# PROCEEDINGS

of the

# The Engineering Institution of Zambia

## 2016 SYMPOSIUM

**"Achieving Sustainable Industrialisation"**

**22nd April 2016**

**Avani Victoria Falls Resort**
**Livingstone**

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## Foreword

Welcome to the Engineering Institution of Zambia (EIZ) 2016 National Symposium at Avani Victoria Falls Resort, Livingstone, 22nd April 2016. The 2016 EIZ Symposium is themed "**Achieving Sustainable Industrialisation**", reflecting the Institution's commitment to contribute to the formulation of industrialisation strategies that would lead to wealth and job creation in our country.

The programme for technical papers presentations is in six sessions which are arranged in three parallel sittings. All the papers in this book of proceedings were refereed through a double blind review selection process. In addition to these parallel paper presentations, we are proud to inform that the programme includes two plenary presentations, a keynote presentation by a distinguished industrialist to be made during the opening session, and a presentation on leadership to be made during the closing session of the symposium. Furthermore, we have included engineering students' project presentations as one way of involving future engineering professionals.

Finally, we would like to express our thanks to the authors of the technical papers and paper reviewers, whose work and dedication made it possible to put together a programme that we believe is very exciting and of interest to the engineering community and the nation at large. Personally, I wish to express my appreciation to the members of the EIZ Publications Committee for coping with the extra work load and ensuring that all the papers were ready for the symposium.

We wish you all an exciting symposium.

Eng Levy Siaminwe, PhD
Chairman, EIZ Publications Committee

April 2016

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# SESSION 2A

# RESEARCH BASED INDUSTRIAL POLICY

# Solar Home Systems in Zambia: Comparative Study with Kenya and Nepal

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## ABSTRACT

*Despite several efforts to increase access to electricity in the Zambian rural areas, statistics show no significant improvement over the last two decades. Inspite of all the talk about solar energy being a faster, cleaner and more convenient way to improve accessiblity to energy sources in Zambia,there has not been a noticeable increase in the use of these systems, especially for the targeted rural population.*

*This study sought to identify the barriers to solar home systems deployment and compare the implementation framework used for rural Zambia to that of Kenya and Nepal. A survey was conducted in Kafubu Farm Block, Zambia, to highlight some of the challenges being faced by the rural population. Nepal and Kenya were selected as case studies to draw out lessons that Zambia can learn. It was concluded that Zambia's current insignificant improvement in the share of solar home systems has a lot to do with the gaps in the existing policies and use of an inappropriate framework among others. A framework for the probable sustainable implementation of renewable energy technologies in Zambia was developed.*

**Keywords:** *Solar Home Systems; Rural; Policies; comparison; Implementation Framework*

## INTRODUCTION

In modern society, electricity is regarded as one of the critical requirements for both domestic and national economic activities. However, access to electricity and other clean energy technologies is still a major challenge especially in developing countries.

### A. The Global Energy Landscape

About one-third of humanity lacks access to electricity and associated services. Around two billion people in the world still rely on firewood, animal grease or kerosene lamps to light their paths and their homes at night, despite all the advancement in technology (World Bank, 2012). This is more prevalent in developing countries, where millions of people as a result suffer from lack of basic medical services, education and other associated facilities denying them possibilities of gaining access to better opportunities (CORE International, 2004). In light of these challenges, achieving universal access to electricity is one of the main goals set by the United Nations for the global energy sector (World Bank, 2012).

### B. The Zambian Energy Landscape

The majority of the population in Zambia does not have access to affordable clean energy. The 2010 draft Renewable Energy (RE) Strategy for Zambia indicated the following as possible renewable energy sources: solar, mini-hydro, biomass, energy crops, and wind energy and geothermal. Currently, the development of these technologies is mainly spear-headed by the Government including the encouragement of energy crops that do not compete with food crops such as Jatropha for bio-diesel and molasses for bio-ethanol. The capacities of the various energy sources are briefly discussed as follows:

- ***Hydro***

Various studies, including the Rural Electrification Master Plan and the Draft Renewable Energy Strategy (IRENA, 2013)have revealed a huge potential for hydropower development. Hydropower resources are estimated to total 6,000 MW, of which 1,760 MW has been developed, including approximately 24 MW of mini-hydro projects (IRENA, 2013).

- ***Geothermal***

Historical surveys have identified over 80 hot and mineralized springs in Zambia. A detailed study by a joint Italian–Zambian venture in the mid-1980s identified five prospective targets in Casho, Chinyunyu, Chongo, Kapisha, and Lubungu. Of these targets, the joint venture selected Kapisha on Lake Tanganyika as the site for a 220 kWh binary geothermal power plant. For various reasons, this plant was never commissioned and the project was passed to ZESCO. A possible rehabilitation program is currently under review. Recently, a private sector exploration company began reassessing the geothermal targets and conducting geophysical surveys on those considered to be most prospective for power generation (IRENA, 2013).

- ***Wind energy***

Wind resources are estimated to be low to fair by international standards. Countrywide data available from the Meteorological Department indicates an average wind speed of approximately 2.5 metres per second (m/s) (Ministry of Energy and Water Development, 2008). Wind resources are estimated to be sufficient in a number of areas for water pumping (for irrigation and domestic use). However, there are some areas with average wind speeds of up to 6 m/s which may be favorable for the development of power generation (IRENA, 2013)

- ***Solar***

Solar radiation levels are considered to be high in Zambia. According to the National Energy Policy, the potential energy output per unit area is approximately 5.5kWh/m$^2$/day (MEWD, 2008). The National Energy Strategy reports that systems have been installed in at least 250 schools and chief's palaces and at 400 households under an Energy Service Company pilot project (MEWD, 2008). The Rural Electrification Authority (REA) has a number of initiatives aimed at increasing the use of solar energy. A 60 kW solar mini-grid to supply a community of approximately 50 households has been developed.

*Why Solar Home Systems (SHSs)?*

The reason why Solar Home Systems (SHSs) were selected to be the focus of this study is their great potential due to the high solar radiation levels in Zambia. Therefore this project sought to bring SHSs on board as a mitigating factor towards addressing the energy demand especially in the rural areas.

The Power Sector Development Plan for Zambia projects that the base case, energy demand of 8.1 terawatt hours (TWh) in fiscal 2007 will increase to 16.6 TWh by fiscal

2020 and 21.6 TWh in fiscal 2030. The figures indicate an average growth rate of 5.7 per cent per annum up to 2020 and 4.4 per cent up to 2030. The increases clearly show the need for Zambia to venture more into renewable energies (Walimwipi, 2012).

The Government, supplemented by external assistance, has tried several programs to overcome this problem, but the electrification levels show no significant change. For instance in the past decade, despite operating the rural electrification fund, the levels have only grown from 2% to 3.1% (REMP, 2009).

The Rural electrification Master Plan and Vision 2030 have set a goal of 50% access to electricity from the current 3% by the year 2030. Off-grid Solar Home Systems have potential to foster electrification of houses especially in the Zambian rural areas where electrification levels are very low (Gustavsson & Ellegard, 2004). The rural electrification projects have faced challenges in the implementation process due to expansion options that tend to mainly focus on grid solutions (World Bank, 2012)

## CASE STUDIES

### *Renewable Energy Sector in Kenya*

The people of Kenya today enjoy a success story in terms of SHS and RETs in general. In recent years, Kenya and China have likely been the fastest growing markets, with annual growth rates of 10-20%. This SHS success began with donor assistance in the 1980s but then later graduated to private sector–led markets in the 1990s. The donor program allowed PV modules and system components to become known and available in Kenya, it provided the basis for development of local capacities in component assembly and installation, repair as well as maintenance of the PV systems. Many of those trained through donor programs went on to build the private industry that followed. This private market was also spurred by an increasing supply of domestically produced components, which lowered the costs, and by the slow pace of rural electrification that increased demand for alternatives like SHS. Common to these successful experiences is fitting the technology to user needs and practices. It is worth noting that many earlier programs were not successful because they did not factor in sustainability and replication (WCED, 1987). Kenya has gone further to partner with a solar sector investor from China to open up a technology transfer and training center near Nairobi to promote the assembly of solar lighting systems as demand for renewable energy resources in the country grows. (Meza, 2015).

### *Renewable Energy Sector in Nepal*

RE development continues to be a high priority program for the Government of Nepal (GoN) as it provides a least cost solution to remote and sparsely populated areas unviable for grid extension, while on the other hand being clean, safe and environmentally friendly. GoN's goal for the next 20 years is to increase the share of RE from less than 1% to 10% of the total energy supply and to increase the access to electricity from alternative energy sources from 10% to 30%. The sources of funds envisaged include government revenue, support from development partners, loan financing from financial institutions and private equity. Complementing the above, the Three Year Plan (2010-2013) envisaged the addition of 15 MW of mini/micro hydro power; **225,000** solar home systems; 90,000 domestic, 50 community and 75 institutional biogas plants. (Government of Nepal, 2011)

## RENEWABLE ENERGY AND MDGs

Renewable Energy Technology (RET) can be linked to all the eight (8) Millennium Development Goals (MDGs) (World Bank, 2012). Despite the numerous benefits of RETs, developing countries experience implementation challenges. The 2008 International Energy Agency (IEA) study observed that most of these challenges are both economic and non-economic. The key barriers identified by IEA as non-economic barriers to scaling up the contribution to renewable and sustainable deployment in developing countries include; institutional, human resource, financing, regulatory, infrastructure, quality assurance, technical, income generation, public acceptance and market barriers .

RETs have proved to be a solution in most of the countries where they have been highly promoted such as India, Nepal and Kenya (Gerber, 2008)

## OBJECTIVES

The objectives of this study were to:

- Identify gaps in the Zambian policies in SHSs
- Conduct a comparative study between the three countries (Kenya, Nepal and Zambia)
- Draw lessons from the SHS implementation projects in Nepal and Kenya.
- Develop a framework for the sustainable implementation of renewable energy technologies in Zambia.

## METHODOLOGY

In this study, qualitative analysis was employed with the evaluation analysis being used to provide useful feedback for decision-making. The following qualitative analyses were done.

- Case Study Analysis: The case of existing renewable policies and SHS implementation in Zambia, Nepal and Kenya were analyzed and provided input to establishing the gaps in the existing policies.
- Interviews Analysis: A face-to-face interview with the Assistant Director of Alternative Energy Promotion Center (AEPC) and another with the manager solar component National Rural and Renewable Energy Programme (NRREP) in Nepal were conducted. Similar interviews via a questionnaire were conducted for both Zambia and Kenya to facilitate conclusive SWOT analysis of the three countries.
- Questionnaire Analysis: A descriptive analysis was used to interpret the range of responses to each question. The data was then classified, for instance *ages* were categorized into age groups to make meaningful comparison of sub-groups, while coding was done to facilitate accurate quantitative analysis.
- SWOT analysis: The Strength, Weakness, Opportunities and Threats (SWOT) analysis was conducted for the three countries to understand the deployment and implementation of RETs with regard to SHSs as well as explore possibilities of new solutions to associated problems. A *comparative analysis* in lessons learnt from the international experience of Nepal and Kenya was conducted.

### *Framework Design Steps*

There are no specific steps for designing a sustainable implementation framework for SHS or RE in general. However, based on the understanding of the task at hand and the findings of the study, the design steps as shown in the flow chart in Figure 1 were adopted in this study. According to the specific conditions, the resulting design can be applicable to any rural area in the country, region or continent.

- Step1: Problem identification and Problem analysis: This step involved analyzing the existing situation surrounding a given development problem. The major problems and constraints associated with the RE development in the area were identified so that the cause and effect could be visualized by comparing the role of each key player and how it was executed during the project formulation and implementation stages. At this stage of analysis the following questions need to be answered:
  - Who is the target group?
  - What is the study area considered, i.e. is it rural or urban?
  - What category of people is the study considering, i.e. are they low-, middle- or high-income households?
  - Were they stakeholders consulted?
- Step 2: Brainstorming: During this step, effort was made to generate as many possible solutions to the challenge, in a spontaneous manner. This was done by analyzing the key stakeholders in the Zambian RE sector such Ministry of Water and Energy Development (MWED) and Rural Electrification Authorities (REA) and the livelihood of the rural people. It is important to understand the problem in depth to ensure the brainstormed solutions are addressing the problem.
- *Step 3: Objective Analysis:* This step involved the development of specific objectives from the problem statement. The problem of lack of access to clean energy was then transformed to a specific objective; to increase from less than 1% to 3% of access to clean and modern energy technologies in this area which in turn will provide sustainable development and achieve MDGs.
- *Step 4: Analysis of alternative solutions and :* This is a broad step and was narrowed down to the analysis of existing financing mechanisms and delivery models of the SHS in Zambia as well as identification of the available RE sources in an area. This assists the involved stakeholders to actually know the available resources and which implementation strategies can be practical.
- *Step 5: Final Design*: This includes building on the findings, it is best to design a tailor made solution for the area, as the sustainable implementation framework cannot be uniform for the entire country, region or continent and in order to achieve successful implementation there are no fast rules for this**.**

## KAFUBU FARM BLOCK

Kafubu Farm Block is situated about 30*km* from the central business district of Luanshya, one of the Zambian towns in the Copperbelt Province. The farm block was initially allocated to a group of Israelis to develop a commercial agriculture block. They later abandoned the project, and the land was demarcated into smaller farm plots and allocated to 17,000 local settlers representing 2,146 households. In spite of the large population the farm block has no electricity (DFID, 2012). For these people, even access to low-power electricity could be life-saving as this may lead to improved health, education, and other services.Low-power electricity here is taken to imply electricity supplied to consumers with low energy needs (low demand).

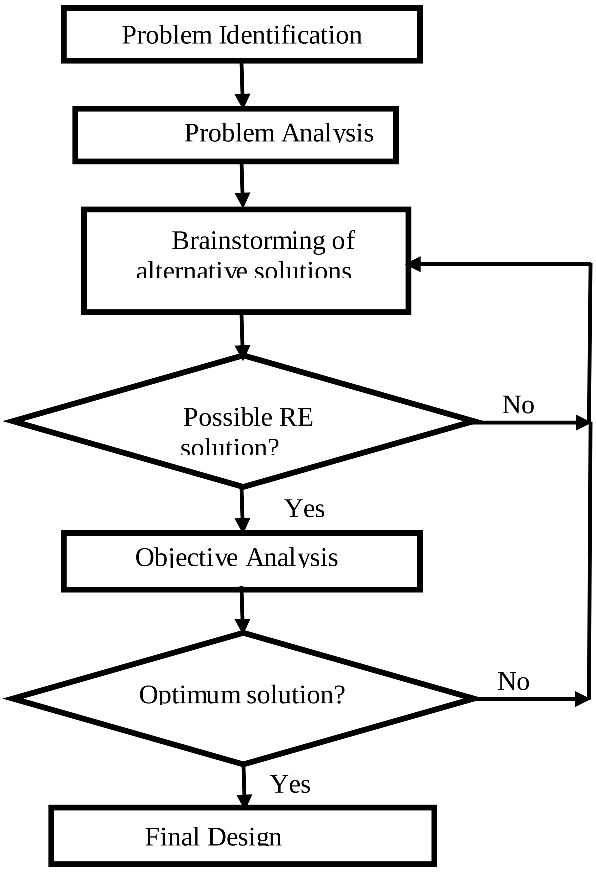

*Figure 1 The process adopted in this study to design the implementation framework*

***Typical houses in the Area***

The typical houses in the Kafubu Farm area mostly comprise of three rooms, with an outside kitchen. Figure 2 shows an example of the house in rural areas.

*Figure 2 Typical houses in Rural Zambia (Luque and Hegedus, 2011)*

The case of Kafubu Farm Block is a clear indication of how the policies on RE development are not reaching out to every Zambian, especially those in rural areas. The area has seen no implementation of any solar technology; at least out of the interviewed people none of them had the SHS or any other renewable energy technology installed. In this area the majority are subsistence farmers and income generation is mostly once yearly from the harvest of the maize crop. In such areas a fee-for-service delivery model would not be the best approach for implementation of the SHS technology.

### *Field visitation*

A questionnaire survey was conducted in the study area, Kafubu Farm Block (KFB), The household questionnaire was administered to 35 homes and 32 were retrieved, which gave 91.4% response rate and a reasonable basis for generalizing to the rest of the population in the area. Of the 32 questionnaires 53.1% were male and 46.9% female. The mean age group was between 44-54 years of which the mean number of people living per household was 5.

- ***Education*:** 46.9% of the participants had some primary education, 43.8% secondary and with only 6.3% tertiary education.
- ***Livelihood*:** 90.6 % of the populations were farmers while 9.4 % are small scale business owners.
- ***Income levels*:** The survey showed that all the interviewed respondents received less than 1000 Kwacha equivalent to $ 194 per month **(Stapleton, Gunarantne, & Konnings, 2002)**
- ***Energy use*:** For cooking and heating charcoal was the primary energy source, while Kerosene and candles were the primary sources for lighting energy. Out of the 32 households, 31.3 % of them spent about 100 to 150 Kwacha on charcoal, 46.9 % spent over 30 Kwacha on candles/kerosene and 40.6 % spent 20 to 30 Kwacha on dry batteries for entertainment in their radios in a month. The households who spent nothing on charcoal are those who directly collected wood fuel for cooking, accounting for 31.3 %.

*Figure 3 studying using a kerosene lamp ( (Luque & Hegedus, 2011)*

Figure 3. shows a small kerosene lamp used for studying by one of the school going children in the rural areas and Figure 4 shows women from Kafubu Block returning from their firewood collection, a process which takes about 2-6 hours of their daily activities.

Figure 3 highlights one of the challenges of studying under the kerosene lamp, though no statistics were collected from the field visit on the health issues affecting these people in the area. It can clearly be seen that the illumination from the kerosene lamp is not sufficient for studying purposes and these children strain their eyes as well as inhale the fumes from the kerosene, which would affect their respiratory systems. In this research no investigations were done to study the impact of using kerosene lamps and candles on the health of the families.

Focus Group Discussion

A focus group discussion was conducted in Kafubu Farm Block. Among the people in attendance were the chairman of the area, one primary school teacher, two cooperative leaders and two household representatives. The meeting was held at the Chairman's premises.

***Focus Group Discussion***

A focus group discussion was conducted in Kafubu Farm Block. Among the people in attendance were the chairman of the area, one primary school teacher, two cooperative leaders and two household representatives. The meeting was held at the Chairman's premises.

*Figure 4 Kafubu Block women on the way home from collecting firewood*

In the discussion what was highlighted, among other things, was their desire to have access to electricity. They stated that despite being close to Luanshya town they were still lacking in a number of services such as a secondary school for their children; they only had one primary school catering for the entire community. The health center was not electrified and pregnant women, people in need of ARVs and other complications had to travel 34km to Luanshya to seek medication as there was only one clinical officer and no doctor at the local clinic.

