from 2000 to 2015, four transitional states are divided as follows, and the circumstances that the grey precision index lies in the state are listed in Table 5.

$$\otimes_1 = [80, 90],\ \otimes_2 = [90,100],\ \otimes_3 = [100, 110],\ \otimes_4 = [110,120],$$

The states are described as shown in Table 5.

Table 5: State division of Zambian Copper mining industry fatal accidents

No. of State	Dividend State	Precision Index Range (%)
1	Strong decreasing year	80-90
2	Poor decreasing year	90-100
3	Poor increasing year	100-110
4	Strong increasing year	110-120

3.5 Calculating transition probability matrix

The transition probability was calculated using equation 23 and the methods explained in section 2.4.2. Table 6 shows the initial states to which the grey precision indexes belong.

Table 6: Initial state of years

Year	Grey Precision Index	Initial state
2001	109	3
2002	84	1
2003	105	3
2004	96	2
2005	114	4
2006	99	2
2007	117	4
2008	109	3
2009	102	3
2010	103	3
2011	105	3
2012	92	2
2013	90	1
2014	105	3
2015	103	3

The resulting transitional probability matrix is as follows

$$P(1)=\begin{bmatrix}0 & 0 & 1 & 0\\ 0.33 & 0 & 0 & 0.67\\ 0.125 & 0.25 & 0.8 & 0\\ 0 & 0.5 & 0.5 & 0\end{bmatrix}\ P(2)=\begin{bmatrix}0 & 0.5 & 0.5 & 0\\ 0 & 0.33 & 0.67 & 0\\ 0.125 & 0 & 0.375 & 0.125\\ 0 & 0 & 0.5 & 0.5\end{bmatrix}\ P(3)=\begin{bmatrix}0 & 0.67 & 0 & 0.5\\ 0. & 0 & 0.33 & 0.67\\ 0.125 & 0.375 & 0.25 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}$$

$$P(4)=\begin{bmatrix}0 & 0.5 & 0 & 0\\ 0 & 0 & 0.67 & 0\\ 0.125 & 0.125 & 0.25 & 0.25\\ 0 & 0 & 1 & 0\end{bmatrix}$$

Due to four states are divided, so latest four years data near to prediction time are selected to make state prediction table (Table 7), the transition steps are defined as 1,2,3,4.

Table 7: State Prediction

	Initial State	Transition	State 1	State 2	State 3	State 4
2015	3	1	0.125	0.25	0.8	0
2014	3	2	0.125	0	0.375	0.125
2013	1	3	0	0	0	0.5
2012	2	4	0	0	0.67	0
Sum			**0.25**	**0.25**	**1.845**	**0.125**

3.6. Calculating forecasting values using the Amended Grey Markov model

The future fatal mine accident deaths toll can be predicted based on the four state transition probability matrices. The fatal mine accident value of 2016 has the high probability of being in state 3. Therefore, the grey precision index of 2016 is likely to be in state 3, [100,110]. The forecast value of 2015 and 2016 calculated by Markov- Grey is as follows;

$$Y'(2015)=Y(2015)\times\frac{1}{2}(A_i+B_i);\ Y'(k)=15\times\frac{1}{2}(1.00+1.10)=15.75$$

$$Y'(2016)=Y'(2015)\times\frac{1}{2}(A_i+B_i)=16\times\frac{1}{2}(1.00+1.10)=17$$

The Amended Markov grey predicted a Value of 17 for the total number of fatal accidents in Zambia compared to the actual value of 19. The relative error of prediction was 0.1.

4.0 Conclusion

The Markov grey model is the best prediction accuracy among the four models used for fatal mine accidents in Zambia. It has the lowest relative error and better reflects the relationship between mine fatal accidents and the number of data series. It takes full advantage of historical data and overcome the data random volatile effects on prediction precision. The proposed model therefore possesses strong engineering application.

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Lessons Learnt in the Hydropower Generation Using Water Floating Turbines in Kavalamanja Area, Luangwa District

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Abstract

ChildFund Zambia requested Rural Electrification Authority (REA) to participate in the installation of the water floating hydro turbines which was undertaken by the supplier of the equipment and also to assess the performance of the system over a period of 4 months then advise the manufacturer accordingly. In order to empower the local community, REA engaged some selected members of the community with technical background to work with them during the process. The technology was of interest to REA considering that it was the first of its kind to be installed in Zambia and further once the technology had been verified, the same could be scaled up to other rural areas in the country.

During the four months of technical assessment of the water floating turbines in Kavalamanja, a number of issues were observed and of interest is the limited power generated by the turbine. Based on this limitation, it was observed that it would be difficult to scale up the use of the technology in terms of rural electrification. Therefore, the manufacturer was advised to consider improving the power generated by this type of turbines.

The purpose of this paper is to provide an overview of lessons learnt over the installation and also the performance of the floating water turbine over the 4 months of operation. The paper therefore brings out lessons that were learnt over the period which could be used as a platform for implementation of future projects.

Therefore, based on the lessons that have been learnt over the 4 months observation period, it is critical that a number of factors are necessary for the successful implementation of off-grid projects using floating water turbines.

Keywords: Floating hydro turbines, technology, electrification, power generated, sustainability

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1.0 INTRODUCTION

1.1 Background

The Rural Electrification Act No. 20 of 2003 established the Rural Electrification Authority (REA) and the Rural Electrification Fund (REF). According to the Act, the Authority administers and manages the REF which it uses to implement the rural electrification programme. The overall mandate of REA is to provide electricity infrastructure to rural areas using appropriate technologies such as grid extension, mini grids systems i.e. solar and hydro, stand-alone solar systems in order to increase rural electricity access rate and contribute to improved productivity and quality of life for the rural population (REA, 2013). Some of the functions of the Authority as outlined in the Act are provided as follows;

1. To administer and manage the Rural Electrification Fund (REF);

2. Develop, implement and update the Rural Electrification Master Plan (REMP);

3. Promote the utilisation of available rural electrification technology options to enhance the contribution of energy to the development of agriculture, mining, industry and other economic activities in rural areas;

4. Mobilise funds within and from outside Zambia in order to carry out rural electrification projects;

5. Offer on a competitive basis, the construction of rural electrification projects

Since 2006, REA has sought to accelerate the pace of implementation of the national electrification programme for rural areas in order to increase electricity access rate from 3.1% in 2006 to 51% by the year 2030 using various electrification methods and in accordance with the provisions of the REF and the estimated financial outlay of about US$50 million to achieve the set targets in the REMP. However, over the years, the trends in allocation of funds to the rural electrification programme have fallen far short of the REMP estimates resulting in fewer numbers of projects being implemented. According to the Central Statistics Office (CSO), 2010 Living Conditions Monitoring Survey (LCMS) Report (LCMS, 2010), the rural electricity access rate stood at about 4.5% as at 2010 for grid connected households while another 4.5% of rural households were reported to have access to electricity using solar technology. Based on the latest LCMS which was conducted in 2015, it is worth noting that the rural electricity access rate for grid connected houses is 3.7%. The reduction in the access rate for grid connected houses is mainly attributed to the growth in population that has not matched with the rate of electricity connections (LCMS, 2015).

Therefore, the Authority has a mammoth task to achieve the targeted rural electrification of 51% by the year 2030 as set in the REMP. In order to accelerate the rural access rate, the Authority strategically partnered with institutions involved in rural development. Therefore, the Authority collaborated with ChildFund Zambia (CFZ) an International Child Protection and Development Agency, working for the well-being of children and the main focus of intervention is based on five program areas: Education, Health, Child protection, HIV & AIDS and Food Security.

In 2013, ChildFund Zambia secured funding for the implementation of Luangwa Integrated Agricultural Project (LIAP) in Luangwa District. The project was aimed at creating sustainable economic development and food security in Luangwa District by 2016. The project was implemented in Kavalamanja which is approximately 70km from Great East Road and 13km off Luangwa road targeting 1,500 households. One of the components of the project was to fence off

355 Ha of arable land in Kavalamanja to reduce human-animal conflict in the area and protect crops from destruction by wild animals such as elephants.

Kavalamanja, however, is a drought prone area and there was no irrigation facility established in the area. As such, there was no water available directly at the farmland and the possibilities of undertaking off season farming were very limited. Based on the estimates, the water demand for a full irrigation of about 10 ha of the farmland was estimated at around 240 m^3/h, requiring a 44 kVA generator or 110 kW of PV installation. To realise this dream, ChildFund had implemented a Power Generation Project whose objective was to supply 120 m^3 of water per day to the fenced area for irrigation purposes. In that regard, a hybrid power generation of two water floating turbines (2x5 kW) and 4 kWp PV panels were installed to provide power to the pump which pumps water to the elevated tanks. The power is also used for lighting at Kavalamanja Primary School and Rural Health Centre. In order to ensure sustainability of the project, the Kavalamanja community was tasked to operate and maintain the systems. However, currently ChildFund is meeting the cost of maintenance for a specified period of time after which the systems will be managed by the community. Refer to Figure 1 showing the storage tanks and the irrigation area.

Figure 1: Storage tanks and the irrigation area

In view of the above, CFZ invited the Rural Electrification Authority (REA) to Kavalamanja project site to witness the installation of the floating hydro turbines and to observe the performance of the system over a period of 4 months then advise the supplier accordingly (REA, 2017). Further, REA was engaged to work with the community so that the project was verified technically during the testing period before the technology was handed over to the community by the contractor. This is the first ever installed turbines in Zambia and REA was interested in learning the operations and maintenance so that the technology could be scaled up to other rural areas in the country. Therefore, the focus of this paper is on the water floating turbines technology.

1.2 Water Floating Turbines

The Hydro Power turbine has been developed to produce a maximum amount of electrical power through a generator with the kinetic energy of flowing waters. The turbine is powered by kinetic energy and not with potential energy referred to as “zero-head” or “in-stream” turbine. As such, no dams or head differential are necessary for the operation of this device. The course of a river remains in its natural state and no high investments in infrastructure are required. The amount of kinetic energy (velocity) varies from river to river, therefore the capacity of the turbine ranges from a minimum of a few watts to a maximum of 5000 watts (5 kW).

The turbine consists of a three-bladed rotor, a 5 kW generator, the floating body consisting of a three-piece diffusor and two floats. The floating body comprised of a diffusor and floats and is designed to adapt optimally to varying water conditions. The diffusor has two main functions; the first increases water pressure on the rotor and minimizes turbulences within the diffusor which therefore produces a maximum output, the latter provides the generator with its stable swimming position in water.

In the core of the turbine lays a horizontal-axis, permanent magnet underwater generator, which is specially developed for Hydro Power generation. In order to increase fish friendliness, a slow-turning generator has been designed so that no suction arises in front of the turbine. The three rotor blades are specifically adapted to the generator and diffusor, so that harmonious operation occurs underneath the surface of the water. The turbine allows for various kinds of installations which depend on the specific demand and the relative possibility. For floating installations, different types of anchor systems are used which always depend on the local river characteristics and conditions. Figure 2 shows the various components.

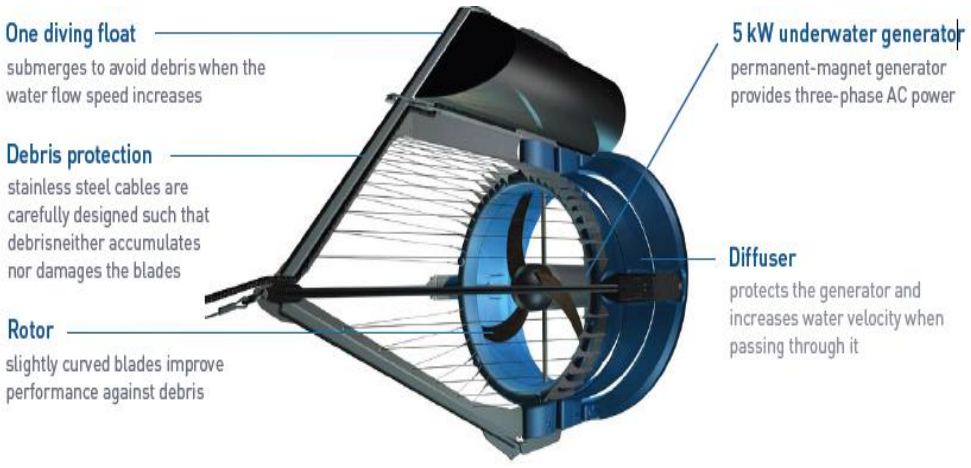

Figure 2. Components of the Floating Turbine (Smart Hydro Power,2018)

1.3 Project Scope

The project involves the installation of the smart hybrid 4 kWp photovoltaic system (16x250 Wp), 2x5 kW Mono float turbines, 35 kWh battery bank, 2.2 kW centrifugal pump and 2 km underground cable distribution system to supply electricity to Kavalamanja Primary School and Kavalamanja Rural Health Centre.

The purpose of this paper is to provide an overview of lessons learnt during the installation, operation and maintenance of the turbines.

2.0 LESSONS LEARNT

The following are the lessons that were leant during the installation, operation and maintenance of the turbines:

2.1 Building a local technical team

In order to sustainably manage the technical aspects of the turbine, there is need to build a local technical team to operate and maintain the turbines. Based on the contract that was signed with the supplier of the equipment, the technical skills were supposed to be passed on to the local staff so that the plant could be managed and operated by the local team. A local team that was selected by ChildFund was not competent to understand the technical aspects thereby making it difficult to effectively manage the operation and maintenance of the equipment. Therefore, this created a risk in terms of sustainability considering that the team had limited technical knowledge. One of the keys to sustainability in terms of technological transfer is to ensure that the right people are trained who in turn should train more staff so that the skills are passed on and in the process the knowledge is improved on.

2.2 Appreciation of renewable energy technologies by the rural community

Kavalamanja area is a drought prone area and there is no water available apart from Zambezi river which is 2.4 km away. Therefore, the possibility of undertaking farming during dry season is limited and the only option is to pump water from the river. The installed 40,000 m^3 water tanks capacity facilitates irrigation and the system is currently supporting 30 households who are cultivating vegetables which are supplied to Luangwa residents. The farming area has been fenced to reduce human-animal conflict in the area and protect crops from destruction by wild animals such as elephants.

From the time the water supply system for irrigation was installed, the local communities through their representatives have been expressing appreciation of the technologies. The representatives have taken keen interest in the operation of the systems. During sensitization meetings that were held , the community expressed their appreciation through songs and drama.

2.3 Potential causes of low power output from the floating turbines.

Based on the power output curve for the smart mono-float generator model shown in Figure 3, the floating hydro turbine was designed to give the maximum output power of 5 kW at the water velocity of 2.8 m/s. This turbine is designed for rivers, featuring a reinforced debris protection and a patented anchoring system. The anchoring can be done at the bottom of the river, at a bridge support, or at a block on the side of a river. This turbine is ready to overcome variable water depth, velocity and floating debris of various materials and sizes. However, considering that the average water velocity which was measured during the installation of the hydro turbine was 2.0 m/s, the expected power output of one turbine was approximately 1800 W at this water velocity. Therefore, the combined power output from the two turbines would be 3600 W or 3.6 kW.

One of the major contributors of low power output from the turbines is the collection of debris at around the turbines, Figure 4. The debris has the potential to slow the water around the turbines thereby reducing the speed of the generator. As shown in the graph, the low water speed has a direct relationship with the power generation. Based on this challenge the supplier was advised

that two options could be implemented to manage the challenge. One option was to create a barrier a few meters from the turbines. However, the barrier should be placed in such a way that the same does not affect the speed of the water after the debris accumulate. One possibility was to ensure that the debris was removed quickly from the barriers so that the water flow was not affected. The other option was to ensure that the turbines were submerged deep in the water so that the debris could pass on top of the turbine.

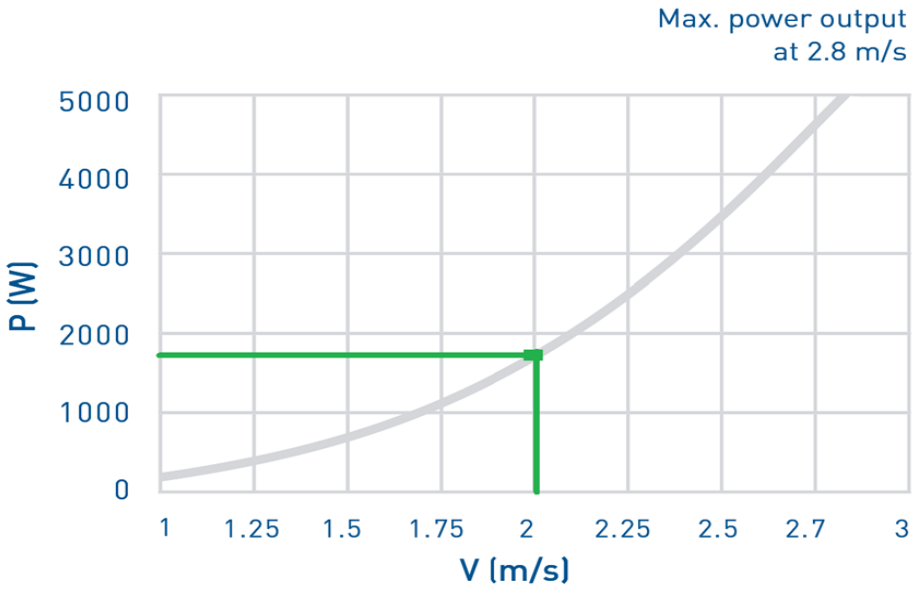

Figure 3: Power output curve of the generator (Smart monofloat generator model)

Figure 4: Debris accumulation around the floating turbine

2.4 Maximising power output from the floating turbines

The maximum flow in the river is obtained at the middle, therefore in order to maximise the power generation, the turbine should ideally be anchored or placed at the middle of the river. However, this cannot be done considering that there is need to design a supporting steel structure long enough to withstand the river flow and debris. When installing the steel structure two design factors are considered namely the anchoring mechanism i.e. the type of rock on the river bank that will hold the steel structure and the length of the arm including the winch which help to lift the steel arm during maintenance.

Therefore, in order to maximise the power generation, a study is conducted in order to find the ideal point where the maximum power generation could be achieved. In the case of Kavalamanja site, the installation had the following parameters. The width of the river was 32 m, the maximum water flow was 2.0 m/sec, while the length of the steel arm to support the turbine was 9m from the river bank. However, after the first few months of operation, the supplier was advised to increase the length of the arm to 12 m as this may enable the turbines to be positioned at a point of high water velocity thereby increasing the power output. Refer to Figure 5 showing anchoring mechanism: steel structure holding the floating turbines and Figure 6 showing the side view of the turbines

Figure 5: Steel structure holding the floating turbines

Figure 6: Side view of the floating turbines

2.5 Installation of water meters to manage water consumption

After assessing the plant operation for 4 months, it was observed that communities were leaving pipes unattended to and this contributed to wastage of water. Therefore, in order to effectively manage water utilization by the farmer, a recommendation was made to ChildFund to consider installing water meters so that the farmers could be billed for the water consumption. In the long run installation of water meters would help the community manage the use of water thereby improve revenue collection which will help also in the management of the power plant.

2.6 Provision of service parts by the supplier

In order to effectively manage the plant's operation, the community would require service parts during the life span of the plant which would go a long way in sustaining the operations of the plant. Considering that the technology is still new in the country ChildFund should engage the supplier to provide service parts for the turbine. The provision of electrification through off-grid solutions does not end with the construction of a power plant and connection of consumers (Dadzie, 2008).

2.7 Recruitment of dedicated staff to effectively manage the power plant

The engagement of a dedicated staff with technical background and experience is key to sustainably manage the power plant. The current staff are not adequately experienced, and they lack basic knowledge to efficiently manage the power plant. Moreover, the staff assigned to manage the power plant want to be paid before they attend to any work on the plant. In view of these challenges, ChildFund was engaged to consider recruiting technical staff who were

dedicated to undertake routine system check-up to assess the system performance which will help to sustain the operation and maintenance of the power plant.

2.8 Willingness to pay by the community

The provision of electricity to remote off-grid communities is not just a business but a social intervention and therefore consumers, in this case farmers, must be screened to identify their willingness to pay. Consumers should have a mind-set of knowing that without fulfilling the obligation of paying for their bills, the power plant including the irrigation plant would close up. Payment of water bills once introduced will go a long way in sustaining the operations of the plant.

2.9 Partnership in undertaking rural electrification projects

According to the Act no. 20 of the Rural Electrification Act, the Authority is mandated to work with strategic partners in undertaking rural electrification projects. This approach is strategic in the sense that more resources will be mobilised for rural electrification and this will positively contribute to increased rural access rate which will contribute to improved social and economic welfare of the rural community. The identification of strategic partners is critical as the sustainability of the power plant is dependent on the type of the identified partner. The contribution from the partner must therefore be screened to identify their commitment to the project. Where possible the identification process should start early enough preferably at design stage so that more time is allocated to the process. Preferably a joint study should be conducted to establish the type of business model that will be used to operate and manage the power plant. This should be done before the detailed design for the power station is made. Strategic partners are key to increasing electricity access rate which can go a long way in improving the livelihood of the rural community.

3.0 CONCLUSION

During the four months of technical assessment of the water floating turbines in Kavalamanja, an observation was made that in order for REA to effectively scale up the implemented technologies in various parts of the rural areas, the manufacturer was advised to consider improving on the amount of power generated from a turbine i.e. 5 kW so that more loads could be connected to the system. Over the years we have noticed that once an area has been electrified, the power demand tends to increase with time. Therefore, the limitation in power supplied to the users could make it difficult to meet future power demand and this might frustrate the consumers in the long run.

In order to pilot various power generation technologies, REA may not be able to exclusively manage to finance such, as a result strategic partners are key to work with REA so that the successful technologies could be scaled up to help electrify rural areas which will be key to improving the electricity access rate. The partners should also be mindful of the various factors that are key to the successful implementation of off-grid projects such as the cost associated with the promotion of the technology, recruitment of key personnel to successfully operate and maintain the technology and identification of strategic partners to help sustain the technology among other factors. Project designers must therefore learn from other projects to avoid pit falls associated with the development of off grid projects (Dadzie, 2008).

The lessons learnt have been categorised under the following themes:

a. Lighting is not the only power requirement
b. Appreciation of renewable energy
c. Prepaid meters versus load limiters

d. Payment models
e. Quality after sales service is essential
f. Dedicated project personnel
g. Beyond education, products must be designed to prevent tampering
h. Anchor loads
i. Willingness to pay
j. Partnership in the management of the plant

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A Review of Mineral Wealth Creation Challenges in the Management of Zambia's Mineral Resource

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Abstract

Zambia is a mineral economy with a high level of macroeconomic dependence on copper mining when compared to international standards. The country is richly endowed with mineral resources which are important for the generation of benefits to the government and its nationals. Mineral resource deposits if left unexploited in the ground are merely potential wealth. Therefore, mineral wealth creation requires that such deposits be discovered, developed and mined. Most resource rich governments concerned with sustainable mineral development face public policy challenges which include creation challenges in their management of mineral resources. This review focuses on understanding challenges affecting the Zambian government in its roles of creating mineral wealth required for economic benefits. Qualitative review of Zambia's position indicates that operational obstacles exist in government institutions dealing with provision of the geological information. Equally, the mineral policy perceptions as assessed in comparison to other jurisdiction using the Fraser Institute Survey of mining companies showed that Zambia has inconsistent policy formulations causing a fall in various policy indices for 2015. The country's taxation system since privatisation has faced fiscal stability confronts that have not achieved equitable share of mineral rents. Furthermore, the combination of fiscal instruments inadequately strike a balance required for the government and investors in terms of risk distribution, neutrality, capturing of equitable economic rents and guaranteeing consistency. The review also established policy implementation challenges that fail to meet some of the social expectations of interested parties consistent with the protection of environmental quality during mineral project development. These include failures to conduct cost-benefit analyses for mineral development projects and deficiencies in inter-agency coordination that influence decision-making on some resource development projects. It is concluded that Zambia faces wealth creation challenges in its management of mineral resources because of poor policy formulation and implementation coupled with weak institutional capacities.

Keywords: mineral policy; mineral wealth; economic rent; creation challenges; cost-benefit analysis.

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1. Introduction

Zambia is endowed with natural resources such as land, forests and water, as well as non-renewable minerals, including copper, cobalt and emeralds (African Economic Outlook, 2014). Zambia is still highly dependent on copper mining as its major productive industry. The national contribution of mining in 2012 is relatively high at 86% of Foreign Direct Investment (FDI) and 80% of export values. However, the contribution is progressively low in other macroeconomic areas with less than 25% of government revenue, less than 12% of Gross Domestic Product (GDP) and only 1.7% contribution to gross employment (ICMM, 2014).

The implementation of appropriate development policies, therefore, has the potential to lead the country to reap the full benefits of its resource endowment (African Economic Outlook, 2014). Mineral wealth creation is an important measure since it can lead to economic development of the country once achieved from the country's mineral resources. Economic Commission for Africa [ECA] (2002) reported that before mineral wealth can be sustained, it must be created since minerals remaining in the ground are simply potential wealth. Eggert (2001) considered minerals as wealth which has the potential to create well-being, if they are discovered, developed, and mined in a way that appropriately protects environmental quality and that is fair to all interested parties involved in or affected by mining.

The key roles of government in mineral resources management is facilitating the creation of knowledge on mineral potential through establishing the legal and regulatory framework in which mineral exploration and development occur (ECA, 2002). In this context, wealth creation requires that mineral wealth be created in the first place, efficiently and in a manner consistent with social preferences for environmental quality and other social and cultural values.

Concepts of mineral wealth creation challenge deal with: provision of geological information required for wealth creation; government's role in the formulation of non-inconsistent mineral policies; assessing options for the taxation types; and policy concerns on social preferences for environmental quality and other social and cultural values (Eggert, 2001). These creation challenge concerns are described within a Zambian context. In order to achieve this, the paper makes reviews focusing on assessing these challenges linked with the roles of government in the creation of mineral wealth for Zambia.

The specific objectives for this review include:

- comprehension of the international perceptions about government's formulated policies on exploration and mineral project development;
- understanding the extent of government's geological data provision needed for investment in the mineral sector of the country;
- evaluating the impacts of mineral taxation system on wealth creation in the sector; and
- assessing how the promotion of environmental quality and social inclinations in mineral resource development is achieved.

2. Roles of different stakeholders

Government, mining companies, and civil society all have important roles to play in the management of mineral wealth and meeting the public policy challenges. These roles of different stakeholders are briefly described.

2.1 Government

According to World Bank (1997), the job of government is to: establish a foundation of law; maintain a non-distortionary policy environment; invest in basic social services and infrastructure; protect the vulnerable; and protect the environment. ECA (2002) specified that minerals in the ground are just potential wealth until sufficient knowledge is gained of the minerals. Government's key role in this area is facilitating the creation of knowledge on mineral potential by putting in place mineral policies to resolve the creation challenges.

Stanley and Eftimie (2005) noted that a mineral policy sets the framework for mining sector objectives defined in a democratic and consultative process involving the government, civil society (including affected communities), and the private sector. Some of the components of mineral policies include; government's will to create a competitive business environment, establishing provisions to attract sector participation, finding a balance between direct taxation and indirect taxation of secondary and tertiary support industries and downstream processing, introducing revenue transparency initiatives, and ensuring the use of concessions, mineral leases, and other assignable mineral rights for essential commodities.

ECA (2002) recounted that national mineral policies should: provide greater access to mineral resources; offer clear and transparent licensing arrangements, security of tenure and the freedom to transfer exploration and mining rights; and allow companies to market their output on commercial terms. These laws are complemented with provisions, sometimes in investment or tax laws, that provide reasonable freedom to dispose of foreign exchange earnings, apply profit-based taxation on internationally competitive terms, and guarantee stability of those terms for a reasonable period.

2.2 Mining companies

Mining companies are responsible to their shareholders who own the capital and require the best return on their invested capital with cash flow certainty. Natural Resource Charter (2014) stated that private sector companies in extractive industry projects should: take steps that go beyond minimum legal requirements to respect the highest environmental, social and human rights standards; avoid corruption; contribute to sustainable development outcomes; and make public and accessible relevant project information. Eggert (2001) noted that once government establishes a framework in which mineral development occurs, mining companies have the central role in creating mineral wealth that has the potential to benefit society.

2.3 Community

Civil society has a critical process role in creating and sustaining mineral wealth - through ensuring that the social and environmental effects of mining are considered in decision making about mine development (Eggert 2001).

3. Zambian government role in managing the wealth creation challenges

Governments are responsible for establishing and maintaining the overall framework for economic development in a nation (ECA, 2002). The Mining Sector in Zambia was governed and regulated by the Mines and Minerals Development Act No. 7 of 2008 which is now replaced by the Mines and Minerals Development Act, 2015 (No. 11 of 2015). The Act of 2008 broadly dealt with: types of mining rights; acquisition of mining rights; rights/obligations conferred on the mining right holder; transferability of mining rights; safety, health and environment and provides for the Environmental Protection Fund; and mineral royalties, fees and charges, and export of minerals (Zambia Development Agency, 2015).

As a way to tackle public policy challenges dealing with mineral wealth creation, governments are required to undertake specific roles as given by Eggert (2001) forming the given specific objectives for this review paper. These roles are discussed below in the context of the Zambian situation.

3.1 Non-distortionary mineral policies

Creation of mineral wealth requires government's facilitation by establishing a non-distortionary policy environment (Eggert, 2001). Non-distortionary policies facilitate the flow of investment to those areas with the greatest commercial attractiveness, whether in the mineral sector or elsewhere in the economy. Policy generally should not distort or steer investment towards particular sectors, unless there are spillover effects on the economy as a whole that otherwise would not be considered by private decision makers. A non-distortionary regime for mineral policy is one that strives for economic efficiency (ECA, 2002).