During the discussion one of the participants stated that the area Member of Parliament visited them after being voted into office and when asked whether the area will be electrified in the near future, he was reported to have said that government could not invest in electrifying the area for it would be a loss of investment since those people were poor and could not afford to pay for the facility. During this discussion, it was clear that this remark left these people with no hope and feeling let-down by the government. Because of this problem, one of the participants expressed doubt as to whether this discussion would result into anything tangible such that to some extent the discussion was received with mixed feelings. In the closing remarks by the chairman, it was stated that the people were interested in solar system technology such as water pumping system that would help ease the women's burden of drawing water for irrigation and household requirements. He also stated that this technology could boost their farming activities and the lighting would increase study hours for their school going children as well provide entertainment and ability for them to know current affairs through local news. The community welcomed the study and wished that it could be a prayer answered for their long desired access to electricity.

### *Energy resources*

Table 1 gives a summary of the Total Primary Energy Supply (TPES) and total installed electricity capacity in each country.

It should be noted in Table 1, that Kenya's share of biomass in the TPES is accounted for in the combined renewable and waste while it is separate for Zambia and Nepal. It can clearly be observed that biomass represents a significant share of TPES in all the countries followed by crude oil, which is imported in all cases. Between Nepal and Kenya, Nepal has a higher share of combined renewable and waste energy supply.

Nepal is leading in hydropower generation followed by Zambia and Kenya. Of the three, Kenya is the only country which has significantly developed energy supply from renewable sources like geothermal, solar and wind. In the case of energy resources for electricity supply, both Zambia and Nepal are predominantly hydro with trace amounts from thermal while Kenya has a relatively low share of hydro but high share of conventional thermal. It can clearly be seen that Kenya has performed very well in the area of electricity supply from renewable energy sources, as the percentages of geothermal, wind and others show.

*Table 1 Total Primary Energy Supply (TPES) and total installed capacity in Kenya, Nepal and Zambia*

| Feature | Zambia | Nepal | Kenya |
|---|---|---|---|
| **Total primary energy supply** | **7,856 ktoe**<br>• Biomass: 80.9%<br>• Hydro-electric: 1.3%<br>• Crude oil: 6.6%<br>• Petroleum products: 1.0%<br>• Electricity imports: 10.2% | **9,779ktoe**<br>• Biomass: 80.9%<br>• Combined renewable and waste: 86.4%<br>• Hydro-electric: 2.7%<br>• Crude oil: 8%<br>• Coal: 2.8% | **18,723ktoe**<br>• Combined renewable and waste: 76.0%<br>• Hydro-electric: 1.0%<br>• Crude oil: 16.5%<br>• Geothermal/solar /wind: 6.2%<br>• Coal: 0.3% |
| **Total installed electricity capacity** | **1,967MW**<br>• Hydro: 95.9%<br>• Thermal: 4.1% | **709MW**<br>• Hydro: 92%<br>• Conventional Thermal: 8% | **1,429 MW**<br>• Hydro: 52.1%<br>• Conventional Thermal: 32.5%<br>• Geothermal: 13.2%<br>• Wind, other: 2.2% |

Generally, the efforts that each country is putting in increasing the share of renewable energy in the TPES, particularly SHS, can be seen from Figure 5.

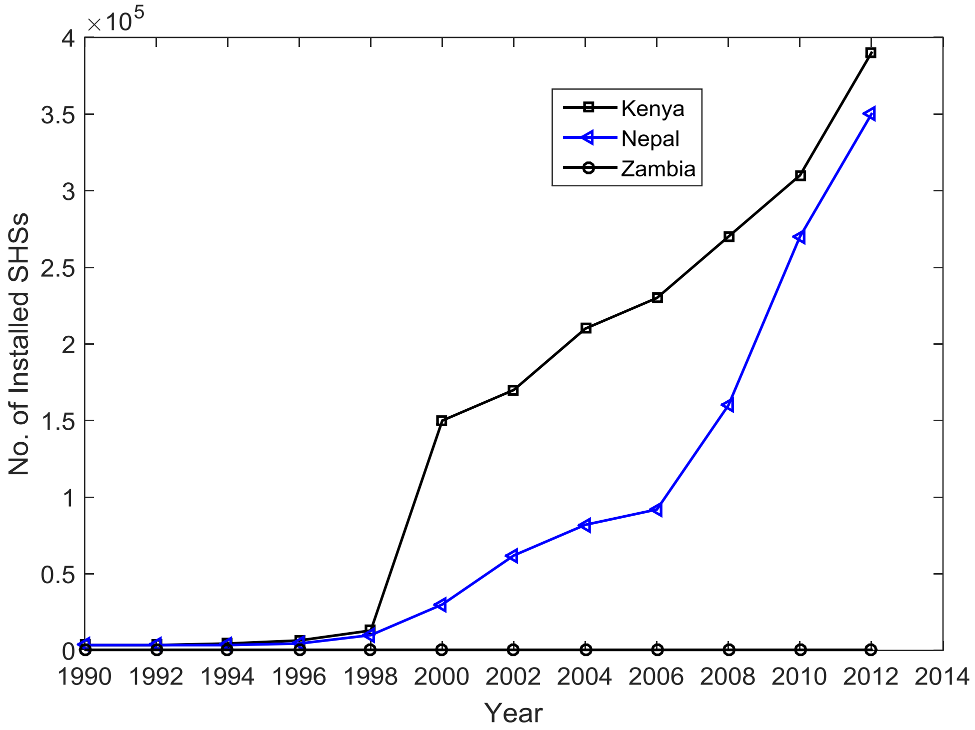

*Figure 5 SHS trends for the three countries: Kenya, Nepal and Zambia ( (Luque & Hegedus, 2011), (Rebane & Barham, 2011), (Mermoud, 1992), (WCED, 1987)*

Figure 5 shows the SHS trends in the three countries. Zambia has shown no recorded significant improvement in the deployment of the SHS since the pilot project in Eastern province. Kenya has had a progressive increase with annual installations of about 20,000 SHS Nepal also shows progressive increase in the deployment of SHS.

### *1) Lessons Zambia can learn*

### A **Framework for sustainable implementation SHS implementation**

To achieve sustainable development through implementation of SHS, flexibility in the sizing of the SHS kits is needed. In the case of Kafubu Farm Block a tailor made solution that would emphasize lighting can effect a huge change in the livelihood of this population and contribute to pollution reduction specifically that from kerosene and candles. Based on the assessed affordability levels, emphasis should be put on introduction of solar lanterns and small PV modules of size 5 to 20 Wp to encourage most people to switch to clean energy for their lighting needs.

Table 2 gives a summary of the lessons that can be learnt by Zambia from the Nepali and Kenyan experiences with the solar energy technology.

### *A Framework for sustainable implementation SHS implementation*

To achieve sustainable development through implementation of SHS, flexibility in the sizing of the SHS kits is needed. In the case of Kafubu Farm Block a tailor made solution that would emphasize lighting can effect a huge change in the livelihood of this population and contribute to pollution reduction specifically that from kerosene and candles. Based on the assessed affordability levels, emphasis should be put on introduction of solar lanterns and small PV modules of size 5 to 20 Wp to encourage most people to switch to clean energy for their lighting needs.

Table 2 Lessons from Nepal and Kenyan experience on SHS implementation

| **No.** | **Description** | **Factors that have promoted the Nepali Kenyan success** | **Lessons Zambia can learn** |
|---|---|---|---|
| 1 | National plans | Both Kenya and Nepal have a solar academy and Local Manufacturing in their plans. | Zambia should do more than tabulating the national plans but also be action oriented by encouraging local manufacturing. |
| 2 | Policy | Introduction of feed-in-tariffs (FIT), appropriate subsidies and lending policies are available. Both have set targets for SHS deployment. | Discussions on FIT, lending policy and smart subsidies should move to implementation with the setting of tangible but realistic targets for SHS deployment. |
| 3 | Delivery mechanism | Cash and subsidies as in case of Nepal and cash sale in case of Kenya. | Zambia should rethink the Fee-for-service model and come up with tailor made solutions in rural areas. |
| 4 | Feed-in-Tariff | Nepal (pilot project) and Kenya have employed this mechanism to encourage investment by private companies in RETs. | Zambia has to speed up in the implementation of this mechanism to attract private companies in RETs. |
| 5 | Model size | Both Nepal and Kenya have encouraged models of 10-50 Wp to allow more rural users of SHS. | Provide a greater variety in the system sizes instead of the one standard 50 Wp that is currently available. Variety in size will accommodate different End-user affordability. |
| 6 | Local and Private sector participation | Both have encouraged local and private sector participation by engaging different vendors in the delivery mechanism. | Zambia should encourage local and private sector participation in this fight of rural energy poverty. |
| 10 | Ownership Capacity building | Both Nepal and Kenya provide training to end-users. | Provide end-user training. End-user training is vital as has been demonstrated by the ESCO project, Nepal and Kenya cases as it allows for sustainable use of the SHS. |
| 11 | Financing mechanism | Both have micro-financing systems and banks are more willing to give RETs loans. | Provide incentives and enabling environment to attract private sector participation in this area. Encourage the provision of affordable financing for RETs. |

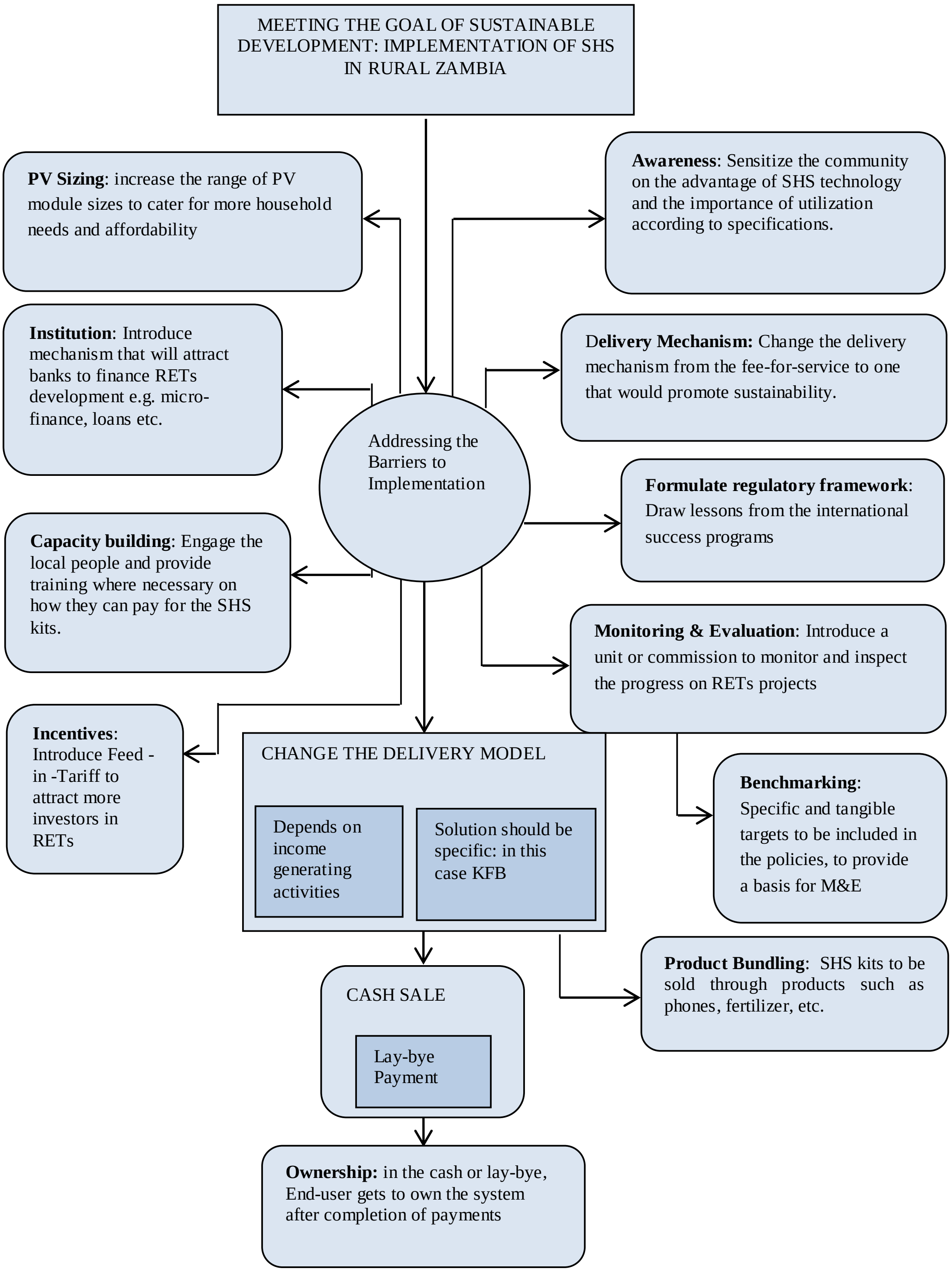

*Figure 6 Sustainable Implementation Framework for SHS in rural Zambia*

The proposed sustainable implementation framework that has been designed for Kafubu Farm Block and rural areas in Zambia, is as shown in Figure 6. The main focus of this design is to meet development for rural areas in a sustainable manner, by implementing the SHS. The design shows that overcoming the barriers is the first step followed by changing the delivery model. Cardinal to these is the monitoring and evaluation framework, legal framework and related institutions to ensure everyone responsible meets their targets by setting milestones and all stakeholders work within the terms and conditions recommended in the framework, respectively.

## DISCUSSION

The fee-for-service models that were used in the pilot project disadvantage most of the people who would like to purchase or pay for smaller SHS units and hence reduce the equipment's reliability as mostly the system would be under or over utilized. Concerned end-users are willing to buy and own the system. The government does not provide incentives to the suppliers and end-users to attract growth in the sector. Awareness levels are vague for the target groups to appreciate the technology. The current paradigm, not based on market approach, does not encourage sustainable growth in the RE sector.

## CONCLUSIONS

Based on the study, it can be concluded that Zambia's current non-significant improvement in the share of solar home systems has a lot to do with the gaps in the existing policies as well as lack of the legal and institutional frameworks. Specifically, policies lack specific and realistic but ambitious and tangible targets best suited to the particular situation for the various rural areas in Zambia. Other gaps identified include

- insufficient variety in the SHSs sizes that are offered to better match end-user affordability
- Lack of appropriate financing mechanisms
- Lack of end-user awareness and training

A framework for the sustainable implementation of renewable energy technologies in Zambia was designed and has been proposed in this article.

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# Re-Engineering the Zambian Electricity Supply and Consumption Network Model to Answer the Aspirations of All Citizens

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## Abstract

*Measurement and determination of power generation, transmission, consumption and efficiency of achievement of all associated functions is dependent on the perspective and concept behind such measurement. Is the system of measurements designed to offer convenience to the utility to manage the system or is designed to facilitate the consumer's power usage verification audit and convenience of power application and safety. Many different perspectives exist that drive the motivation of a metering and control system instrumentation. In this regard the efficiencies and cost determinations of supply and demand will be in conflict depending on the basis used for each such determination. It is always classified as technical performance when contrasted with financial performance when system efficiencies are determined from the utility perspective. To the user, the supply consistency and failure severity determine the benchmark of supply efficiency and service reliability received. However, the truth comes to bear when major problems arise which cannot be shelfed under or casually glossed over as both sides have to endure the consequences of mis-representation. Subsidy or technical failure, good service or shoddy!*

*Cost is easily passed on to the end-user even in cases where serious justification does not arise. It is true that water always flows downhill but also retention mechanism reduces the flow rate from free fall to some acceptable level to allow for natural draining and storage in the surrounding area including the hilltop. Therefore, a determination of the real cost against measured merit should be the flow rate passed down or referred to the user downstream. The route taken to supply a client referred to power route character establishes the cost of supply, technical efficiency of such supply, operational efficiency by way of maintenance and the financial efficiency by way of capital idling or equity return on the resource investment. This approach should be the real motivation behind any instrumentation and the yardstick for gauging service performance on either side of the supply and demand side divide.*

*An evaluation of the real generation capacity measured against the impact on the respective loads would give the indexed measure of generation capacity. The performance of the various elements introduced in the supply chain must be assessed and determined whether they are a cost more than a benefit on the cost-benefit analysis. The sustainability index comes in to evaluate the financial implications against a measured service to determine whether it's a well-placed growth industry or a subsidised unsustainable service regardless of the convenience associated to it.*

**Keywords:** *Generation real capacity; Power route character; User power consumption; Technical efficiency, Operational efficiency, Financial efficiency; Tariff and Sustainability*

## Preamble

Electricity in Zambia is not a community service but a revenue earning enterprise. In this regard there are attendant rights and privileges accruing to suppliers and users in accordance with the commercial memorandum of service consented to by both parties. It is however, a matter that has been relegated to the horse and the rider relationship as only one party seems to have the monopoly of decision making that alters the destiny of the other by unilaterally shifting the goal posts in the supply contract without recourse by the other party. They simply tag along with hardly any choice or voice of opinion.

The money that is budgeted by the user for payment towards the service is eroded at will by the suppliers (by ever buying less and less from the same amount) citing rising cost of production and maintenance all disguised in the phenomenon of cost reflective tariffs. This paper aspires to equalise the playing field and bring accountability and decency in the supply and utilisation of electrical power. It is evident by the skyrocketing of prices and the downsizing of production across the industrial world, that electricity is a strategic industry of national importance with serious ramifications on livelihood. In this vein care must be taken by all concerned parties on matters that shift the balance of use and supply without mutual consent and consensus building.

Since much of the system measurements have been institutionalised at only the utility side, now the power supply cost parameters will be shifted to be measured at the user or consumption end. In short the consumer will measure the cost of receiving such electricity as the supplier may use different generation points and transmission routes. This allows the consumer to question the efficiency of supply and make an informed input on the cost charged. This makes the unilateral decisions by the supplier to inflate the cost of supply a difficult point to gloss over. In short a meritorious increase will not be opposed while the tantalising operational failure derived increments will be rebuffed. Professionalism will be brought to bear on both users and suppliers alike.

## Introduction

To innovate with downward compatibility is to ensure a smooth ascension to the higher quality of life and living (standard) without the shock of backlash of job losses and industrial closures of existing companies which create an unstable social environment that generally makes everyone scared of new ideas. Therefore, the implementation of the user terminal power control and analysis module is done next to the meter box of the user installation point. This allows the utility to continue with the supply metering for billing purposes while also allowing the user perform a billing reconciliation audit and further verify source power available and enroute losses encountered. The premium benefit is the according of the opportunity to the user to select which power source to give priority amongst the host of supplies in this supply pooling system employed in Zambia.

This paper describes the scientific basis of the module while specific engineering design of each module will be left to an assortment of manufacturers bidding for the production. The module placed immediately after the utility metering box will have many interactive features that it is not opportune time to dwell on now. The full complement of such interaction is beyond the scope of this paper.

The emphasis of the distance from the generating station qualified by the specific routing and the qualified contribution of each generating station in the network elaborates the specific relationship that exits between the specific generating station and the instantaneous power demand and utilisation by the load under focus. The paper then gives the scientific basis of cost of supply analysis, further, making the case for justifiable and non-justifiable tariff allocation. All the electrical components of transformers, network compensating capacitors, matching inductive units together with their associated electronic controls are all summed up into four-terminal networks with only input resultant parameters and the corresponding output parameters being the elements of consideration.

The paper concludes with the proposition for the electrical system that would work wonders for Zambia.

## Supply and user technical relationship

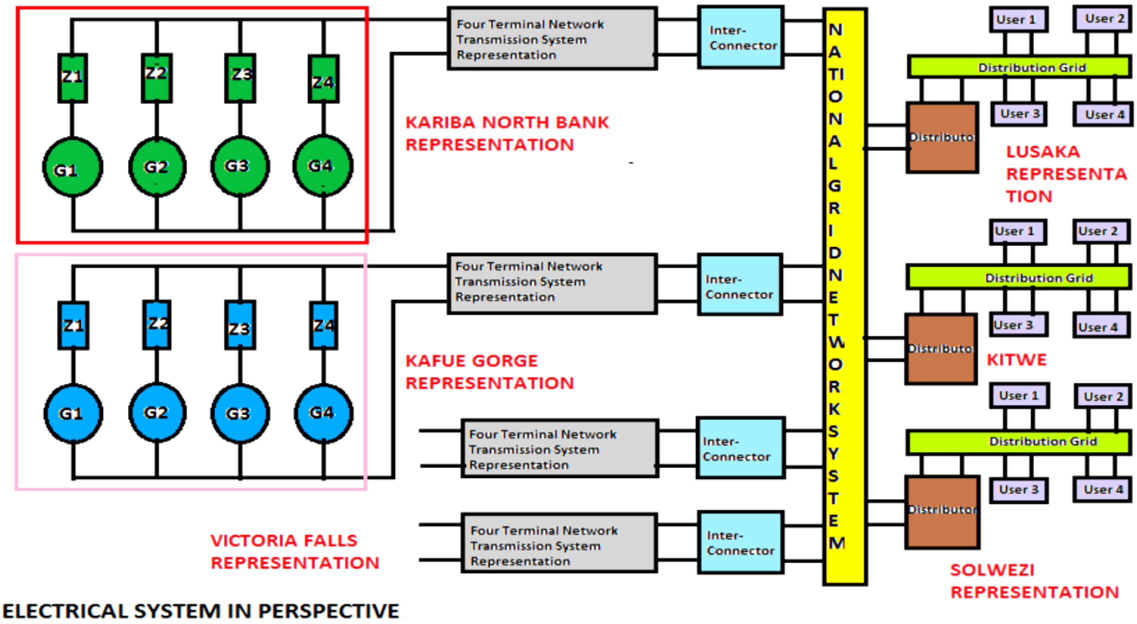

Figure 1: The Zambia Electrical System Illustration
Source: Rare Fruit Estates TFCLS Company Publication 2015 Original

Refer to Figure 1 for the following description. The generators are driven by prime movers which do not show signs of micro-departure movements within the general perceived rotation. But these micro departures which determine the ability to deliver power to a given load are measured evidentially by the impedance variation of the generator output impedance. Therefore in a paralleled system consisting of many generators running as one system, the load take up capacity of each generator will be different within very narrow limits. It is this character that leads to the development of control systems that ensure load balancing amongst the generators. As much as this may be successfully done, some level of imbalance will still exit which makes the load intricately choose one generator over the others for an instance and another generator the very next instance. The overall picture is that all generators are supplying the loads as one unit. Immediate example that is commonplace in our daily experience is the cell imbalance that arises after successive use of the car battery. Each start cycle will be perceived differently by each battery cell. The argument is that cells connected in series will have the same current hence uniform power drain. The reality is different and cell imbalance arises.

### Detection or Sensory System

From figure 2, the sensory or detection system which constitutes the measurand determination consists of a pair of eight laser diode and avalanche photo diodes arranged as four segments of detection points. The geometry of the arrangement is crucial to the operation of the entire system. The laser diode projects a laser beam towards the photodiode traversing the area of influence of the conductor's energy field. The beams are radiated to follow straight path profiles that should only reflect on contact with the conductor to achieve a perfect reflection that should land at the detector position. However, this path profile is modified by the presence of the electric field and the magnetic on the conductor by virtue of conveying power (current and voltage). The amount or intensity of each respective field alters the path to seem to be originating from a different position. Laws of optics observed the virtual position can be resolved and the departure from the designated position becoming a function of the field interaction. Therefore, the measurand is established upon which the quantification of the phenomenon can be predicated.

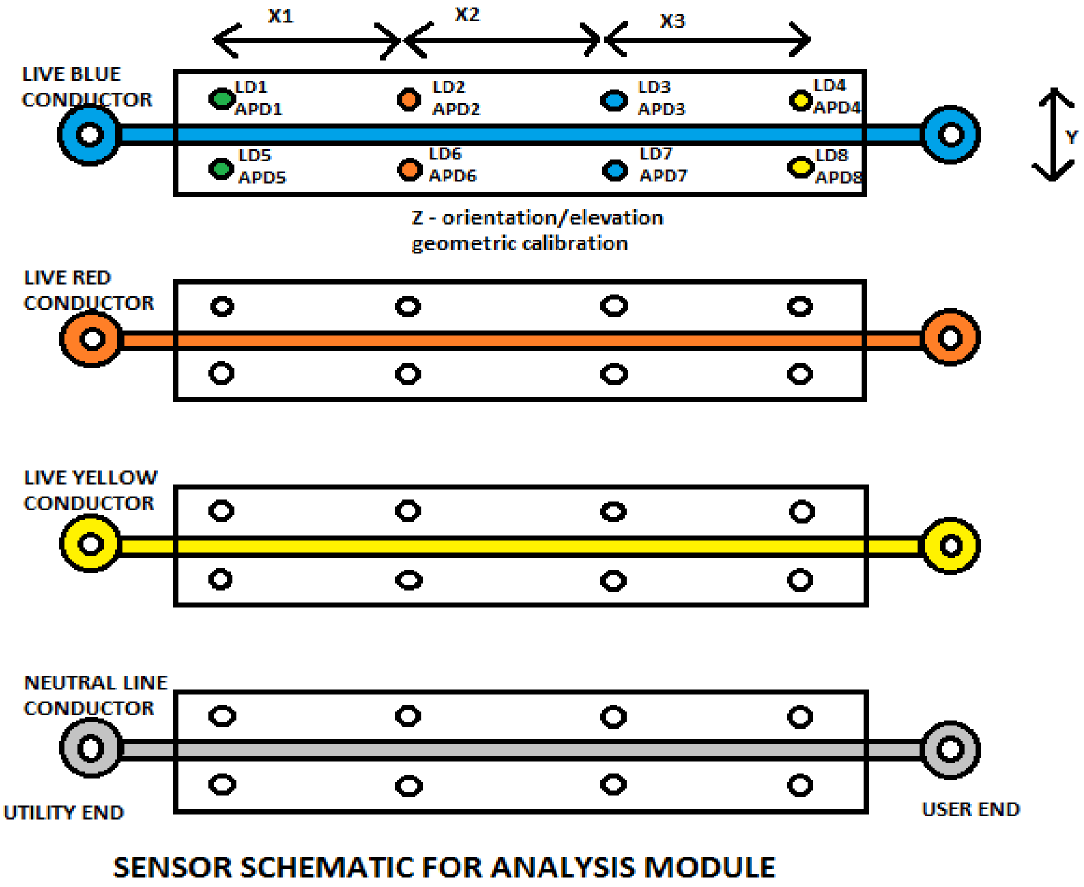

Figure 2: The Power Analysis and Control Module Sensor Schematic

Source: Rare Fruit Estates TFCLS Company Publications 2015 Original

Each laser point can be controlled from intensity of radiation to have the reception point maintained whilst relating the field interaction to the intensity variation. Various profiles can be obtained by the ingenious design of the system architect and the power of the deployed digital computation. The measurement resolution can be very fine indeed as it reduces to the timings and space segments that those timings entail. For instance, a laser pulsed at a terabit rate divides the 50Hz cycle waveform into tera count. The segments are so small for common level measurements but for the detailed time dependant impedance which is used to ascertain the signature of the power generator station supplying the designated load, becomes the sure path to an accurate determination. At such small time intervals, the power is best described as the instantaneous power intensity as opposed to the voltage and current as the later are considered summative evaluations or average circuit conditions.

Four sensory modules are required in the data collection for a three phase feed while only two are required for a single phase domestic feed. The dimensional flow analysis lends credence to the LD1 to APD1 as a current vector determination whilst the LD1 to APD2 gives the voltage vector. As such much derivative information can be acquired that relate to the impedance of a line by noting the voltage gradient over consecutive points which translate in attenuation factor from which impedance can be a derived quantity.

When information is collated over a period, the signature of each respective generating station can be identified. With this identification the voltage and current schedule reaching from that source can be ascertained as it droops with its unique character owing to the various elements in that specific route all collectively affecting the drooping rate.

### Supply Disturbance Effect on User – Determination of the User Vulnerability Assessment Index

Each user whether domestic or industrial will have the susceptibility to absorb the mighty of a power disturbance on the supply line measured where the susceptibility index is found too high, the supply is restrained as a safety and security measure to the user equipment and personnel. This susceptibility could be dependent on the location of the user in relation to the entire network and proximity to the originating disturbance. This assessment and determination will be performed in the analysis unit and preventative action readiness initiated or armed. This should act as an insurance policy to the electrical equipment against surge and consequential fire hazard.

### User Disturbance Effect on Supply – Determination of Supplier Vulnerability Assessment Index

Each user can measure the disturbance introduced on the supply line by virtue of its use of certain loads that use power not consistent with the norms. The example in this category is when an electric stove is not firmly connected to its feed wiring such that ionization corrosion takes place simultaneously as the cooking power of the hotplate is discharged. The level of power consumption will not be consistent with the norms established and therefore generates system disturbances onto the power line.

Depending on the power involved the disturbance can be system threatening.

### Multiple supply sources (pooled resources) – Supply Security and Rotating Vector Determination

Generators connected in parallel act like big motors when the line voltage falls below the network voltage. Off-course the generator control unit (GCU) critically monitors for this condition and directs increased excitation or prime mover torque increase as appropriate. Situations arise where the various generators keep “motoring” each other up consuming critical power instead of supplying the commercial loads. The cost of supply analysis will reveal this condition and postulate the power deficit cause other than low water level.

### Multiple users from common supply (supply utility versus isolated discreet system) – Distributed Disturbance Assessment index

Where many users are connected to the supply line, each other's generated disturbance is distributed to the neighbouring users which may result in localised adversity or poor supply quality experience. This can be measured and determined by the analysis unit as the signature for a power supply is different from the user generated signature. As a good social citizen the evaluations and determinations made can be raised in community meetings as a way of improving the quality of electricity and also raised up to the standards body for appropriate use regulations and standards enactment.

### The generalised consumption and supply metering theory and parameter determination

The generalised supply and consumption metering theory prevails on the instantaneous power as opposed to the consideration of the average power over a cycle of the supply frequency. The summation of the instantaneous power demands, starting with the minimum defined time interval at the specified field intensity on a generalised route modified by route profile indexing gives the total power generated or consumed (depending on the measurement point being at the source end or load destination end).

$$\sum\{[f(P_n)t]_a^q\} \cdot K_{\text{nominal}} \cdot R_{\text{profile}} = P_{\text{generated}} \tag{1}$$

where: $P_{\text{n}} = P_0 + P_1 + P_2 + P_3 + \ldots\ldots + P_{(\text{n-1})} + P_{\text{n}}$ = connected loads

$K_{\text{nominal}}$ is the nominal route factor (standard) determined by the circuit elements involved

$R_{\text{profile}}$ is the indexing factor on the nominal route which is used as the correction factor on that route as distinguished from the standard route. This is determined by the distinct tones and overtones positions and levels as measured

The range $a$ to $q$ defines the time interval as a function of the duty cycle of the tera bit count measurement interval specification

Equation (1) is the basis for the software and spectrum distribution analysis.

Therefore, the power received by the designated load is a summation of the respective contributions of all generators in the network according to their instantaneous impedance that determine the load take-up capability.

For power supply to decouple from one generator and couple to another without switching over harmonics implies the finite energy quantum delivery associated with each coupling. Therefore the time segmentation performed at the load end as a means of evaluating the supply configuration is actually the statement of fact that energy supplied is in finite successive disbursement that accumulate to present the total energy delivered in a given time interval.

By exploiting further this scenario, the signature of the generating station can be deduced in relation to a specific load at a specified destination or location from the analysis of coupling and decoupling sequencing. Armed with this information, each signature tapering profile can be used to deduce the path profile as the distance is an easier call, a matter of radar distance along the propagation route. Other overtones associated with a particular signature gives the elements involved in its route and the extent of the route losses. It is then possible to compute the cost of receiving such electrical power. The determination from all generating stations involved gives information of expensive routes, cost effective routes and inefficient routes. Further this information is acquired on a dynamic and continuous basis such that transmission routes can be assessed over a 24-hour period and longer as appropriate (as of necessity).

### Mechanism to efficiently allocate electrical resource on account of route cost efficiency, operational cost efficiency and financial efficiency

From the discourse given in item 9 foregoing, the impedance and specific phase variation will be deferent on each generator arising from driving a given load at a specific destination. The transmission line is not an instant conveyance route but a progressive propagation phase changing route. This means that the act of demand and supply are not simultaneous in time but are successive events. The demand initiates a disturbance in the supply which depending on the delay line network will respond by supplying the demand (not necessarily in the format demanded as the delay mechanism also performs demand modification, inductive capacitive and resistive tower-rail transmission system, that suits the supply). The observable effects are that a voltage drop immediately follows the activation of a load demand which then gradually picks up to the standard voltage as the supply meets the new demand. This signature of load on to the supply and supply on to the load may be micro-voltages in nature depending on the relative size of the power demand in relation to the capacity of the supply.

### Route Cost Efficiency (a direct result of accurate and strategic metering by sensory modules)

1. Technical Efficiency consideration for route resource allocation
   Where it is desirable for keeping a network in sound health, it may be imperative to direct the power resource not necessarily to consumption centres of most economic value, but rather balancing the load impedance by tuning out some route inconsistences with other route deficiencies thereby achieving an overall balance as seen by the generator. This makes the system to run smoothly without any adversity. In the evet of demand increase beyond supply capacity, the ensuing load-shedding would not automatically cut off non-essential loads but would follow the load isolation sequence that preserve generator balance more than commercial incentive.

2. Operational Efficiency resource allocation on account of low operational cost
   Where it is desirable to allocate power resource to areas easy accessibility and defined regimes of power utilisation such as known industrial activity and predictable power usage, more than revenue maximisation, this route is taken. It is more convenient for maintenance, customer quick response and easy service rollout. This route will have a higher service reliability, stable power quality and friendlier environment.

3. Financial Efficiency consideration for route resource allocation to maximise revenue
   The route that has the highest percentage utilisation of all the capital equipment and the highest utilisation to tariff ratio making the biggest economic incentive becomes the main driver of resource allocation to the route. The tariff to that area may be low

but the scale of use and consistence of use makes the scale of numbers a reality thereby maximising the revenue.

## The proposed electrical supply standard for Zambia

Figure 3 gives the illustration of the minor in detail but elaborate in action of the changes to be embodied on the Zambia electrical supply network to achieve the best management of the available power generation resource to satisfy the current and growing user base.The electrical system proposition for Zambia requires minimum but effective changes to the system in view of the current serious economic malaise. The proposition simply reinforces what has already been well understood and practised quite universally. In order to lower transmission losses as the power demand gets higher, raise the voltage! This is now achieved by integrating the conditioner which simply makes transmission voltage a function of the current to ensure minimum power loss.

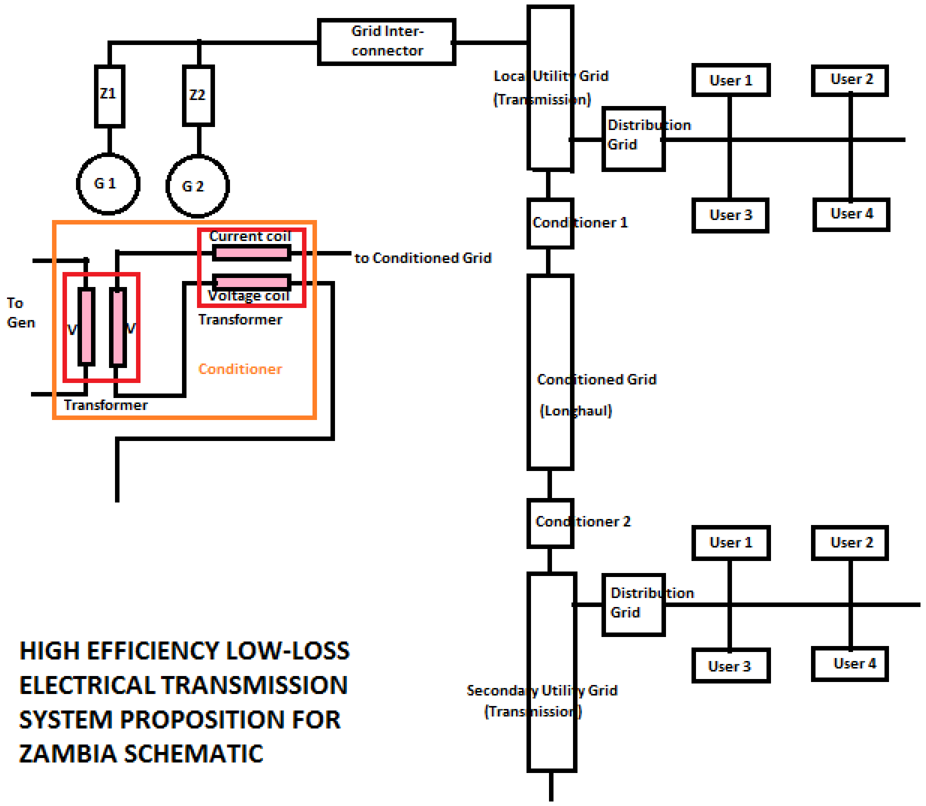

Figure 3: The Proposed Electrical Supply Scheme for Zambia
Source: Rare Fruit Estates TFCLS Company Publications 2015 Original

The current system is extremely lossy such as in times of high power demand, the same voltage is used causing higher power loss by higher current which in most cases outstrips the increased generation to meet the increment demand. This practise leads to unnecessary load-shedding and revenue loss.

The generating station will supply by feeding into the transmission system as raw power where the power conditioning is done before feeding into the user distribution network. As the power demand increases, the voltage of the transmission system is raised to supply the increased demand at a reduced loss level thereby conveying the incremental without an associated increase in transmission loss.

The generating station is allowed to generate at its most optimal point at a fixed voltage to optimise and augment the functioning of the generator control unit as the impedance variations on the user are addressed by the transmission system.