The Zambian government adopted a pragmatic mineral policy in 1995 designed to enhance private investment in the mining industry and to ensure the development of a self-sustaining minerals-based industry. The Mineral Resources Development Policy (MRDP) of 2013 specified that implementation of the 1995 Mineral Policy was expected to yield the following outcomes: development of new mines; increased government revenue; increased generation of foreign exchange earnings; industrial growth; employment opportunities; and development of infrastructure and social services.

However, the 1995 Mineral Policy had a number of outstanding challenges (MRDP, 2013) which pointed to the urgent need to reform it. These challenges, *inter alia*, included: inefficiency in the administration of mining rights; skills inadequacy, gender imbalances, inadequate innovation and lack of Research and Development facilities; low revenues from the mining sector to the treasury; poor infrastructure development in mining areas; inadequate investment in downstream

processing and value addition; and low levels of ownership and participation by Zambians in mining companies and the associated business of supply of inputs, sub-contracting and other support services. The 2013 MRDP was formulated to overcome the 1995 Mineral Policy challenges. This was meant to contribute to the creation of a sustainable and orderly mining industry contributing to the economic development of the country by: attracting both local and foreign investment in the sector for the orderly and sustainable exploration and exploitation of mineral resources; integrating the mining sector in the domestic economy; and ensuring acceptable standards of health, safety and environmental protection.

The Policy Perception Index (PPI) measure as given by Taylor and Green (2016) provides a comprehensive assessment of the attractiveness of mining policies in a jurisdiction and can serve as a 'report card' to governments on how attractive their policies are from the point of view of an exploration manager. Zambia's PPI in 2015 scored 62.69 against a region's score of 61.5 and Latin America's score of 55.2. The country was ranked 61st from the 109 countries surveyed and its position in terms of PPI relative to other selected jurisdictions is given in Figure 1. This indicates that Zambia's mining policy is attractive for investment from investors' perception with respect to African region and based on the selected countries for comparison.

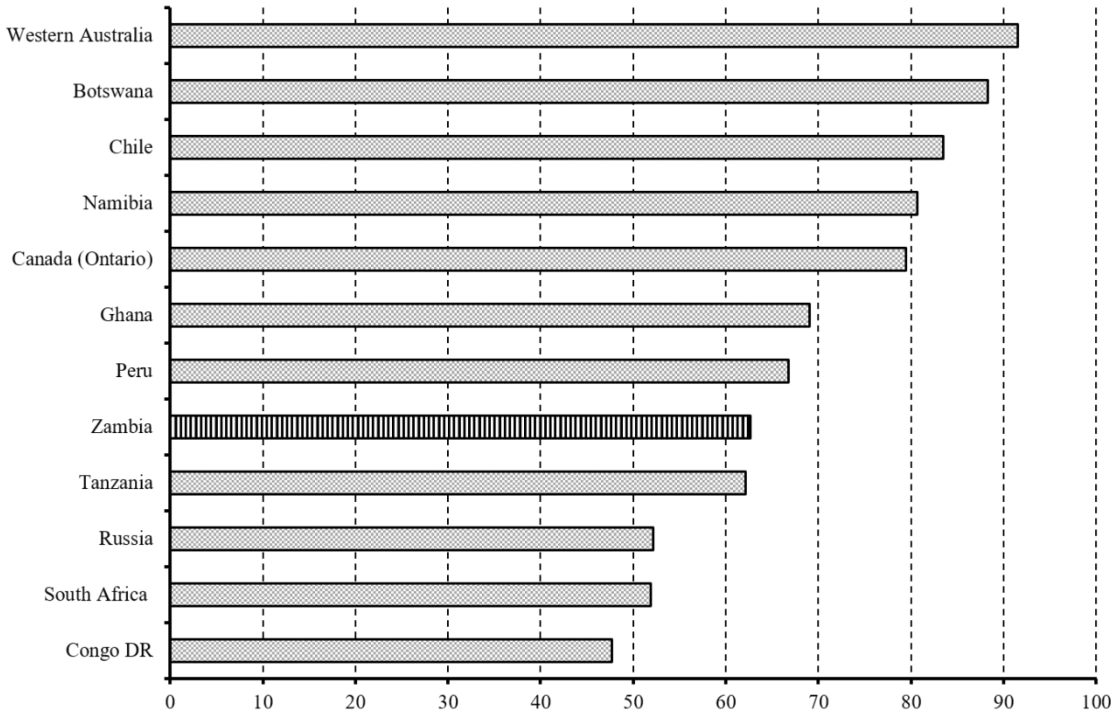

Fig.1: Policy Perception Index (Taylor and Green, 2016)

3.1.1 Policy changes in the sector

Investors seek policy consistency and stability for continued investment in a jurisdiction. Zambia's score in terms of the key policy indices measured from the authoritative Fraser Institute's Survey of mining companies for the period 2011-2015 is presented in Figure 2. These indices have been showing improvements since 2012 until 2015 when there was a fall of more than 10 points for each of the indices. This fall was partly due to uncertainty in terms of drastic

fiscal regime changes Zambia made to mineral royalty tax variations in January of 2015. These royalty rates do not take into consideration a project's profitability.

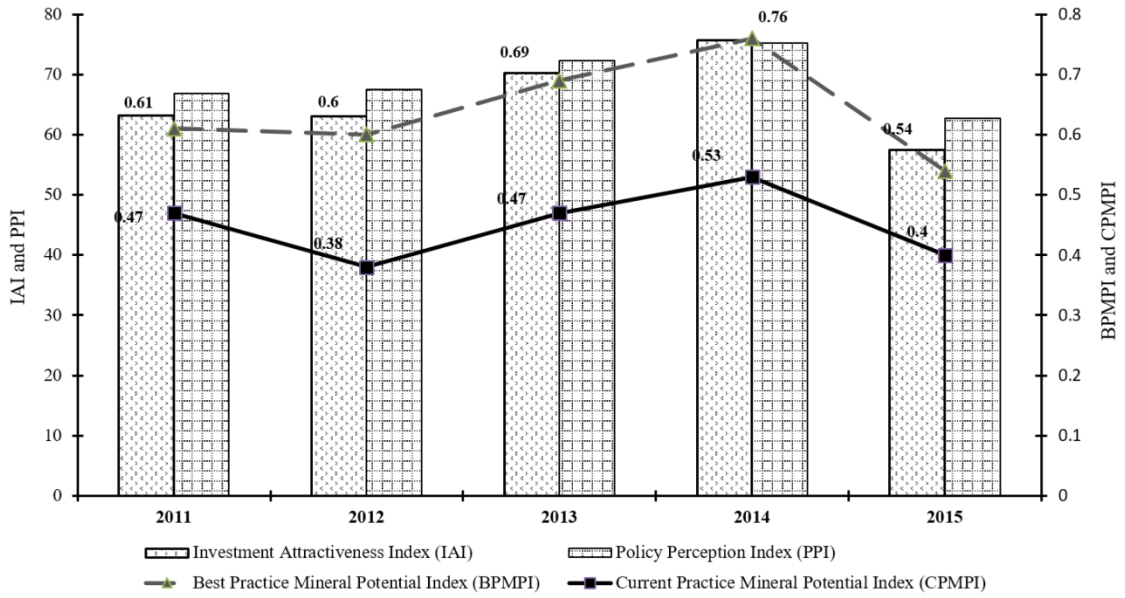

Fig.2: Zambia's scores on policy indices (Taylor and Green, 2016)

3.1.2 Investment attractiveness

Taylor and Green (2016) indicated that an overall Investment Attractiveness Index (IAI) is a composite index that combines both the PPI and results from the Best Practice Mineral Potential Index (BPMPI), which rates regions based on their geologic attractiveness. A best practice environment is one that contains a world-class regulatory environment, highly competitive taxation, no political risk or uncertainty, and a fully stable mining regime while the policy perception index is a composite index that measures the effects of government policy on attitudes regarding exploration investment.

The average score for African countries surveyed under Taylor and Green (2016) is 58.7 indicating that Zambia's investment attractiveness at 57.48 can be considered comparable in the region and higher than the average of 51.9 registered in the Latin American region. However, based on the used countries for comparison, Zambia's attractiveness is less competitive (Figure 3).

3.1.3 Infrastructure quality (road, railway and electricity)

Stürmer (2010) noted that infrastructure is an important investment condition which is essential if investment is to increase since the extractive industry relies heavily on transport and electricity. Many African countries currently lack the infrastructure needed for the expansion of the extractive sector and related processing industry.

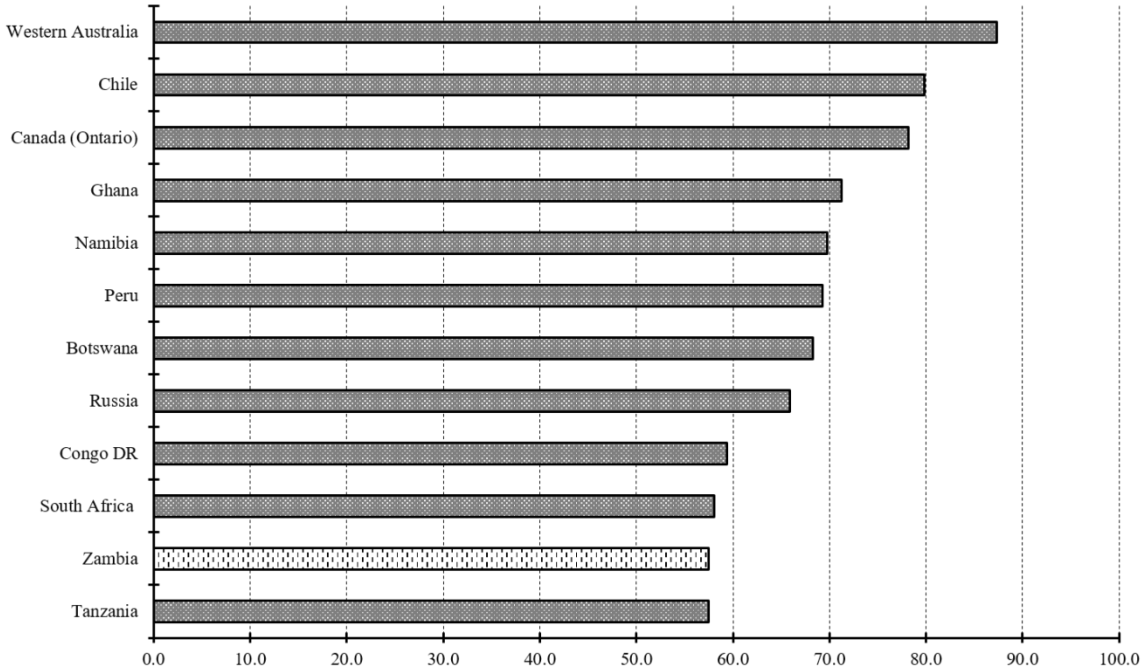

Fig.3: Investment Attractiveness Index 2015 (Taylor and Green, 2016)

In Zambia, there has been a shortage of electricity which has partially affected the growth of the mining industry. The mining sector consumes more than 50% of power supply. The main challenge for the mining industry is to obtain reliable and sufficient power supply as this could otherwise affect copper production in the future (African Economic Outlook, 2014). Equally, the railways system in Zambia is neither properly managed nor operational to entirely support the mining industry. In terms of the country's road networks, Zambia has most of the copper mines overburdening the road network through transportation of their inputs and products. CUTS (2013) noted that there is a shift from trains to road traffic estimated to cost the Zambian economy US$100-150m per year in increased road deterioration and fuel costs.

Zambia's position in terms of infrastructure quality as a non-deterrent to investment and encouraging investment when compared to other jurisdictions has a combined rank of 29 percent just above Russia and Congo DR (Figure 4). However, the country ranks less based on most of the used countries for comparison.

3.1 Government's role in the provision of basic geological information

Governments play a supportive role by ensuring that it provides the necessary maps and other basic geological information which exploration companies need to adequately define the prospective regions. ECA (2002) noted that basic geological information is the basis for perceptions of geological potential, which in turn importantly influence the commercial attractiveness of investment in mineral exploration and mine development. Basic geological

information is usually collected and disseminated by government geological surveys. Halland *et al*. (2015) recounted that a government with a good understanding of the country's geological potential can use this informational base to better manage the country's subsoil resources.

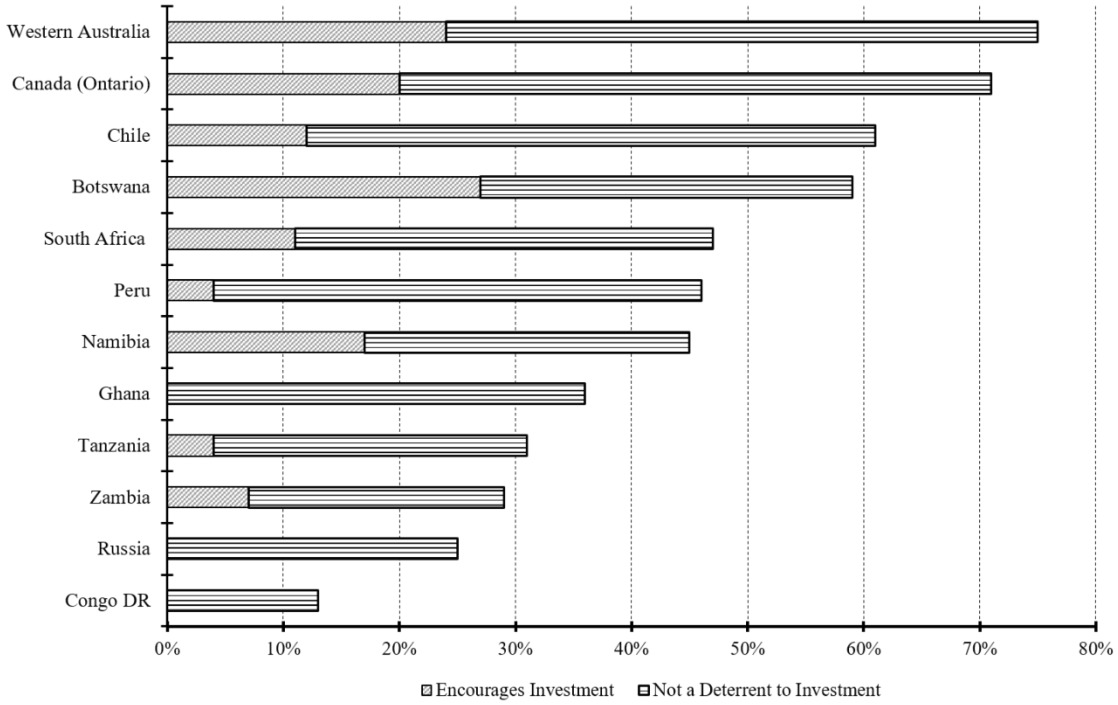

Fig.4: Infrastructure quality as non-deterrent to investment (Taylor and Green, 2016)

In Zambia, just like other countries, the Geological Survey Department (GSD) has the primary objectives of providing geological and geochemical data on a countrywide basis, to act as a national depository for all geology information of Zambia, and to provide support and advisory services to the public.

Scott (2013) studied the obstacles to operational effectiveness of the Geological Survey of Zambia (GSZ) in its role of providing reliable information to support; marketing the mineral resource potential of the country, and the provision of geoscience understanding for wider socio-economic planning initiatives. The knowledge and skills gap identified (Scott, 2013) included; inadequacies in data governance framework, weak stewardship and custodianship role in information delivery, fragile data integrity and data security, and deficiencies in data storage and access technologies.

A survey by Taylor and Green (2016) using the BPMPI ranks a region's attractiveness based on the perceptions of mining company executives of a jurisdiction's geology. Zambia ranked 73rd out of 109 jurisdictions at 0.54. Zambia, Botswana and Tanzania have their performances in terms of geological attractiveness below the region's average at 0.59 (Figure 5).

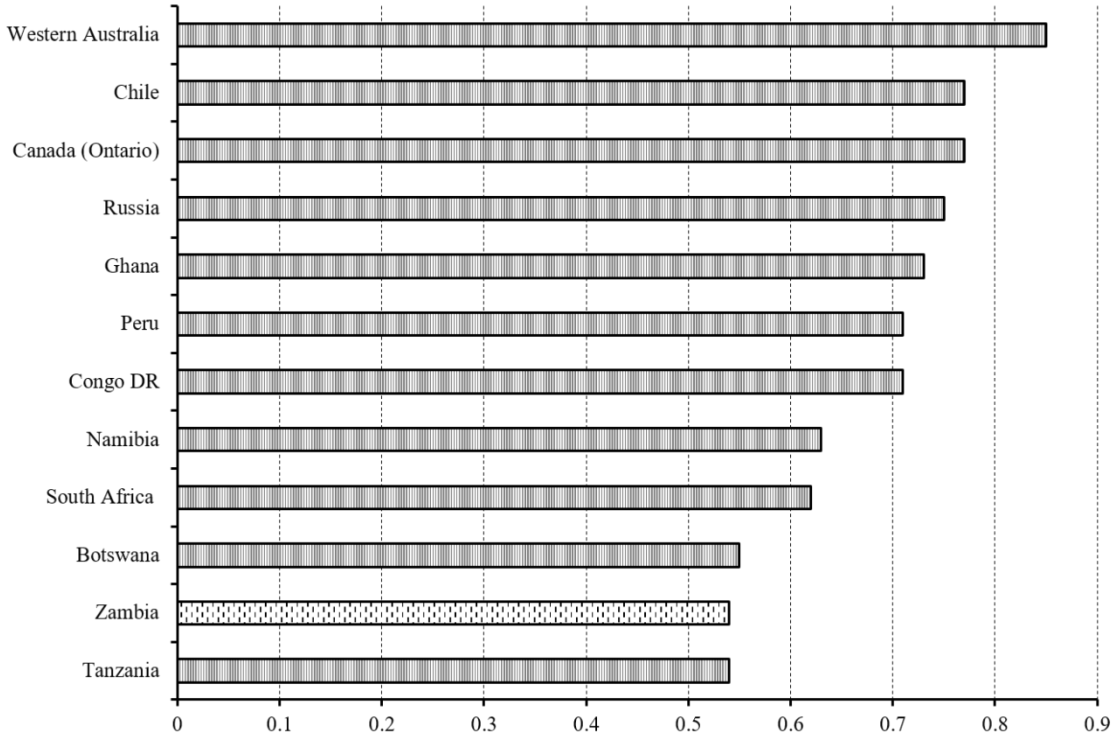

Fig.5: Best Practices Mineral Potential Index (Taylor and Green, 2016)

Stürmer (2010) narrated that most sub-Saharan African (SSA) countries are well endowed with mineral resources, but there is a lack of proper public geological surveys. The geological surveys in these countries are often poorly equipped and lack the resources to undertake exploration. It is mostly private mining companies which explore for new deposits. As this activity is very costly and risky, the main motive for private companies is to extend production or to replace reserves that have already been mined. Therefore, basic geological data covering the whole country are mostly lacking or inadequate.

These challenges where most of the governments including Zambia largely depend on private mining companies to generate data on mineral deposits lead to government's failure to verify information received from the private companies. In such conditions, there is information asymmetry which may disadvantage the government during negotiations regarding the new concessions. Stürmer (2010) further reported that this makes it virtually impossible for governments to check tax statements, since it is difficult to verify information, for example, on reasonable production costs without having a detailed knowledge of the underlying geology of a project.

3.2 Influence of taxation system on mineral wealth creation

The overall tax system, the combination of mining-specific provisions and general tax rules applicable to all business, influences the attractiveness of investing in a region (ECA, 2002). The root of the disagreements for Zambia over the tax regime is the inability of the government and

industry to find an equitable balance between the commercial interests of the industry and the industry's contribution to national prosperity (World Bank, 2011).

Aspects of taxation system design linked to wealth creation are discussed and include: effective tax rate (ETR) and optimal investment; fiscal stability concerns; selection of types of tax instruments applied; risk sharing, economic rent appropriation and volatility of the commodity market. The position of Zambia's taxation regime as a non-deterrent to investment compared to other jurisdictions is given in Figure 6. The country' poor score at 33 percent, though above Russia at 17 percent, in 2015 was because of the changes made to the taxation regime which created a lot of uncertainty for mine investment.

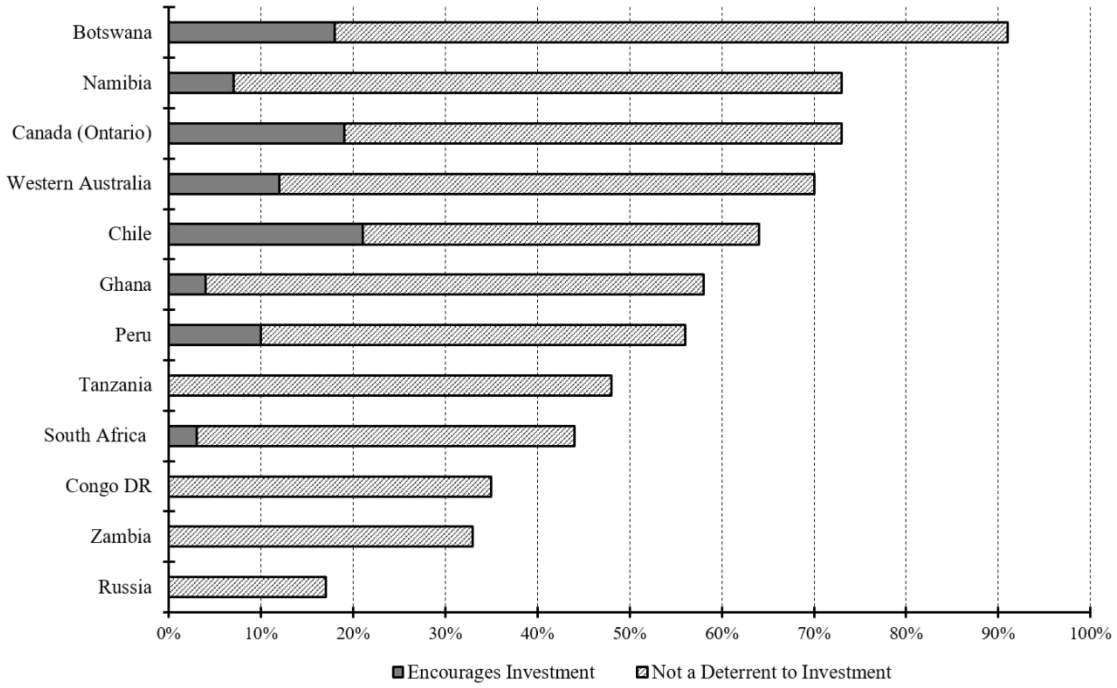

Fig.6: Taxation regime as a deterrent to mining investment (Taylor and Green, 2016)

3.2.1 Effective tax rate (ETR) and optimal investment

Otto *et al*. (2006) affirmed that governments generally like to collect at least some tax revenue from all mines regardless of their profitability. ETR measures a mining company's tax bill as a percentage of taxable income described by Manley (2012) as the proportion of a company's income (gross profit) that is taken in tax. For most nations, the optimal ETR is between the international range of 40 and 50 percent (Otto, 2007). The estimated effective tax rates (World Bank, 2015) for the period 2014 for different mining companies in Zambia under the controlling parent companies of First Quantum Minerals (FQM), Vedanta, Glenore and Barrick Gold varied between 44 and 66 percent.

Some explanations (Otto *et al*., 2006; Tadros and Svensson, 2010), indicate that a tax regime should not distort mining investment, production, or extraction. A good tax policy should strive

to set the effective tax rate at *T* *, as presented Figure 7 which gives a mix of taxes resulting in an optimal net present value (NPV) of government revenues.

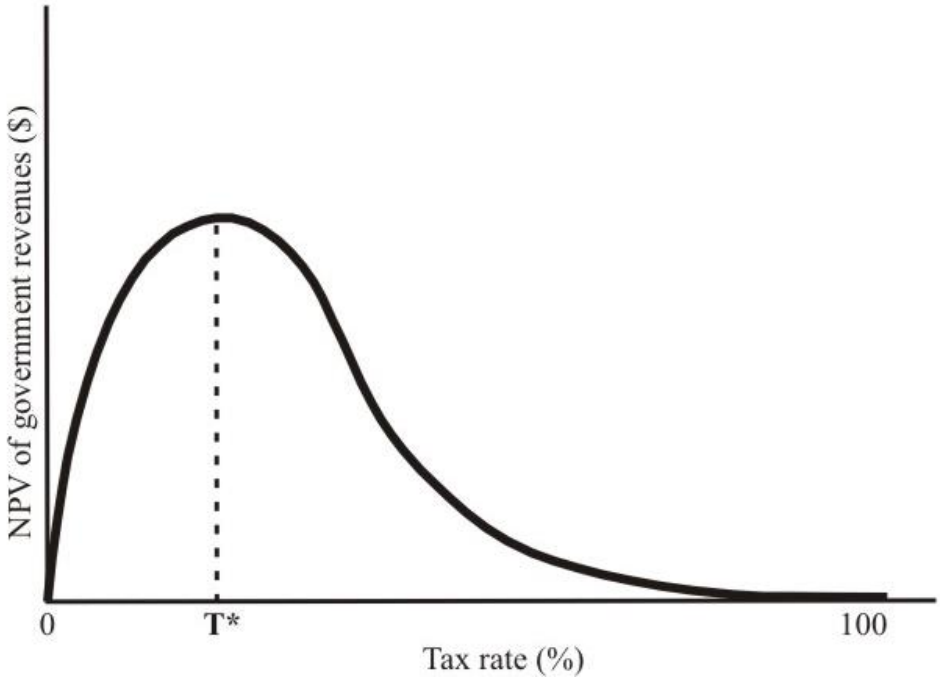

Fig. 7: Optimal taxation (Otto et al., 2006)

Tadros and Svensson (2010) argued that tax administration and auditing issues create large gaps for many countries between mining taxes - which should be paid based on effective tax rates - and the amounts actually received. The reasons for discrepancies are tied to tax administration, including limited capacity to enforce contracts, lack of coordination between ministries of mining and finance, non-transparent contracts, and rent seeking.

Zambia is still faced with a challenge to strike a win-win situation in terms of appropriating an equitable share of 'government take' based on the combination of the taxation tools applied.

3.2.2 Stability of the fiscal regime

Frequent changes to taxation policies of any jurisdiction, increases the perception of risk and instability, which has been observed to be deterrent to investment attractiveness (Otto et al., 2006). Tax stabilisations are found to be attractive to companies while many governments are hesitant to use them. The governments have a dilemma because on one hand, stabilisation agreements enhance the potential for mineral development, and on the other, they complicate the tax system and raise administrative challenges (Otto, 2007).

The mining taxation regime in Zambia has evolved in important ways since the government's privatisation of the mines. The authorities have changed elements of the regime in response to changing market conditions, evolving public policy needs, and as the authorities have developed

experience with regulating private businesses after the years of state ownership (World Bank, 2015). Zambia has been making changes to the fiscal regimes since privatisation as a means to optimise the country's benefits from the copper mining sector.

3.2.3 Production-based or profit-based tax regimes

Mining is taxed in different ways in different countries through royalties, income taxes, property taxes and using a variety of non-profit taxes. Otto *et al*. (2006) specified that the geological, economic, social, and political circumstances of each nation are unique, and an approach to royalty taxes that is optimal for one nation may be impractical for another while Eggert (2001) equally indicated that no fiscal system is ideal in all respects.

Royalties are usually categorised as an output related tax, while corporate tax, additional profits tax and withholding taxes are classified as profit related (Kumar, 1991). Zambia's mineral fiscal regime contained four key elements namely: mineral royalty; the generally applicable corporate tax (including some withholding taxes on remittances to non-residents); a variable profits tax; and equity participation (Conrad, 2012). These tax instruments and other imposts are broadly identified into two tax regimes namely profit-based and production-based fiscal regimes (Table 1; Figure 8).

Table 1: Some elements of profit - based versus production- based taxes

Profit based taxes and royalties	Production based taxes and royalties
Corporate Income Tax (CIT): Fee paid by every firm based on profit. For 2016, the rate still applied for Zambia is 30% for mining companies.	Royalties: both based on units and value. A 4-6 % sliding gross based royalty rate is used for Zambia
Profit tax on dividends: a share of dividends from non-resident investors is withheld and paid to the government by the company	Withholding tax on loan interests and services: a share of interests generated by the investment which have to be paid to a non-resident investor is withheld and paid to the government by the company
Royalty: based on profit/income measure	VAT (Value Added Tax): a percentage tax paid on every purchase) Applied rate is about 16.5% in Zambia
Withholding tax: on remitted dividends. This is still at 15% in Zambia	Export duty: fee paid for selling goods abroad
Resource rent tax: tax on surplus profits (economic profits) generated from exploiting non-renewable resources	Payroll tax: deductions from an employee's wages and taxes are paid by the employer on behalf of employee to the government
Variable profit tax: This was applied when the taxable profits / sale revenue > 8% for the pre-2015 mine tax regime in Zambia.	Sales and excise tax: specific amount charged on each production-for-sales unit within a country.

Tax on profits (CIT) is normally paid by every corporate entity, though there is a tendency for significant mineral producers to apply different rates for mining when compared to normal corporate rates (Kumar, 1991). Under the CIT method, taxes are only due when annual revenue exceeds some measure of costs and allowances. Therefore, the key elements of this tax form are the definitions of taxable income and the rate applied to it (Tordo, 2007).

Royalties are attractive to the government because they ensure an up-front revenue stream as soon as production commences and they are easier to administer than many other fiscal instruments (Baunsgaard, 2001). Royalties based on either the volume or the value of production or export

have historically been the most common method used by governments to gain revenue from the exploitation of the nation's mineral endowment. Therefore, royalty base vary and can be calculated on: units of production, value (*ad valorem*), profit, economic rent and incomes (Tordo, 2007). Royalties are relatively simple to administer from an accounting perspective but require significant and highly specialised capacity for physical audit, including specialised skills in mineralogy to determine ore grades, volumes, and value. A major advantage of royalties, as seen by many governments, is that they provide revenue from the start of production (Halland *et al.*, 2015).