## Conclusion

The system that is backed by information on both sides of the supplier and the user, an integrity management of the resource is promoted as all decisions will be arrived at through consensus building mechanism. The electricity industry will be elevated to a higher standard of service and remuneration as both the aspirations of the supplier towards growth and profit will be balanced by the user's sustained supply requirement meeting their demand and the quality meeting a diversity of uses.

The following are the main conclusions drawn:

1. The tariff allocated will always be cost reflective. All the elements involved in the supply chain will be cost sensitive from the technical, operational and financial efficiency standpoints.

2. In times of supply capacity deficit arising from natural or man-made conditions, power will be rationed more equitably and sustainably as costly routes will be avoided. Importation of more foreign power to send to a cost inefficient route will only result in resource wastage as such power will likely cause a serious system disturbance that may affect the whole network. Such routes will be avoided or improved upon before resource allocation is effected.

3. The cost indexing provides a platform for the transmission grid to be availed to private developers as the associated costs will be independently index by firms other than the investing firm. A grid code sharing platform can be established in a fair and transparent manner devoid of data concealment leading to undue profiteering by some at the expense of the others.

4. Standards and compliance will easily be enforced as the basis of conformity assessment will be data based as opposed to speculative trends. Sensitisation programs become more simply defined for maximum impact as direct relations between conservative good practices and bad practices are easily distinguished from an accessible record of events.

5. The attribute of making the impedance transformation a function of demand current makes the generator source appear more and more ideal source as an infinitely low output impedance which makes it more resilient to deliver higher and higher current without drop in efficiency. At the conditioner not only is the voltage transformed, but also the impedance undergoes transformation.

## References

The following references highlight the attribution of load-shedding by the various interest groups in Zambia and beyond, whereas the foregoing text gives the solution which immediately makes the difference. Errors of omission, commission, judgement or decision making, and assortment of diagnosis and prognosis have been given but the other side of the equation (perspective of consideration) to justify an action or reaction has not been given. That constituted the essence of this paper. These references may not be captured word for word but the sentiment has been taken into account. In short the references indicate the heat (focal point of opinion and commentary) around the subject.

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# MULTI-FACILITY ECONOMIC ZONES IN ZAMBIA: IS THE LOCAL MANUFACTURING INDUSTRY READY?

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## Abstract:

*China's use of Special Economic Zones (SEZs) to spur its remarkable economic development was seen as the way to go, particularly for developing economies. Zambia, like most African countries, has established these zones with the help of the Chinese. In Zambia, the zones are called Multi-Facility Economic Zones (MFEZs), and are to operate as platforms for industrial development and creating value chains in addition to the much-needed jobs. Based on the Chinese experience and lessons, MFEZs are designed to be integrated into the domestic economy, as they are in China. It is envisaged that this approach would, through foreign direct investment (FDI), enhance the transfer to local industries the much-needed knowledge and technology, a prerequisite for modern industrialisation. If the MFEZs attract a critical mass of FDI, stimulate high value-added manufacturing activities, and generate productivity spillover, their impact on industrial development in Zambia would be dependent on the domestic linkages created and the technology transfer achieved, both of which are a function of the local manufacturing absorptive capacity. This paper reports on the results of a survey undertaken to assess whether the Zambian manufacturing firms had the capacity or "technological readiness" to adopt any spillover and/or absorb any technology transfer that takes place. The variables considered in this assessment were types of technologies and methods of production, manufacturing systems, and human resources development. The study established that there were low levels of advanced technologies, weaker innovative capacity and lower human capital (skills) threshold in local firms. To address these short-comings, recommendations in form of a two-pronged paradigm, involving the local manufacturing industry on one hand and Government on the other hand have been made.*

**Keywords:** *Foreign Direct Investment (FDI), Local Manufacturing Industry, Multi-Facility Economic Zone (MFEZ), Value Addition, Zambia*

## Introduction

A strong and competitive manufacturing sector is a foundation for any country's economic growth. The manufacturing sector in Zambia has generally performed below expectations for the past three decades due to low or lack of investment in advanced technologies and innovations needed to add value to raw materials (World Bank, 2009). Other barriers include undeveloped infrastructure such as energy, transportation and telecommunications, the high financing costs, macro-economic instability and administration (Micro-economics), crime and corruption (World Bank, 2009). The Forum on China–Africa Cooperation (FOCAC) held in 2006 presented an opportunity to address most of these constraints and long-term prospects for industrial development. At this FOCAC, the Chinese Government pledged to support the establishment of Special Economic Zones (SEZs) in Ethiopia, Mauritius, Nigeria, and Zambia (Davies, 2010). Böhmer and Farid (2010) present the internationally accepted definition of Special Economic Zones as "larger estates that could be considered cities on their own. They usually cover all industrial and service sectors and target both foreign and domestic markets. They provide an array of incentives ranging from tax incentives to regulatory incentives. In addition, they permit on-site residence".

Drawing from its own successful development experience, the Government of the Peoples Republic of China (PRC) proposed that Zambia develops its manufacturing sector through the establishment of the Multi-Facility Economic Zones (MFEZs) (World Bank, 2009). A MFEZ is a specific geographic area with quality physical and special infrastructure, where economic policies are more liberal than in the rest of the country in order to attract and facilitate establishment of world-class enterprises within the zones (Deborah and Tang, 2011). It is a business model which sets a platform for enhancing the competitiveness, diversification and stimulating industrialisation in the economy, hence creating quality jobs for indigenous population, which is key to economic growth. The MFEZs, just like SEZs, blend the best features of the Free Trade Zones (FTZs), Export Processing Zones (EPZs) and the industrial parks (IPs) concepts and create the administrative infrastructure, rules and regulations that benchmark among the best dynamic economies. A MFEZ is a comprehensive laboratory in which fully-fledged economic reforms can be piloted and cover large areas such as an entire province or a city, while IPs or high-tech parks are a supporting component of MFEZs, but with an industrial focus encompassing only part of a city (Deborah and Tang, 2011). A MFEZ is a township in its own right incorporating factories, housing units, medical, schools and recreational facilities, with reliable road and rail linkages, uninterrupted electricity and water supplies, improved telecommunications infrastructure, and efficient waste disposal systems.

The MFEZ strategy is to cluster smaller, downstream manufacturing firms and industrial operations around major industries based in the zones. As these MFEZs and IPs adopt different preferential policies, they play the dual roles of "windows" in developing the foreign-oriented economy; generating foreign exchanges through exporting products and importing advanced technologies; and of "radiators" in accelerating inland economic development (Deborah and Tang, 2011). The MFEZs cater for both domestic- and export-oriented industries, which utilise mainly local raw materials and sub-contract sections of their production to local manufacturers, aiming at (ZDA Act No. 11, 2006):

(i) Attracting more Domestic and Foreign Direct Investment;
(ii) Enhancing local business expansion and competitiveness and diversification;
(iii) To improve factor productivity and economies of scale;
(iv) Enhancing spatial transformation thus stimulating industrialisation in the economy; and
(v) Creating and accelerating new economic growth poles through technology and skills transfer, job creation and increased foreign exchange.

In Zambia, MFEZs are established under the ZDA Act No. 11 of 2006, and are broken down into two types, namely Production MFEZs (for manufacturing related businesses) and Export Trade MFEZs (for commercial trading, warehousing and many others to exploit export markets). The focus of this paper is on Production MFEZ. Table 1 shows six such type of MFEZs being established in Zambia (GRZ, 2011).

Table 1: A Summary of Production MFEZs in Zambia

| **MFEZs/IPs** | **GEOGRAPHICAL LOCATION** | **OWNERSHIP OF FIRMS IN MFEZs/IPs** | **SUITABLE INDUSTRIES** | **DEVELOPMENT STATUS AS AT DEC 2012** |
|---|---|---|---|---|
| Chambishi/ Forest Reserve | Copperbelt: Chambishi - 12° 39′ 0″ South and 28° 04′ 0″ East of GMT | TNCs, MNCs, SMEs, Sino-Foreign JVs & Strategic Alliances | Copper and copper related industries, agro-, household appliances, motor parts, explosives | 12% operational; Chambishi Smelter, BGRIMM Sino Metals/Acid, REBA |
| Lusaka East/ Sub-Zone/ Forest Reserve | 15° 20′ 0″ South & 28° 24′ 0″ East. Near Kenneth Kaunda International Airport | SMEs, Equity JVs and Private Partnership, Contractual JVs | Copper related industries, food, garments, electric, electronic, Car and bicycle assembly | Construction Stage (access roads done) |
| Lusaka South/ Forest No. 26, 2,100 hectares | 15° 30′ 0″ South and 28° 22′ 0″ East Chifwema Rd, 1.8 km off Leopards Hill Rd | PPP, SMEs, Equity JVs, TNCs Private | Food, garments, ICT, appliances, tobacco, beverages, research, Agro, diagnostic/medical | 414 hectares on Eastern side of zone developed; two phases remaining |
| Lumwana/ Forest Reserve (1, 300 ha) | 11° 50′ 0″ South and 25° 08′ 13″ East, South-east of T5 road | Equinox-owned company-Lumwana Mining Co. | Explosives, fishery, agro construction, electrical, electronics, chemicals, machinery, hospitality | Construction Stage (60% residential areas done) |
| Sub-Sahara Gemstone Park/Trade Fair ground | 13° 01′ 20″ South and 28° 39′ 28″ East along Crompton road off Kabwe Rd | SMEs, Equity & Contractual JVs, Private Partnerships | Lapidary, plastic, paper pulp, non-ferrous metals, wood, electro-winning & brick manufacturing | Partial operation and on-going construction |
| Roma Park/ 104 ha La Soleil Farm | 15° 23′ 0″ South and 28° 18′ 0″ East of GMT | SMEs, Equity JVs & Private Partnership | Manufacturing, real estate, commercial and retail service sectors | Construction Stage |

*Creating Domestic Linkages*

The success of Economic zones depends on the extent to which they create linkages with the local economy thereby generating employment and increasing transfer of know-how (Böhmer and Farid, 2010). MFEZ approach to industrialisation is FDI-led and its implementation is anchored on supportive policies from Government to Micro, Small and Medium-scale Enterprises (MSMEs) and FDIs, in order to stimulate industrialisation through business linkages. It is generally accepted that sustainable industrialisation through MFEZs route is possible if the local industrial capital is able to replace foreign investment in management, technology, design, factory operations, logistics, quality management, and marketing (UNCTAD, 2006). Business linkages between TNCs and local manufacturing firms are a structured approach which foreign and local enterprises can use to support each other's economic performance, through concrete collaboration in areas such as skills and managerial development, technology upgrade, distribution and access to new markets (UNCTAD, 2006). The interaction of these major stakeholders in the MFEZ set-up must be supported by the flow of information among research and technology institutions like universities and colleges, industry and Government, as shown in Figure 1.

There are two major policy areas on each side of the stakeholders that are relevant for building TNCs - local manufacturers/MSMEs linkages, namely (UNCTAD, 2006):

(i) "Improving the investment climate" and "attracting FDI strategically" on the TNCs' side;

(ii) “Strengthening the local absorptive capacity” and “developing domestic suppliers” on the local manufacturers/MSMEs’ side.

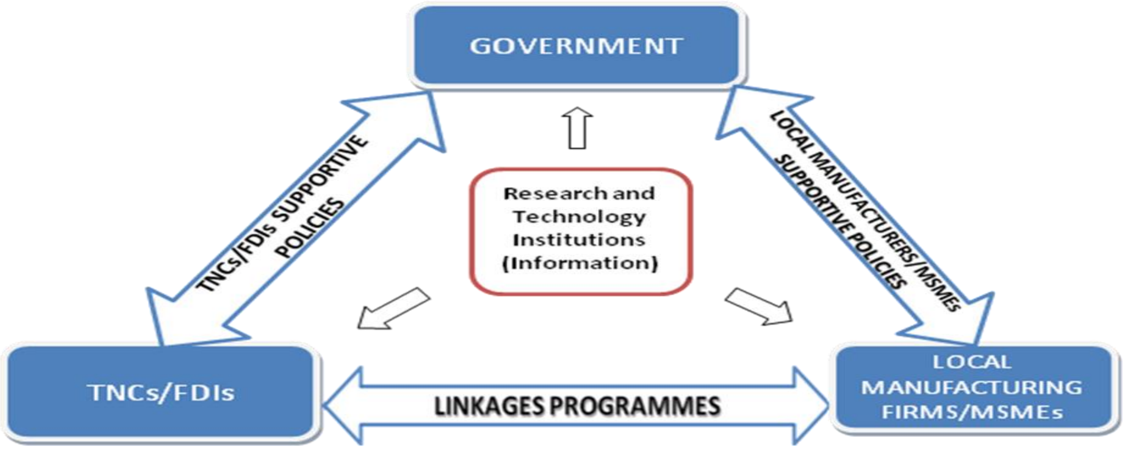

Figure 1: Stakeholders Interactive Triangle

Business linkages programmes can take different forms depending on what objectives the Government wants to achieve. These include (UNCTAD, 2006):

(i) *Forward linkages with customers* that allow marketing outlets to be outsourced;
(ii) *Backward linkages with the suppliers* that offer new market opportunities for local firms;
(iii) *Linkages with competitors* through which foreign investors may set new standards for local firms to compete with;
(iv) *Linkages with technology partners* through which TNCs may initiate common projects with indigenous MSMEs, including joint ventures, trade, licensing and strategic alliances;
(v) Other spillover effects: Labour migration; trained personnel may leave the investor to work with a local firm or set up their own MSMEs, resulting in human capital spillover.

To make the development of business linkages easy, local manufacturers (MSMEs) must be prepared, able, and interested to serve MFEZ firms in terms of quality, scale, price and delivery requirements (World Bank, 2008). Moran (2012) indicates that surveys show that foreign investors in SEZs tend to help indigenous suppliers set up production lines, train them in quality control, and coach them in management, strategy and financial planning. Further, they also provide advance payments and other kinds of financing and introduce their suppliers to export markets. Therefore, the scope and quality of linkages formed will depend on the existence of MSMEs which are able to meet high TNCs’ standards, or at least have the potential to achieve such standards within a short period. When there is a good fit between the TNC characteristics and MSME characteristics, more and better long-term partnerships that can potentially improve development tend to occur.

The question then is: How ready is the Zambian manufacturing industry to participate in the Production MFEZs?

To answer this question, we considered the fact that to have any beneficial linkages between local manufacturers and MFEZ firms, local manufacturers must possess technology and know-how for quality, cost, flexibility, service, and delivery performance. These are embedded in such variables as human resource, knowledge and skills, processes, equipment, machinery and systems like Lean Production and Total Quality Management (TQM) which increase business performance. These were used as assessment parameters for company readiness in the study reported in this paper. The study covered the period between 1964 and 2013, and targeted active manufacturing firms located in towns in the geographical areas chosen for the establishment of the MFEZs, which are Lusaka, Kabwe, Ndola, Chambishi, Solwezi and Livingstone.

## Methodology

The study was undertaken from March, 2011 to November, 2013 for data collection and industry visitations in selected sites. It utilised a questionnaire survey, a literature review, personal and telephone interviews (structured and unstructured), and observations of process lines during industrial visitations to collect both qualitative and quantitative data.

### *Survey Study and Study Population*

The sampling frame covered areas which were selected for the establishment of the MFEZs or IPs such as Lusaka, Copperbelt, Southern, Eastern and North-Western Provinces. The Primary sector (mining and minerals) was included for comparisons sake due to its backward and forward linkages. Eleven manufacturing sub-sectors, three Government departments in the Ministries of Labour and Social Security (productivity), Commerce, Trade and Industry (ZDA), and Finance (CSO) and three foreign missions to Zambia directly linked to MFEZ development (Japan, Mauritius and China), were purposively included in the sampling frame.

In order to ensure reliability and validity, a random sample size of 10 percent of the population was picked, which translated into 30 firms out of 297 active manufacturing firms. The companies chosen for study were a cross-section that included both foreign- and local-owned, and small- to large-scale. For qualitative data, purposive sampling was used on company executives and representatives and Multi-stage sampling for other stakeholders such as Government departments and foreign missions. Twenty-seven questionnaires were administered in person while three were e-mailed to the firms which could not be reached or as per their request.

### *Data Analysis*

The quantitative and qualitative data was analysed using Excel Spreadsheet format as well as the Statistical Package for Social Sciences (SPSS) software, in order to cross-tabulate and analyse the manufacturing sub-sectors and generate appropriate tables, graphs and charts which were used to display the trends on technology types, manufacturing management systems, human resources development and sources of inputs and modes of transportation.

## Survey Findings and Discussion of Results

To assess how easy it could be for the local manufacturing firms' strategic integration into MFEZ manufacturing networks, the collected survey data was analysed under three major themes, namely:

(i) Types of Technologies and Methods of production;
(ii) Technological Innovations, Best Practices and Manufacturing Systems; and
(iii) Human Resources Development (Skills, Managerial Capabilities and Employment Ratios).

In addition, respondents were requested to indicate what they felt would improve the situation to enhance their firm's competitiveness. Out of the 30 distributed questionnaires, 21 were returned, representing a 70 percent response rate. This was deemed sufficient for analysis. The analyses of the results, shortened in this paper, are provided together with the presentation of results.

### *Types of Technologies and Methods of Production*

Based on Figure 2, the study revealed that only the respondent firm in the Paper and Paper Products sub-sector had invested in Programmable Logic Controller (PLC), Automated Part Identification (bar-coding) and Automated Vision-based Systems, while 20 percent, 60 percent and 40 percent of respondent firms in Food, Beverages and Tobacco sub-sector had installed CNC, PLC and bar-coding systems, respectively.

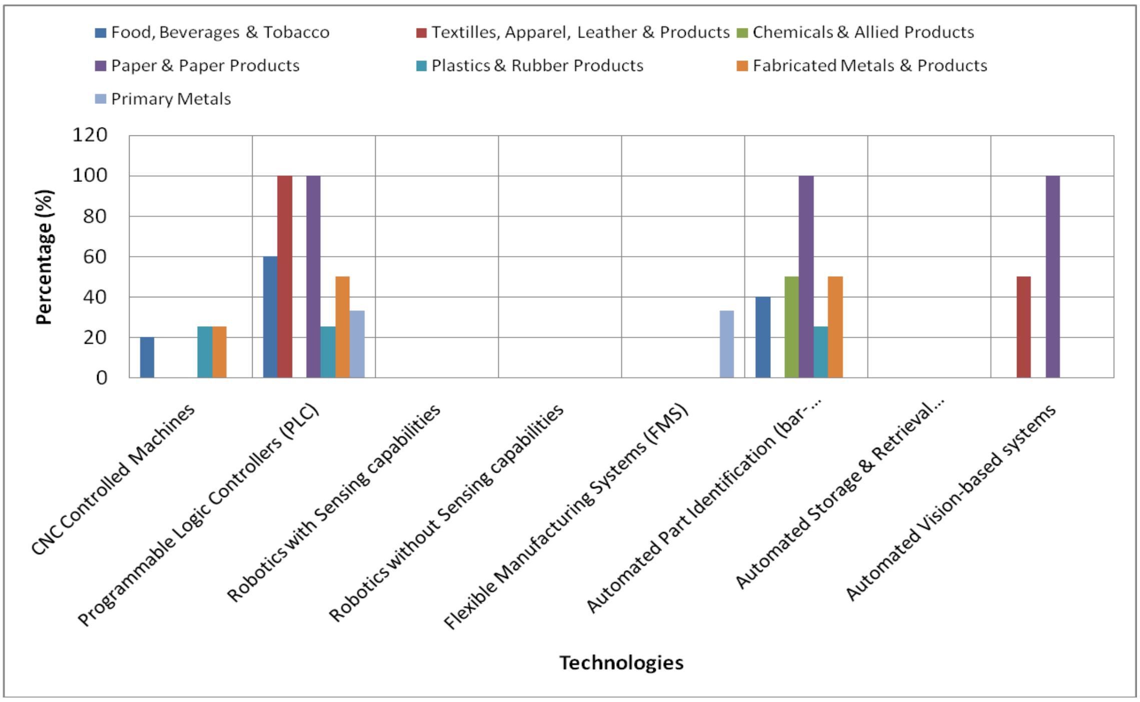

Figure 2: Existing Processing, Assembly, Material-handling and Inspection Technologies

Generally, there was substantial investment in PLC, except Robotics, Flexible Manufacturing System (FMS), Automated Storage and Retrieval Systems, Material-handling and Inspection Systems. However, 20 percent, 50 percent and 25 percent of the respondent companies in Food, Beverages and Tobacco, Textiles, Apparel and Leather, and Fabricated Metals and Products sub-sectors, respectively, indicated that they had planned to install these technologies in the next 2 years.

TNCs command an ever more important role in the economy of a host country. They possess technological capabilities to develop, search for, absorb, and exploit knowledge commercially (Fagerberg *et al.*, 2009). They boast of advanced technologies in manufacturing operations such as designing, engineering, processing, assembly, material-handling and inspection. It is believed that for technology transfer and manufacturing growth to be realised, the technology gap between the TNCs and the local manufacturing firms must be narrow. This gap refers to the absorptive and sustainability capacity to acquire and work with the new technology. According to Blanco de Armas *et al.*, (2002), when the host countries' level of technology is similar to that of the home country, the establishment of SEZs/MFEZs is likely to post economic growth. This is closely linked to host countries' human resources development. Nonetheless, the Zambian local manufacturing sector was characterised by outdated technologies with limitations. The absence of robotics, FMS and Computer Integrated Manufacturing (CIM) systems, among other is a clear indication of lack of modern manufacturing approaches, which would hinder smooth integration of the local manufacturing companies into the MFEZ value chains.

*Technological Innovations, Best Practices and Manufacturing Systems*

Referring to Figure 3, the survey revealed that all firms had installed almost all innovative systems in varying degrees with the exception of Lean Production in Chemical and Allied Products sub-sector (50 percent), Statistical Process Control (SPC) in Food, Beverages and Tobacco sub-sector (20 percent)  and Business Process Re-engineering (BPR) in Textiles sub-sector (50 percent).

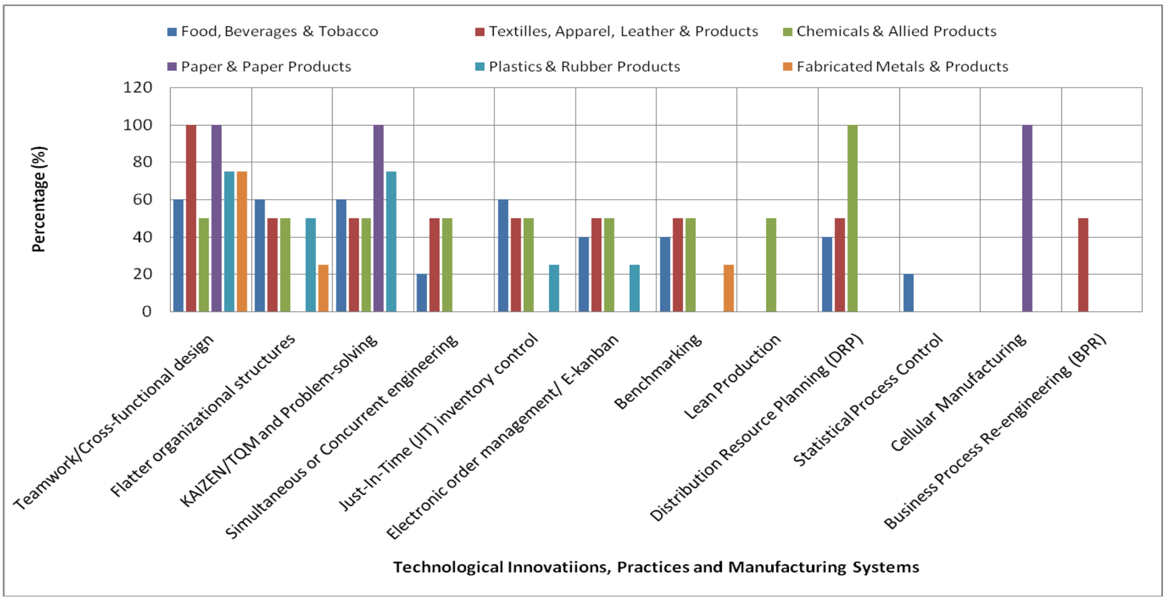

Figure 3: Existing Innovations, Best Practices and Manufacturing Systems

For technology transfer and manufacturing growth to be realised, the 'technological gap' between TNCs and MSMEs must be narrow. However, given the prevailing low absorptive and weaker innovative capacities, the local firms were faced with challenges of integration into MFEZ value chain. Some firms were still using inherited mechanised machinery from privatised parastatals installed in the 1960s, and experienced frequent breakdowns.

Recent innovation studies suggest that both technology transfer and local R&D capabilities are necessary conditions for technology upgrades in developing nations, which have the ability and motivation to absorb advanced technology and management know-how (Zhiqiang, 2000). Specifically, TNCs' presence must alter the innovative behaviours of a domestic firm such as R&D expenditure, and number of scientists and engineers (Galina and Cheryl, 2007). Nevertheless, from personal interviews conducted with CEOs and company representatives, the prevalent conditions especially in the plastics and rubber products and food, beverages and tobacco processing, depicted a weaker and porous conduit for technology and skills transmission from TNCs to local firms. The number of employees in R&D area remained negligible, about 0.12% of the total work-force.

*Human Resources Development – Skills, Managerial Capabilities and Employment Ratios*
Most companies' representatives indicated that they did not have medium- to long-term human resources development plans for their employees especially at the shop-floor, as shareholders were more concerned with profit maximisation. The average employment ratios of locals to expatriates in terms of specialisation, across all manufacturing sub-sectors surveyed, were not inspiring. For instance, according to Figure 4, the 6 to 1 represents the ratio of workers employed in production department, while human resource and purchasing departments had a 4 to 1 ratio. Engineers' ratio was 5 to 1, with Technologists and Technicians' ratio standing at 7 to 1, while the Artisans' and craftsmen's ratio was the highest at 21 to 1.

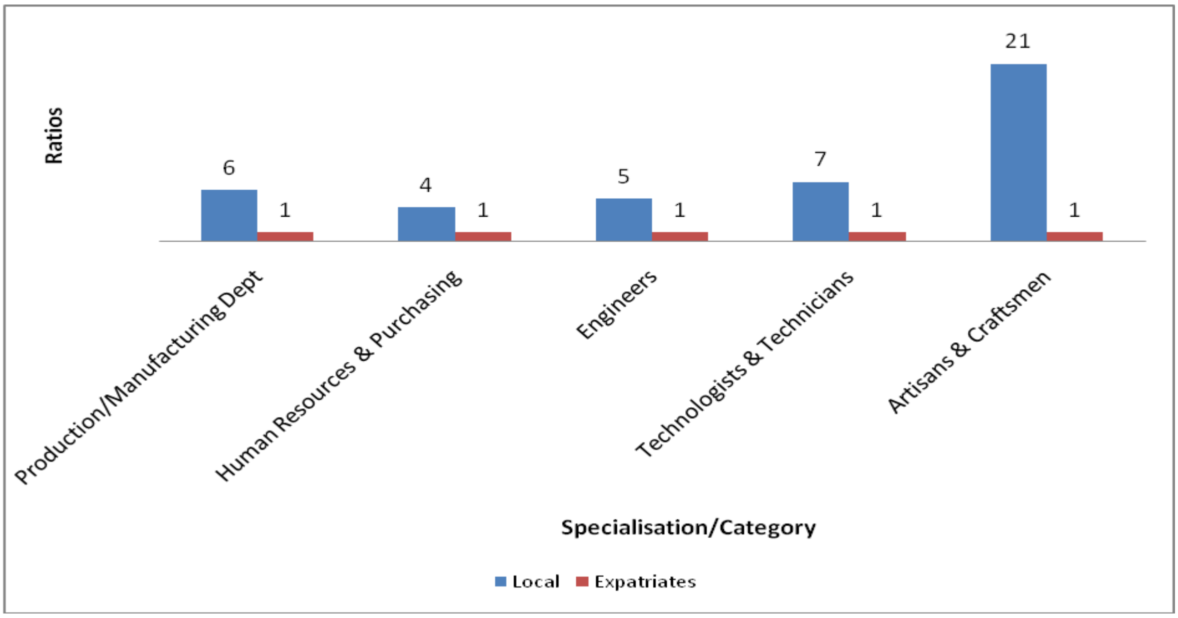

Figure 4: Employment Ratios (Locals to Expatriates) - Aggregated Manufacturing Sub-sectors

One striking feature worth noting is that 33 percent of the respondent firms in the Fabricated Metals sub-sector revealed that there were neither local Engineers nor Technologists employed, and the number of local Technicians was less than that of expatriates, standing at 1 to 3.

Further, the survey revealed that, like any other new project, the implementation of the MFEZ/IP is expected to face challenges such as Government's lack of clearly defined policy framework to buttress the implementation of the MFEZs/IPs concepts.

Besides technology, TNCs bring into the host country the needed complementary resources such as experience, entrepreneurial abilities and stock of knowledge, through formal training programmes and learning by doing within foreign affiliates. There is a positive relation between FDI and Total Factor Productivity (TFP) growth when a host country has achieved a minimum threshold of human capital development. However, lack of highly skilled labour has often been identified as an impediment to economic growth on the African continent (Farole, 2011). Evidently, the research revealed that most local manufacturing firms' human capital threshold was far much below for effective technology and skill spillover, especially in metal fabrication industry where neither local engineers nor technologists were employed.

Besides, there were more expatriate technicians than local ones which defeated the objective of local labour integration.

The survey also revealed the inability of the Zambian Government to provide equal opportunities for both foreign and local investors. A visible instance was the Chambishi MFEZ, where local vendors had been marginalised in business contraction. They complained that there were no regulations in place that compelled Chinese investors to source materials and services locally. Worse still, the investment threshold of not less than an equivalent of US$500,000 set for a manufacturing investor to operate in MFEZ/IP, was beyond the capacity of most local entrepreneurs, which would hinder their participation in the zones (ZDA Act No. 11, 2006). Under these circumstances, it is difficult to expect major positive outcomes from MFEZs and IPs.

*Critical Factors in the Manufacturing Firm's Business Strategy*

According to Figure 5, 62 percent of the respondent firms in aggregated manufacturing sub-sectors revealed that 27.3% of the critical factors (investments in advanced technologies, cost reduction in manufacturing, improvements in the manufacturing processes, and developing new products) had 72.7% impact on the achievement of business strategies, hence called the 'vital few'. In addition, 38 percent of the respondent firms disclosed that 72.7% of the critical factors like using team-based manufacturing systems such as cross-functions, improvements in marketing activities, personnel strategies (staff training and pay-for-skills), entering new markets, added-value services, using new materials and investment in information technology systems had little effect (27.3%) on the performance of the manufacturing firms. These factors are usually referred to as 'trivial many'.

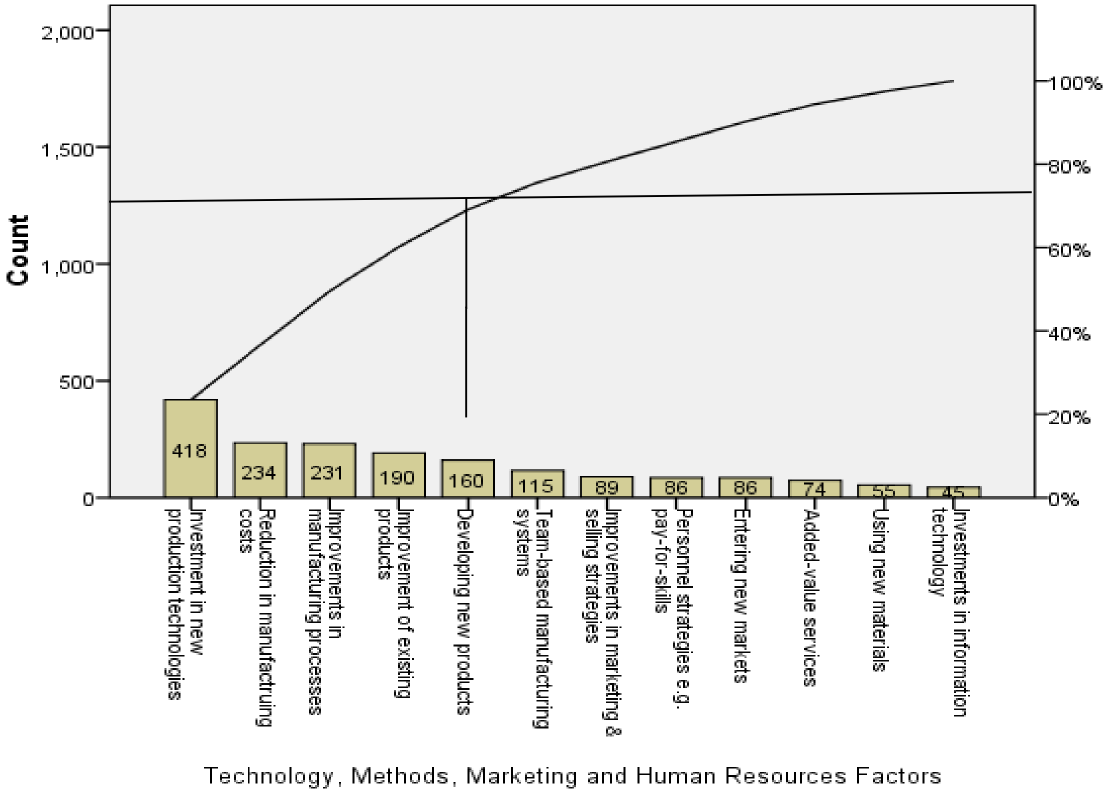

Figure 5: Importance Levels of Critical Factors in the Firm's Business Strategy - PARETO Curve

## Conclusions and Recommendations

### *Conclusions*

1. The technological gap between TNCs and local manufacturing firms was wider hence, reducing the absorptive and sustainability capacity, especially in Engineering-related, Plastics, Rubber and Chemicals sub-sectors.

2. The local manufacturing sector had a weaker innovative capacity as best practices like Lean Production, CM, SPC and BPR were not widely appreciated. It was characterised by an inability to diversify into new high value-added and dynamic products.

3. Most local manufacturing firms did not meet the minimum human capital threshold required for technology and skills transfer such as management experience and entrepreneurial abilities, as the bulk of their workforce was unskilled. In addition, the average employment ratios of locals to expatriates in terms of specialisation especially engineers, technicians and technologists, were too low to not only stimulate meaningful labour integration, but also animate internalisation and specialisation of skills. The current skills were only suitable for current lower levels and out-dated production technologies.

### *Recommendations*

#### ***A. The Manufacturing Industry Prong:***

1. Investment in advanced technologies such as CAD, CAE, CAM, FMS, PLC, Robotics, Field-bus among others will boost absorptive capabilities.

2. Investment in innovations and manufacturing systems like JIT, BPR, SPC, GT and Benchmarking will improve efficiency and productivity.

3. There is need for interactions among the firms, with academia, government and other stakeholders, in order to take advantage of synergy effects across the manufacturing sector.

#### ***B. The Zambian Government Prong:***

1. The Government must enact an investment policy with a clear focus on technology up-gradation and transfer, job creation and human resources development. For instance, it must introduce such linkages promotion programmes as Singapore Local Industry Upgrading Programme (SLIUP) and the Ireland's National Linkage Programme (NLP) in order to identify and upgrade local enterprises that have the potential to add value to the locally available resources and either export or supply to TNCs within the local market. Created in 1986, and financed by Economic Development Board (EDB), SLIUP's objective seeks to encourage TNCs to second an engineer to local sub-contractors and suppliers who will assist them in improving overall operation efficiency and in acquiring new technological knowledge. During this stage, the EDB pays the engineer's salary (Sánchez *et al.*, 2009).

2. The Government must establish think-tanks in respective industries, which are going to identify specific sectors and activities of investments to encourage production and entrepreneurship (capacity building) among native people. Furthermore, it must establish Business Incubators (BIs) in each province for strategic industries connected to native natural resources beneficiation. A BI refers to an economic development tool designed to accelerate the growth and success of entrepreneurial companies through an array of business support resources and services such as training, finance, quality and networking, among others (business.webcrawler.com).

3. The Government must offer incentives to TNCs which not only encourage in-house technical training and skills development, but also offer businesses to local suppliers, for instance double-deductions for HRD. In the same vein, it must enact enforceable policies that would facilitate exchange of technology and skills, like limiting the number of expatriates, preferably one expatriate to 10 locals.

4. Expansion of telecommunication systems, and improvement of the rural road network will help exploit investment opportunities and development of the manufacturing firms in relatively isolated (rural) areas which may be operating outside the MFEZs' and IPs' provisions.