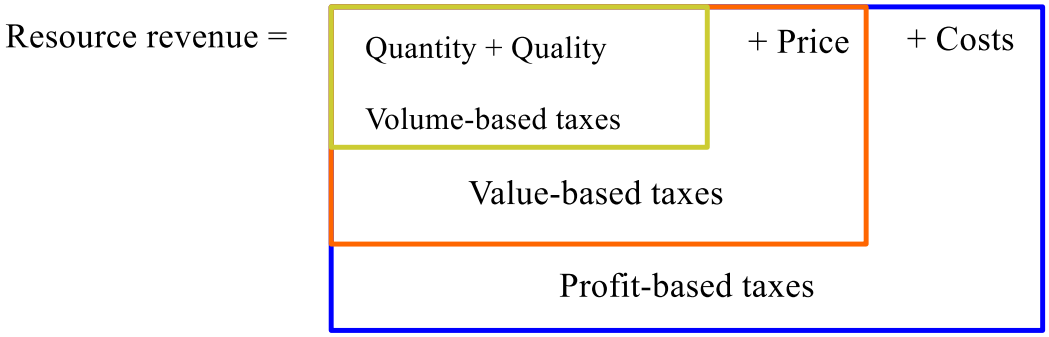

Fig. 8: Stylised representation of volume-value- and profit-based taxes (Halland et al., 2015)

Arguments by Eggert (2001) indicated that governments tend to prefer royalties based on gross revenues or production, even though such royalties discourage investment to a greater degree than net-income royalties. Gross revenue royalties involve less risk for government in the sense that government gets its share before profits are determined. Such royalty payments also tend to come sooner in the life of a project, are more stable, and are more predictable. They also tend to be easier and less expensive to administer than net income royalties. They do not require detailed accounting rules (to define what costs are allowable) and control systems (to ensure that companies do not under-report their net income).

The Zambian government has challenges in terms of fixing a royalty rate that is considered equitable to both parties as evidenced by the changes made to the 2015 Mineral Royalty Tax regime which changed within a shortest period of time. Zambia's changes to the royalty regime were necessitated by the desire to achieve a more equitable distribution of the mineral wealth between the government and mining companies. Tordo (2007) noted that some countries apply sliding scale royalties based on production levels or sales values as a means to mitigate their regressiveness. During the June 2016 mine fiscal regime, Zambia introduced a sliding scale royalty system adjusted to price movement. This approach requires investing adequately in equipping the taxing authority with efficient tax administration and monitoring capacities if the country will have to appropriate equitable revenues from its mineral resources.

3.2.4 Risk sharing

There are a number of risks that make the resource revenue volatile; changes to prices, costs and geological uncertainty being prime examples. These risks affect the value of the resource and the total income from the extraction process (Natural Resource Charter, 2014). Mining risks have wide implications for all involved in the sector more for the governments that depend on taxes and other payments from mining. Otto *et al.* (2006) indicated that taxation on profits encourage risk sharing between the company and the state, and take into account the fluctuations in global prices, changes in the geological and technical determinants of the mining operations as well as financial and political factors over the mining cycle. Therefore, a corporate profits tax tends to distribute the risk of mining evenly between the state and companies.

Equally, the form of a royalty or tax influences the sharing of risk between government and mining company. A gross-revenue royalty allocates the financial risks to the mining company and government gets its "take" off the top before profits are determined. A net income royalty, on the other hand, can be thought of as a risk-sharing partnership between government and mining companies. Government receives royalty payments only when there are surpluses or profits and not just when a mine is in production (Eggert, 2001). The taxation challenge for Zambia is that profit-based taxes like CIT meant to share risk by nature are constructed with huge capital cost recovery and loss carry forward provisions which lead to low taxable incomes and sometimes zero profits.

3.2.5 Economic rent capturing

Economic rents (Figure 9) are any payments to a factor of production in excess of the cost (including capital and returns to capital) needed to bring that factor into production (Halland *et al*., 2016). Economic rent of a mineral resource is the value of the product when all necessary costs have been deducted (Garnaut and Ross, 1983). Basing the tax upon economic rent as argued by Calder (2014) is consistent in principle with raising substantial revenue without distorting production decisions.

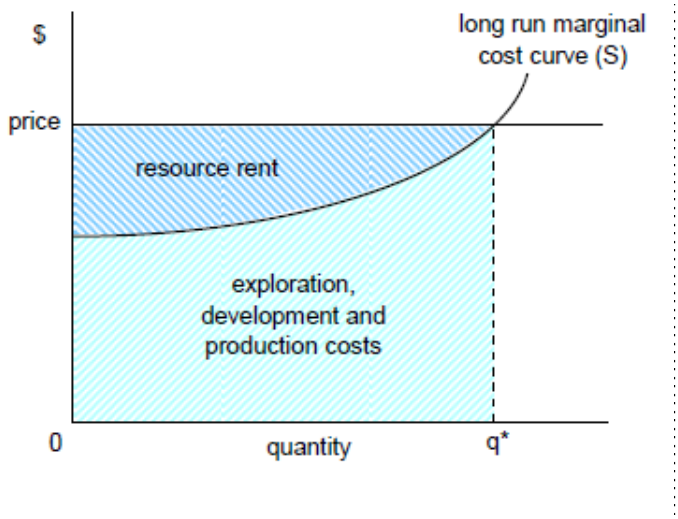

Fig.9: Economic rent (Hogan, 2010)

World Bank (1992) stated that the total rent in a mineral deposit will vary according to its technical characteristics (such as reserves, grades) and physical factors (such as location and infrastructure). The fluctuation of mineral prices will also affect the distribution of rents over time. The uncertainty of costs and prices means that rent actually generated may be higher or lower than initially expected. Sometimes it will be non-existent. Further, World Bank (1992) indicated that the magnitude of the rent also depends on the investors risk premiums. Since the rate of return is a component in the calculation of available rent, the lower the rate of return required by the investor, the higher the realizable rent.

Resource rent taxes have sometimes been imposed because of public pressure during commodity price booms to increase government revenues initially based on regressive royalties (Halland *et al*., 2015). Most tax or royalty systems do not capture the differential rents as intended and systems based on gross value do not use rents as the tax base. Systems based on net income have to create accounting systems of allowable costs, which tend to skew incentives and encourage re-allocation of costs for tax purposes rather than rent creation (Eggert, 2001).

Zambia after discharging the windfall profits tax (WPT) and later on the variable profits tax (VPT) still faces mining taxation challenges of capturing additional profit surpluses. This is because the current taxation system has no progressive tax instruments indexed to price, except for the sliding mineral royalty, which can capture surplus profits. To date Zambia is still faced with the challenge of determining appropriate economic rent for taxation purposes due to variations in costs, quality and quantity of resources and failure to determine the investors' rates of return which remain a secret for most of the mining companies.

3.2.6 Market Volatility

The volatility of primary commodity markets causes considerable fluctuations in government revenues and foreign exchange earnings for mineral-dependent developing countries. These fluctuations make planning more difficult, and may as a result hinder economic development programs (Davis and Tilton, 2002).

Metal price volatility affects performance of certain regimes if they are not robust and fail to respond to the uncertainty in the market environment. On several occasions, unstable commodity prices have created major challenges for countries like Zambia that depend on copper exports for foreign exchange. Depressed copper prices result in contracted export earnings contributing to reduced forex supply in the market and depreciation of the local currency-Kwacha (Figure 10). This causes acrimony in the local mining sector with some mining companies reacting by threatening to disinvest or reduce labour force. Price volatility always creates challenges for wealth creation in the sector since it has influences on the restructuring of the mine fiscal regime in Zambia.

In managing challenges related to price volatility, Fischer (2007) indicated that mineral revenue management requires that stabilisation funds get created to cope with commodity price volatility. Zambia should consider establishing the stabilisation funds, as practiced in other jurisdictions like Canada, Chile, Norway and Botswana. Davis and Tilton (2005) reported that governments can

mitigate the fluctuations in government revenues and export earnings by putting some of their commodity revenues into a stabilisation fund when mineral markets are booming.

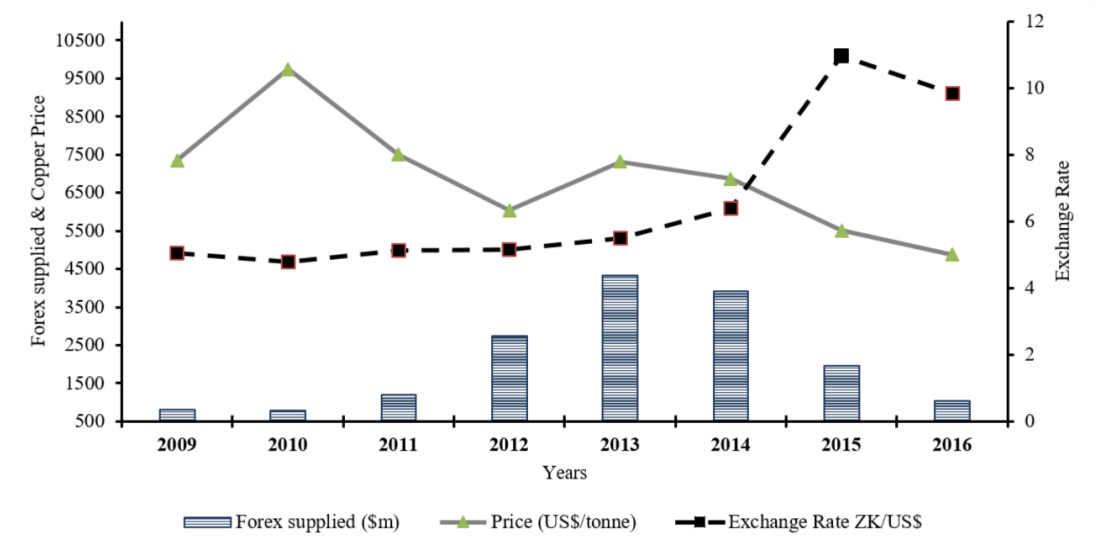

Fig.10: Price volatility and impacts on forex supplied and exchange rates (Bank of Zambia, 2013-2016)

Zambia also needs to actualise economic diversification concept. This is in line with observations by UNCTAD (2006) that reduction of the dependence of the economy for foreign exchange earnings and income on a single commodity, copper, has been a long-term objective of subsequent Zambian governments. Since price volatility has implications for taxation, the Zambian government should also ensure that it puts in place fiscal regimes with progressive tax rates and resource-rent tax. These taxation tools once properly implemented can increase revenue flows, from the country's mineral resources, with a corresponding increase in prices resulting in reduced impacts occasioned by volatility in commodity prices.

3.3 Policies embracing preferences for environmental quality and other social and cultural values

The key challenge within the wealth creation is to have a non-distortionary and efficient policy regime that includes social preferences for environmental quality and other social and cultural values into decision making about mineral development. From an economic perspective, incorporating social preferences into decision-making can be regarded as including the external costs and benefits of mineral development into decisions (Eggert, 2001). However, developing such policies is not a simple matter and a partial solution requires social cost-benefit analyses associated with mine development. The full social costs and benefits include estimates of the value of environmental damage or social disruption that would be caused by a mine and, in addition, estimates of what it would cost to avoid these environmental and social damages (ECA, 2002).

Investments will likely run into problems at some point in their life cycles if there are imbalances in the sharing of fiscal, economic, environmental, and social costs and benefits (International

Finance Corporation, 2015). Revenue distribution should be decided through equitable decision-making structures involving representatives of the affected stakeholder groups (MMSD, 2002). In Zambia, there are still challenges of full engagements in consultative agreements to decide the allocation of rents to parties affected.

Communities and governments should also analyze costs when they consider a mining proposal (Power, 2008). These stakeholders cannot rely on the evaluations of the mining companies, which may shift or externalise many of the costs onto other parties - workers, communities, and nations - in order to boost a project's net commercial benefits. Costs that may be shifted by mining companies include; significant, often permanent environmental damage; major social and cultural costs; and economic risks associated with unstable world markets and volatile metal prices. Furthermore, Power (2008) noted that while mining companies and the governments supporting new mining proposals have emphasised the national benefits created by mining, sectors of civil society are more concerned with the long-term costs and the role of communities in making decisions.

In Zambia, the Auditor General Report (2014) noted existing challenges of public interest dealing with lack of consultations with the communities/stakeholders on mining projects. The country has no sound legal framework outlining the rights of the local communities in matters to deal with mineral exploitation or resource exploration in inhabited areas. Occasionally, the only input emanating from communities is through consultations during the Environmental Impact Assessments (EIAs) prior to mineral project development.

Mining in Zambia has environmental costs and other indirect impacts (Boocock, 2002; Lindahl 2014). To date, contraventions attributed to mining companies of failing to mitigate pollution, environmental degradation and unjust displacement of locals still exist. The Auditor General Report (2014) indicated that the minimum standards which government has put in place to safeguard the environment are not being strictly adhered to by the mining companies indicating that the goal set by government for environmental protection and management is ineffective. World Bank (2012) recounted that government agencies should provide a clear and robust framework for mining project development, throughout the project life cycle (i.e. exploration to post-closure). However, in mineral wealth creation, there are complications of inter-agency coordination as indicated by GOXI (2015) that it is not unusual to find a situation in which some ministries or agencies are actively encouraging new investment while at the same time others are creating barriers. This can obviously create additional risks for investors and fewer benefits for government.

In Zambia it is not uncommon to have greenfield mining projects, approved with exploration and development rights granted, facing developmental obstructions because of the bureaucracy existing in related government agencies. For instance, African Economic Outlook (2014) observed that concerns around mining and the environment have increased recently due to the awarding of a mining licence in the Lower Zambezi despite warnings by the Zambia Environmental Management Agency (ZEMA) and a parliamentary select committee. Although mining companies will have to comply with the environmental regulatory framework, the new Mineral Resources Development Policy does open up the possibility of mining in sensitive areas such as game parks.

A summary of measures from the aforementioned government roles needed for consideration by the Zambian government as a way to enhance mineral wealth creation is presented in Table 2.

Table 2: Measures to enhance mineral wealth creation

Area of Concern	Action to enhance Mineral Wealth Creation
Geologic data provision	Government needs to improve capacities and resource allocation to the Geological Survey Department assigned with the roles of providing geological information needed for facilitating investment in the mineral resources sector.
Policies consistency	Policymakers should ensure that stability in the formulated policies is upheld as a means to offer predictable regulation. Government should actualise effective implementation of policies.
Investment attractiveness	Government through relevant institutions should conduct competitiveness evaluations of the sector to create a favourable investment climate from an international investor's perspectives.
Infrastructure Development	The state should improve the quality of infrastructure required by the extractive industry which serves as a catalyst for economic development.
Economic rent generation	This requires policymakers to gain full appreciation of the various deposit characteristics as a means to reduce on information asymmetry. Once comprehension is done, it can assist with appropriate design of workable rent-based fiscal regimes.
Taxation and fiscal regime	The state should introduce progressivity in the fiscal regime by incorporating tax instruments adjusted to price movements. Policymakers should put more emphasis on production-based fiscal tools which are relatively easy to verify. Government must improve institutional capacities to manage complex tax administration procedures associated with the mining industry.
Market volatility	The Zambian government should consider setting up stabilisation funds. Zambia should work on implementing and actualising the economic diversification concepts. Policymakers should introduce workable progressive tax instruments in the fiscal regime indexed to volatile commodity price.
Social preferences and environmental quality	State to perform cost-benefit analysis of social investment projects. The government must reduce on the existing overlapping mandatories in relevant government institutions (improve inter-agency coordination). Policymakers should enhance regulation on environmental protection and pollution control by strengthening environmental pollution penalties to dissuade pollution activities perpetrated by some mining houses. Government to engage in multi-stakeholder consultations on the sustainability of mine development projects beyond the traditional EIA provisions.

4. Conclusions

Zambia is still dependent on the extractive industry for its macroeconomic benefits. The full benefits from its mineral wealth are affected by deficiencies in tackling wealth creation challenges during the management of its mineral resources.

The accessibility and provision of geological information needed for investment in the extractive industry has gaps with the country's geological survey department still experiencing capacity and resource constraints. Inconsistencies in the policies applied resulting in distortionary effects in mineral resource management equally exist. Zambia's configuration of the mine taxation regimes

does not satisfactorily create; a win-win situation, fiscal stability, and enhanced revenue appropriation for the state. Additionally, the policy implementation meant to create more benefits than costs from the activities of mine development are not very effective and the country is still faced with challenges of environmental pollution and inter-agency coordination in the development of mineral projects in the sector.

This review makes recommendations that the government needs to; improve capacities in institutions providing geological data needed for investment, undertake consistent and non-distortionary policy formulation, improve its tax administration capacities and design fiscal regimes ideal to create reasonable flow of rents needed to sustain other socio-economic development. Zambia also needs to conduct cost-benefit analysis of mineral projects to meet the social aspiration and improved environmental quality.

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Determination of the optimum position of the mining drive when exploiting ore in the deeper section at Mufulira mine, Zambia

Jason Reynolds Ngoma[1] and Victor Mutambo[2]

Abstract

Recent production statistics from year 2014 to 2016 at Mufulira mine have shown that the current arrangement of mining drive has, to some extent, an effect on the recovery of ore from the stopes owing to the fact that the ore body geometry keeps varying as mining progresses at depth. As a result, some fragmented ore of about 15% fails to flow into the draw point areas where it can be recovered because the inclination of the footwall is smaller than the 50º effective angle of draw of the fragmented rock. Inclination angles vary between 40º to 50º. However, from the year 2006 to 2014 production statistics shows that the current problem of ore recovery was not major issue because the ore body dip from surface to 1390mL was fairly stip in the range of 48º to 55º and mechanized continuous retreat two (MCR2) and three (MCR3) mining methods were used. These variants (MCR2 and MCR3) involve two to three sublevels respectively during extraction. MCR2 and MCR3 were abandoned in the deeps section of the mine due to water and stress problems.

Hence, this study was aimed at determining the optimal position of the mining drive that will enable optimal exploitation of the deeper resource below the current production levels from 1407mL, 1423mL, 1440mL and 1457mL.

The study involved review of actual average yearly stoping performances for the mine and compared the same with the set targets for mechanized continuous retreat one (MCR1) a sublevel open stoping mining method. The stress re-distribution around the excavation openings were analyzed using rock mechanics software Examine 2D while simulation of various options for the possible positioning of the mining drive was done using AutoCAD. The simulated positions were analyzed based on recovery and stability of the drives due to re-distributed stresses around the excavation.

The study has established that the causes of poor stope recovery and dilution are attributed to wrong position of the mining drive and the varying dip of the ore body as this affects amount of ore that will flow from the stope by gravity assist. Hence, based on numerical analysis of stress using Examine 2D and ore recovery from the stope, it was established that the optimal mining drive arrangement is option 2 where the mining drive is positioned 30% in the footwall and 70% in the ore body.

K**eywords: Angle of draw, Recovery, Stress, Examine2D, Optimal mining drive**

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1. Introduction

Mufulira mine has three superimposed ore bodies namely A, B and C which lie between 40º to 55º from east to west (Sililo, 2006). The mining method being used utilizes gravity assist in terms of flow of ore into the stope. The effective angle of draw at which broken ore flows into the stope is between 45º to 55º. The mining method called mechanized continuous retreat one (MCR1) incorporates a 4.0x4.0m mining drive developed along the strike of the ore body, 4.0x4.0m footwall drive positioned 30-50m away from the geological footwall contact of the ore body and cross cuts which are developed at 50m interval plus a 3.8m stub drive between the ore body cross cuts. The position of the mining drive is dictated mainly by the dip of the ore body to ensure optimal ore recovery (Kampeni, 2010). When the ore body is dipping within the range of the angle of draw (45º - 55º) most of the ore gravitates into the stope though some ore (10-15%) from footwall contact side still fails to flow from the stope due to the position of the mining drives and dip of the ore body as can be seen in Figure 1. This problem brings about low recovery of 65% against target of 80% ore from the stope due to the poor combination of the ore body dip with the mining layout (position of the mining drive and the ore body dip). The effective angle of draw at Mufulira mine is 50º below this angle fragmented materials find it difficult to flow into the draw point where it can be recovered.

1.1 Mining drive position

The problem with the current position of the mining drive is that a good percentage (15-20%) of ore remains in the stope unrecovered on the footwall contact side. This is due to the high angle of repose of 50º at which the broken ore gravitates into the draw point by gravity assist against the lower angle of inclination which are between 40º to 50º of the footwall contact where the material is sitting resting. The ore can't flow by gravity into the stope and loaders can't climb to muck the ore that is sitting resting on the footwall contact as shown in figure1. As the ore body gets flatter the amount of ore that remains unrecovered on the footwall contact increases from 15% to 25%. Hence the current problems of low recovery of about 65% and increased dilution of more than 30% is partly due to the poor combination of the ore body dip and mine layout, mining drives in particular. After blasting ore remains in three different places in the stope as shown in Figure 1;

1- The ore in area 1 is not mucked because the loaders (LHD) cannot reach it due to safety reasons but some of the ore about 5% is usually recovered using remote loaders. The remainder of about 15% stays in place waiting to be mucked in the lower level when the chain pillar collapses; in the meantime it is subjected to high levels of dilution from the hanging wall.

2- Only the ore with angle of repose more than angle of draw is recovered, the remaining ore is not mucked because a loader cannot go into an open stope due to stope safety reach limit as it is unsafe but with a remote loader it is recovered.

3- The ore in area 3 remains in its place because the angle of repose of the material is higher than the angle of inclination of the footwall contact hence it won't report into the draw point by gravity.

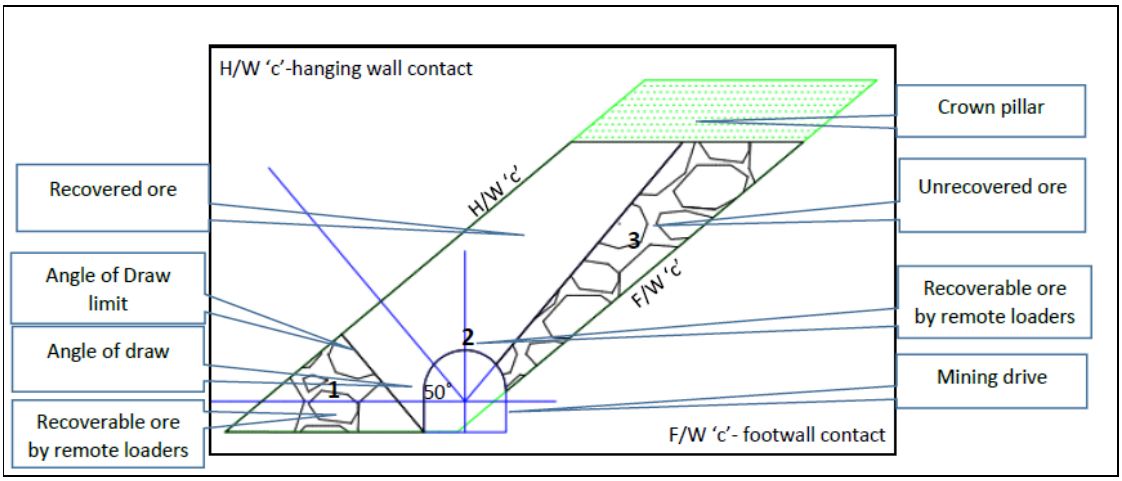

Figure 1: Cross section of the stope

In order to recover the material in area 3 in figure1 a proposal was made in the past to develop an additional mining drive in waste and push the current mining drive completely inside the ore body, but this proposal proved to be expensive owing to high development cost, support and materials handling cost especially waste from development.

The bedding plane (boundaries) that separates the ore body and the footwall is a major discontinuity but has a very smooth surface which is naturally a plane of weakness (stress relaxation zones). This affects the strength of the rock mass which in turn affects the stability of the mining drive (Owusu-Sar 2012). Another factor affecting extraction of ore in deep section of the mine is related to mine stresses which lead to rock bursts, spalling and wedge failure (Brady etal, 2004). Consequences associated with such conditions are collapsing of the mining drive along the bedding plane (footwall contact of the ore body) until the stresses stabilises. Hence, in the design of excavation one design factor (state of stress at the excavation boundary (Goodman 1989) and in the interior of the rock mass) has to be considered to ensure integrity of the drives and optimal exploitation of the ore through optimally positioning of the mining drive. In addressing different design factors, it is necessary to consider different deformation modes of the excavation's near field rock (Mine, 2004).

Since an excavation must satisfy different rock mass performance criteria for the various modes of failure. This implies that it may be necessary to iterate in the design process to satisfy the various performance requirements simultaneously while considering also the recovery, dilution of the ore and stability of the mining drive.

The initial step is to determine the stress distribution in the rock medium around the excavation boundary using numerical modelling softwares Examine 2D. The next step was to define zones or areas of tensile and compressive stresses and determine the extent of the zone around the excavation in which slip can occur on bedding planes. Particular zones to be examined are the roof and sidewalls of the excavation where the planes of weakness are being intersected. Therefore, the optimal arrangement of the mining drive should ensure optimal ore recovery and safety in terms of stability of the drive while keeping costs of operations at a minimum.

2. Materials and Method

The following methodology was applied:

Step 1

The mining method currently employed was reviewed in relation to the position of the mining drive. This involved reviewing the ore body characteristics such as dip angles, stope layouts and rock mass characteristics of the ore surrounding rock. Stoping statistics from year 2014 to 2016 were reviewed in terms of recovery with the current arrangement of the mining drive.

Step 2

In order to understand the prevailing geotechnical conditions at the mine, stress re-distribution around the boundary of the stope was analysed using numerical analysis aided by geotechnical software Examine2D.

Step 3

Some of the positions of the mining drive under consideration for analysis were simulated at an ore body dip angle of 43° as a worst-case scenario using AutoCAD. The different options of arrangements of the mining drive was analysed in terms of recovery and geotechnical condition of the mining drive in the course of mining (drive stability).

3. Results and Discussion

Using Examine 2D and AutoCAD the redistribution of stresses around an open excavation were analysed and various options of the mining drive simulated respectively. The main factors analysed using Examine 2D are maximum principal stress and maximum shear strain as shown in Figure 2 and 3.

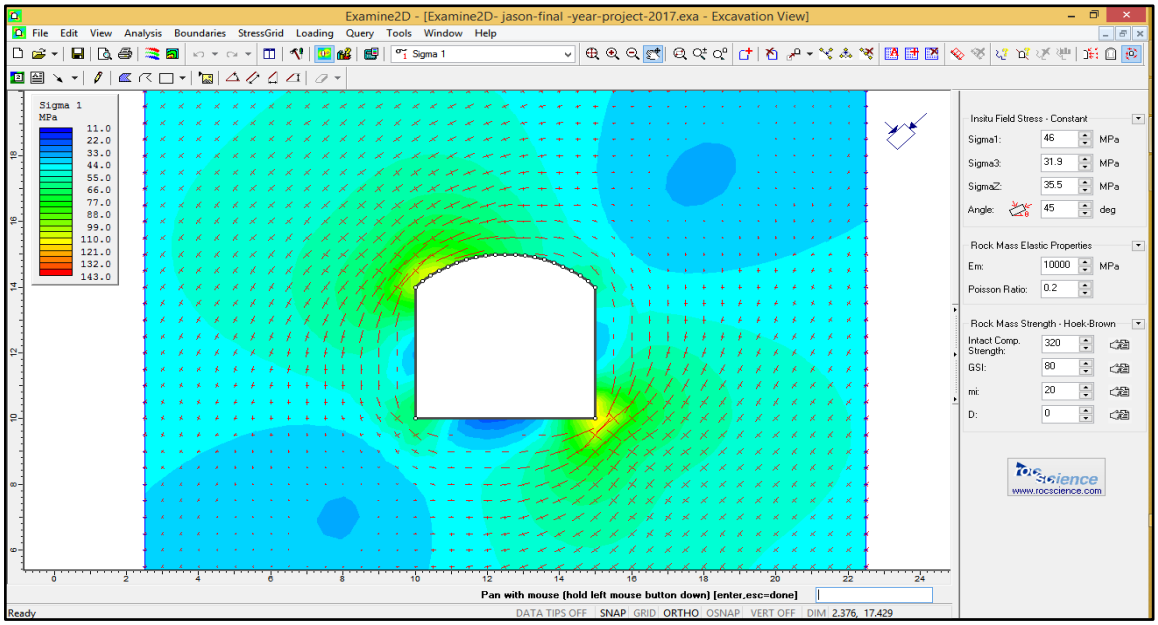

Figure 2: Maximum principal stress profile at Mufulira mine

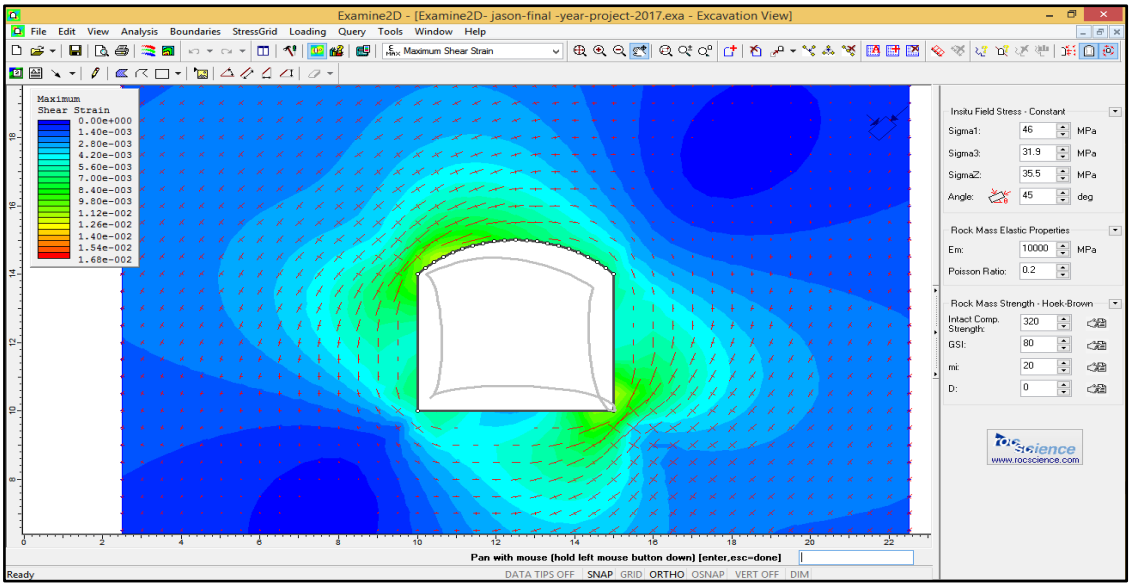

Figure 3: Maximum shear strain profile at Mufulira mine

The results shown in Figure 2 and 3 show areas where maximum principal stress and maximum shear strain occurs around the mining drive respectively of which σ1 is 46MPa and act at an angle of 45º. In Figure2 the highly stressed areas experience spalling caused by rock crushing in those regions due to tensile and compressive stresses interactions. This brings about the formation of dog ear ring at the left top corner which may initiate rock bursts compromising the stability of the mining drive. Since the ore body is more competent (with a compressive strength of 310MPa) than the footwall quartzite's (270MPa) and from structural survey no serious joint sets exist in the ore bodies which are conducive to wedge formation unlike in the footwall quartzite, the only serious plane of weakness is the geological footwall contact of the ore body. This zone of relaxation of stresses adds to instability problems of the mining drive due to stresses if it passes right through the region of high stress.