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# REVIEW AND RESTRUCTURE OF ZAMBIA'S 2008 MINING WINDFALL TAX

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## ABSTRACT

*Zambia is richly endowed with mineral wealth. However, it is still encapsulated in the resource curse conundrum. This is because the benefits of mineral wealth have not translated in public development. This has sparked a lot of debate among the Zambian mass as to whether the mineral fiscal policies have been robust in capturing mining revenue. One issue has always stood out in these mineral taxation debates and this is the reintroduction of the 2008 mining windfall tax. Though this is the case, the Zambian mass has not been informed of the various issues leading to its revocation. This paper tries to undertake a critical review and restructure of this tax instrument with an aim of rectifying the inherent technical lapses in its design. This has been realized by treating the payable amount of this tax as a deductible expense in the income statement and by indexing the trigger prices for inflation. The results of this research indicate that the restructured tax instrument has the potential of maximizing the capture of windfall gains without imposing a higher than normal Average Effective Tax Rate (AETR) burden on a mining firm's pre-tax cash flows. This in turn retains capital to the mining firm for further exploration and other mine developmental activities. However, this tax needs to be balanced with other robust tax instruments for greater efficiency and effectiveness in its application. This calls for sound judgement on the part of politicians to advance this cause.*

***Keywords:*** *2008 windfall tax, Restructure, Review, Zambia, Average Effective Tax Rate (AETR)*

## 1.0 INTRODUCTION

Windfall tax can be defined as a tax levied on the gross sales value in which the rate fluctuates with the price of the mineral (Manley, 2013). Appiah (2013, p.19) defines windfall tax as " a levy that governments employ to collect extra rent generated by mining companies during times of windfall profits, arising from high mineral prices or discovery of unusually high quality deposits". This tax is economic rent[1] based and aims to capture windfall gains. A windfall gain is a sudden, unanticipated piece of good fortune. Therefore, this fortune should

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[1] Economic rent is surplus revenue over and above the sum of production costs and a minimum return on capital. See Otto *et al*. (2006) for a detailed discussion on economic rent.

accrue to the citizenry of the Host State (HS) where mining is being undertaken rather than to a foreign dominated mineral enterprise[2]. However, it should be noted that this tax is not based on the strict principles of economic rent because it does not encompass operating costs in its computation process. This fact makes the windfall tax a substantial incentive for mining companies to undertake cost saving which is an essential benefit to all players of the economy. Thus, it can be deduced that windfall tax provides a win-win situation amongst the direct participants of the economy. Windfall tax targets prices that are above the range of prices extractive industries use in their economic estimates. It acts as a safety valve that controls the capture of revenue influx occurring in long sustained periods of high prices as a result of higher supply relative to demand (International Council on Mining and Metals (ICMM), 2009). A strong support for its implementation lies in the fact that it does not distort investor decisions which would have been made in its absence. In public finance, a tax that does not distort investor decisions when legislated is termed to be neutral[3]. Apart from these advantages the windfall tax reinforces the fiscal stability of mineral fiscal agreements. It does this by capturing large amounts of revenue in times of high mineral prices and becomes inapplicable at lower price levels. This act financially blankets the companies against loss. Undertaking this helps to douse the electorate's motivation to mount pressure on the government so as to undertake unilateral alteration of fiscal terms in periods of high prices. Designing mineral fiscal frameworks that encourage efficient resource development and a stable fiscal environment augments the magnitude of revenue to be shared (Sunley and Baunsgaard, 2001).

Despite these advantages this tax has found little or no application in most jurisdictions. This has been attributed to the fact that no country has been implementing the windfall tax correctly. Most countries that have advocated and implemented the tax instrument have done this with flaws in its design, some of these countries include Zambia, Mongolia and the United States of America (USA).

This paper therefore seeks to review Zambia's 2008 windfall tax with an aim of undertaking a restructuring process that will rectify the flaws in its design.

## 2.0 HISTORICAL EVENTS LEADING TO ZAMBIA'S 2008 WINDFALL TAX INTRODUCTION

Zambia's ownership structure of the mines has made a transition from private hands to national ownership and back to private hands. In 1969, the Zambian government through the Matero reforms had gained majority ownership in the mining companies (Lungu, 2009). This was necessitated by the need to maximize revenue generation which was to be channeled for infrastructure development. Full state control of the mines was achieved in 1972 under the hospice of the United Nationals Independence Party (UNIP) government led by President Kenneth Kaunda. It is important to note that during this period no substantial reinvestment

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[2] However, another school of thought argues that this fortune should accrue to the mining firms in order to provide them with the incentive to undertake exploration in areas previously inaccessible.

[3] See Daniel *et al*. (2008).

was made in the mining industry. This led to the de-rehabilitation of most production facilities leading to contracted production values. Low copper prices coupled with these low production values led to a myriad of sector economic problems which stifled foreign exchange gains and export earnings. This fact contributed to the UNIP government being unpopular within the Zambian society. In 1989, there were large industrial unrests in the mineral sector which proliferated the unpopularity of the UNIP government. By 1990, Fredrick Chiluba who was the leader of the Zambia Congress of Trade Unions (ZCTU)[4] formed the Movement for Multiparty Democracy (MMD) and ascended to power in 1991. Fredrick Chiluba's campaign was mostly centered on adopting a neo-liberal approach of economic management which was centered on privatizing state owned enterprises. In 1997 and 2000, the state embarked on a huge privatization program under the leadership of President Fredrick Chiluba[5]. However, it must be mentioned that the privatization of the mines was not the sole wish of the Zambian government but rather there was persistent pressure from the World Bank and IMF for Zambia to undertake structural reforms to its mining sector before any donor funding was receipted. Despite, the pressure from Civil Society Organisations (CSOs) not to privatize, the Zambian government went ahead and privatized. The Mines and Minerals Act of 1995 facilitated this process. It also allowed the government to enter into Development Agreements (DAs), which were binding contracts between mining firms and investors on a project by project basis. Making a transition from a background of low copper prices and loss making mines, it was imperative for the government to sign these agreements that were lopsided in favor of the mining investor. These agreements were supposed to be instrumental in attracting FDI in the sector. To further attract FDI, the DAs had a proviso of fiscal stabilization agreements. These agreements committed the government not to alter mineral fiscal policies for a period of 15-20 years. If one party felt the other party was not holding part of the bargain it had the right to seek an arbitration process. It must be put on record that most of the DAs that were signed at privatization stage were not made available to the public for review and scrutiny[6]. These controversies surround the DAs taxation era.

The following were the features of the DAs:

- Mining firms were allowed to carry forward their losses for a period of 15-20 years on a "first-in, first-out basis".
- Mining companies were further allowed to claim capital allowance on capital investment at a rate of 100%
- Corporate Income Tax was reduced from 35% to 25%
- Export duty exemption was provided
- There was signing of fiscal stability agreements committing the government not to alter mineral fiscal policies for a period of 15-20 years. This fact made the DAs legally binding.

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[4] See http://www.zctu.org.zm

[5] However, the Zambian Government still retains minority shareholding in a number of mining companies through Zambia Consolidated Copper Mines Investment Holding (ZCCM-IH)

[6] Some Development Agreements are available from http://www.minewatchzambia.blogspot.co.uk.

After the presidential rule by Fredrick Chiluba which lasted for 10 years from 1991 to 2000. President Levy Patrick Mwanawasa ascended to power under the same party (MMD). The MMD government being led by President Mwanawasa faced internal and external pressure to revise the DAs signed in the privatization era. This was because the mining industry which was once faced with low copper prices was now characterized by a boom in these prices. This made the electorate to have a perception of low gain in mineral resource revenue. Due to this pressure, the government was under duress to unilaterally alter the mineral fiscal policies. In 2008 the Mwanawasa government enacted the 2008 Mines and Minerals Development Act which canceled the DAs to implement a uniform mineral tax system across the board. This of course brought about mixed feelings on the investors side as some mining corporations did not recognize it as legally binding. As such, some companies threatened to take the matter to international courts.

The mineral fiscal regime that was introduced in 2008, post the DAs had the following tax structure

- Corporate Income Tax (CIT) stood at 30%
- Mineral royalty stood at 3% of the gross revenue
- A withholding tax of 15% on interest, royalties, management fees and other bases was implemented.
- A variable profit tax of 15% was enacted when the ratio of taxable income to sales exceeds 8%.
- A windfall tax to be triggered at different cobalt and copper price threshold was implemented
- Capital allowance which stood at 100% was reduced to 25%
- The reference price on which taxes were to be based was the price tenable at the LME, metal bulletin or any other metal exchange market recognized by the Commissioner General.

These measures were expected to bring an additional $415 million into government coffers from the mining industry in 2008 (Lungu, 2008). However, this taxation regime was short-lived when President Mwanawasa died in that year. The succeeding President, Mr. Rupiah Banda did not possess the late presidents doctrine of mineral taxation, this coupled with the pressure from the mining investors made him abolish the windfall tax in April 2009. This was justified by its inherent weaknesses which made the entire tax regime to have an Average Effective Tax Rate (AETR)[7] beyond normal. It is estimated that the Marginal Effective Tax Rate (METR) of the 2008 regime was above 80% in some cases, while the AETR was only 47% (Economic Association of Zambia (EAZ), 2008). Most mining companies attributed this high AETR and METR to the inherent weaknesses of the windfall tax instrument.

## 3.0 TECHNICAL REVIEW OF THE 2008 WINDFALL TAX INSTRUMENT

This section undertakes an in-depth technical review of the windfall tax instrument applied to copper and cobalt in 2008. This tax instrument was not to be applied to any person solely carrying on mineral processing activities. However, mineral processing that was done in

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[7] See Daniel *et al*. (2008) and Devereux and Griffith (2003)

conjunction with mining constituted mining operations. It should be noted that the payable amounts of this tax instrument were supposed to be remitted on a monthly basis to Zambia Revenue Authority (ZRA).

## 3.1 Application of the 2008 windfall tax on copper

Table 1 depicts the trigger prices of the 2008 windfall tax related to copper. The windfall tax was calculated on a cumulative basis using three rates. These include 25%, 50% and 75%.

Table 1: Trigger prices of the 2008 windfall tax related to copper (ZRA, 2008)

| **DESCRIPTION OF TRIGGER PRICE** | **AMOUNT ($/t)** |
|---|---|
| First trigger price | 5,512 |
| Second trigger price | 6,614 |
| Third trigger price | 7,716 |

**a) Definitions of technical terms**

The following are the definitions of the parameters used in the equations of windfall tax.

1) *Monthly Average Price (MAP)***:** This is the weighted average London Metal Exchange (LME) copper price in respect of a calendar month. This parameter is expressed in United States (US) dollars per metric tonne. It is calculated by Equation 1

$$MAP = \frac{Q_1P_1+Q_2P_2+Q_3P_3+\cdots+Q_{n-1}P_{n-1}+Q_nP_n}{Q_n} \qquad [1]$$

Where:

$Q_n$ = The quantity of copper or recoverable copper sales in metric tonnes in a calendar month

$P_n$ = The corresponding London Metal Exchange daily closing cash seller price in United States dollars per metric tonne for Grade A cathode

n = The aggregate number of copper or recoverable copper sales invoiced in the relevant calendar month

2) *Ruling Exchange Rate (RER)***:** This is the Bank of Zambia monthly average Kwacha to United States dollar currency exchange rate.

**b) Computation of windfall tax payable on copper**

The following list provides the standard application of the 2008 windfall tax on copper:

1) Where the average monthly price does not exceed the First Trigger Price (FTP) windfall tax is not payable

2) Where the average monthly price exceeds the FTP but does not exceed the Second Trigger Price (STP), windfall tax is calculated using Equation 2

$$WT = (RER * Q_n)[25\% \, (MAP - FTP)] \qquad [2]$$

Where:
WT = Windfall tax payable for the month ($)

3) Where the average monthly price exceeds the STP but does not exceed the Third Trigger Price (TTP) windfall tax is calculated according to Equation 3

$$WT = (RER * Q_n)\{[\, 25\% \, (STP - FTP)] + [50\%(MAP - STP)]\} \qquad [3]$$

4) Where the monthly average price exceeds the TTP, windfall tax shall be calculated in accordance with Equation 4

$$WT = (RER * Q_n)\{[25\% \, (STP - FTP)] + [50\% \, (TTP - STP)] + [\, 75\% \, (MAP - TTP)]\} \qquad [4]$$

### 3.2 Application of windfall tax to cobalt

Table 2 depicts the windfall trigger prices related to cobalt.

Table 2: Trigger prices of windfall tax related to cobalt (ZRA, 2008)

| DESCRIPTION OF TRIGGER PRICE | AMOUNT ($/t) |
|---|---|
| First trigger price | 55,116 |
| Second trigger price | 77,162 |
| Third trigger price | 88,185 |

### a) Definitions of technical terms

The following are the definitions of the parameters used in the equation of windfall tax for cobalt.

**1)** *Monthly Average Price (MAP)***:** This is the weighted average Metal Bulletin cobalt cash price in respect of a calendar month. It is calculated by Equation 5

$$MAP = \frac{Q_1P_1 + Q_2P_2 + Q_3P_3 + \cdots + Q_{n-1}P_{n-1} + Q_nP_n}{Q_n} \qquad [5]$$

Where:

$Q_n$ = The quantity of cobalt or recoverable cobalt sales in metric tonnes in a calendar month

$P_n$ = The corresponding Metal Bulletin daily closing cash seller price in United States dollars per metric tonne

n = The aggregate number of cobalt or recoverable cobalt sales invoiced in the relevant calendar month

**2)** *Ruling Exchange Rate (RER)***:** This is the Bank of Zambia monthly average Kwacha to United States dollar currency exchange rate.

### b) Computation of windfall tax payable on cobalt

The standard application of the 2008 windfall tax on cobalt is the same as that of copper explicated in Section 3.1.

## 3.3 Pitfalls associated with Zambia's 2008 windfall tax instrument

There are two criticisms of the 2008 windfall tax instrument (EAZ, 2008)

- Firstly, unlike mineral royalties, windfall tax payments could not be deducted from profits for income tax purposes. This meant that in times of high mineral prices the mining company would pay colossal sums of CIT and windfall tax. This increased the tax burden to levels above normal.
- Secondly, the tax instrument was too onerous, given the rest of the tax regime burden.

Additionally, the price thresholds were set too rigid. Since copper and cobalt prices are expressed in monetary terms, their money value depreciates over time. Therefore, it is imperative for these trigger prices to account for inflation.

This paper tries to rectify these lapses by treating the windfall tax instrument as a deductible expense in the income statement and by indexing the trigger prices for inflation.

# 4.0 RECTIFICATION OF THE 2008 WINDFALL TAX INSTRUMENT

This section presents the rectification process of Zambia's 2008 windfall tax instrument. It begins by illuminating the inflation indexation process of the trigger prices. This is then proceeded by an explication of the effects of treating the windfall tax as a deductible expense in the income statement.

## 4.1 Indexing copper and cobalt windfall trigger prices for inflation in US dollar terms

Since copper and cobalt prices were expressed in US dollars it is only rational to index these trigger prices for inflation using US parameters. Inflation rate applied to windfall trigger prices can mathematically be defined as:

$$\mu = \frac{CP_2 - CP_1}{CP_1} * 100\% \quad [6]$$

Where:

μ = Inflation rate (%)
$CP_1$ = US consumer price index in the first month of the fiscal year (January)
$CP_2$ = US consumer price index in the month windfall tax is payable within the fiscal year

The monthly consumer price indices defined in Equation 6 can be obtained from the U.S Department of Labor (Bureau of Labor Statistics). The parameter definition in Equation 6 asserts that inflation rate in the first month of the fiscal year (January) is always zero.

Indexing the FTP for inflation gives:

$$= (FTP * \mu) + FTP \quad [7]$$

$$= FTP(1 + \mu) \quad [8]$$

Similarly, indexing the STP and the TTP for inflation gives

$$= STP(1 + \mu) \quad [9]$$

$$= TTP\ (1 + \mu\ ) \quad [10]$$

The following list redefines the application of the windfall tax instrument after indexing the trigger prices for inflation.

1) Where the average monthly price does not exceed *FTP(1+μ)* windfall tax is not payable

2) Where the average monthly price exceeds *FTP(1+μ)* but does not exceed *STP(1+μ)*, windfall tax shall be calculated using Equation 11

$$WT = \ (RER * Q_n\ )[25\%\ (MAP - FTP(\mu + 1))] \quad [11]$$

3) Where the average monthly price exceeds *STP(1+μ)* but does not exceed *TTP(1+μ)*, windfall tax shall be calculated according to Equation 12

$$WT = (RER * Q_n)\{[\ 25\%\ (STP - FTP)(\mu + 1)] + [50\%(MAP - STP(\mu + 1))]\} \quad [12]$$

4) Where the monthly average price exceeds *TTP(1+μ)*, windfall tax shall be calculated in accordance with Equation 13

$$WT = (RER * Q_n)\{[25\%\ (STP - FTP)(\mu + 1)] + [50\%\ (TTP - STP)(\mu + 1)] + [\ 75\%\ (MAP - TTP(\mu + 1))]\} \quad [13]$$

The windfall tax equations above apply both to copper and cobalt. These equations reflect an indexation process related to the US inflation rate. However, it must be noted that if the US was to face a substantial inflation rate, this modus operandi of indexation has the possibility of rendering the windfall tax inapplicable. This in turn exposes the state to financial risk because of the stifled mineral revenue generation in times of high mineral prices. However, it must be mentioned that the US has one of the most stable macroeconomic environment in the world hence the application of its parameters in the indexation process.

This research does not index the trigger prices based on inflation in Zambia because of its unstable macroeconomic environment. The high inflation rate experienced in Zambia can render the windfall tax inapplicable even if copper and cobalt prices were to increase substantially. This is because it can push the trigger prices so high above normal.

## 4.2 Treatment of windfall tax in the income statement

Another rectification of the 2008 windfall tax is to treat it as a deductible expense in the income statement. This means that in times of high mineral prices, the investor will disburse a colossal sum of windfall tax and a reduced amount of Corporate Income Tax (CIT). This initiative reduces the AETR of the CIT in times of high mineral prices when the two tax instruments are applied concurrently. Equation 14 shows the AETR of the CIT when the windfall tax is treated as a deductible expense in the income statement.

$$AETR_{CIT} = \frac{(NPV_{TI} - NPV_{WT}) * CITR}{NPV_{MF}} X\ 100\% \qquad [12]$$

Where:

$AETR_{CIT}$ = Average Effective Tax Rate for CIT (%)
$NPV_{TI}$ = Net Present Value of taxable income ($)
CITR = Corporate Income Tax Rate (%)
$NPV_{WT}$ = Net present value of windfall tax payable amount ($)
$NPV_{MF}$ = Net present value of a mining firms pre-tax cash flows ($)

The same principle used to calculate the AETR of the CIT can be extended to calculate the AETR of the entire tax regime when windfall tax is treated as a deductible expense in the income statement. Equation 15 shows the AETR of a mineral tax regime as a whole.

$$AETR_{TR} = \frac{(NPV_{TI} - NPV_{WT}) * (CITR + TR_O) + P_O}{NPV_{MF}} X\ 100\% \qquad [13]$$

Where:

$AETR_{TR}$ = Average Effective Tax Rate of mineral tax regime (%)
$NPV_{TI}$ = Net Present Value of taxable income ($)
CITR = Corporate Income Tax Rate (%)
$NPV_{WT}$ = Net present value of windfall tax payable amounts ($)
$NPV_{MF}$ = Net present value of a mining firms pre-tax cash flows ($)
$TR_O$ = Total rates of other taxes that use taxable income as a base (%)

$P_O$ = Payable amounts of other taxes ($)

As can be deduced from the restructuring process, indexing the windfall trigger prices for inflation pushes these prices high (i.e. by a factor of 1+µ) thus giving financial relief to high cost mining companies. This is because the high cost companies will be able to attain normal profits before the tax kicks in. This is consistent with adhering to the *ability to pay principle*. Additionally, treating the windfall tax as a deductible expense in the income statement will reduce the AETR of the CIT and the taxation regime as a whole. This means in times of high mineral prices the mining company will pay windfall tax but a reduced amount of CIT. This reduces the tax burden of the mining firm whilst disbursing a fairly substantial amount of revenue into government coffers.

The restructured model of windfall tax in this research is based on the principle of economic rent and thus does not affect the operating cost of a mining company. This is because it will be applied in times of high mineral prices. This gives a windfall share of profits to the government whilst returning substantial profit to the mining company for continued operation. In times of low price outcomes, this tax will be inapplicable as it is concerned with optimal taxation in high mineral prices. Therefore, the tax will give financial relief to mining investors at low commodity prices. This will benefit the government and the state as a whole as it will help retain mining investment in Zambia's mineral sector.

The rectification process has shown that it is possible to reintroduce a robust windfall tax structure on the Zambian mining industry. However, this calls for sound judgement on the side of politicians to advance this cause.

## 5.0 CONCLUSION AND RECOMMENDATION

This paper has undertaken a critical review and restructure of Zambia's 2008 windfall tax. The technical lapses of this tax instrument have been rectified by treating it as a deductible expense in the income statement and by indexing the trigger prices for inflation. Following this undertaking, it was concluded that these rectification's aid to reduce the AETR of the CIT and entire tax regime in general. This promotes a win-win situation between the mining investor and government. Since windfall tax is more concerned with optimal taxation it is only right and rational for it to be implemented on the Zambian mining sector. This is because it will act as a safety valve for capturing revenue influx in times of high mineral prices whilst giving financial relief at low prices. However, to prevent the implementation of a futile windfall tax on the sector as that seen in 2008, a proper restructured scheme as the one being proposed in this paper must be legislated. In addition, the windfall tax must be harmonized with other robust tax instruments in order to generate a robust tax regime. This calls for sound judgement on the part of mineral policy formulators, analysts and politicians.

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# SESSION 2B

# HUMAN CAPITAL DEVELOPMENT

# A Review of Engineering Education in Zambia for the 21st Century: Historical, Current and Future Trends Part I

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## Abstract

*Engineering Education (EE) in Zambia, as in many developing countries around the globe, is considered as one of the main key drivers to development. EE in Zambia dates as far back as 1969 when the first and still the largest School of Engineering (SoE) was established at the University of Zambia (UNZA).*

*This paper reviews the current state of EE in Zambia and critically analyses the current challenges and emphasizes the need to prepare an engineering workforce relevant to the 21st century aspirations. The short fall for engineers in Zambia from 2012 to 2016 is in the range of 22.2% - 27.9%. The evolution of EE in Zambia has also been analyzed and the current trends in engineering in recent years have been considered to ensure an informed approach to building strategies for EE for the 21st century. Regional and global methodologies that are either in existence; piloted or under consideration have also been discussed.*

*The review further proposes a study to obtain an overall insight of the effectiveness and perceptions of EE in Zambia. Finally, the paper provides some future directions or opportunities that EE in Zambia should contemplate exploring in educating the 21st century engineer.*

**Keywords:** *21st Century Engineer, Engineering Education, Development.*

## Introduction

In the 20thcentury engineering recorded its greatest achievements, which were reported as widespread development and distribution of electricity, clean water, automobiles, antibiotics, telecommunications and computers to mention a few. Despite these achievements the current century is envisaged to pose greater challenges than those from the past millennia (National Academy of Sciences, 2008).

The National Academy of Engineers identifies 14 Grand Engineering Challenges that engineers of the 21st century need to solve to improve livelihoods around the world. Proposed solutions to the grand challenges include developing Engineering Education (EE) programs that will focus on training graduates with the technical, social, political and ethical leadership skills appropriate to address these grand challenges.

Since these first EE programs were launched the understanding of how people learn has significantly improved, more effective teaching tools have been developed and Industrial technology has changed very significantly. In order to prepare engineering graduates for the global challenges, educators must review both the content and the delivery of program material. Unfortunately, few engineering schools have made major updates to their programs over the past few decades (Davidson *et al*., 2010).

## Engineering Challenge in the 21st Century-A Global Perspective

While the 21st century challenges are issues for the entire world, they are more acute for the developing world. Asia, a continent with a good number of developing countries (with the exception of Japan, Korea and Singapore), faces the following challenges in the 21stcentury; population explosion; depleting natural resources; environmental degradation; social tensions due to youth unemployment; high impact of technology; demand for mass education for improvement in living standards; rapid urbanization and globalization.

Possible solutions to some of the Asian challenges include the provision of high quality, globally benchmarked, technical educational opportunities for aspirants from Asia; meeting manpower needs of the respective Asian countries, keeping in view of the regional and global demands; networking at national, regional and global levels on developmental programs and bilateral and multilateral cooperation in education.

The percentage of Asians going into higher education systems in developing Asia is relatively low. At the same time the rate of growth in the continent is phenomenal. The demand for technical education is growing at a much faster rate than other disciplines. For example, in India; every year nearly one million nationals aspire to enter an engineering degree program.

It is an accepted fact or a reality that due to globalization there is an overall mobility as technical manpower from Asia is in demand all over the world, in particular North America and to some extent Australia. There are two reasons for this:

- Asian countries have to train sufficient number of engineers to meet their own demands as well as global demands and;
- Asian educational systems have to conform to global systems to allow for the mobility of Asian graduates.

Focusing on a rising economic power in Asia, The People's Republic of China, it is envisaged that during the 21st century, China will inevitably run into the following major challenges; high population growth in a country that already has a population of 1.4 billion; excessive consumption of energy and natural resources as China strives towards developmental growth, thus leading to increased environment degradation; and massive urbanization.

The Chinese government acknowledges science and technical innovation as being crucial for national growth and job creation and has made the training of Chinese engineers a major national priority for the decade 2010-2020. China produces more than 700,000 engineering graduates each year and in cases where appropriate specializations are scarce, the sponsoring of Chinese students by government to study abroad is encouraged.

In several oil-rich countries such as the Middle East there is an understanding that there must be a diversification of their economies and utilization of significant amounts of their income from the sale of oil and gas to invest in future commercial efforts. In particular, several countries from this region are focusing on developing “knowledge economies”, by developing higher education programs that will provide the human capacity to initiate and support such new economic thrusts. High quality engineering graduates are a key component in building this human capacity.

On the African continent, in spite of progress in some areas, the continent still faces daunting challenges such as poverty traps involving high fertility, reliance on subsistence agriculture, lack of nutrition and inadequate education. Africa is home to the only three countries globally that have a lower Human Development Index (HDI) today than in 1970 (Zimbabwe, the Democratic Republic of Congo and Zambia) (Cilliers *et al.*, 2011). It is worthwhile to note that these three countries are all located in Sub-Saharan Africa. Erinne (2015), states that the greatest challenge for Africa in the 21st century is to re-order its economy in such a way as to create an industrial base, using the abundant natural resources prevalent on the continent as primary inputs.

Unemployment and under employment are extraordinarily high across much of the continent. There is still excessive dependence on primary agricultural and mineral commodities, and low levels of industrial manufacturing activities. Rapid urbanization and changing economic structures bring their own problems, such as social discontent and sociopolitical disruption (Cilliers *et al.*, 2011).

In addition, there are new and emerging problems such as those associated with Climate Change whose impacts are envisaged to have greater effects on the continent due to its lower economic standing on the global stage.

The potential drivers of development on the African continent are engineers. Therefore the education and training of future engineers on the continent is critical for the economic emancipation of Africa in the 21st Century (Erinne, 2015).

The Sub-Saharan region of Africa suffers a chronic lack of indigenous capacity in engineering. Quantitatively, there are insufficient numbers of engineers graduating to meet demand in some Sub-Saharan African countries. In addition, engineers are graduating without the necessary skills and experience to be employable in the global economy.

The inadequate capacity of the engineering profession in Sub-Saharan Africa (SSA) is a substantive obstacle to achieving almost all development goals, from the provision of basic sanitation to the reduction of rural poverty. However, there are a number of practical ways that could enable the engineering workforce in Sub-Saharan African countries to gain the skills and experience needed to facilitate development. Progress can be made in the fields of education, policy making, strengthening of professional bodies, and in better engaging the private sector.

The Europe 2020 strategy plan (launched in 2010) sets out a vision for smart, sustainable and inclusive growth for Europe by 2020, based on five headline targets:

- To have at least 75% of people aged 20-64 in employment;
- To invest 3% of GDP in research and development;

- To cut greenhouse gas emissions by at least 20%, increase the share of renewables to 20% and improve energy efficiency by 20%;
- To reduce school drop-out rates to below 10% and increase the share of young people with a third-level degree or diploma to at least 40% ;
- To ensure that 20 million fewer people are at risk of poverty or social exclusion.

Europe has recognized that there is an urgent need for the EE system to reform and adjust curricula to conform to the European unification process and the European Higher Education. This will also ensure that ecology and sustainability become an established part of EE worldwide while the national education systems will continue to express the cultural identity of their respective countries.

Requirements to establish a state-of-the-art engineering education will enable future graduate engineers to address and tackle the challenges of the future. A realization that the most important educational goal for any engineer must be to use knowledge gained to develop the expertise needed for future tasks.

The United States National Academy of Engineering (NAE) has identified the following challenges currently faced by the engineering profession:

- Moral and ethical challenges of making developmental (social & economic etc) benefits available to those in the developing world;
- EE not keeping up with the technological changes;
- Ethics;
- Safety; and
- Inability to predict the future.

This list represents a response to a recognition that some of the current challenges will continue to be so in the 21st century.

Engineering education in the North American context has been at the forefront of working with industry and governmental organizations to create solutions for many of the engineering challenges that the continent experiences. However, EE continues to struggle to keep up with innovation and technological changes.

In Russia, in a survey of specialist training (Ogorodova *et al.*, 2012), 83% of experts approached, stated that the state of engineering in Russia was unsatisfactory mainly due to a weak research base. As a solution, Russia has developed and adopted national engineering standards, designed an internally recognized engineering accreditation system, created scientific research institutes and adopted laws specifically targeting the engineering profession to mention but a few.

Historically, South American engineers have faced challenges similar to those faced by other developing regions including problems of diseases, safety and nature. Current challenges are mostly due to population growth and also the growth of technology around the world.

The South American response to these challenges has included:

- Increasing the number of institutions of higher education in the region;

- Restructuring engineering courses to produce engineers who are recognized regionally and internationally;
- Enhancing the practice of engineering, making engineering information available and facilitating communication of best practice in the profession;
- Increasing the number of students studying engineering by enhancing project work; and
- Developing policies to improve water supply and sanitation in the region.

South America foresees the current challenges still being there in their future, therefore the region is currently working on future challenges and sustainable solutions through new technologies, techniques and research and teaching to mention but a few.

## Engineering Education in Sub-Saharan Africa (SSA)

Provision of technological solutions to challenges faced by humanity in Africa goes back to the beginning of human civilization with the development and use of stone and bone tools and implements based on archeological evidence. The first two universities in the world were established in Africa viz. the Université Al Quaraouiyine in Morocco (founded in 859 AD) (Al Quaraouiyine University, 2015) and the Al-Azhar University in Egypt (founded in about 975 AD) (Muslim Heritage, 2015). These universities started as religious universities but introduced the teaching of Islamic science as well (Collegestats.org, 2015). Western type universities were introduced after the arrival of missionaries and colonialists after 1800. Some of the oldest “western” type universities include Stellenbosch Gymnasium now Stellenbosch University which was founded in 1866 (Stellenbosch University, 2015), Gordon Memorial College now University of Khartoum founded in 1902, Egyptian University now Cairo University founded in 1908 (Cairo University, 2015), Algiers University founded in 1909 (Algiers University, 2015) and the Uganda Technical College now Makerere University founded in 1922 (Juma, 2015).

The Stellenbosch University established its Engineering School in 1944 while Cairo University established its School of Engineering in 1834 to train technicians for civil and military projects. The development of universities in North and South Africa happened a lot earlier and was somewhat different from that of SSA; therefore the rest of this discussion is going to focus on EE in SSA without South Africa.

Most of the early EE programs in SSA were established in the 1950’s and 1960’s. These early programs were started as affiliates of similar European programs such as those offered by the University of London. The curricula in most cases was imported and was intended to satisfy the skills needs of the new colonies as seen from the eyes of the colonial agencies. With the coming of independence the priorities changed somewhat as the new empowered indigenous leaders sort to establish viable governing systems. The focus immediately after independence in most cases was the training of government functionaries and managers for these newly freed countries (Juma, 2015). As a result higher EE suffered neglect due to insufficient investment in equipment and facilities. In the 1970’s and into the 1990’s EE suffered even more due to among other things:

- Austerity measures imposed on many countries by international financial institutions such as the International Monetary Fund (IMF);
- Shift of funding priority to primary education;

- Political instability;
- Brain drain as many senior faculty members left their home countries and moved to Europe and America;
- Brain drain as many young and upcoming academics left for graduate studies in the west and did not come back;
- Exploding populations of young people needing to be trained; and
- Exploding number of publically funded universities and introduction of new programs.

All these factors and more led to the chronic lack of indigenous capacity in engineering in Sub-Saharan Africa that is still experienced in many countries (Royal Academy of Engineers, 2012). This lack is evidenced in a number of ways including:

- Insufficient number of graduating engineers to meet local demand;
- Students graduating without the necessary skills and attitudes;
- Grossly under-equipped training laboratories;
- Underfunded and understaffed engineering schools;
- Minimal research output;
- Weak graduate programs;
- Large undergraduate student numbers that in many cases far outweigh the available resources; and
- Weak university-industry partnerships.

## Engineering Education in Zambia

It is acknowledged world-over that an engineering school is a primary center of excellence for research and training aimed at offering practical and workable answers to the challenges mankind faces. Therefore, the EE at a university occupies a critical position in any nation (The Zambian Economist, 2015). The first Zambian Republican President, Dr. Kenneth David Kaunda, is quoted (The Zambian Economist, 2015) in his inaugural speech as Chancellor of the University of Zambia (UNZA) in 1966 saying that, '*a University is one of the keys that can open the door to the future of our nation and help us to overcome the persisting evils of poverty, ignorance and diseases without such an institution we cannot hope to become the nation we want to be.'*

In 2006, Dr. Kenneth David Kaunda's view was echoed in a similar fashion by Gabonese President Omar Bongo at the Association for the Development of Education in Africa Conference held in Gabon, in which he stated that, '*effective learning institutions were powerful weapons against most of Africa's challenges including poverty, ignorance, diseases and illiteracy*.'

Clearly, the above view is perceived as the main drive before UNZA was brought into legal existence in November 1965 (University of Zambia, 2015). The university began with three Schools: Education, Humanities and Social Sciences, and Natural Sciences - but quickly realized the need to develop the School of Engineering (SoE) in 1969. Thus, the SoE at UNZA became the first engineering school to be established in the country and is still to date the largest in Zambia.

Since its establishment, the need for engineering graduates in the country has been on the rise. This is evidenced by surveys (University of Zambia, 2015) conducted by Hamukoma (2011) projecting shortfalls of engineers in the country as shown in Figure 1.

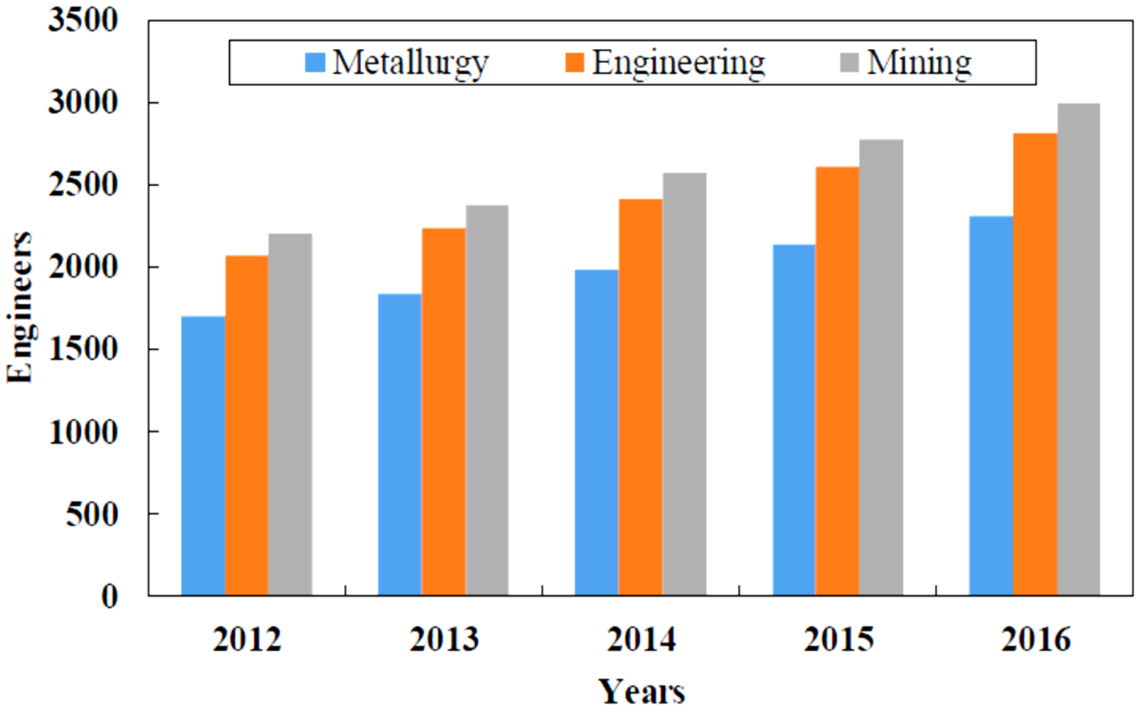

Figure 1. Demand for skills 2012 to 2016, excluding increase in demand from new mines (Hamukoma, 2011).

Currently, these short falls continue to increase due to migration of young professionals out of the country and the increased demands from industry for specialized skills. Therefore, the national importance of EE cannot be over-emphasized.
The UNZA - SoE started with programs including:

1. Mechanical Engineering taking up 30% of the total engineering students.
2. Electrical and Electronic Engineering with 28%.
3. Civil Engineering with 22%.
4. Agricultural Engineering with10%.
5. Surveying taking up 5%.
6. Mining Engineering 5%

Zambia’s industrial base has for a long time depended on copper mining. Therefore, engineering schools attracted a lot of mining and mineral processing engineers, including chemical engineers at the time. Therefore, in 1973, University of Zambia established School of Mines to offer Mining, Metallurgy and Mineral Processing Engineering. Furthermore, this saw the initiation of the Chemical Engineering program by year 2000 at the Copperbelt University.