The various options of positions of the mining drive in Figure 4 were analysed in terms of mining drive stability and stope recovery. The analysis of stability potential of the mining drive was done in relation to the geological footwall contact relative to the high stress areas around the mining drive as follows:

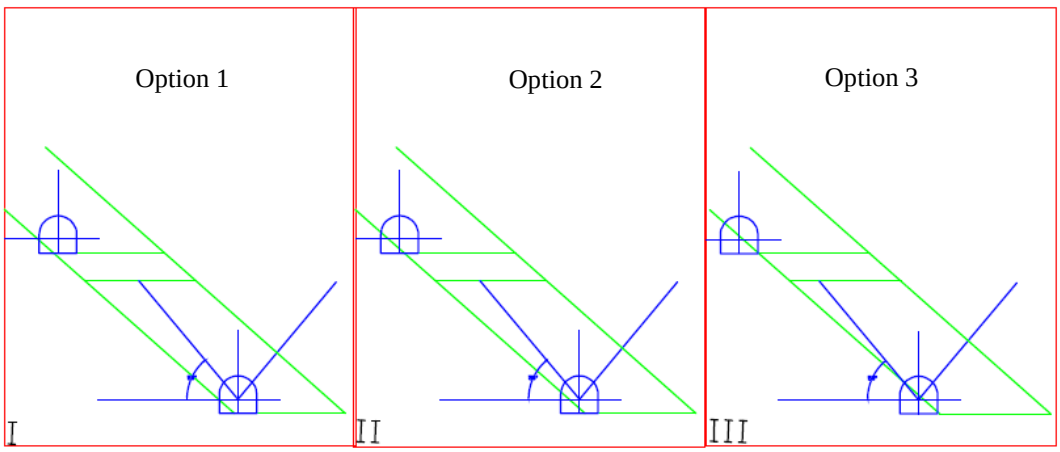

Figure 4: Three options of the position of mining drive

3.1 Mining drive position (Option 1)

This arrangement of the drive is actually the current position of the mining drive at Mufulira mine developed 20% in the footwall and 80% in the ore body. The footwall contact (bedding plane) cuts through the left side wall of the stope boundary which is less stressed as shown in Figure 5. Therefore, problems of instability of the mining drive is not an issue unless in areas where the ground is very highly stressed. According to the analysis of stresses around the mining drive it shows that the side wall where the contact passes is less stressed as compared to the roof as shown in Figure 5. Therefore, this position of the mining drive is more stable as a result problem of spalling won't affect stability of the mining drive. The only setback with this position is that more broken ore (15-20%) fails to flow into the stope because the angle of repose (50º) of the material is higher than the inclination of the footwall (43º) hence a great deal of ore about 15% remains sitting on the shallow inclined footwall side. Because of this, recovery at this position is low of about 66% ore. It is easy to control the ground in this situation in terms of wedge failures because the ore body has no discontinuities that are conducive to wedge formation.

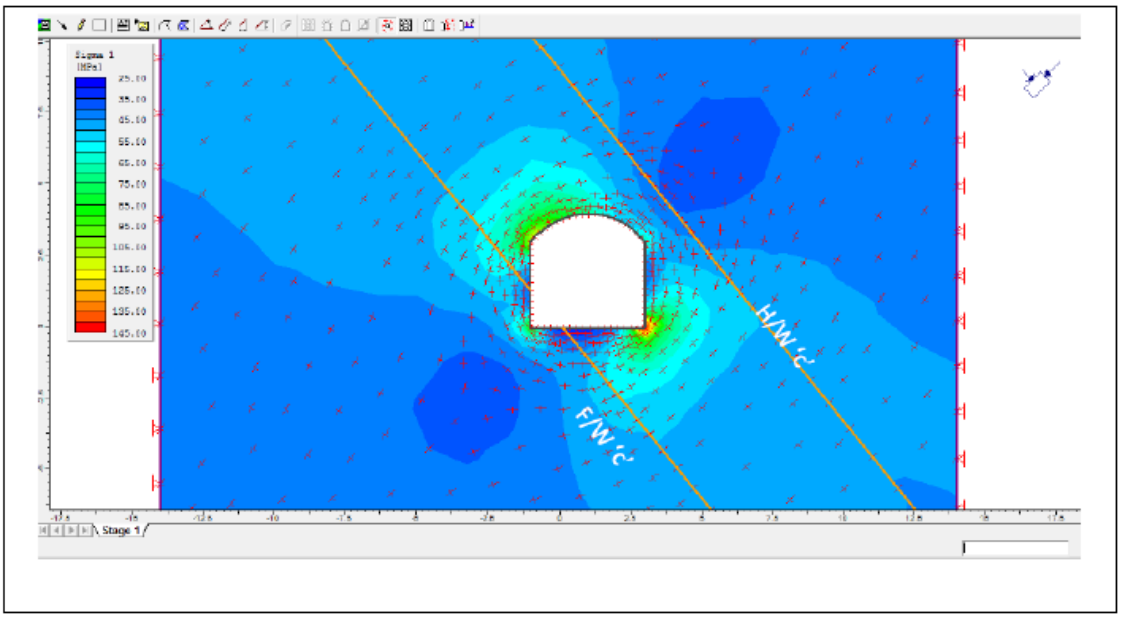

Figure 5: First arrangement of the position of mining drive

3.2 Mining drive position (Option 2)

Considering the second arrangement shown in Figure 6 where the mining drive is positioned 30% in the footwall and 70% in the ore body, the arrangement still doesn't compromise the stability of the mining drive to some extent. This is because the ore body geological footwall contact cuts through the left side wall just before the left top corner where high stresses are concentrated. This means that spalling of the roof on the top left corner due to high stress in that region has less effect on the stability of drive because the stresses are more concentrated outside the plane of weakness existing there. It can be argued that at this position the amount of ore that would remain on the less inclined footwall side is greatly reduced by 8% as compared to the previous position because shifting the position from the ore body slightly into the footwall tries to recover the potential ore that fails to flow from the stope. Hence, recovery of ore at this position is improved by 7% to 73%.

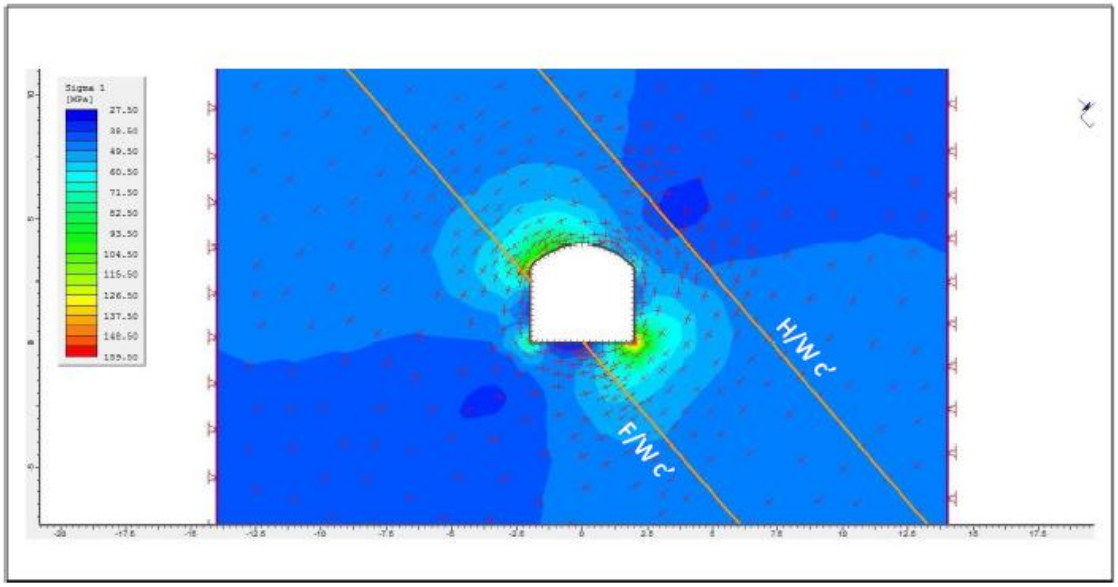

Figure 6: Second arrangement of the position of mining drive

3.3 Mining drive position (Option 3)

However, in the third scenario as shown in Figure 7 the plane of weakness passes right through the zone of high principal stresses and maximum shear strain, meaning that the problem of spalling can be accelerated by the stresses acting in the roof. This would lead to accelerated spalling along the plane of weakness (geological footwall contact).. This would cause the mining drive to continuously cave, initiated by spalling of the roof until the stresses in the area stabilise. Despite this stress problem, this position of the mining drive would drastically reduce the potential ore by 10% that will be left from the stope which fails to naturally flow into the stope hence offers increased ore recovery of about 76%. However, excavating the mining drive at 50% in the footwall exposes unfavourable structural features which are conducive to wedge formation.

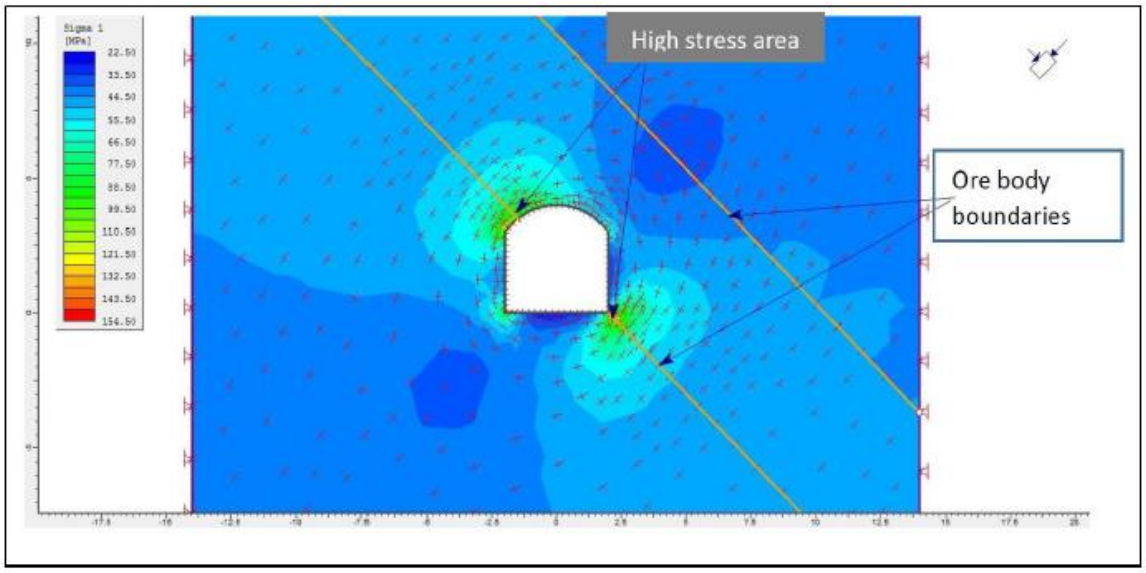

Figure 7: Third possible arrangement of the position of mining drive

3.4 Effect of changing the mining drive position on ore recovery

As can be seen from Figure 8, the effect of changing the position of the mining drive affects the amount of fragmented ore that is able to flow into the draw point. For example, placing the mining drive 40% in waste 60% in ore would result in recovery of 76% against the planned 80%. Due to lack of particle flow simulation software the values of recovery in Table 1 were calculated using a conventional method of calculating potential recovered ore by dividing recoverable area with the total area of the stope cross section as shown in Figure 8. Total Area of Stope (A2) is 146 and A4 is the cross section area of the mining drive.

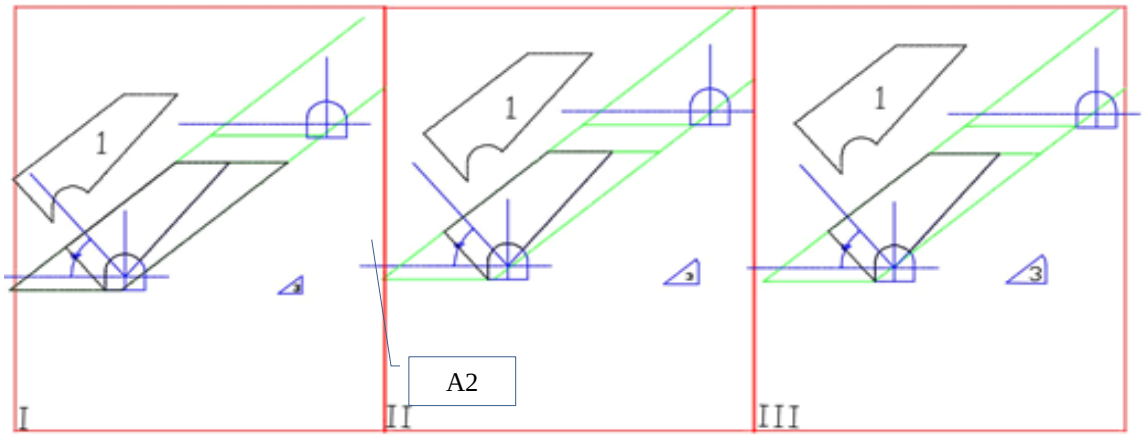

Figure 8: Expected recoverable area of ore in the stope (area 1)

Table 1: Shows the recovery against position of the mining drive

	Drive %In waste(A3/A4)	Area 1 (ore)	%Recovery (A1/A2)	%Dilution
I	20	97	66	30
II	30	106	73	30
III	40	111	76	30

4. Conclusion

The study carried out has established that the problem of low recovery at the mine is attributed to failure of the fragmented rock material to flow into the stope due to the improper location of the draw point and inclination of dip of the ore body. This is because the inclination of the footwall is less than the angle of repose of the fragment rock hence ore remains sited on the footwall. This makes the current position of the mining drive not ideal as the ore body dips below 45º.

Based on the analysis of stress re-distribution around the drive using Examine2D and ore recovery from the stope, it has been established that option 2 is the optimal position for the mining drive because it offers increased ore recovery of about 73% against target of 80% without compromising safety or stability of the drive. Option 2 has the mining drive positioned at 30% in footwall quartzites and 70% in the ore body.

5. Recommendations

1. Adequate geological information of the ore body should be readily available in time during the mine layout design as this will provide adequate information needed for optimal planning of stopes.
2. Development priority of the footwall should be strictly followed so as to timely enable geologists to properly map the ore body and provide mine planners with the required information necessary for optimal planning of the mining drive position.

Acknowledgement

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Sustainability, closure and rehabilitation of mine sites: A recap of best practices

Bunda Besa[1] and George Muwowo[2]

Abstract

Today, there is increasing awareness of the need to provide for 'sustainability' of ecological and social settings in which mines are developed, operated and closed. Mining is a temporary landuse which should be integrated with, or followed by other forms of landuse. Rehabilitation of mines should be aimed towards a clearly defined future landuse for that area. Different components of a mine (e.g. open pits, waste dumps, tailings dams, plant and office sites, ore stockpiles, etc.) may have different post-mining landuses. This paper highlights the guiding principle of mine closure and rehabilitation as well as the steps in closure plan, based mostly on best practices obtaining in Australia. Examples of sustainable mine practices are also discussed in this paper. The paper also identify and demonstrate best practice mine closure and rehabilitation standards and principles, and hence establish guidelines to ensure improved mine closure practices and the development of sustainable mining. The most effective mine closure plans are those that are integrated with the long term operational plans for the mine and are subject to regular review and monitoring to accommodate regulatory, technological and economic change

Keywords: **Sustainability, mine closure, rehabilitation, landuse, stockpiles**

1. Introduction

In an ideal situation, mines should only close when their mineral resources are exhausted and a mine closure plan is in place and progressively implemented. In this case, there is time available for planning, monitoring and trials and funds are readily available to cover the costs of implementing the closure plan. Additionally, stakeholders are prepared for the intended closure date, employees have arrangements for alternative employment, and the community has the opportunity to work with the

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mine to ensure sustainable benefits from the mining activities. In the real world, however, mines extract reserves, not resources. The grade and tonnage of reserves vary from day-to-day depending on the commodity price, ore quality or grade, further exploration results, geotechnical complications and other factors which can result in mine closure before the estimated reserve has been fully extracted. This situation can create significant problems for the mining company, the community and the regulator. Research shows that almost 70 per cent of the mines that have closed over the past 25 years in Australia have had unexpected and unplanned closures (Australian Government, 2016a P7; Laurence, 2006).

As we progress into the twenty-first century, there is increasing awareness of the need to provide for 'sustainability' of ecological and social settings in which mines are developed, operated and closed. Therefore, there is need to do more than 'Design for Closure' i.e. we also need to prepare 'Post Mining Sustainable Use Plans' for the mine site and affected area (Robertson and Shaw, 1999). Thus, mine closure is an important issue for many governments, stakeholders and the mining industry. When a mine is closed, there can be serious impacts on the local community. This is the case especially if the mine had been a major economic player in the region providing substantial revenue and social services, such as water, power and health care. The closure of a mine can also raise environmental concerns (Figures 1 and 2) about the historic management, and continuing management plans, for the mine.

Fig 1: Environmental effects of mine closure (PHOTO CREDIT: B. Besa, Adelaide, South Australia)	***Fig. 2: Water pollution due to acid mine drainage, Macalder, Kenya (PHOTO CREDIT: Phil Hill/Science Photo Library)***

Rehabilitation is the process used to repair the impacts of mining on the environment. The long-term objectives of rehabilitation can vary from simply converting an area to a safe and stable condition, to restoring the pre-mining conditions as closely as possible to support the future sustainability of the site (Australian Government, Undated). Rehabilitation normally comprises the following:

- Developing designs for appropriate landforms for the mine site;
- Creating landforms that will behave and evolve in a predictable manner, according to the design principles established; and
- Establishing appropriate sustainable ecosystems.

Sufficient resources must also be allocated to enable the rehabilitation aims to be met. Comprehensive and accurate records should be kept of all rehabilitation activities. The long-term objectives of rehabilitation vary, but can be categorized as follows;

- Restoration of an area so that the pre-mining conditions are replicated as closely as possible with all the area's environmental value intake;
- Reclamation of the area so that the pre-mining landuse can be re-established under similar conditions; and
- Developing the area for a landuse significantly different to that which existed before mining, such as converting mined land into wetlands, recreational areas, urban development, forestry, and agriculture land (Figures 3 and 4).

Mt Sisa—August 1997 Mt Sisa—February 2006

Fig 3: Misima Mines Mt Sisa Pit after Rehabilitation (PHOTO CREDIT: Sustainable Mining Strategies Pty Ltd)

Fig 4: Rehabilitated open pit mine at Tiffany Kafue Zambia, now serving as recreation facility (PHOTO CREDIT: B. Besa)

2. Rehabilitation challenges

Rehabilitation of degraded landscapes due to mining is regarded as a crucial economic activity in Zambia and worldwide. As highlighted above, mining has a significant negative impact on environment due to its nature, especially opencast mining which inevitably leads to serious degradation on ecological and aesthetic values of the landscape. Topography and drainage, air, soil and water quality, vegetation including forest ecosystems, human health and habitation can be listed as the typical parameters that are mainly affected by mining activities. However, mining companies in Zambia rarely conduct mine closure and rehabilitation of mine sites. This is attributed to the following;

(i). Lack of strict environmental policies that will compel mining companies to conduct rehabilitation
(ii). Lack of enforcement of laws by enforcement agents to force mining companies to progressively rehabilitation their mine – punitive measures for failures to rehabilitate are not perceived as a real risk.
(iii). Most mining companies focuses on profits than rehabilitating the mines

This paper therefore, discusses mine closure plan that considers the long-term physical, chemical, biological and social/land-use effects on the surrounding natural systems in closed mine areas. Steps in mine closure as well as sustainable mine development and rehabilitation best practices are highlighted in the paper.

3. Mine Closure Plan

Mine closure involves planning adequately for the after-mining landscape, that is, all activities required before, during, and after the operating life of a mine that are needed to produce an acceptable landscape economically. Decisions made during the mine planning and development phase – and even earlier, during the exploration phase – have profound effects on the ultimate closure plan, its cost, and the resulting landscape performance. These decisions need to be made within a framework of closure planning to realize successful land reclamation (Sassoon, 2000). Mine owners are therefore, encouraged to develop a mine closure plan as an integral part of a project life cycle. Figure 5 shows seven mining phases that must be integrated within a closure system (Australian Centre for Sustainable Mining Practice, 2011). Mine closure plans should ensure that:

- Future public health and safety are not compromised;
- Environment and resources are not subject to physical and chemical deterioration;
- The after-use of the site is beneficial and sustainable in the long term;
- Any adverse socio-economic impacts are minimized; and
- All socio-economic benefits are maximized.

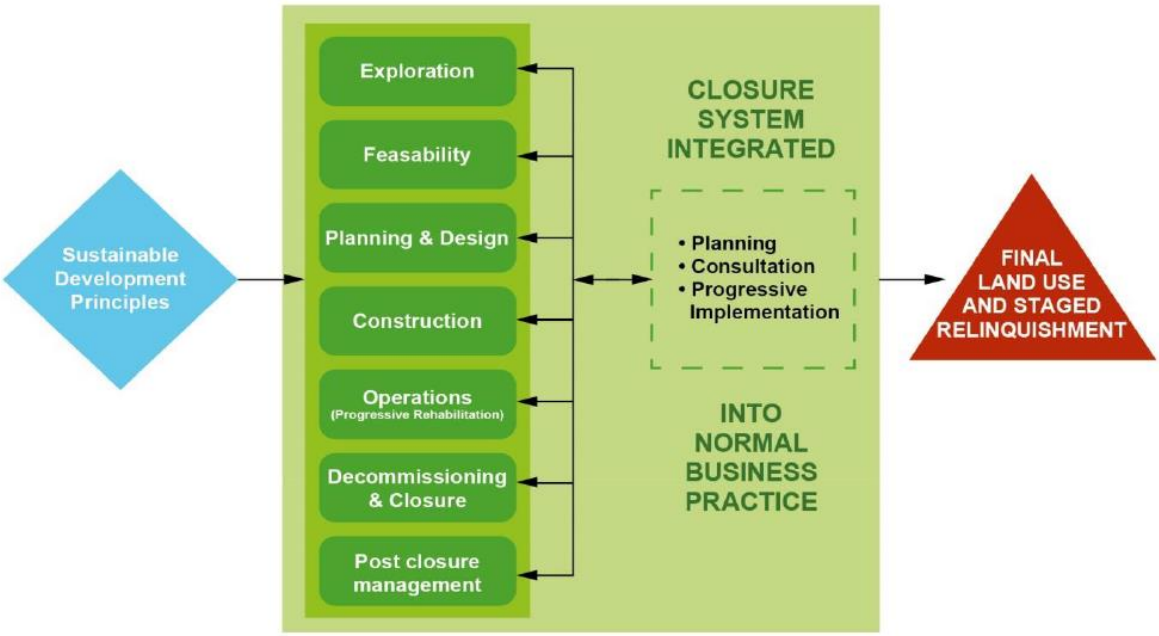

Fig. 5: The phases of a mining project with closure plan (Australian Centre for Sustainable Mining Practice, 2011)

3.1 Steps in mine closure plan

The typical steps for closure planning are shown in Figure 6. These steps provide a logical order in which to develop and present the various sections of a Closure Plan Report (Robertson and Shaw, 1999). Any closure plan must consider the long-term physical, chemical, biological and social/land-use effects on the surrounding natural systems, such as aquatic, groundwater, and surface water. Therefore, there must be an understanding of the pre-mining environment (step 1) and the effects of past and future mine development (step 2) on the pre-mining environment. Operational control measures must be selected (step 3) for implementation during mining in order to minimize the impact on the surrounding ecosystems. Impact assessments (step 4) must be done prior to measures selection as well as periodically during operations in order to determine the success of the measures implemented. Alternative mine closure measures are developed (step 5) and assessed (step 6) during mine design to ensure that there are suitable closure measures available to remediate the impact of the selected mine development.

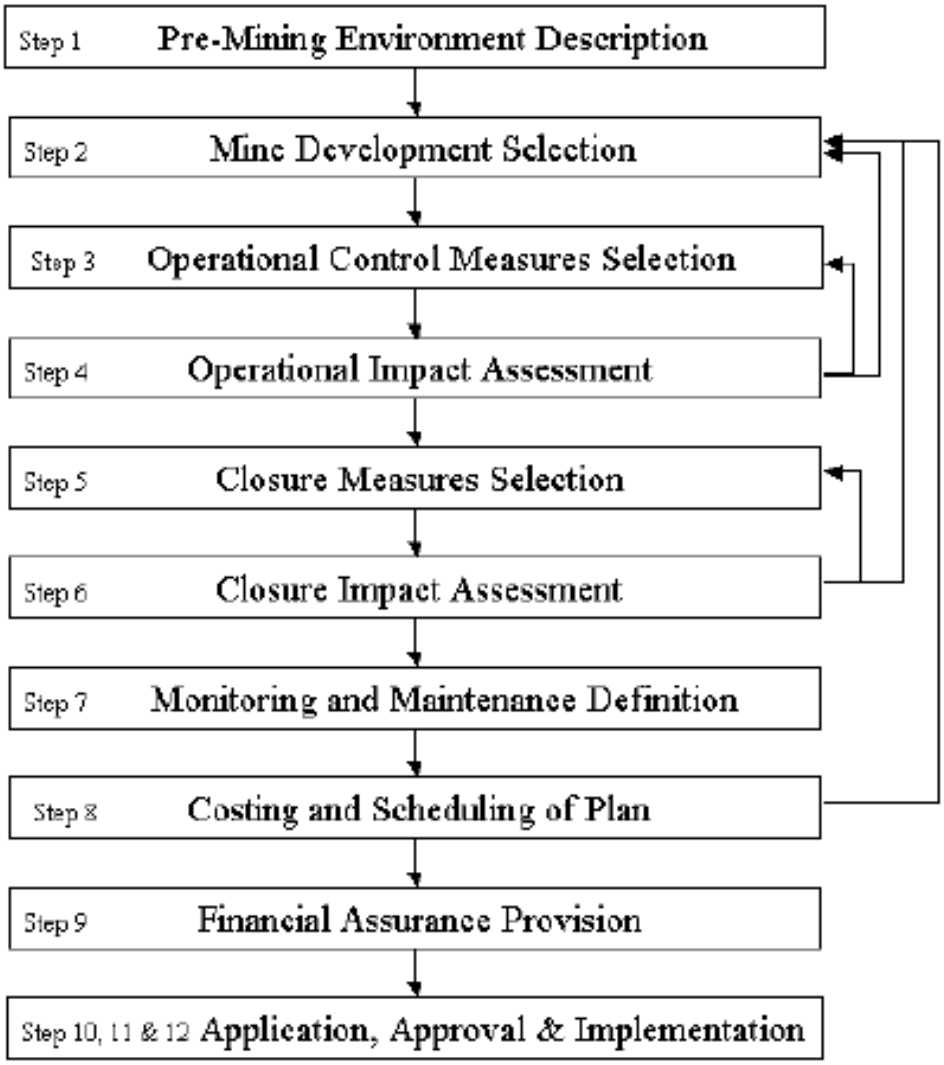

Fig 6: Typical Steps in the Closure Plan Development Process (Robertson and Shaw, 1999)

4. Sustainable mine development and Rehabilitation

According to Brundtland Report (1987), sustainable development means that investments in minerals projects should be financially profitable, technically appropriate, environmentally sound and socially responsible. Therefore, poorly closed and derelict (orphaned and abandoned) mines provide a difficult legacy issue for governments, communities and minerals companies and, ultimately, tarnish the mining industry as a whole (Australian Centre for Sustainable Mining Practice, 2011). Additionally, poor planning increases the costs of rehabilitation and mine closure and decrease overall profitability. Taking a more integrated approach to mine rehabilitation, and doing it progressively, can achieve effective mine rehabilitation.

4.1 Environmental issues

Mining is a temporary activity, with the operating life of a mine lasting from a few years to several decades. Mine closure occurs once the mineral resource at a working mine is exhausted, or operations are no longer profitable. Mine closure plans are required by most regulatory agencies worldwide before a mining permit is granted, and must demonstrate that the site will not pose a threat to the health of the environment or society in the future. Depending on the site, the mine may be repurposed for other human uses or restored to its pre-mining use following closure. The following are the environmental challenges caused by mine closure;

(i) Abandoned mine equipment and plant
(ii) Acid Mine Drainage
(iii) Fugitive Emissions
(iv) Land Degradation
(v) Water quality, environmental safety and dust generation remain with mining communities long after mine closure

Therefore, central to a closure plan is the development of a progressive rehabilitation plan which ensures that:

- the post-mined landscape is safe and is stable from physical, geochemical and ecological perspectives;
- the quality of the surrounding water resources is protected;
- the agreed sustainable post-mining land use is established and clearly defined to the satisfaction of the community and government; and
- success criteria are agreed with relevant stakeholders, monitored and reported to stakeholders.

4.2 Socio-economic issues

Community development programs provide an important mechanism through which a mining company can contribute to social sustainability. Community development is centrally concerned with increasing the strength and effectiveness of communities in determining and managing their own futures (ESMAP/World Bank/ICMM, 2005). It involves planning and implementing initiatives, often in partnership with other stakeholders, to provide long-term positive outcomes for affected communities.

5. Rehabilitation planning

Rehabilitation is a costly process, and opportunities to repeat unsuccessful rehabilitation works are often limited, so it is important that work consistently achieves acceptable outcomes. In order to be successful, rehabilitation programs must follow a number of steps (Figure 7).

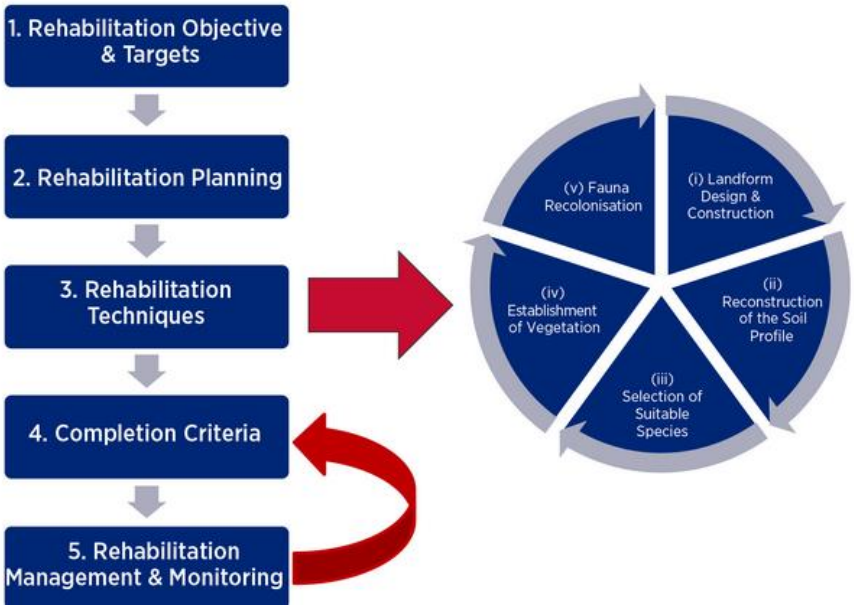

Fig 7: Stages of rehabilitation planning and implementation (Australian Government, 2016b))

5.1 Risk Management

Given the long-term implications of decisions made at the project development phase, it is vital that risk assessment workshops are held at key stages – usually at pre-feasibility, feasibility and project execution stages. The outcomes of these risk workshops should drive decisions on the future direction of the project. The nature of mining can often present a range of uncertainties – on the extent of environmental impacts, social benefits, economic outcomes, geologic conditions and even political risks. Stakeholders will have different perceptions of uncertainty and the various aspects of mining.

5.2 General Rehabilitation Requirements

5.2.1 Bush Clearing

The area cleared should always be the least necessary for safe operations of the mine. Where possible, a use should be found for the cleared vegetation. It is often used during rehabilitation as a source of seed, as a mulch to protect soil from erosion or as habitat for fauna.

5.2.2 Soil handling

Topsoil is the most important factor in successful rehabilitation, particularly where the objective is to restore a native ecosystem. It refers to the horizon of the soil, which is darker than the underlying soil because of the accumulation of organic matter. If the topsoil contains large numbers of seeds of undesirable species, then it may be better to use the sub-soil as a substrate for rehabilitation. However, in most situations, the topsoil from all areas being cleared should be retained for subsequent rehabilitation. This is because the topsoil contains the majority of the seeds and other plant propagules.

5.2.3 Replacement and stockpiling

Topsoil should be replaced along the contour where possible. This will help erosion control by reducing water flow down-slope and increasing water storage. Wherever possible the topsoil should be immediately replaced on an area where the landform reconstruction is complete (direct return).

5.2.4 Landform design and reconstruction

The re-shaping and grading of a site is an essential aspect of rehabilitation. The need for extensive re-shaping of spoil piles can sometimes be minimized by good mine planning and management. The final landform must be hydrologically compatible with the surrounding area. Slopes must be stable and will be less obtrusive if they have a similar gradient to natural slopes in the area (Figure 8)

Fig. 8: Landform design during mine rehabilitation in Orange Australia (PHOTO CREDIT: B. Besa)

5.2.5 Erosion control

Control of erosion is important both during mining and in the rehabilitation program (Figure 9). A major objective of rehabilitation should be to establish an adequate cover of vegetation to stabilize the site and prevent or control erosion. Until an adequate cover of vegetation has been established, it is imperative that provision be made to control erosion from disturbed areas.

Fig. 9: Erosion control during Rehabilitation (Lower: Nickel mine in the Philippines - Vetiver and coir matting used to protect the slope) (PHOTO CREDIT: Noah Manarang)

5.2.6 Revegetation

When attempting to restore a native ecosystem, the initial revegetation effort is unlikely to produce a vegetation identical to the original. The initial revegetation effort must establish the building blocks for a self-sustaining system, so that successional processes lead to the desired vegetation complex. The best time to establish vegetation is determined by the seasonal distribution and reliability of rainfall (Figure 10).

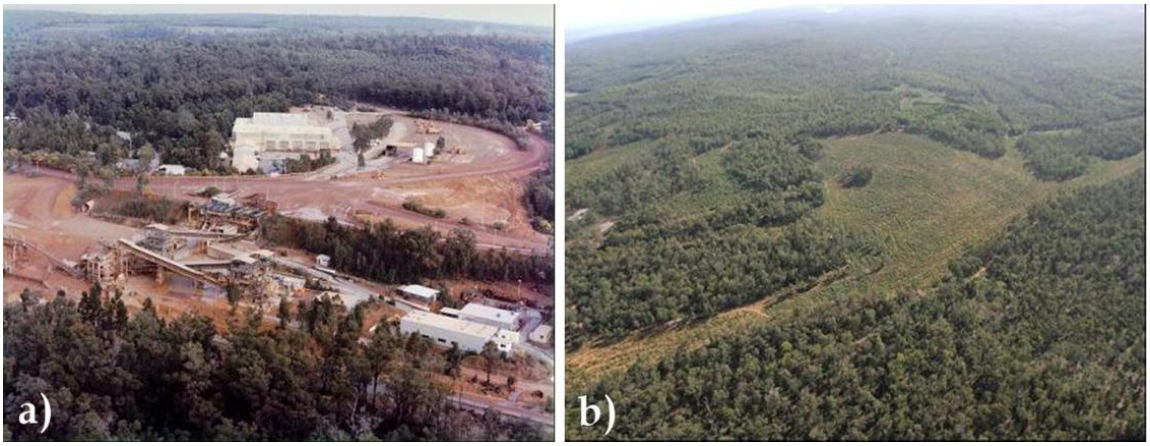

Fig. 10: The original Jarrahdale crusher circle before its closure in 1998, and b) the same crusher circle site at Jarrahdale, after rehabilitation has been completed (Alcao, 2012)

6. Conclusion

In order to meet the mining industry's principles of sustainability and to maintain its right to access resources for the benefit of all, the industry needs to ensure that comprehensive mine closure is

maintained within the broader context of the issues of social/economic equality and sustainable development. Decisions made during the mine closure planning and development phase – and even earlier, during the exploration phase – have profound effects on the ultimate closure plan, its cost, and the resulting landscape performance. These decisions need to be made within a framework of closure planning to realize successful land reclamation. Mine owners are therefore, encouraged to develop a mine closure plan as an integral part of a project life cycle. The seven (07) mining phases highlighted must be integrated within a closure system. Poorly closed and abandoned mines provide a difficult legacy issue for governments, communities and minerals companies. Additionally, poor planning increases the costs of rehabilitation and mine closure and decrease overall profitability. Therefore, taking a more integrated approach to mine rehabilitation, and doing it progressively, can achieve effective mine rehabilitation. Furthermore, strict environmental policies that will compel mining companies to conduct progressive rehabilitation bust be put in place. Also enforcement agents should ensure that environmental laws are enforced so as to compel mining companies progressively rehabilitation their mine since current punitive measures for failures to rehabilitate are not perceived as a real risk by mining companies.

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Integrated Agro/phyto-mining and Bioenergy Production to Promote Zambia's Industrialisation: a review

Thomson Sinkala[1]

Abstract

Pollution by mining industry activities is a source of concern world-over, Zambia included. Mining activities and pollution have taken away valuable land for people's livelihoods and wildlife existence. For example, Zambia's mine dumps in the Copperbelt alone have occupied more than 216,000 hectares. Meanwhile, efforts to rehabilitate the polluted areas using traditional physical and chemical remediation approaches have proven very expensive.

Phytoremediation, which is the use of various types of plants and their associated microorganisms to remove, degrade or isolate toxic substances from the environment; and Phytomining which is the use of hyperaccumulating plants to extract metals from soils and subsequently commercially recovering desirable metals from biomass, have increasingly become global areas of interest aimed at providing a cost-effective and sustainable remediation technology. A recent study has revealed that Zambia has more than 30 Cu-Co hyperaccumulator plants which accumulate extraordinarily high concentrations of Cu and Co metals in their living tissues. Another emerging area is Agromining, a variant of phytomining targeted at low productive agricultural land. This has been suggested because of its potential to recover land for farming while generating better economic returns for the farmers.

In this paper, literature is reviewed to identify opportunities for industrialization that would be triggered by integrating bioenergy production in agro/phyto-mining programmes. In Zambia's context, it is found that industrialisation would sprout from new economic activities such as processing plants for extracting metals from bioenergy waste, production of biofuels and appropriate co-products, production of various inputs for biofuels production, and development of infrastructure to service the needs and demands of expanded and new industry. Realisation of such opportunities would not only add to new income streams in mining areas, but would also put Zambians on inclusive growth path while also creating a foundation for a sustainable industrialization of the country. Zambia should therefore explore the possibility of implementing this approach in polluted mine areas such as Copperbelt and Kabwe.

KEYWORDS: Pollution, hyperaccumulator plants, phytomining, agromining, bioenergy.

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1. Introduction

Since the commencement of the first commercial copper production in Zambia (then Northern Rhodesia) in 1908 at Kansanshi, Solwezi (RCM, 1978), and the subsequent several more mines after that, there has been cumulative pollution from mining activities, especially in the area of about 50 Km by 150 Km stretching from Ndola to Konkola in the Copperbelt. The pollution has caused great concern to the mining host communities (Ettler *et al.,* 2012; Irin, 2008; Kribek *et al.,* 2012).

Current physical and chemical approaches to remediate the environmental degradation caused are expensive. For example, following privatisation of the Zambian mines, Government set up an Environmental Management Facility (EMF) to take up ownership of all environmental liabilities that were not taken by new mine owners, and the estimated cost for the EMF was US$ 200 million (Sikaundi, 2008).

The physical remediation technology which mainly includes soil replacement and thermal desorption is large in working volume, expensive, and is only suitable for soils within a small area which are severely polluted (Yao *et al.,* 2012). The thermal desorption which is on the basis of pollutant's volatility and heat the contaminated soil using steam, microwave, infrared radiation to make the pollutant (e.g. Hg, As) volatile, is limited in its application in the soil remediation because of expensive devices, long desorption time, and risk of leaving even more problems in the environment.

Mining industry world-wide is therefore in search of environmental remediation approaches that are technically, environmentally and financially sustainable. In this regard, there is concerted effort to research on phytoremediation, which is the use of plants including trees, shrubs, grasses and aquatic plants and their associated microorganisms in order to remove (extract), degrade or isolate toxic substances from the environment (Favas *et al.,* 2014). As a consequential or concurrent incentive, there is interest to commercially produce valuable metals from these plants if such metals can be found in reasonably high concentrations. Phytomining is therefore another ("sister to remediation") area that has attracted interest (Favas *et al.,* 2014; Lamb *et al.* 2001, Renault *et al*., 2000).

Based on the economic potential of both valuable heavy metal and bioenergy industries, the objective of this review paper is to identify industrialization opportunities that can arise from integrating bioenergy production in agro/phyto-mining programmes if implemented in degraded mine areas in Zambia. A successful implementation of this would create multiple income streams for mining industry, thus also minimizing costs for rehabilitation of degraded mine areas. For mine host communities, the resulting new industry and rehabilitated agricultural land would mean increased jobs and more sustainable livelihoods. Overall, this would also improve socio-economic infrastructure in the target areas.

The review starts by explaining phytomining and agromining and areas where they are best applicable, followed by this author's proposal to integrate bioenergy production in the Zambian

context which also takes into account the available policy of ethanol and biodiesel blending targets of E10 and B5 respectively. The extent of polluted land in Zambia, which would be the target for this proposal, is then reviewed using Copperbelt of Zambia as an example. The review thereafter looks at examples of heavy metal and bioenergy economic indicators to provide an investment impression, following which economic examples based on international bioenergy industry are presented and the Zambian industrialization context provided, before concluding.

2. Pytomining and Agromining

In phytomining, hyperaccumulator plants are used to take up metals from soils (phytoextraction). The harvestable biomass from these plants are then dried and incinerated to generate a high-grade bio-ore, following which the bio-ores are chemically or electrolytically reduced in the same way mineral ores are processed (Lamb *et al.*, 2001; RSC and Reckitt Benckiser, *Undated*).

Plants accumulate metals in roots, stem and leaves differently. Therefore, not all hyperaccumulator plants are suitable candidates for phytomining since the viability of a plant species for phytomining is ultimately determined by the harvestable biomass and the harvest cycle (Favas *et al.*, 2014; Van der Ent *et al.,* 2015a).

Another phytomining branch being considered is the need to improve food crop production in agricultural land with poor soil fertility. Van der Ent *et al.* (2015a) have coined a new term called "agromining". They have pointed out that agromining (a variant of phytomining) could provide mining host communities with an alternative type of agriculture on degraded lands, whereby the communities would now be farming not for food crops, but for metals such as nickel, gold, copper and cobalt (Van der Ent *et al.*, 2015a). They have argued that agromining which involves growing hyperaccumulator plants as a crop, then harvesting biomass, drying, ashing and processing it to recover target metals is most efficient using perennial species that regenerate aboveground biomass rapidly after harvesting; ensuring that the substrate-stabilizing function of established vegetation is maintained. They have suggested that phytomining is best suited for degraded or mined land as part of a broader rehabilitation strategies for metal laterite mines, smelter contaminated land, ore beneficiation tailings or otherwise degraded metal-rich land. Phytomining can in such cases progress as part of the rehabilitation strategy to generate cash flow from laterite projects during the project development phase, using overburden that would be cleared before extracting the underlying minerals. On the other hand, they have proposed that agromining should be done on low-productivity agricultural soils, targeting large and relatively flat ultramafic areas which have low productivity for food production, which they say would generate better economic returns to farmers compared to conventional farming.

3. Integrating Bioenergy Production into Phyto/agro-mining

In the Zambian context, this author proposes to add bioenergy to phyto/agro mining to further improve the economies of soil remediation strategies. Bioenergy forms include gaseous (biogas), liquid (e.g. bioethanol and biodiesel), solid (e.g. charcoal) and electricity and are derived from biomass, such as agricultural crops and forest material. Biodiesel is also produced from animal fat which, however important, will not be discussed further here.

From biomass, we can produce ethanol/biodiesel, carbon dioxide (using fermentation process for ethanol), biogas (from waste/vinasse), electricity (from biogas, ethanol/diesel), fertiliser (from vinasse and digestate), plastics and many other products. By adding this branch of activity, we will have three main income streams, namely metals, food, and the many bioenergy products. This would make remediation of expansive polluted land self-financing, with large profit margins after remediation expenses. Furthermore, the food/bioenergy industries would remain sustainable sources of livelihood during and beyond mine life, for mining host communities.

The importance of integrating bioenergy in phyto/agro-mining is the participatory nature of the industry. Furthermore, markets for ethanol, biodiesel, electricity and organic fertiliser when they are competitively priced are assured. For example, the Zambian government has already set 5% blending target for biodiesel into diesel and 10% blending target for bioethanol into petrol (Sinkala *et al*., 2013). At daily consumption rates of 2.309 million litres of diesel and 1.269 million litres of petrol indicated on the Energy Regulation Board website, these targets translate to assured markets of 42.14 million litres of biodiesel into diesel and 46.32 million litres of bioethanol into petrol per annum, respectively.

Assured markets would give stability to business value chains in Zambia. With dominant participation of locals in the value chain, phyto/agro-mining will create a firm foundation for Zambia's sustainable industrialisation.

4. Target Areas for Agro/phytomining with Bioenergy Production

According to the Zambia Environmental Management Agency (ZEMA), the land covered by mine dumps including overburden, waste rock, tailings and slugs is 216,257 hectares (Sikaundi, 2008), broken down as shown in Table 1. This does not include dumps by the new mines within the Copperbelt, the entire North-Western Province and the rest of the country, such as small to medium scale mines. In addition, there is also degradation beyond dumps and their surroundings, caused by dispersion agents such as wind and surface water run-offs. Apart from surface pollution, there is also ground water pollution in various forms.

Table 1: The area covered by mine waste dumps in the Zambian Copperbelt

DUMP TYPE	TONNAGE (Million)	AREA COVERED (Hectares)
Overburden waste	1,899	206,465
Waste rock	77	388
Tailings	791	9,125
Slug	40	279
TOTAL	2,807	216,257

Compiled from Sikaundi (2008)

Mining pollutants can spread far beyond mine licence areas, depending on the dispersion agents. For example, a study by Renault *et al*. (2000) in Canada has shown that dispersion of heavy metals from mining and milling operations by wind has covered distances as far as 250 Km for manganese and 60 Km for copper. They have pointed out that the major source of soil

contamination in areas surrounding the mining operations is in fact pollutants spread by wind. Such cases make remediation efforts even more difficult and expensive.

Kribek *et al.* (2012) undertook a study on contents of metals and arsenic in the leaves and tubers of cassava (*Manihot esculenta*) and sweet potatoes (*Ipomoea batatas*) growing on uncontaminated and contaminated soils of the Zambian Copperbelt mining district covering an area of about 60 Km by 150 Km. The study found that the contents of Cu, Co, As and Zn in leaves of cassava and sweet potatoes growing on contaminated soils were higher compared with uncontaminated areas. Specifically, the contents of copper in cassava and sweet potato leaves growing on contaminated soils were as high as 612 mg/kg and 377 mg/kg (total dry weight [dw]) respectively, whereas in uncontaminated soils the highest copper contents were up to 252 mg/kg and 198 mg/kg dw in cassava and sweet potatoes leaves, respectively.

SGAB *et al.* (2005) studied metal concentrations in the leaves of cassava and sweet potatoes in the Copperbelt area, where they found 10% of the copper, arsenic and cobalt samples analysed had hazardous levels of metal concentrations for human consumption. The samples displayed decreasing metal concentrations with increasing distance away from the smelter. Also studied by SGAB *et al.* were metal concentrations in fishes from the Kafue River and various tailings dumps in the Copperbelt mining area. Results of the study showed that the metal (especially Cu and Co) concentrations in the samples were significantly elevated compared to fish from the background locality at Raglan's Farm. Also, fish from the tailings dumps were generally higher in copper, cobalt, zinc and lead compared to fish from the Kafue River.

Based on the evidence from the above two studies, metal concentrations due to mining activities in the Zambian Copperbelt area covering approximately 60 Km by 150 Km stretching from Ndola to Chililabombwe are elevated compared to areas outside of the mining area. This can be the target area for studies and subsequent implementation of the phyto/agro-mining programme. Other target areas can be the new copper mining activities in North-Western Province, gold mining areas in Rufunsa, Petauke and Mumbwa, and agricultural locations with ultramafic soils laden with nickel at Munali Hills and elsewhere in the country.

5. Some Economic Indicators for Agromining and Bioenergy

Various research works have discovered hyperaccumulator plants for metals including As, Se, Cd, Cu, Co, La, Mn, Ni, Pb, Tl, and Zn (Baker *et al.*, 2010; Favas et al., 2014; Sarma, 2011; Van der Ent *et al.*, 2015b), so that it is now possible to extract these metals using agromining (Van der Ent *et al.*, 2015a). In particular, Van der Ent *et al.*(2015b) conducted a study which revealed that there exist more than 30 Cu-Co hyperaccumulator plants, which accumulate extraordinarily high concentrations of Cu and Co metal in their living tissues, in the Copper-Cobalt belt of the Democratic Republic of Congo and Zambia. Such plants, they say, can be grown and harvested to remove Cu-Co from (polluted) soils, thus serving to remediate contaminated soils in the belt. Some published copper ore grades by surface mines in Zambia are as low as 0.46% (or 4.6 kg/tonne). In soils, the highest detected copper content of 612 mg/kg found by Kříbek *et al*. (2013) translates to 0.0612% grade (or 0.612 kg/tonne), while the highest 958 mg/kg of copper detected by Van der *et al.* Ent (2015b) translates 0.0958% grade (or 0.958 kg/tonne). Meanwhile, the highest 3038 mg/kg Cu detected by Van der Ent *et al.* (2015b) in Apiceae cf. *Diplolophium* sp,

and the 1060 mg/kg Co in Amaranthaceae *Celosia trigyna L.*, translate to 0.3058% and 0.1068% copper and cobalt, respectively. Considering the likely low investment for agromining compared to traditional open pit mining, these grades are attractive to make a follow-up research on possible implementation of agro/phyto-mining in viable areas. Among the items to be studied can include the various types (starchy, sugar based, or other) of hyperaccumulator plants, the yields of the harvestable biomass of the plants per area per harvest cycle, the extractable amounts of metals from the harvested biomass, the various products and co-products associated with plants and production technologies, and the extent of the areas with elevated metals.

The economic feasibility for metals of interest can be determined based on the information on the above parameters and the prevailing metal prices, examples of which at present stand at US$ 11,305/tonne Ni, US$ 6,756/tonne Cu, US$ 65,500/tonne Co and US$ 41,240/Kg Au.

Van der Ent *et al.* (2015) have reviewed various field trials undertaken with Ni hyperaccumulator species such as *Alyssum murale* or *A. corsicum*. They have estimated a harvest of 5−10 t of dry matter per ha containing 2% Ni, yielding 100-200 kg Ni / Ha. At the above Nickel price of US$11.31/Kg and a potential yield of ≥100 kg Ni /Ha, they argue agromining could become a part of a substantial and integrated income stream for "metal farmers" worth more than most food crops.

When bioenergy production is integrated, metal extraction from biomass may usually not involve burning or reducing biomass into ash. If, for example, the intention is to produce ethanol bioenergy, metal extraction would have to be from vinasse, the material that remains after the distillation process. Also, for non-starch and non-sugar biomass, advanced generation biofuels production technologies would be required to produce ethanol, but metal recovery would still be from vinasse.

The production cost of bioenergy depends on the costs of feedstock and its supply logistics, ethanol production technology, and co-products of the bioenergy type which should generally share production cost. In the USA, the price of corn-based ethanol, which is about 56 billion litres per year (Souza et al., 2015), is averaging at about US$ 0.53/litre, while the co-product distiller's dried grains with solubles (DDGS) price is averaging at about US$150 per tonne. The price of cellulosic ethanol at Los Angeles Harbour in California, USA, is US$ 0.41 (ibid). In Brazil, the country that produces about 30 billion litres of sugarcane based ethanol per year, the ethanol cost is US$ 0.50 for anhydrous ethanol and US$ 0.44 for hydrous ethanol, excluding bioelectricity co-product (PECEGE and CAN, 2016). In Thailand, production cost of cassava based ethanol, currently at 1.2 billion litres per year, is US$ 0.65/litre while the petrol pump price is US$ 1.04/litre.

In Africa, the ex-distillery price of cassava based ethanol without co-products, for example, is generally about 0.85 to 1 US$ per litre (Joshi, 2017). Compare this with the current pump price of petrol going at K13.75 (about US$ 1.375) in Zambia. Continual improvement in production technology and feedstock production and supply logistics should bring this price downwards, similar to production cost levels attained in the above examples of Brazil, Thailand and USA.

6. Some Economic Examples of Bioenergy-based Industrialisation

A study by Neves et al (2010) on the economy generated by the sugarcane industry in Brazil revealed that for every US$ 1 economy created by ethanol, US$ 6 extended economy was stimulated upstream, lateral and downstream. Another study by Hodur and Leistritz (2009) on the economic impacts of biofuel development revealed that an investment of US$ 176.5 million into the production of 190 million litres per year of ethanol in North Dakota, USA, resulted in an annual operating expenditure of US$ 74.6 million. Of this, US$ 53 million were payments to North Dakota entities, by far of which the largest expenditure item ($36 million, or 68%) went to feedstock purchases and related supply logistics. In Thailand, a study by Silalertruksa *et al* (2012) showed that producing ethanol and biodiesel require about 17–20 and 10 times more workers than gasoline and diesel as per energy content, respectively, and that direct employment in agriculture contributes to more than 90% of total employment. In a projection up to the year 2022, the estimated employment generation was found to be around 238,700–382,400 person-years, additional GDP was around US$ 150 million, and savings in imported goods worth US$ 2.547 billion compared to petroleum fuels.

In the context of Zambia's degraded mining areas, industrialisation would sprout from a number of new economic activities, including processing plants for extracting metals from bioenergy waste material such as vinasse, glycerol and ash; production of liquid biofuels and appropriate co-products such as CO2, fertiliser, electricity and plastics; production of gaseous and solid biofuels; production and supply of various inputs such as feedstock, chemicals, starch, fertiliser, machinery and electricity to the above activities; and development of infrastructure such as roads, electricity, water and housing to service the needs and demands in areas where the activities will be taking place.

7. Conclusion

The above review shows that there is clear evidence that the Zambian Copperbelt has been polluted with heavy metals, albeit to different degrees. It is also clear that plants that accumulate heavy metals from contaminated soils in mine areas do exist in Zambia. Based on reported experience elsewhere in the world, these plants can be used to cost-effectively remediate the polluted environment.

Beyond remediation, hyperaccumulator plants can also be used for phytomining where valuable metals can commercially be produced, thus adding new income stream for the mines.

For phytomining to be viable, large and predictable hyperaccumulator plant biomass has to be produced, which consequently calls for agricultural approaches to sustainably grow such plants. A related activity, "agromining", has thus also been mooted, to promote rehabilitation of degraded agricultural soils for food crop production.

Due to the anticipated large biomass from plants harvested in phytomining and agromining areas, as well as the possibility to grow oil crops that can be used for biodiesel production and starch-/sugar-based crops that can be used for bioethanol production in these areas, this author has also proposed to add a bioenergy production dimension; to be another income stream in mining areas.

Integrating bionenergy production in agro/phyto-mining programmes, all of which have assured markets, will put Zambians on an inclusive growth path and will cultivate a firm and sustainable foundation for Zambia's industrialisation.

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Multi-Port Converter Based Hybrid Off-Grid Power System Using Hydro-PV-Battery for Ngwerere Residential Area

Wamundila Akabondo[1], Luka Ngoyi[2]

Abstract

This paper proposes a standalone microgrid configuration which comprise of a micro-hydro and an integration of energy storage units and solar (PV) using a multi-port DC-DC converter. The multi-port converter considered has four ports and integrates the energy storage units, solar (PV) and any other auxiliary DC loads. The fourth port of the converter is used to connect the integrated PV/storage hybrid system to the micro hydropower plant via a voltage source converter. The idea is to make the proposed power system resilient and reliable while meeting the energy demands at all times. The electrical design of the micro hydropower plant which is to be implemented on Ngwerere wastewater stream has been developed and verified by simulations in MATLAB/Simulink environment.

Keywords: Multi-port converter, Standalone, Resilient, Hybrid, Integration.

1. Introduction

Presently, the existing power system in Zambia is failing to meet the demand of the people. The country's installed capacity is 2,411 megawatts, virtually all of which is hydro. According to the Zambia Development Agency, the demand for electricity in the country has been growing at an average of about 3%, or between 150MW and 200MW, each year (ZDA, 2014). This is partly because of increased population growth, increased economic development, increased industrial and domestic usage of electricity and largely because of the realities of climate change.

To overcome the above challenges which are not just peculiar to Zambia, the world's power system which is largely centralized is facing a paradigm shift towards a much more decentralized power system. The decentralized power system is to be largely operated on renewable energy sources (RESs) such as solar, wind and biomass which are cheap to install and operate, Rezkallah *et al* (2014). Unfortunately, most RESs are highly variable and cannot be used to directly dispatch power to the loads. Therefore, energy storage units are usually connected in parallel with RESs to balance up the power during periods of high demand and low generation. Remote areas which

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are along streams more often called run-of-river (ROR), can have their demand met by a micro hydro power plant (MHPP) because it offers clean energy and are cheap to install. However, according to (Ion and Marinescu, 2013), MHPP cannot satisfy the load demand especially in dry season. Therefore, additional energy supply from other sources such as solar, wind coupled with energy storage units (ESU) sources has been proposed to balance power deficiency, Mendis *et al* (2014).

Mostly, MHPP is driven by squirrel cage induction generator (SCIG) due to couple of advantages, such as robustness, low cost, and less maintenance requirements. Furthermore, it can dispatch power directly to the AC local grid without using power electronic converters, which is not the case with the PV array. Several schemes and control algorithms have been proposed in the literature to operate optimally the PV and MHPP together in remote areas as a hybrid power generation (Junhui Z et al (2012) and Zhou J.H et al (2013)). In most of the reported work, voltage and frequency are regulated by controlling voltage source converter (VSC), and the maximum power point tracking (MPPT) of PV system is achieved by using DC-DC boost converter to feed DC bus of VSC. Authors have proposed hybrid power generation system using PV, BESS and MHPP and VSC for grid tied applications, Rezkallah *et al* (2015).

To integrate PV and storage, a four port type of multiport converter will be used. The multiport converter is used to provide isolation for loads, PV and storage through a single four winding high frequency (HF) transformer.

This paper proposes developing Ngwerere wastewater stream into a hybrid PV-battery-hydropower scheme for power generation. Reuse of wastewater can be a stable, inflation proof, economical, reliable and renewable energy source of electricity. The wastewater includes household waste, liquid waste from toilets, showers and kitchen sinks. The wastewater must be treated before it is conveyed to the forebay.

The outline of this research is as follows: section 2 gives a brief description of the proposed hybrid system. Section 3 deals with mathematical modeling of a photovoltaic solar panel and control of the VSC while section 4 deals with design considerations of a MHPP. Section 5 shows the simulation results that were done in MATLAB/Simulink. Section 6 is about Demand side management while section 7 discusses the findings of section 4 and finally section 8 is the conclusion.

2. Proposed System

Fig. 1 shows the proposed system which consists of two eco-friendly energy systems; hydro and solar PV array with a battery energy storage system. A Micro hydropower plant (MHPP) consists of a prime mover which is represents a crossflow turbine working at one operating principle i.e almost constant mechanical power. The QAB converter is used to integrate PV and storage (battery bank) through a single four winding high frequency (HF) transformer. When the generated power from hydro is lower than the load demand, then the deficit will be supplied from the PV and battery. A VSC is used to convert DC power to AC power to supply the AC loads. It is also used for maintaining the system voltage and frequency.

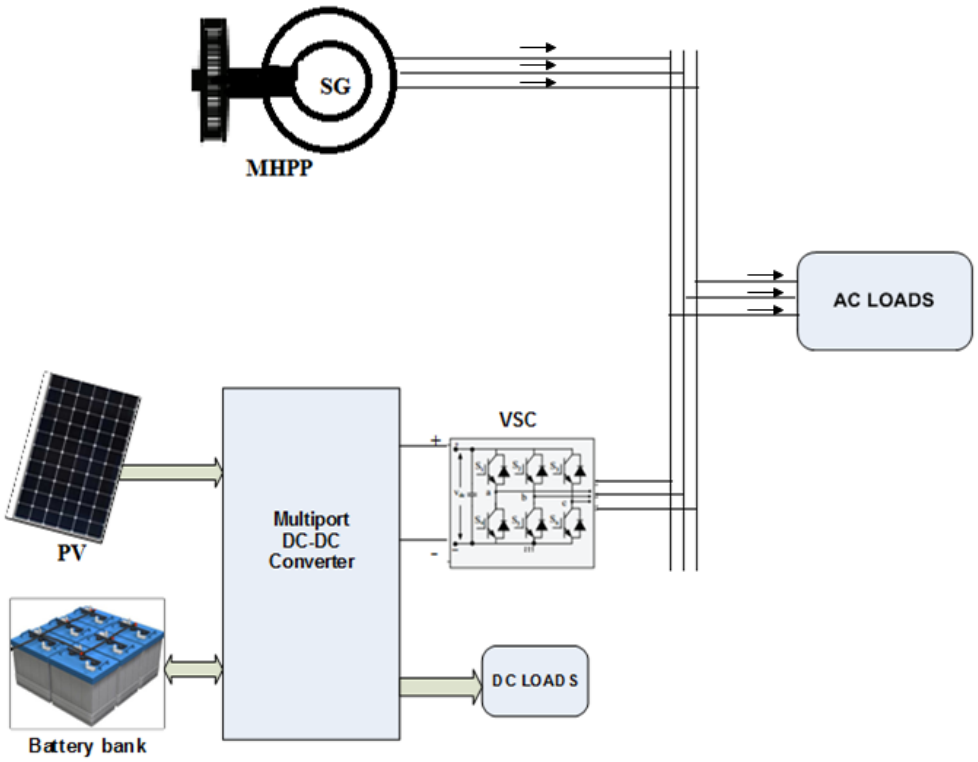

Fig 1: block diagram of the proposed Hydro-PV-battery system

3. Modeling of a Photovoltaic Solar Panel and Control of the VSC.

3.1 Photovoltaic Solar Panel

The equivalent circuit model of solar PV system according to Rezkallah *et al* (2016) consists of a light-generated source, diode, series and parallel resistances and capacitors. Its mathematical model is given as,

$$i_{pv} = i_{ph} - i_D[\exp\left(\frac{qv_{pv}}{K_b\theta A}\right) - 1] \quad (1)$$

Where the light generated current i_{pv} and the PV saturation current i_D are given as,

$$i_{ph} = G[i_{scr} + K_i(\theta - \theta_r)] \quad (2)$$

$$i_D = i_{rr}(\frac{T}{T_r})^3 \exp[\left(\frac{qE_g}{KQA}\right)\left(\frac{1}{\theta_r} - \frac{1}{\theta}\right)] \quad (3)$$

Where i_{pv}, v_{pv}, θ,G, θ_r, i_{rr}, i_{scr}, K_i, q, K_b, E_g, Q and A denote the output current, voltage of PV, cell temperature, solar irradiance, reference temperature, saturation current, short circuit current, short-circuit temperature coefficient, charge of an electron, Boltzmann's constant, band-gap energy of the material, total electron charge and ideality factor respectively.

3.2 Control of the VSC

Fig.2 show the developed control strategy for the VSC based on synchronous reference frame theory, Rezkallah *et al* (2015).

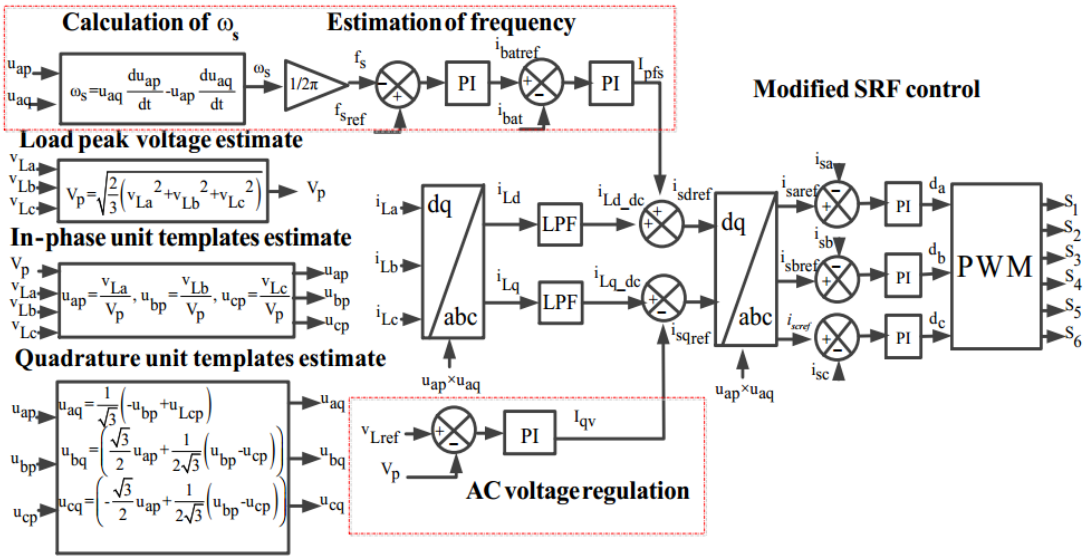

Fig. 2: Modified SRF control for VSC. Rezkallah et al (2015).

3.2.1 Control of the system frequency

As shown in Fig. 2, the control of the system frequency is obtained through comparing the reference frequency (f_{sref}), which is equal to 50 Hz with estimated system frequency (f_s) using the proposed phase locked loop (PLL), which is based on estimate of in-phase and quadrature templates.

The system frequency error Δf_s is calculated as,

$$\Delta f_s = f_{sref} - f_s \tag{4}$$

The obtained Δf_s is supplied to a frequency PI controller and its output represents the battery current reference.

$$i_{batref} = \left(k_{pf} + \frac{k_{if}}{s}\right)\left(f_{sref} - f_s\right) \tag{5}$$

The sensed battery current (i_{bat}) is compared with battery reference current (i_{batref}) and the obtained error is fed to PI battery current controller as:

$$I_{pfs} = \left(k_{pbat} + \frac{k_{ibat}}{s}\right)\left(i_{batref} - i_{bat}\right) \tag{6}$$

Where I_{pfs}, k_{pbat} and k_{ibat} denote the output of the PI battery controller and proportional and integral gains, respectively. The (I_{pfs}) is added with the d-axis DC component of the sensed load currents (I_{Ld_dc}) which are extracted using low pass filters (LPF) as shown in Fig.2.

3.2.2 Control of AC Voltage

The amplitude of AC voltages, which is equal to the load voltages is regulated at its reference value by comparing its reference amplitude (V_{Lref}) with its sensed amplitude (V_p). The amplitude of AC voltages is obtained using sensed three-phase voltages as:

$$V_p = \sqrt{\frac{2}{3}(v_{La}^2 + v_{Lb}^2 + v_{Lc}^2)} \quad (7)$$

The voltage error is fed to voltage PI controller as follows,

$$I_{qv} = \left(k_{pv} + \frac{k_{iv}}{s}\right)\left(V_{Lref} - V_p\right) \quad (8)$$

Where k_{pv} and kiv denote proportional and integral gain constants of voltage PI controller, respectively.

The q-axis DC component of load currents (I_{Lq_dc}) is compared with output of voltage PI AC voltages controller (I_{qv}). Estimated source currents, which represent the sum of the hydropower currents and the PV currents, are obtained using inverse park transform. The sensed sources currents (i_{sa}, i_{sb} and i_{sc}) are compared with estimated sources currents (i_{saref}, i_{sbref} and i_{scref}).

The output of the PI controllers (d_a , d_b and d_c) are compared with triangular carrier signals with frequency of 10 kHz to generate switching signals for VSC switches (S1- S6), as shown in Fig.2.

3.2.3 Proposed Phase locked loop

The proposed PLL used for estimating the system frequency, and AC voltage phase angle is based on in-phase and quadrature unites templates.

The in-phase unit templates are calculated as:

$$u_{ap} = \frac{v_{La}}{V_p},\ u_{bp} = \frac{v_{Lb}}{V_p},\ u_{cp} = \frac{v_{Lc}}{V_p} \quad (9)$$

Where V_p represents the amplitude of the AC voltages.

The quadrature unit templates are obtained as follows,

$$\begin{cases} u_{ap} = \frac{1}{\sqrt{3}}\left(-u_{bp} + u_{cp}\right) \\ u_{bq} = \left(\frac{\sqrt{3}}{2}u_{ap} + \frac{1}{2\sqrt{3}}\left(u_{bp} - u_{cp}\right)\right) \\ u_{cq} = \left(-\frac{\sqrt{3}}{2}u_{ap} + \frac{1}{2\sqrt{3}}\left(u_{bp} - u_{cp}\right)\right) \end{cases} \quad (10)$$

The system frequency is estimated using (6) and (7) as,

$$\omega_s = cos\theta\,\frac{d}{dt}(sin\theta) - sin\theta\,\frac{d}{dt}(cos\theta) \quad (11)$$

Where, ω_s represents the angular frequency in (rad/s).

The (cos θ) and (sin θ), are expressed as,

$cos\ \theta = u_{Laq}$ and $sin\ \theta = u_{Lad}$ (12)

The system frequency (fs) is described as:

$f_s = \frac{\omega_s}{2\pi}$ (13)

4. Design considerations of micro hydropower plant

To design a micro hydropower plant, there are many considerations to be prepared and taken into account in the design procedure. These considerations are:

4.1 Field survey

This involves getting the coordinates of the proposed site. Coordinates are important because they show the location of site and where the power house will be built. Other aspects that are looked into are: assess road to the site, to see if there are houses at the proposed site and to check if villagers engage in activities such as farming and fishing near the proposed site. Environmental assessment is also done to see if there will be major environmental and social impacts anticipated during development and construction of a power station at the proposed site.

4.2 Head and Flow Rate Assessment

4.2.1 Measurement of Head

The head is defined as the vertical height in meters from the level where the water enters the penstock to the level where the water leaves the turbine housing. A Global Positioning System (GPS) receiver was used to calculate the "head" during the field survey. The measured head is calculated as the difference in elevation between the intake point and the power house.

4.2.2 Flow rate measurement

Flow rate is defined as the quantity of water flowing past a point at a given time. Stream flow rate in this research was measured using the float method also known as the velocity-area method. It involved the measurement of the cross-sectional area of the stream and the mean velocity of the water through it.

4.2.2.1 Measuring the cross-sectional area (Ar):

The cross-sectional area was determined by multiplying stream width by average depth of the stream. This can be obtained using equation 14.

$Ar = B\ \left(\frac{\sum h}{n}\right)$ (14)

Where Ar = cross sectional area, B = stream width and h = depth of the stream and n = number of times the experiment was repeated.

4.2.2.2 Measuring the velocity (Vr):

Since the velocity both across the stream and vertically through it is not constant, it is necessary to measure the water velocity at a number of points to obtain a mean value. A floating object (a bottle) was tossed from upstream of the stream of known length and the time taken to traverse that distance was noted.

The surface speed (m/s) is given as:

$$Vrs = L/t\ (m/s) \quad (15)$$

To estimate the average flow speed (Vr), the following equation was used:

$$Vr = 0.85 * Vrs\ (m/s) \quad (16)$$

Where Vr is the average velocity and 0.85 accounts for the surface roughness.

Therefore, the flow rate was calculated using the formula:

$$Stream\ flow\ rate\ \ Q = Ar * Vr \qquad (m^3/s) \quad (17)$$

Where Q = stream flow rate and A = cross sectional area.

Table 1: Mean monthly flow rate of Ngwerere Stream

Month	monthly discharge of the stream ($\mathbf{m^3/s}$)
March	2.0
April	2.0
May	1.78
June	1.50
July	1.35
August	1.30

4.3 Penstock design

According to Kunwor (2012), the first step in penstock design is to choose the material. After selecting the material for the penstock, it is necessary to determine its length, diameter and thickness. It is also important to determine the velocity at which the water will be flowing in the penstock. The fundamental dimensions of the penstock were estimated according to Boahen (2013).

4.4 Design of a Turbine

After the flow rate and head was determined, the turbine selection chart was used to determine the type of turbine that will be used. On the chart, the horizontal axis is the flow rate while the vertical axis shows the net head. Since the turbine type depends on the flow rate and head, the flow rate that was determined was 2 m^3/sec and the head was 4 meters. The region where the two parameters intersect will give the suitable type of turbine to use.

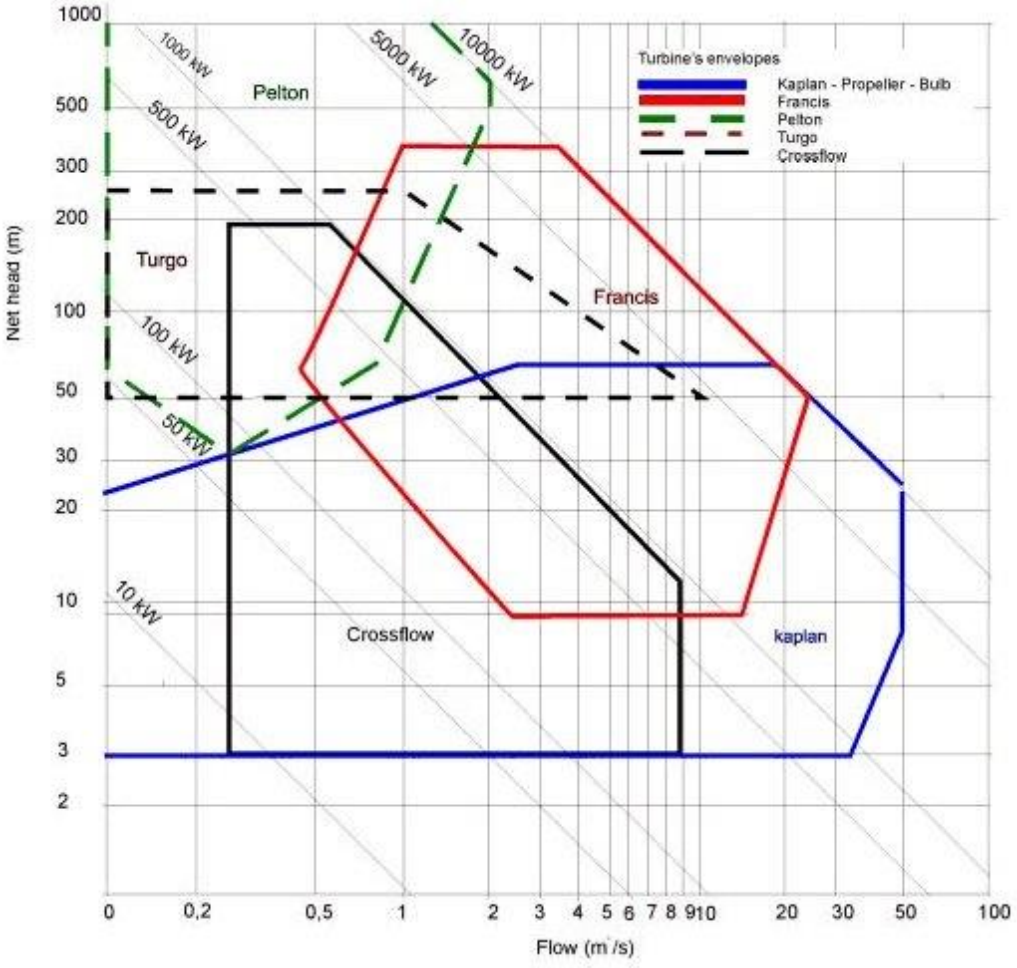

Chart: Turbine Selection Chart (Bjørnåvold, H, 2013)

The suitable turbine for this plant is Crossflow turbine. After selecting the suitable turbine type, the fundamental dimensions of the turbine were estimated according to Nasir (2013).

4.5 Generator Specifications

The output of synchronous generator in kVA is calculated from the following equation;

$$\mathrm{P\ (kVA)} = \frac{\mathrm{P\ (kW)}}{\mathrm{pf}} \qquad (18)$$

Where P (kW) is the mechanical power of the turbine and pf = power factor which is 85%.

The rated rotational speed is specified according to the frequency of power network and the number of poles as shown in the equation

$$N_s = \frac{120f}{P} \quad (19)$$

Where N_s= the synchronous speed f = frequency of the system and p = number of poles.

The number of poles is calculated by rearranging equation (19). Therefore, $p = \frac{120f}{N_s}$

Table 2: Summary of Project Technical Specifications for a MHPP

Components	Critical Dimensions
Location of site	Latitude 28° 19' 53.22" E and Longitude 15° 19' 54.26" S
Gross Head	4 meters
Mean Flow rate	1.66 m^3/s
Penstock	Material – Mild Steel
	Diameter – 1.22m
	Thickness – 5.5mm
	Length – 100m
Turbine	Crossflow – (64 kW)
	Rotational speed – 750 rpm
	Runner diameter – 0.11m
	Runner length – 7.87 m
Generator	Size - 75 kVA
	Rotational speed – 750 rpm
	No. of poles – 8 pole generator

4.6 Demand Assessment

It is very important to carry out the demand assessment in order to know if the power that will be generated can meet the demand. Demand can be calculated as shown in table 3. The table shows the connected Load in kW for each connected device.

Table 3: Calculation of electricity demand

Device	No. of households having device	Quantity	Power rating (W)	Connected Load (W)
Energy saving bulb	20	5	15	20X5X15 = 1.5kW
55” LED LG TV	20	1	67	20X1X67 = 1.34kW
Multi-Choice decoder	10	1	45	10X1X45 = 0.45kW
Irrigation pump set	10	1	5.5hP=4.1kW	10X1X4.1 = 41kW
Home theatre	10	1	90	10X1X90 = 0.90kW
Refrigerator	05	1	600	25X1X600 = 15kW

5. Simulation Results

5.2 Simulation results of a MHPP

The following figures shows the simulation results that were obtained in MATLAB/Simulink. Fig. 3 shows the stator three current characteristics with respect to time. The magnitude of the phase current observed is 56 Amperes which is the rated phase current of the generator. The stator phase voltage is plotted as shown in fig. 4. The magnitude of the phase voltage output is observed to be 240.4 volts which is the phase voltage output of the generator. The three phases lag each other by 120 degrees.

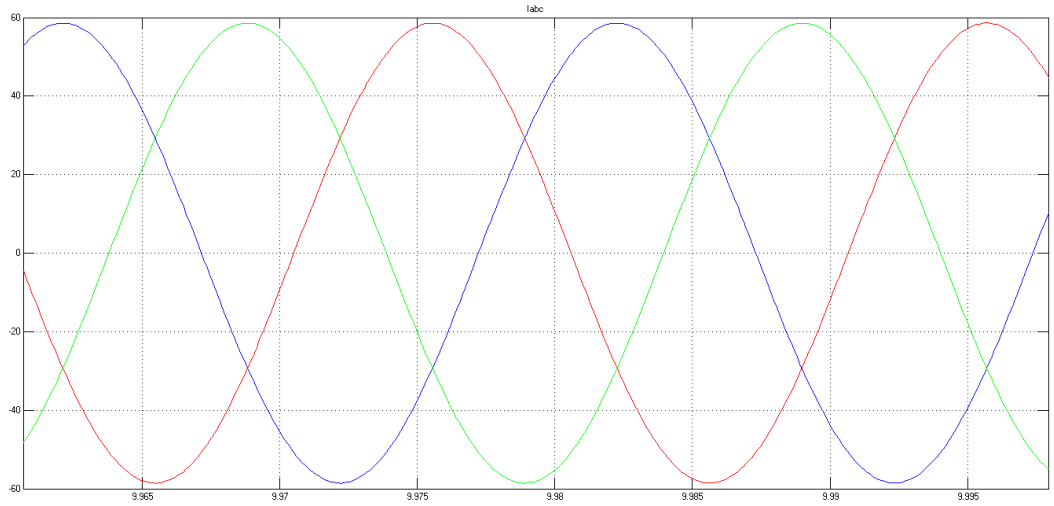

Fig. 3: Three phase current characteristics with respect to time

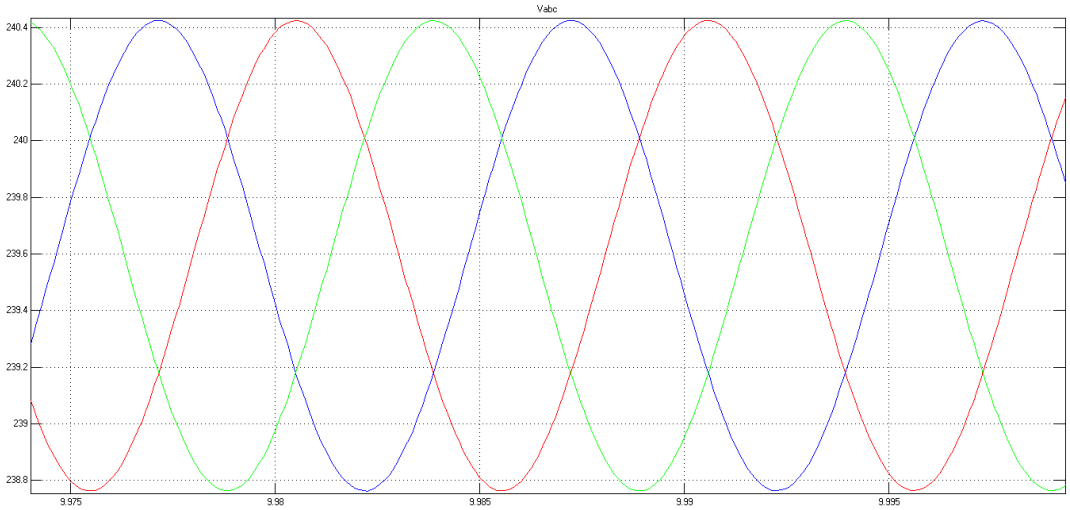

Fig. 4: Three phase voltage characteristics with respect to time

5.2 Simulation results of a QAB converter.

Fig. 5 below shows the simulation graph of how a QAB converter operates. From time t=0.5 sec to 1 sec, the solar (PV) is producing 25W while the battery produces 124.92W to supply a load of 150W. When a step change in load current is applied at time t=1 sec, the battery discharges more power to meet the demand since the PV continues to produce 25W. When the power produced from solar increases from 25W to 125.7W, the power needed from the battery to meet the load demand of 270W is 144.24W. At time t=3 sec, there is a step change in line current. The load is now drawing power from 3 sources; solar, battery and mains.

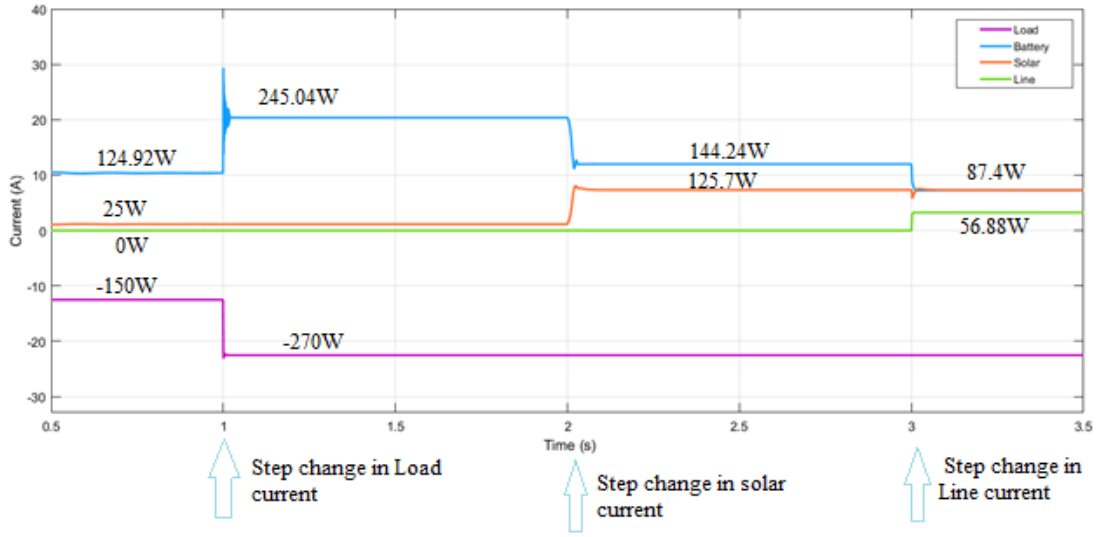

Fig 5: Simulation results of a QAB converter

6. Demand side management

Demand side management (DSM) has two aspects: develop efficient utilization for electricity, (less electricity for each utilization) and take measures to encourage the customer to help flattening the load curve.

Customers are encouraged to use energy efficient bulbs. The government has banned the use of incandescent bulbs from 2016 onwards. This implied that only energy efficient bulbs would be allowed to be sold to customers in Zambian shops. For example, changing a 100-watt incandescent light bulb with a 23-watt CFL reduces energy use by 77-watts when the light bulb is in use. Some of the bulbs which can be found now on the market have motion detectors, implying that they come on once they detect the presence of a person in the room. This is a very efficient way of utilizing electrical energy as it avoids wastage, Mpanga, *et al* (2016)

The customers should be encouraged to switch off lights during the day and in the night when not needed. This is extended also to switching off other appliances which are not in use. For cooking purposes, gas stoves are now being preferred to electric stoves.

Farming is one of the common along Ngwerere stream. Therefore, the power generated from hydro can be used run the pumps. Some common pumps are rated in the range of around 1 HP drawing power of about 1.2 kW for pumping operations.

7. Discussion

Arising from the findings in section 4, it was observed that the stream flow rate was changing all the time. And so, it is important to measure the flow rate at various intervals of the year. The flow rate measurements were done twice a month for the whole academic year using the velocity-area method because the proposed site has no flow records or gauging stations. The best estimation of water flow rate is obtained when measurements are done for at least one year. It is recommended that the river should be gauged to obtain accurate discharge information before any serious hydropower development can be done.

Furthermore, a detailed feasibility study should be carried out. The feasibility analysis should include survey regarding hydrological, geological and topographical analysis. Based on this data, appropriate location for water intake, headrace canal, forebay and the size of the powerhouse can be determined.

8. Conclusion

This paper developed an electrical design of a micro hydropower plant to be implemented on Ngwerere stream. The penstock material selected was mild steel with the following dimensions; diameter of 1.22m, thickness of 5.51mm and length of 100m. The choice of turbine depends mainly on the pressure head available and the water flow rate. Crossflow turbine was selected as the suitable turbine since it meets both head and power requirements which can be produced by the plant and also maintains appreciable efficiency at low flow rate. The turbine was sized to produce power output of 64 kW with a runner diameter of 0.10m and a runner length of 7.87 m.

An 8 pole synchronous generator with a rated power of 75 KVA and a rotational speed of 750rpm was selected.

The micro hydropower plant will be coupled to a hybrid of PV-battery system through a four port DC-DC converter and the voltage source converter. Each port of the converter is rated at 300 W. From the simulation results, it was shown that the load was able to draw power from different energy sources. However, detailed simulation results were not carried out to show how voltage is maintained at the point of common coupling.

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Design of a Subsonic Table Top Wind Tunnel

Kelvin Chongo[1], Haggai Kasawa, Philimon Sakala, Phillip Kayuni, Wezi Nyimbili[2]

Abstract

The Aeronautical Engineering Department after its establishment and introduction of the Aeronautical Engineering degree program at the Copperbelt University has faced the challenge of lack of teaching aid, as is the case in other tertiary education institutions in Zambia (Writer, 2017). The acquired knowledge from the program has fortunately been used to help alleviate this challenge, by developing a vital tool required for visualization of flow and predicting approximate aerodynamic effects around objects, an open circuit subsonic wind tunnel. This paper describes the design and fabrication of a subsonic Table top wind tunnel by demonstrating the application of the Bernoulli and Continuity equations. The significant properties studied in this wind tunnel are, Drag force, flow visualization and lift force generation. By fixing the test cross section size to 0.15m × 0.15m, and conducting calculations assuming isentropic flow; a 2425mm long, 565mm wide and 540mm high wind tunnel was designed and fabricated using cheap plywood and Perspex glass.

Keywords: Wind tunnel, aerodynamics, subsonic, flow visualization

1. Introduction

Understanding and predicting the performance of an Aircraft before mass production is just as vital as the production itself, inaccurate performance prediction can lead to the Aircraft not entering service and loss of huge sums of money (Thurber, 2006). Apart from use of CFD simulations which are, cheaper, reliable and trustworthy to predict performance (Jha, 2016), the wind tunnel is another means that has stood the test of time. Despite also being a form of approximation, understanding its limitations and benefits helps the engineer leverage the results to get closer to the real world effects (4y, n.d.). An understanding of aerodynamic behavior is necessary in the calculation of products' performances and loads, and the innovation for the optimization of conditions they face in their environment (Schneider, 2001).

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The purpose of this project is to design an experimental device for the study of aerodynamic effects and understanding flow characteristics at various subsonic velocities. The results obtained would provide researchers and/or students with practical results on a number of experiments, help in understanding the Bernoulli and continuity equation applications and also help to visualize the actual flow (Rubiaco, 2016).

A wind tunnel is a tube shaped facility that allows air to move over or around a vehicle or object as if it were flying (May, 2014). By moving the air around the object, the conditions of the object in flight are simulated and this has proven to be very helpful to researchers as they learn more about how an aircraft will behave in actual flight (May, 2014). The properties and characteristics studied in a wind tunnel are, pressure, Drag-lift forces and air flow direction affecting the object (unknown, 2017).

Wind tunnels can be classified according to speed regime in the test section (Subsonic, transonic, supersonic or hypersonic) or according to tunnel geometry (open return, closed return or blowdown). Sometimes, they can also be classified according to the working fluid (water or air) (hall, 2015). The ratio of the flow velocity to the speed of sound is referred to as Mach number and works as a classifying point under speed regime. The Wind tunnel that was designed is an open return subsonic wind tunnel with Mach number 0.1 (zero point one) in the test section and was named HAVIN-PHIL[3]. Open return wind tunnel is one that is open on both ends and draws air from the sorrounding into the tunnel and then goes out the other end (hall, 2015), it was chosen because of the low construction cost and less physical space demand. The development of this tool has enhanced practical knowledge and deeper understanding on subsonic flow effects over and around objects.

2. Wind tunnel Design

The wind tunnel has five important sections: the settling chamber, cone section, test section, diffusing section, and the fan. Several considerations had to be made in order to achieve desirable wind tunnel properties. Factors considered in designing this wind tunnel are:

- Low cost
- Portability
- Ease of fabrication
- Test section dimensions (Length ×width × Height): 30 ×15×15cm
- Maximum operating speed in the test section of 34 m/s

[3] HAVIN-PHIL – Named after the names of the four students who designed the wind tunnel. **HA** from **Ha**ggai, **VIN** from Kel**vin**, **PHIL** from **Phi**limon and P**hi**llip.

2.1 Wind tunnel parts

2.1.1 Settling Chamber

The purpose of the settling chamber is to straighten the airflow (Hall, 2005). The material used to make the honey comb was domestic drinking straws of about 5mm in diameter and were cut to a length of about 80mm and attached using an adhesive.

2.1.2 Contraction Cone

The contraction cone takes a large volume of low-velocity air and reduces it to a small volume of high velocity air without creating turbulence (Chandler, 2017).

2.1.3 Test Section

The test section is where the test models are placed (Hall, 2005). Perspex glass was used on the test section because it is shatter proof, flexible and easier to fit (international, 2000). Three plies of Perspex were used in the sides and a double Perspex ply was used on the base. In order for the test section to be accessible for the insertion of various test models, a single Perspex ply top part was designed with an opening mechanism using two butt hinges on one side and a simple bolt and nut handle on the opposite side, the section was designed with overlapping outer plies to facilitate attaching and detaching of the test and cone section assembly.

2.1.4 Diffuser

The diffuser slows the airflow speed of the wind tunnel (Hall, 2005) and is 1200mm in length with a square cross section of 150mm on the test section side and 260mm on the fan section side. The length of the diffuser is designed to have a relatively longer length in order to decrease the flow velocity gradually.

2.1.5 Fan Section

The fan section contains a fan that provides a force that causes the air to move through the wind tunnel by suction (Hall, 2005). In order to attach the fan to the diffuser without changing the calculated measurements of the wind tunnel, a semi diffuser assembly was designed as a permanent attachment to the fan casing.

2.2 Assembly

The five sections where constructed separately and assembled into two sub-assemblies to enable portability of the wind tunnel.

The settling chamber, contraction cone and the test section make up the first sub assembly (assembly 1) while the second assembly (assembly 2) is made up of the diffuser, and fan section.

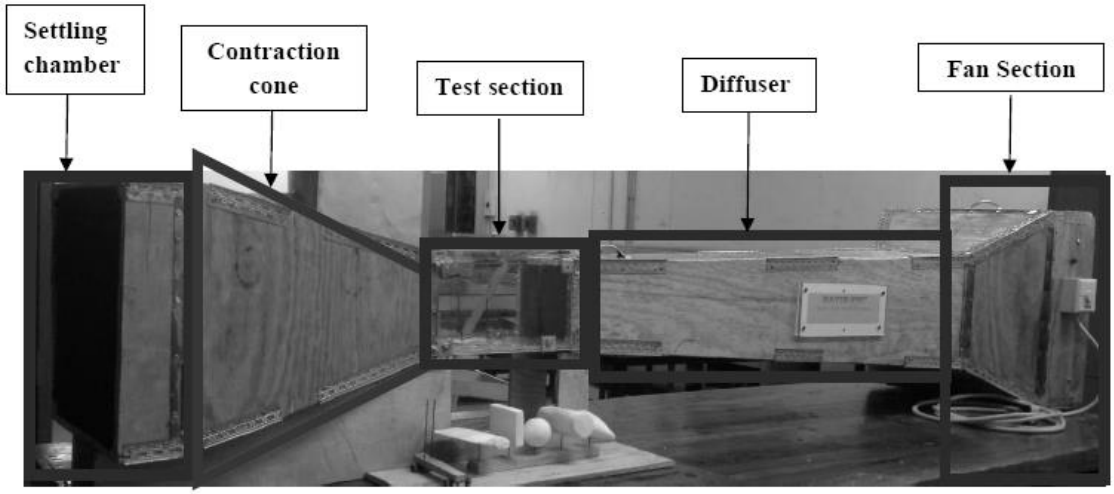

Figure 1: Wind tunnel assembly showing parts

The method used to join the different parts in the mentioned sub-assemblies was use of piano hinges, wood glue and silicon sealant. Air tightness in the joints was achieved by, firstly putting wood glue in the joints and closing up the joint with a layer of silicon sealant.

3. Testing

Five different test models were made out of Styrofoam and were tested in the wind tunnel (See figure 2) the shapes (models) made were;

- Cylinder
- Sphere
- Cambered Aerofoil wing
- Flat plate
- Spherical cone

Apart from flow visualization, all the other tests were made possible by use of a spring scale graduated in Newtons, the different models were attached to the spring scale via a thread.

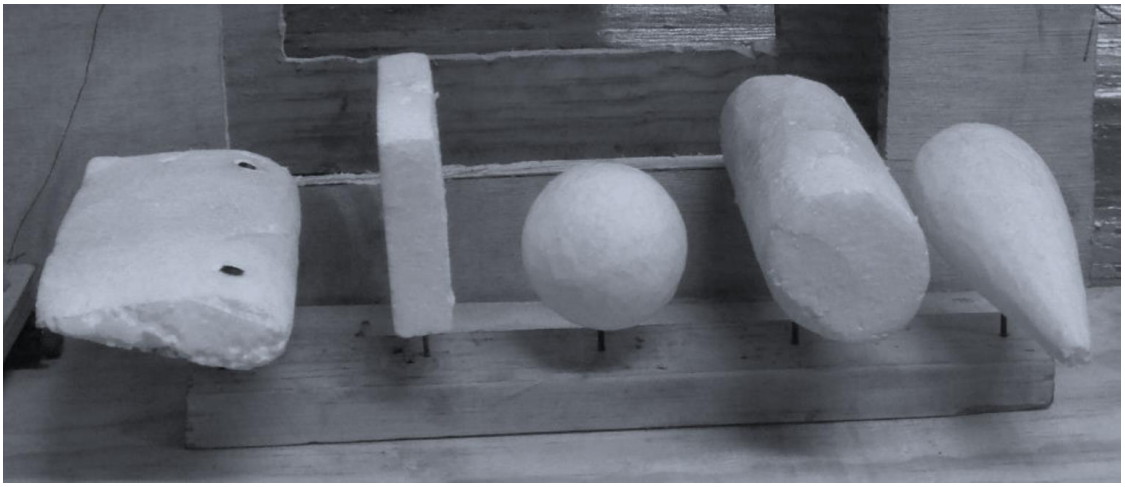

Figure 2: Test Models

The cylinder, sphere, spherical cone and the flat plate where tested for profile drag while the cambered Aerofoil was tested for lift and drag. The cambered Aerofoil was also used for Flow visualization in the test section by use of a cotton thread.

4. Conclusion

A complete Open circuit subsonic wind tunnel was designed and fabricated. All the desired tests were conducted and hence the objectives of the design were met. The wind tunnel is good for laboratory purposes and as teaching aid for the demonstration of flow around objects. It will serve the need to alight the researcher and/or student to real life situations in terms of flow visualization and other related experiments.

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Design and Fabrication of an agitated Grain Sieving Machine

Luhanga Mbela[1], Darlington M. Masendeke[2]

Abstract

This paper presents the design and fabrication of an agitated grain sieving machine. The agitated grain sieving machine is aimed at eliminating dirty particles from the grains thereby satisfying customers' safety needs. The machine can also be used to separate different types of grains by taking advantage of their differences in sizes. In this machine, material separation is made easier by inducing vibrations which in turn agitates the materials to be separated. The objectives of this research were to generate concepts, evaluate concepts, select the best concept of the agitated grain sieving machine, to build and test the working prototype of the machine. The sieving machine is made up of a supporting frame, a tilting frame, four compression springs, an assembly of sieve stacks consisting of the upper mesh, lower mesh and the small particles collector. Other components include the vibratory motor, AC/DC adapter and three delivery chutes. The vibratory motor powered through an AC/DC adapter to step down voltage from 240V AC to 12V DC, is mounted to the base of the sieve stack assembly, to transmit vibratory motion to the material to be separated. The separated materials are delivered to their respective collectors (containers) through delivery chutes. In this research data was collected through conducting literature survey and site visitations. Concepts were then generated and evaluated. Finally, the working prototype of the selected concept was fabricated for testing. Five experiments were conducted by varying two parameters namely, the eccentric mass added to the motor and the angle of inclination of the sieve stack assembly. From the experiments it was noted that the optimum operating values for the eccentric mass and angle of inclination are 30g and 15°, respectively.

Keywords

Grain, Sieving machine, Agitated, Design, Fabrication

1. INTRODUCTION

A sieve is defined as a device for separating wanted elements from unwanted material, typically using a woven screen such as a mesh or net or metal [1]. Therefore, in this design an agitated sieving machine is aimed at separating grains from dirty particles. Sieving plays an important role in food industries where sieves are used to prevent the contamination of the product by foreign bodies [1]. In addition, high quality sieving of

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grains is of great importance to the food processing industry in order to satisfy customers' needs. Sieving can also be referred to as screening [2]

The agitated grain sieving machine which is electrically powered is an alternative technological invention that can help in sieving grains to remove dirty particles by means of delivery chutes placed between the agitated sieve stack and the collectors. In this design, the motion of grains to be sieved is initiated by vibrations induced to the sieving machine. Furthermore, the provision of delivery chutes ensures that the separated materials are delivered in an environmentally friendly manner. This technology ensures that there is a reduction in direct human labour. Furthermore, it also saves on time owing to the sieving machine vibrations that ensure easy and efficient sieving. Thus, using vibrating sieving machines is more efficient compared to manual processing of grains [3]. All in all, this machine can be manufactured by local industries in Zambia using the locally available materials to help food processing industries, farmers and marketeers in sieving their grains in an environmentally friendly manner.

The agitated grain sieving machine is made up of a supporting frame, a tilting frame, four compression springs, an assembly of sieve stacks, vibratory motor, AC/DC adapter and three delivery chutes. The four compression springs are brazed to two plates at the top and bottom and are mounted to the assembly of sieve stacks and to the tilting frame by means of bolts and nuts. The springs keep the sieve stack assembly in suspension, to facilitate vibration. The tilting frame is hinged to the supporting frame so as to allow for angle adjustments during sieving. The vibratory motor powered through an AC/DC adapter to step down voltage from 240V AC to 12V DC, is mounted to the base of the sieve stack assembly, to transmit vibratory motion to the materials to be separated. The separated materials are delivered to their respective containers through delivery chutes.

Two other design concepts of the agitated grain sieving machine were also generated. In one concept, the rotary motion of the motor was converted to reciprocating motion of the sieve stack. To achieve the reciprocating motion, two links connected by a pin were used. One link was firmly fastened to the sieve stack while the other link was connected to the motor by a pin at an offset distance from the centre of the motor shaft axis. The challenge with this concept was that the material to be separated was repeatedly thrown back and forth thereby delaying the separation time. The other concept was the rotary sieve stack. In this concept, the motor was positioned with its shaft axis in the vertical orientation. The base of the sieve stack was perpendicular to the motor shaft axis. This concept was not selected owing to the difficulty of collecting the separated grains.

As part of concept generation, other sieving technologies were also considered such as the vibratory sieve shakers, the AS 200 Series, the AS 300 Series, the AS 450 Series of sieving shakers, horizontal sieve shakers, tap sieve shaker and the Roto-sieve drum

screen. All these technologies were found to be good at sieving solid particles but have limitations in terms of their applications. For example the Roto-sieve drum screen is used to remove solid particles from waste water [4].

2. METHODOLOGY

The methodology employed in this research was both qualitative and quantitative. It was qualitative in the sense that the data was generated through conducting literature survey and interviewing marketeers. The literature survey helped in the generation and evaluation of concepts. On the other hand, interviewing marketeers helped in developing the design of the machine based on their sieving concerns such as sieving time, labour etc. The quantitative aspect of the methodology involved the fabrication of the working prototype of the sieving machine, testing and conducting experiments. The experimental data were tabulated and results plotted on a graph for analysis. Thus, prototype verification and validation were successfully done.

3. THE WORKING PROTOTYPE

3.1. Design Components

The design components of the agitated grain sieving machine as shown in Figure 1 consist of a supporting frame, a tilting frame, four compression springs, an assembly of sieve stacks consisting of the upper mesh, lower mesh and the small particle collector, vibratory motor, AC/DC adapter and three delivery chutes. The four compression springs are brazed to two plates at the top and bottom and are mounted to the assembly of sieve stacks and to the tilting frame by means of bolts and nuts. The springs keep the sieve stack assembly in suspension, to facilitate vibration. The tilting frame is hinged to the supporting frame so as to allow for angle adjustments during sieving. The vibratory motor powered through an AC/DC adapter to step down voltage from 240V AC to 12V DC, is mounted to the base of the sieve stack assembly, to transmit vibratory motion to the material to be separated. The separated materials are delivery to their respective containers through delivery chutes.

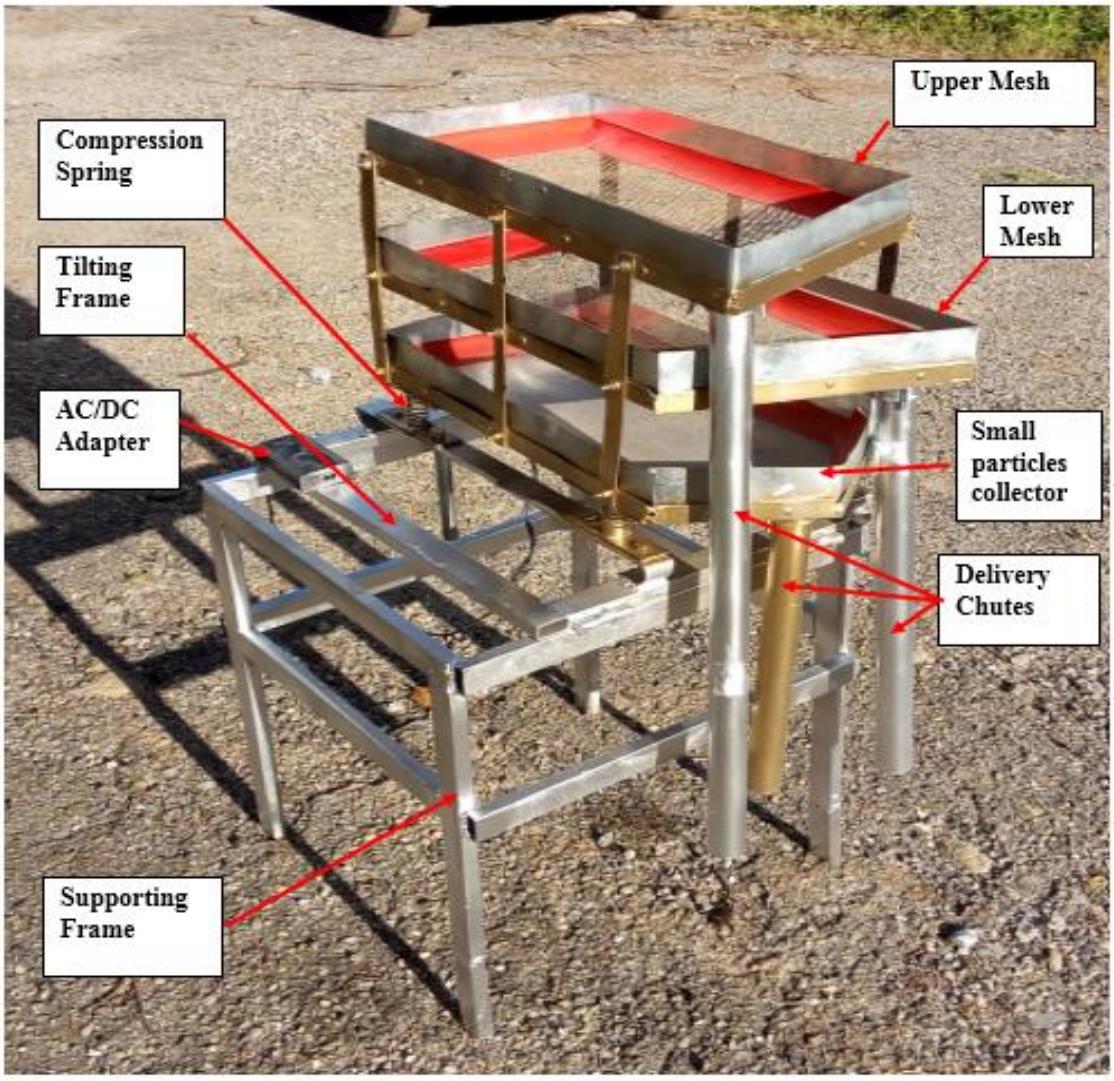

Figure 1: Components of the Grain sieving machine.

3.2. Operation of the agitated Grain Sieving machine

The operation of the agitated grain sieving machine has been explained by means of the function analysis approach, where the inputs, the overall function broken down into interconnected sub-functions, and the outputs of the grain sieve have been provided. The function analysis of the agitated grain sieving machine is illustrated in Figure 2.

To operate the agitated grain sieving machine, connect and supply electricity power to a 12V DC motor through an AC/DC adapter. The AC/DC adapter steps down voltage from 240V AC to 12V DC. Once the motor starts running, vibrations will be set up due to the imbalanced mass on the motor shaft. Then load grains on the upper mesh. Particles that are bigger than the grains will be separated from the grains by allowing the grains and other smaller particles to pass to the lower mesh where the smaller particles are separated from the grains. The sieved grains are then delivered through the chutes for storage. The separated particles from the grains are also delivered through chutes and discarded. All in all, the separation of materials is facilitated by vibrations that initiate their motion.

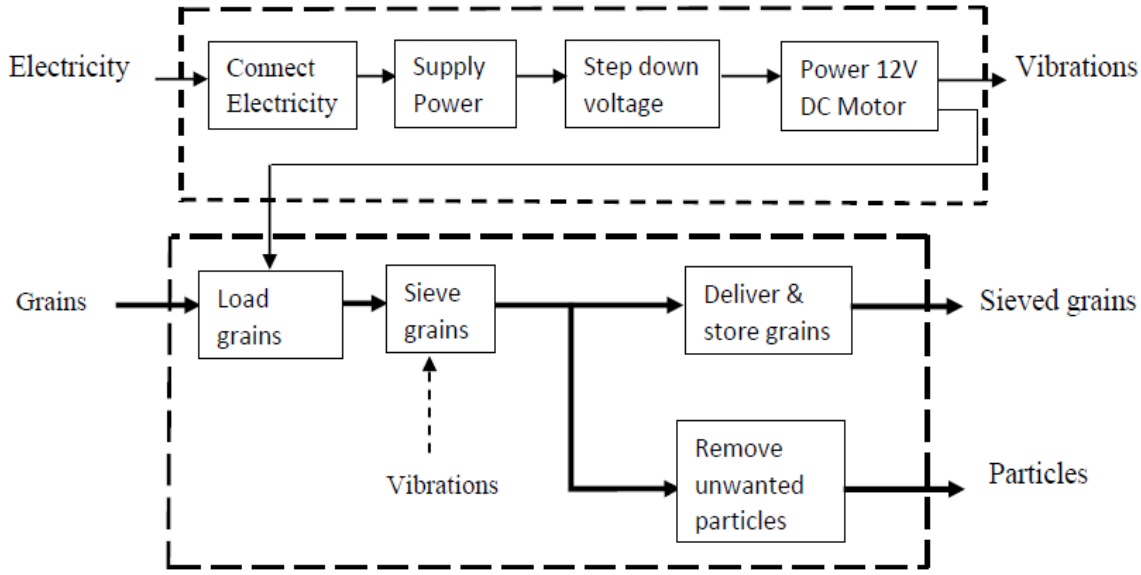

Figure 2: Function analysis for the agitated Grain sieving machine.

3.3. Prototype verification and validation

Verification tests were conducted against the following parameters;

- Eccentric mass, to determine the required size
- Angle of inclination, to determine optimum value for efficient and effective sieving

Prototype validation was achieved by doing demonstrations based on the achieved results.

4. RESULTS AND DATA ANALYSIS

Five experiments were carried out to compare the effect of changing an eccentric mass to the output at constant inclinations per experiment. These experiments were conducted at intervals of two (2) minutes. As noted from experiments 1 to 5, the output increased with an increase in eccentric mass and angle of inclination.

Table 1: Experiment 1

Eccentric mass (g)	Inclination in degrees	Output (kg)
10	0	0
20	0	0.1478
30	0	0.3036
50	0	0.3574

From experiment 1, the sieves were set at an angle of 0^0 while changing the eccentric mass. There was a steady flow throughout this experiment except for the 50g eccentric mass which caused splattering of the grains due to excessive vibrations. Generally the flow rate at 0^0 was low.

Table 2: Experiment 2

Eccentric mass (g)	Inclination in degrees	Output (kg)
10	5	0
20	5	0.4149
30	5	0.6392
40	5	0.6058
50	5	0.5672

From experiment 2, the sieves were set at an angle of 5^0 while changing the eccentric mass as in experiment 1. It was also observed that for the 40g and 50g eccentric masses, grains were splattering due excessive vibrations hence causing reduced output in the collecting vessels. In the second experiment, the rate of flow had generally increased compared to the first experiment.

Table 3: Experiment 3

Eccentric mass (g)	Inclination in degrees	Output (kg)
10	10	0
20	10	0.003
30	10	0.8038
40	10	1.0014
50	10	0.9966

From experiment 3, the sieves were set at an angle of 10^0 while changing the eccentric mass as well. It was also observed that for the 40g and 50g eccentric masses, grains were splattering due excessive vibrations hence causing reduced output in the collecting vessels. In the experiment 3, the rate of flow had generally increased compared to the flow in experiments 1 and experiment 2.

Table 4: Experiment 4

Eccentric mass (g)	Inclination in degrees	Output (kg)
10	15	0.1603
20	15	1.0481
30	15	1.2254
40	15	1.2719
50	15	1.2179

Table 5: Experiment 5

Eccentric mass (g)	Inclination in degrees	Output (kg)
10	20	1.2324
20	20	1.2431
30	20	1.2719
40	20	1.2719
50	20	1.2719

From experiments 4 and 5, similar results were obtained except that in experiment 5 the sieving time was very little hence causing the grains to be collected together with the unwanted particles meant to be separated from the beans.

From all the five experiments conducted, it was found out that the optimum operating conditions for the agitated grain sieving machine were at values of 30g eccentric mass and 15° angle of inclination of the sieve stack.

The graph in Figure 3 below shows the effect of eccentric mass on grain output.

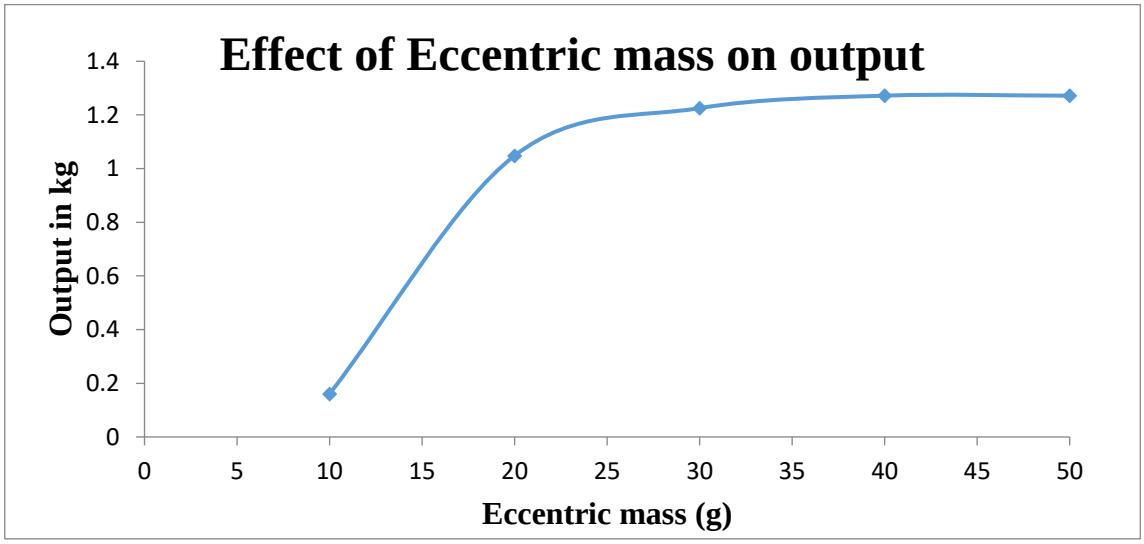

Figure 3: Effect of the Eccentric mass on output

5. CONCLUSION

A working prototype of the agitated grain sieving machine was successfully designed, fabricated and tested. Thus, this paper has demonstrated that dirty particles can be eliminated from grains by mechanical means thereby minimizing direct human effort during sieving of grains. Therefore, this machine can help food processing industries, farmers and marketeers in sieving grains in an easy and environmentally friendly manner.

From the experiments conducted it was observed that the flow rate of the material was affected by the size of the eccentric mass added to the motor and also the angle of inclination of the sieve stack assembly. It was further noted that the optimum operating values for the eccentric mass and angle of inclination were 30g and 15°, respectively.

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Lab Demonstration Unit for Traffic Lights

Chembe Banda[1], Grace Chirwa[2], Leah Musonda[3], Sonile Musonda[4]

Abstract

In this digital era more than ever an Electrical Engineering graduate needs to acquire practical skills in design and implementation of circuits that involve the use of Programmable Logic Controllers, Micro controllers and Microprocessors. In Zambia the mining, manufacturing and road transport sectors are in need of this skill. The Copperbelt University has demonstrated the ability of imparting these skills at Diploma and Degree level as they designed their own resilient traffic lights which were installed on campus. In addition a solar powered version of the traffic lights was also designed by graduating students. However, in reality, the students that had their skills developed in this area were those who undertook the project. To ensure that all students needing this skill acquire it adequately, there is need for labs to be done by students to fully understand the technology used in traffic lights. This project aims at building a Lab demonstration unit for traffic lights to be used for this purpose.

Keywords: Lab Demonstration Unit, Traffic Lights, Practical Skills.

1. Introduction

Engineering education is a progression focused on teaching tools such as mathematics, software, and engineering. The process is an inherently theoretical system. In many cases, students graduate believing that they know everything needed to be engineers, but they do not. They currently learn how to operate their tools, but they need more practical training on how to use the tools they have been given over the life of their education. This includes teaching them how and when to apply the mathematics, physics, chemistry, English, and communications courses they were required to pass on route to their degrees.(Slater, 2012)

Engineering schools should focus on teaching students critical thinking skills to address why concepts and techniques are applicable to a problem. Students need to understand the underlying principles behind their tools. Most young engineers can run a MAT-LAB simulation to do a long integration that finds the area under a curve. It is only via a practical thought process that they will understand not only that the simulation needs to be done but what the area means, how to manipulate it, and why their efforts would further from such information. (Slater, 2012)

It is for this reason that we decided to create a lab demonstration unit for traffic lights. This demonstration unit was designed to be used to teach students some fundamental techniques and principles such as how relays, microcontrollers and transistors work; their applications in real world systems, as well as the process of selecting components to implement a system.

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Traffic lights were chosen for this lab demonstration unit because of the different methods in which the same systems can be built. It offers flexibility into how the students design the circuits to have working traffic lights, their ability to select different components to vary the timing of the traffic signals, and helps them feel and understand the differences that technological advancements have made in making such systems simpler by letting them build the system with old school components such as relays, counters and transistors; all the way up to the modern approach of using microcontrollers or programmable logical controllers (PLCs).

The use of modern tools such as microcontrollers and PLCs also teachers students another valuable skill in this modern day, programming. In this Information Age, most of our systems and equipment are being run by computer programs. To be able to write software that can simulate traffic lights is a simple start, but could ignite the interest in programming for students to seek more programming knowledge and venture to build the programs that run our systems of the future.

1.1 Project Introduction

Traffic lights are signalling devices used to indicate when it is safe to drive, ride or walk at a road intersection, rail or pedestrian crossing. They use three universal coloured lights of red to mean stop; green to mean go; and yellow/amber to mean ready to stop. Traffic lights have many benefits, including reduction of congestion at intersections, saving people time, as well as making the road safe for drivers as well as civilians crossing the roads.

1.2 Problem Statement

Only students that undertake projects involving relays, PLCs and microcontrollers gain the skills and understanding to design and implement them. The technologies used in traffic lights range from relay controlled, to PLC and microcontroller controlled systems. If students don't undertake projects involving these technologies, they graduate without gaining a practical understanding of how they work.

1.3 Objectives

- To understand the structure and operations of Relays, PLCs and microcontrollers.
- To write a program that will run on the microcontroller to control the traffic lights.
- To build a model of the traffic lights system with relays and microcontrollers.
- To make a manual for the traffic light system.
- To provide detailed labels and guidelines on the model that make it easy to learn about the circuit specifications and how it works.

1.4 Relevance to society

This project will educate other engineering students who didn't undertake the project on the various technologies that they learn about (relays, PLCs, microcontrollers), and how they are applied. The school will have a working model for practical teaching for the generations of students to come.

2. Literature Review

The conventional traffic light used relay and plc to control the going on and off the tree light that were employed in the system. Currently the system now is being implemented by microcontrollers; all the technologies that were used in traffic lights will be discussed briefly.

2.1 Relays

A relay is an electromagnetic switch operated by a relatively small electric current that can turn on or off a much larger electric current. The heart of a relay is an electromagnet (a coil of wire that becomes a temporary magnet when electricity flows through it). A relay can also be defined as an electromechanical device that is actuated by an electrical current. The current flowing in one circuit causes the opening or closing of another circuit. Other operating principles are also used, such as solid-state relays (Chrispin, 1997).

2.2 Programmable Logic Controller

Traffic lights can also be employed using Programmable Logic Controller (PLCs) as the controller or brain of the traffic lights. A Programmable logic controller is defined as miniature industrial computer which contain hardware and software used to perform control functions. To be more specific, a PLC is used for the automation of industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or food processing. It is designed to have multiple arrangements of digital analogue inputs and outputs with extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact (Bolton, 2006).

2.3 Microcontroller

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. They often include program memory in the form of Rom or flash memory, with a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes (Arduino Overview, 2017).

3.0 Circuit design and Analysis

3.1 Relay Block Diagram

Figure 1 shows a relay block diagram of the circuit design.

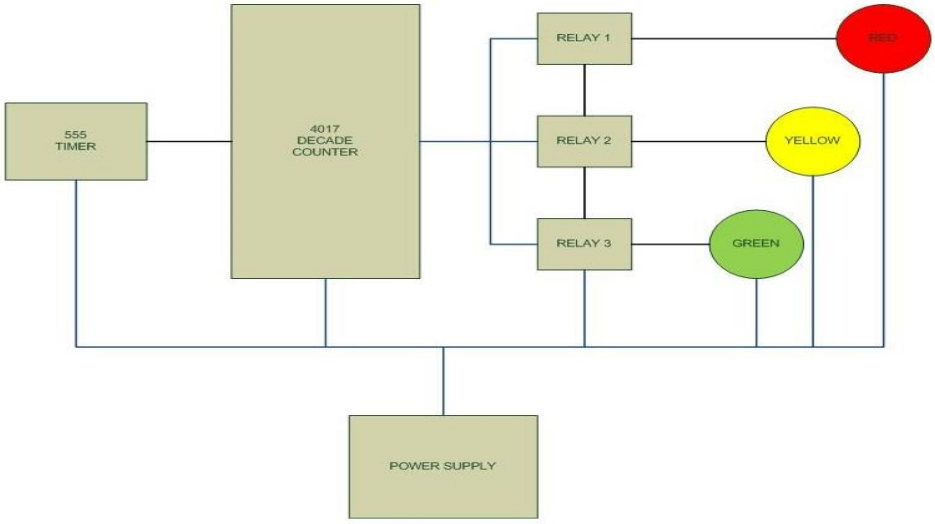

Fig. 1: Relay Block Diagram

The relay circuit uses relays to control traffic lights. It is how traffic lights were controlled in the days before microcontrollers and relays. From the block diagram presented above, each component will be explained in detail, how it operates and the purpose of it in the circuit.

3.1.1 555 timer

The 555 timer is an integrated circuit (chip), figure 2, used in a variety of timer, pulse generation, and oscillator applications. The 555 timer can be used to provide time delays, as an oscillator, and as a flip flop element.

Depending on the manufacturer, the standard 555 package includes 25 transistors, 2 diodes and 15 resistors on a silicon chip installed in an 8-pin mini dual in line package.

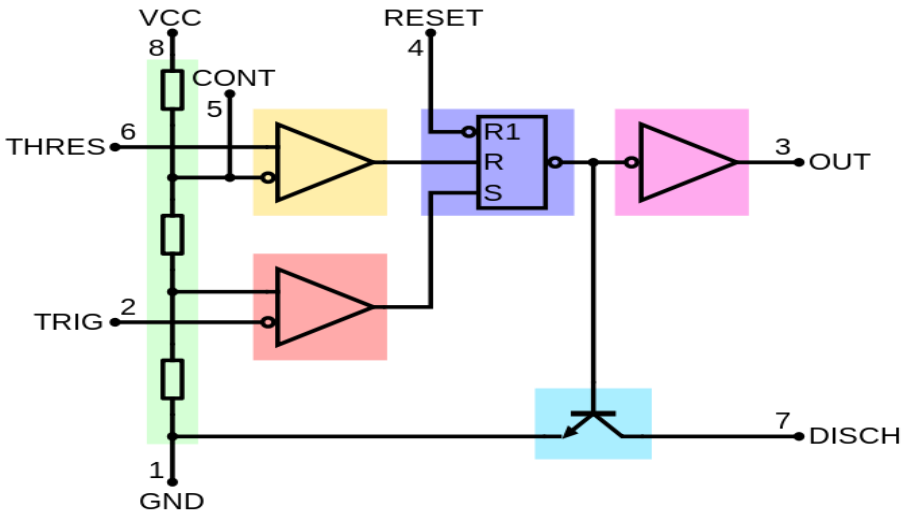

Fig.2: Pin Configuration of 555 Timer

1.3.2 Decade counter

This is also known as a BCD counter. A binary coded decimal (BCD) is a serial digital counter that counts ten digits. And it resets for every new clock input. As it can go through 10 unique combinations of output, it is also called as "Decade Counter". A decade counter, figure 3, can count 0000, 0001,0010, 1000, 1001,1010, 1011, 1110, 1111, 0000, and 0001 and so on as shown in Table 1.

Fig.3 External View of Decade Counter

Table 1: 4017 Decade Counter Pin Configuration

Pin No	Name	Function
1	6	The 6th sequential output
2	2	The 2nd sequential output
3	1	The 1st sequential output
4	3	The 3rd sequential output
5	7	The 7th sequential output
6	8	The 8th sequential output
7	4	The 4th sequential output
8	0 V_{DD}	The connection to the 0 V rail
9	9	The 9th sequential output
10	5	The 5th sequential output
11	10	The 10th sequential output
12	CO	**C**arry **o**ut output - outputs high on counts 0 to 4, outputs low on counts 5 to 9
13	LE	**L**atch **e**nable - latches on the current output when high
14	CLK	**Cl**ock in
15	RST	**Res**et - sets output 1 high and outputs 2 through 10 low, when taken high
16	+9 V, V_{CC}	The connection to the +V_{CC} rail (voltage between +3 V and +15 V)

The decade counter is being used for clock generation. It provides the counts for the traffic lights.

3.1.3 Description of a Relay

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two contacts in a relay), figure 4. The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. The armature is held in place by a spring so that when the relay is de-energised there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relays are acting as switches to the circuit.

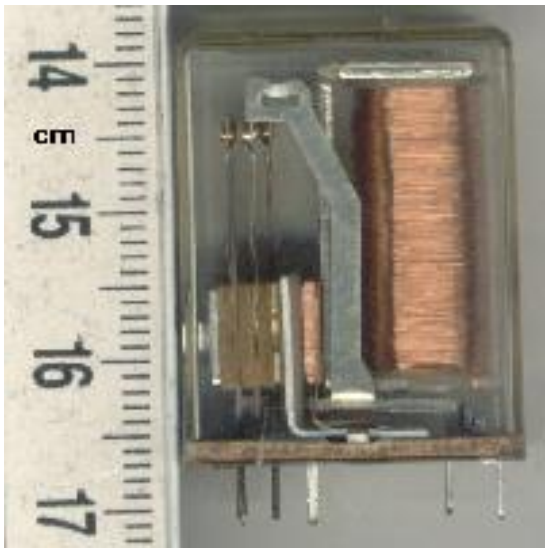

Fig.4: Physical View of Electromagnetic Relay

3.2 The Power Supply

The power supply, shown in figure 5, supplies dc power to a system when supplied with ac power and in this case a power supply was designed to power all the electronic devices that were built in this project with the desired dc voltage.

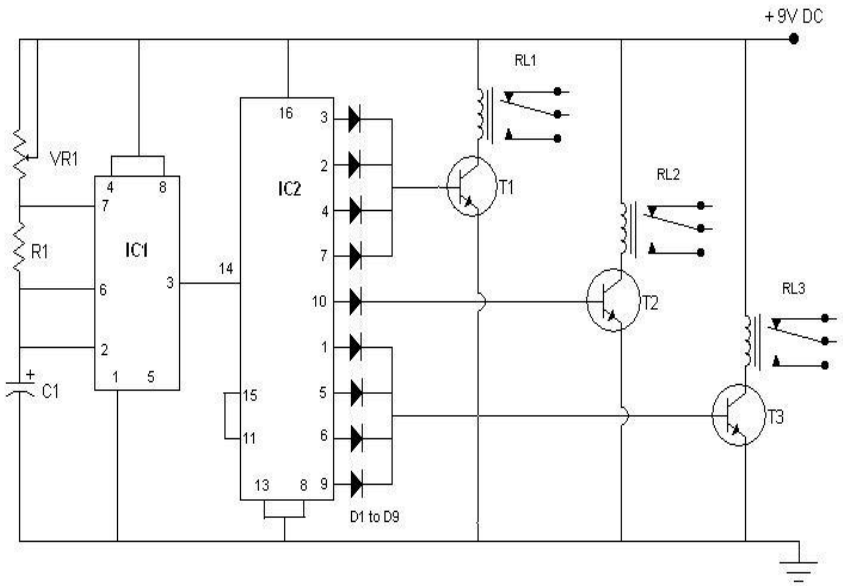

Fig.5: Circuit diagram

3.2.1 Principle of Operation of the Circuit Diagram

For every pulse fed to pin 14 of the CD 4017-decade counter, potential shifts continuously from one diode to another in cyclic order. The 555 timer is a pulse generator. It feeds the pulses to the decade counter at regular configurable intervals. The interval is determined by the value of the variable resistor. There are three transistors connected to relays on one end, and diodes on another end. The first transistor is connected to four diodes, and stays on as long as there is potential on

each diode. The relays are then connected to different coloured lights: red, amber/yellow and green. The number of diodes connected to each transistor determines how long each light at the relay stays on. So, that is four cycles for red, one cycle for amber and four cycles for green. The actual time interval is variable with the resistor.

The power supply is supplying power to the 555 timers, decade counter and the relays. The 555 timer is providing the pulses that will trigger the relays. The decade counter is providing the count for the LEDs, the count depends on the amount of time allocated to each diode. The diodes change accordingly. When red goes on the vehicles have to stop, the amber goes on in readiness for the vehicles to start and green goes on to allow vehicles to start moving.

3.3 Description of Microcontroller Controlled Traffic Lights

In this type of traffic light system, the microcontroller controls how long each light stays on, and can perform other activities like displaying on a seven segment display how long each light stays on. This is done according to the program that is running in the microcontroller. Figure 6 shows a block diagram of a microcontroller based system.

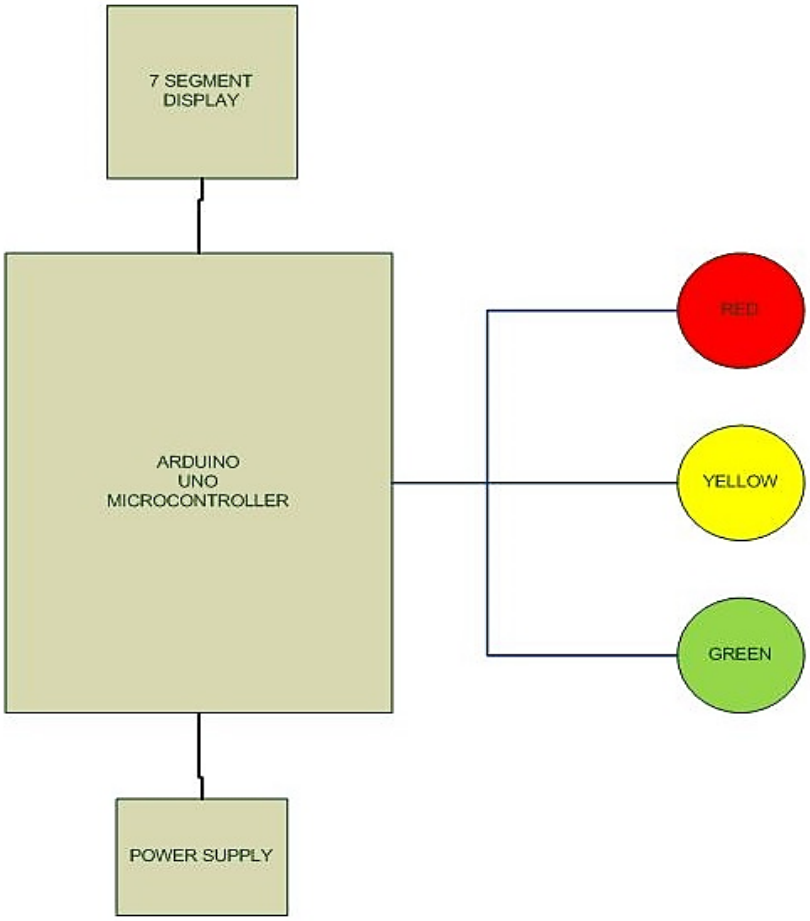

Fig.6: Microcontroller based system

The microcontroller is the main component in this circuit; it is the device that controls the turning on and off of the light emitting diodes. It can also be considered as the controller or brain of the entire system. The specific microcontroller used in this project is the Arduino Uno. Arduino Uno is an open-source physical computing platform based on a simple I/O board and a development environment that implements the C programming language. Arduino can be used to develop

stand-alone interactive objects or can be connected to software on a computer (e.g. Flash, Processing, Max/MSP). Figure 7 shows a picture of the Arduino Uno microcontroller device.

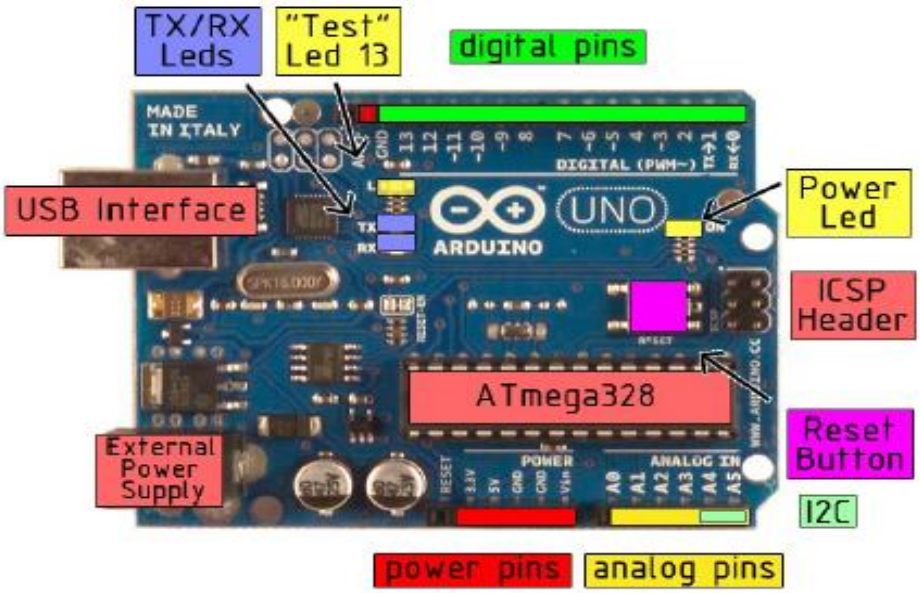

Fig.7: Microcontroller Aduino Uno

3.3.1 Types of Light Emitting Diodes (LEDs)

The light emitting diodes used here are red, yellow and green (figure 8) for signalling, the red light always means stop, the amber or yellow light comes after green and indicates that the lights are about to turn red and a green light means you can go, as long as it's safe to do so. In this project, the LEDs represent what has been mentioned above. Below show the three LEDs that are going to be used.

Fig.8: Types of LEDs

3.3.2 Description of the Seven Segment Display

A seven-segment display (SSD) is a widely used electronic display device for displaying decimal numbers from 0 to 9. They are mostly used in digital clocks, timers and calculators to display numeric information. As its name indicates, it is made of seven different illuminating segment which are arranged in such a way that it can form the numbers from 0-9 by displaying different combinations of segments. It is also to form some alphabets like a, b, c, d, e, f, g. In this project the 7-segment display is employed to indicate how long each LED will stay on. Figure 9 below show a picture of a 7-segment display.

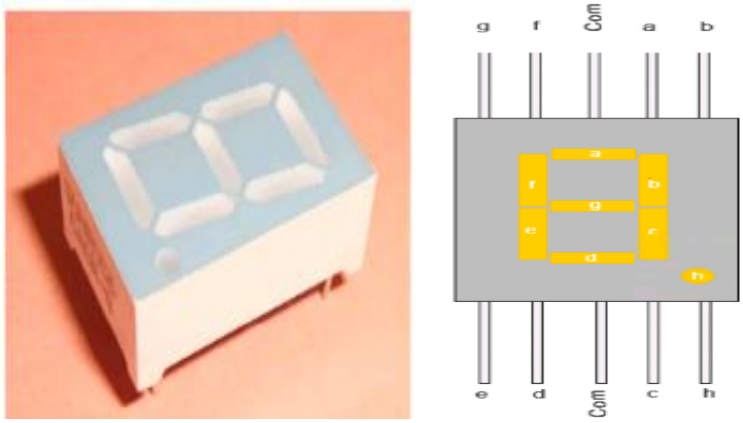

Fig.9: Seven segment display

The diagram in figure 10 shows how a seven segment display is wired to the microcontroller controlled traffic lights.

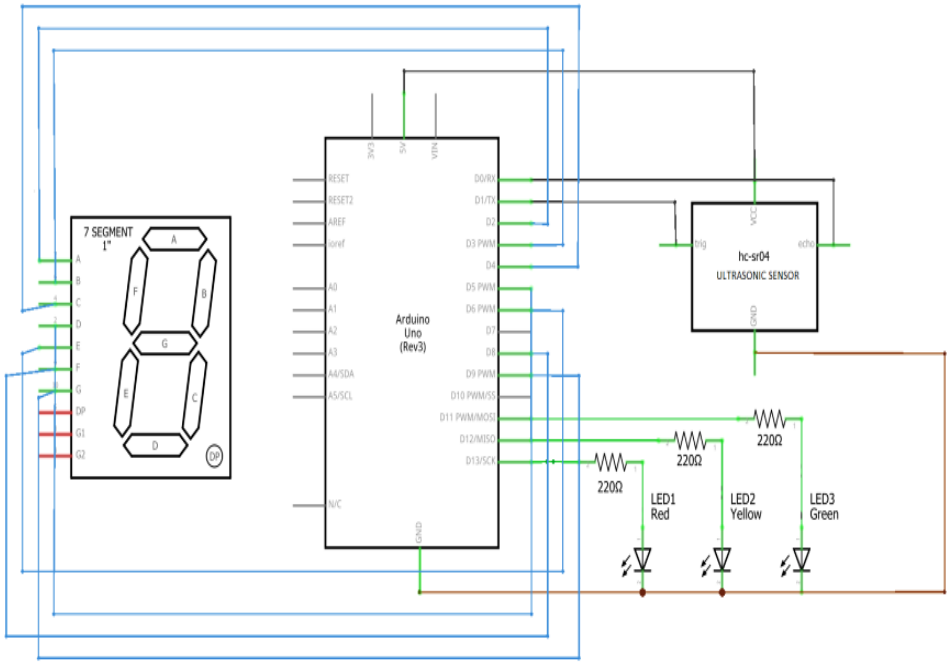

Fig.10: Circuit for Microcotroller based System

3.3.3 Principle of Operation of the Arduino Uno controlled Traffic Lights

The Arduino Uno will run in accordance with the program written on it (for the program running in the Arduino see the index at end of this thesis) and will supply power to the LEDs that will go on for a programmed period of time. Resistors in this circuit are used to protect the diodes from blowing up since they only require 0.7V and are being supplied 5V from the Arduino microcontroller. The 7-segment display is used to display a countdown of how long each of the diode stays on.

4.0 Simulations

Simulations of the relay traffic light system were carried out using Proteus, figure 11, and the results were as expected.

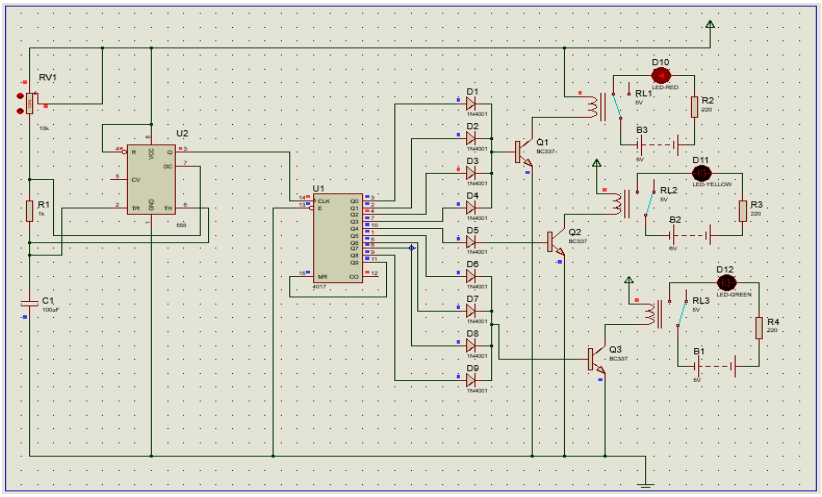

Fig.11: Sumulation for Relay based system

The program loaded on the Arduino, is represented in the flow chart shown in figure 12.

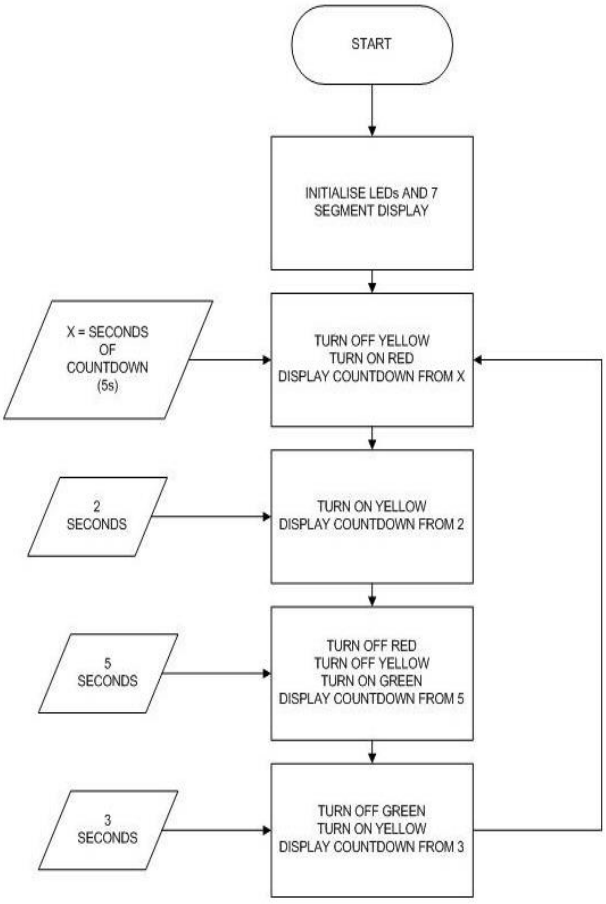

Fig.12 Program Flow Chart

From the above flow chart, the program runs in a continuous loop turning on the traffic light LEDs in the set sequence of red, then yellow, then green. This goes on and on till the Arduino is turned off. The timing of each of the LEDs is set in the program by using the delay() function between turning on and off of the lights. To turn off an LED, you use the digitalWrite() function and pass an argument of either LOW, or HIGH, in the brackets i.e. digitalWrite(PINNUMBER, LOW) or digitalWrite(PINNUMBER, HIGH). So, using these commands, we can control the signals and timing of our traffic lights, programming the sequence of light changes and the amount of time between changes.

4.1 Arduino Simulation

The simulations of this system were done using Proteus 8.4. The simulation was run successfully, the Arduino turns on the traffic lights as programmed. The result of the simulation is as shown in figure 13.

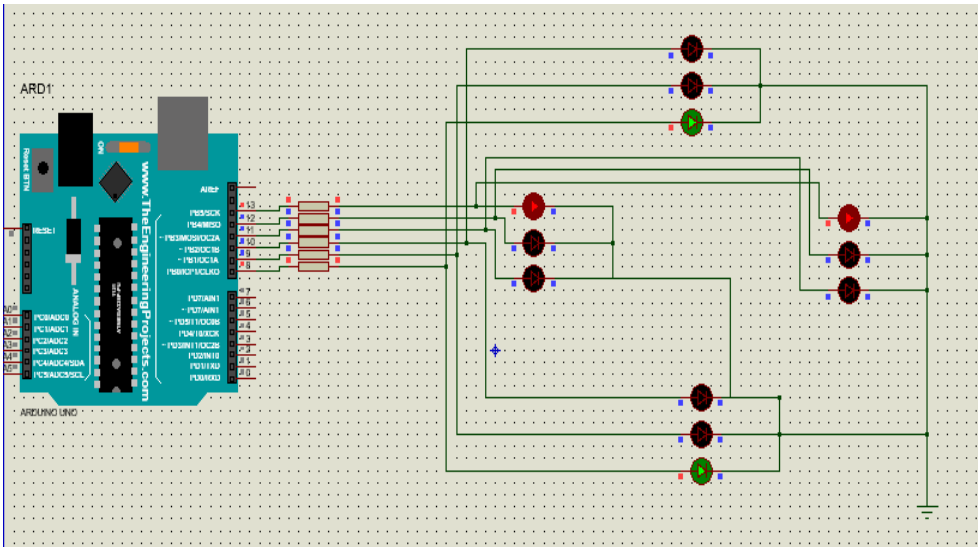

Fig.13: Simulation of Microcontroller based system

Figure 14 shows a picture of the final assembled unit.

Fig.14: Demonstration Unit for Traffic lights

5.0 Conclusions

In conclusion, the Lab demonstration traffic light unit is a system that was designed to equip student with the necessary in information and practical skills of how electronic components are assembled together to create a working model that is beneficial to the world around us and how the various advancements in technology have brought greater benefits and simplified our way of doing things in the traffic light signalling industry.

This project was a success as all the objectives and goals where meet. In fact, the model for traffic lights was designed and made, the circuits where designed and wired and are working as required.

This was an undergraduate project carried out in which, while learning to build and implement our system, we also ventured to teach to our fellow students the knowledge we gained from undertaking the project. Each year, over a dozen projects are undertaken by students, in which a lot of hard work and money is put in, only to be packed up after their final presentations. If these projects were used as teaching aids for students of the following year, we wouldn't have a shortage of demonstration units in our labs, and our students would be better off.

It is our hope that more engineering schools in the country can adopt more lab demonstration units that impart practical skills into our students. This will not only increase the quality of engineers in industry, but could help improve the manufacturing and value addition industry as more engineers equipped with practical skills are a vital part of any industry. They will be able to deliver anything that is needed with the right training. It only takes initiatives such as these to improve engineering education.

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