Later, the SoE also introduced post-graduate programs to include (University of Zambia, 2015):

1. Master of Engineering in Power Electrical Engineering (Taught or by Research)

2. Master of Engineering in Agricultural Engineering (Taught).
3. Master of Engineering in Environmental Engineering (by Research)
4. Master of Engineering in Geodesy and Surveying (by Research)
5. Master of Engineering in Geographic Information System and Remote Sensing (by Research)
6. Master of Engineering in Production Engineering and Management (Taught or by Research)
7. Master of Engineering in Renewable Energy Engineering (Taught)
8. Master of Engineering in Structural Engineering (Taught or by Research)
9. Master of Engineering in Thermo Fluids Engineering (Taught or by Research)
10. Master of Engineering in Water Resources Management and Water Resources Engineering (by research)
11. Doctor of Philosophy

The School of Technology (SOT) at the Copperbelt University (CBU) was the second largest engineering school to be established in 1989 from the then Zambia Institute of Technology (ZIT). The school started offering the following B. Engineering programs in 1996 which include:

1. Electrical/Electronic Engineering
2. Chemical Engineering
3. Computer Science
4. Mining Engineering
5. Metallurgy and Mineral Engineering

Civil Engineering programs were offered in the School of Built Environment (SBE). In 2010, SOT was split into the School of Engineering and the School of Mines and Mineral Sciences (SMMS). The programs that are currently offered by these two schools include:

**Diploma Programs**

1. Diploma in Telecommunications
2. Diploma Electrical Engineering
3. Diploma in Civil Engineering Technology
4. Diploma in Environmental Technology
5. Diploma in Chemical Technology
6. Diploma in Mine Ventilation
7. Diploma in Mining Engineering
8. Diploma in Mine Survey
9. Diploma in Metallurgy
10. Diploma in Small Scale Mining
11. Diploma in Geomatics Engineering

**Undergraduate Programs**

12. Aeronautical Engineering (Hons)

13. Civil Engineering with Construction Management (Hons)
14. Civil Engineering (Hons)
15. Mechanical Engineering (Hons)
16. Mechatronics Engineering (Hons)
17. Telecommunication & Electronics Engineering (Hons)
18. Electrical/Electronics (Power)
19. Electrical/Mechanical Engineering
20. Environment Engineering
21. Chemical Engineering
22. Mining Engineering
23. Metallurgical & Mineral Processing Engineering
24. Mining & Exploration Geology
25. Geomatics Engineering

**Postgraduate Degree Programs**

26. Integrated Masters of Engineering Degree with Honours – in one of the eight (8) pathways, namely M. Eng. (Hons) in:
    a) Aeronautical engineering
    b) Automotive Engineering
    c) Mechanical Engineering
    d) Mechatronics Engineering
    e) Electrical/Electronic Engineering
    f) Communication, Network & Signal Processing Engineering
    g) International Construction Management & Engineering
    h) Masters of Science Degree

27. Masters of Philosophy Degrees
28. Doctor of Philosophy Degrees

The Schools of Engineering at the UNZA and CBU produce the majority of engineering graduates employed in Zambia, and therefore this paper review will focus on EE as it is provided at the aforementioned institutions of higher learning. On the websites of these schools the purposes/visions are stated as:

UNZA – "The purpose of the School of Engineering is embedded in the purposes of the University of Zambia, which are to:

- Fulfill the historical purpose of a university through the pursuit of teaching, research and scholarship;
- Advance national development through the application of learning and research;
- Promote learning by offering opportunities for advanced education to all suitably qualified persons without distinction of race, gender or political affiliation; and
- Enhance Zambia's potential to promote the goals of the wider African and international communities." (University of Zambia, 2015).

CBU – “The mission of the School of Engineering is to advance knowledge and educate students in science and technology that will best serve Zambia and the world in the 21st century. We are committed to supporting talented Zambians and international students, and to developing partnerships with industry, funding bodies and government agencies, in order to create an exemplary environment where discovery, scholarship, innovation, commercial exploitation and public engagement thrive” (Copperbelt University, 2015).

According to a report (Zambia Development Agency, 2014), it is evident that very little has changed in the engineering industry since the inception of the first engineering school. The minerals extracted, mining being the major manufacturing factor, are still exported as raw materials with very little value addition being made in terms of processing into intermediate and finished engineering products. Engineering products such as mining and construction equipment are imported for various industries as opposed to local manufacture from local raw materials. Most foreign investors would prefer to bring in their own state-of-the-art equipment and facilities and this suppresses the young engineer’s innovation and creativity in providing engineering solutions. Instead, most engineers are pushed to the “maintenance inclination” rather than the “design perspective”.

In addition, the other reasons why Zambian engineering graduates end up being maintenance engineers could be because:

1. Design and analysis training is weak; and
2. There appears to be an over concentration on just the technical aspects and very little on other factors such as innovation and entrepreneurial elements that are important for developing new and creative ways for value addition.

According to UNESCO, 1997, the challenges outlined in the report which relate to the case of Zambia were:

1. Decline in resources (funding)
2. Increasing student numbers without corresponding increase in resources, for example:
   - Library resources;
   - Laboratory facilities;
   - Lecture space;
   - Places for industrial attachment.

3. Credibility of engineering education programs:
   - Acceptability of graduates by employers’ associations
   - Acceptability of graduates by regional/international institutions to undertake postgraduate studies
   - Acceptability for professional licensing of graduates with regional/international engineering professional associations

4. Absence of legal instrument to carry out/enforce the accreditation of engineering education programs.
   - Engineering professional institutions
   - Industry
   - Society
   - Academic staff from faculties of engineering

5. Lack of recognition of engineering education programs by third country professional bodies;

6. Too few lecturers registered as professional engineers;
7. Inadequate quality assurance because of prohibitive cost of bringing external examiners from universities outside Africa;
8. Examination procedures are not sufficiently complied with;
9. Lack of formal mechanism for transfer of credits between institutions in the region;
10. Absence of Peer mentoring of undergraduate students by senior students;
11. Inability of universities to attract and retain staff ;
12. Inadequate industrial input for curriculum review or changes to programs;
13. Inadequate funds to sustain or conduct industrial training;
14. Inadequate cooperation between industry and university on student attachment;
15. Curriculum reviews not done regularly;
16. Inadequate laboratory/practical training facilities;
17. Poor and inappropriate student projects; and
18. Inadequate or lack of managerial programs in entrepreneurship and economics.

UNESCO (1997) also reported that many African Engineering Schools (Zambia inclusive) have for a long-time operated with methodologies and facilities developed in foreign countries and these EE strategies often times are not compatible with the local environment. Zambia could adopt some workable strategies to respond to its current and possibly future EE challenges. It is further encouraged that while most of the adopted successful industrialized strategies would provide guidance, there is need to formulate mechanisms for transforming EE in Zambia to align with the current scenario.

If Zambia were to develop their own EE model for the region devised through collaborative and creative efforts with potential end users, then training based on this model would ensure that graduates are employable both in the local and regional labour markets. In addition, the graduates would be relevant to both the urban and rural areas; providing intellectual solutions to problems. The concept would result in both national and personal development well-adjusted to conform to the realism of the Zambian environment and society. Therefore, the Zambian context needs to reflect a balance of the local, regional and global current trends in EE. Also while engineering schools copied a training model from Europe many decades ago, many other models have since come into the market that may best meet the Zambian needs.

On the other hand, EE in Zambia cannot turn a blind eye to the on-going technological advancements. Therefore, the involvement of the generation of people born during the 1980s and early 1990s is quite critical to developing meaningful strategies for the future. This forward looking and dynamic model of EE could be encouraged through youth participation to exploit their high mental potential and freedom. Graduates from this type of approach to EE would therefore successfully compete at international levels and exhibiting an innovative capability to generate and evaluate new ideas and make well-informed decisions to adapt to prevailing and future situations. Considering that Zambian engineering graduates need skills that can be applied globally for instance, working for multinational companies operating in Zambia, there is need to benchmark against EE globally and regionally. This will require EE educators to have an effective interaction with engineers from other parts of the world.

## Conclusions

The paper reviewed the current global and regional challenges and emphasized the need to prepare an engineering workforce relevant to the 21st century for Zambia. To ensure an informed approach to building strategies for EE for the 21st century current trends in engineering in recent years should be considered. Finally, the paper provided some future directions or opportunities that EE in Zambia should contemplate exploring in educating the 21st century engineer. This requires a study to obtain an overall insight of the effectiveness and perception of EE in Zambia. This is important because Engineering education is crucial as it enables future engineers to fully assume that leading role in serving as engines of innovation whose developments will benefit the people of Zambia.

## Acknowledgements

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# Human Capital Development in Achieving Sustainable Industrialisation in Africa – A Lens for Engineers: Leveraging Current Capital

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## ABSTRACT

*Many African countries have not achieved developed country status and remain in the process of doing so. They are typically characterised by low national income as well as low Human Development Index values. In order for Africa to achieve sustainable industrialisation it must leverage its human capital in meeting this objective. Industrialisation remains one of the important processes through which African countries can achieve economic growth with alleviation of poverty. Governments in partnership with the private sector, as leading drivers of industrialisation, must use the available human capital to achieve economic growth that is largely irreversible and thus achieve sustainable industrialisation. Industrial policy formulation must match the aspirations of sustainable economic growth. Engineers as part of a nations' human capital are well placed to contribute to sustainable industrialisation through application of their skills and development of innovative solutions to Africa's unique challenges.*

**Keywords**: *Sustainable Industrialisation, Human Capital, Africa, spill-over effect, Innovation*

## INTRODUCTION

Much of African economies are currently not highly industrialised and still remain in the process of moving to the state of industrialised economies, or otherwise known as the process of moving from an undeveloped to a developed state. This is also seen as moving from low to high income nation status. Although various criteria are used to define the divide between undeveloped and developed states the more common are Gross Domestic Product (GDP), Gross National Product (GNP), per-capita income and the Human Development Index (HDI). These are indicators of the level of economic growth attained and the level of development. All these to some extent give a measure of the living standards prevailing for the general population in a country. African countries still score low on all four and this is a reflection, not only of the nature of economic output of these countries but also, of the mostly poor living conditions that prevail for many of its peoples. The journey for Africa seems long and hard beset with many instances of taking some steps forward and then followed by some steps backwards. Africa needs to find ways and means of sustaining its economic activities geared towards achieving industrialised nation status and this calls for some astute thinking and strong will from all key players involved in driving this process. The achievement of sustainable industrialisation depends on many variables. This paper specifically addresses the role that engineers, as part of a nations' human capital, can play in ensuring that sustainable industrialisation is achieved. In this paper sustainable industrialisation and sustainable economic growth are seen in the same light as one leads to the other.

## HUMAN CAPITAL

Human capital can be defined as a populations’ knowledge, skills, abilities, and competencies. Human capital is acquired through education, many other learning avenues as well as through experience. It is recognised as being an important factor for achievement of economic growth as supported by authors such as Pelinescu (2014) and Ziderman (1997). Although the literature suggests an on-going debate on both the extent and nature in which human capital contributes to economic growth there remains a consensus that it is a necessary factor for economic growth. While there are many factors leading to sustainable industrialisation, El-Sharkawy (2009) proposes ten, which are highlighted in Fig.1. Human capital, presented by the author as ‘qualified labour force’, is certainly one of the important factors. Human Capital can also enhance some of the other factors shown; for instance in a study that looked at various human capital indices Salike (2016) found that human capital has the potential to attract foreign direct investment (foreign capital) and hence enhance economic growth. Although the human capital of a nation cuts across many disciplines, engineers form a part of this resource and have a significant contribution to make as some of the other factors rely on the services of or input from engineers. A look at Fig.1 shows that some of the other areas identified require the input of an engineer either directly or indirectly. Engineers are technically skilled individuals who apply scientific, mathematical and other principles in meeting the needs of society through provision of services, products and infrastructure. The skills that engineers have constitute a form of capital wherein these skills can be harnessed for transfer to other individuals and for developing appropriate innovations that could contribute significantly to economic growth of a nation.

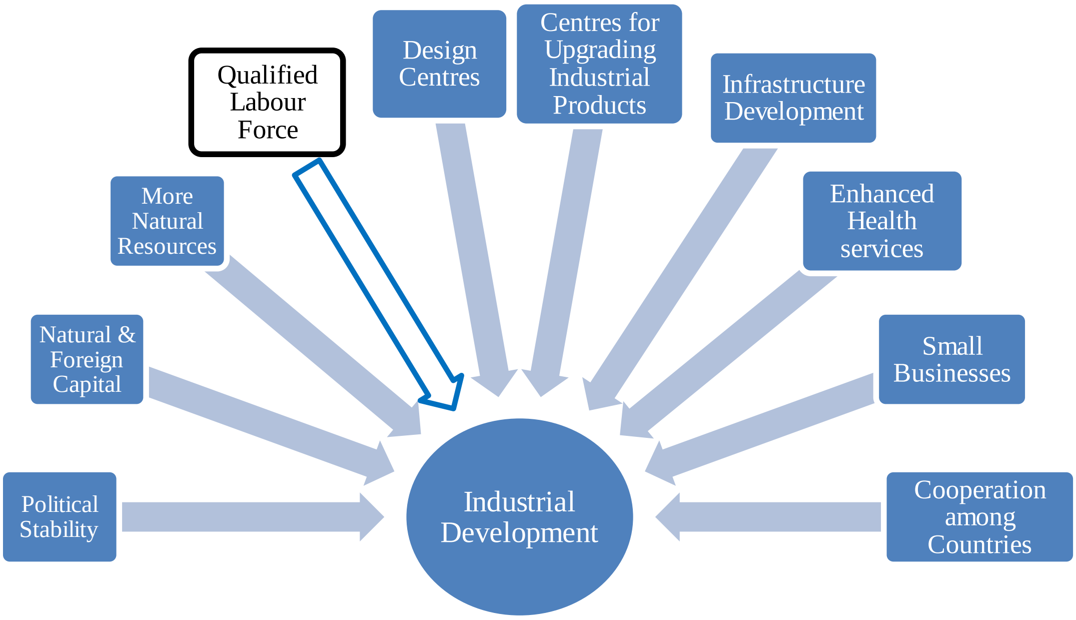


Fig.1 Factors leading to Industrial growth and development

## WHAT INDUSTRIALISATION IS

Industrialisation involves transformation of a human group from an agrarian society into an industrial one characterised by extensive activity in the manufacturing sector. As industrialisation takes place this should lead to increased wealth as well as increased markets for consumer goods and services. These then provide further opportunity to industrial investment and economic growth.

Countries that have achieved developed nation status have all gone through the process of industrialisation to get where they are. The direct and indirect benefits have been increased GDP with high HDI leading to low poverty levels. Other benefits have included improved employment opportunities and high labour productivity. It is therefore apparent that Africa needs to accelerate the process of industrialisation so that it too can reach this state. This should be the long term goal of African countries so that its peoples can be uplifted from poverty and living conditions can be improved to an extent where the quality of life is of a high standard with services that function efficiently at all levels.

## WHY SUSTAINABLE INDUSTRIALISATION IS IMPORTANT

Unless Africa embarks on a sustainable path to industrialise the problems of mass unemployment, poor standards of living and poverty will persist. The nature of industrialisation embarked on must be sustainable and not what Ogbimi (2007) describes as 'trivial growth'. In differentiating between 'trivial growth' and 'true growth' Ogbimi (2007) describes true growth as one that increases national and individual competencies so that growth is sustainable and largely irreversible whereas 'trivial growth' seeks only to grow GDP, foreign reserves and capital investments but does not grow the competencies mentioned above and ultimately proves to be unsustainable and reversible. Author Pritchet (2000) noted that many sub-Saharan nations failed to achieve true growth in the period from 1960 to 1992. A study by Melamid, *et al* (2011) looked at 24 growth episodes from the 1980s, 1990s and 2000s. The study showed that in 18 out of the 24 episodes that had achieved economic growth poverty was reduced. Although the authors acknowledge the complex relationship between economic growth, employment and poverty it is clear from the results that economic growth is an important factor in alleviating poverty.

This paints a bleak picture and although many African countries have grown at phenomenal rates in the past few years the worry that most of this growth is trivial growth is a genuine one to have as these gains could easily be wiped out by shocks that may hit these countries. Africa can ill afford to remain in this predicament. With low levels of industrialisation, low skills base and heavy dependence on few commodities nations leave themselves vulnerable to shocks that could send them spiralling back to mass unemployment and poverty, usually with little or no social safety nets.

In some countries growth has taken place at rates which the infrastructure could not cope with eventually leading to economic stagnation due to the burden placed on the infrastructure. Energy, transport, and communication infrastructure are some examples. When industry has to scale back or shut-down due to inadequate infrastructure this undermines economic activity potentially leading to slowdown in economic activity as well as job losses. All this in addition to discouraging any further investments.

Sustainable industrialisation, where appropriate industrial policy is developed with scenario planning applied prudently, is a vital necessity for African nations. Only by identifying inherent strengths and building on these can this objective be achieved. According to Ogbimi (2007) building up individual and national competence, in essence human capital, is the most important step to getting poor nations to achieve sustainable growth. The notion of human capital being a major contributor to economic growth is supported by Hanushek & Kimko (2000) who stated from the findings of their study that economic growth is closely related to the cognitive skills of a population. The quality of the human capital was shown to be very significantly related to economic growth. The aggregate skills of a country therefore form its knowledge or human capital. When one looks at the factors of production from an economics point of view the physical capital is a form of wasting asset whereas human capital is a non-wasting asset that can be harnessed for increasing returns through skills and knowledge that increase productivity. Authors Ziderman et al. (1997) notes that investment in human capital is no longer seen as a benefit stemming from economic growth but rather an investment that makes sustained economic growth possible.

## THE ROLE OF GOVERNMENTS AND THE PRIVATE SECTOR

To be sustainable, industrialisation must be driven in a very systematic manner. The government of a nation as custodian of the development agenda normally leads the planning function and policy formulation whereas the private sector carries out the economic activities and provides some capital outlays to finance some of these activities. Therefore the Government and the private sector are some of the leading drivers for industrialisation to take place. Their roles are discussed below.

In understanding the roles that these two sectors play it is important that one notes the different, sometimes seemingly opposing, motivating factors that could drive the two. Governments are largely driven by a social agenda that involves uplifting mass populations from poverty to some decent living standard which involves large capital expenditures on infrastructure and services. This may entail subsidising some expenses to make the expenditure burden of households lighter. The private sector on the other hand is driven by maximising returns to shareholders, which means it is profit driven otherwise known as the 'bottom line', which is revenue after expenses have been taken off. Because the private sector needs to make profits it will naturally hold back on expenses or look at ways of reducing them.

Both parties may call on the engineer to innovate for what could be seen as different reasons. The Government may call for innovative solutions that make use of indigenous resources, where they present a competitive advantage, to alleviate social problems and maximise the 'reach' of the limited revenue that Government may collect mostly from the private sector. The private sector on the other hand may require engineers to innovate solutions for them that lead to lower expenses on the part of the organisation. In order for the situation to be a win-win or sustainable the private sector must be allowed an environment where innovation, while leading to reduced expenses, leads to higher productivity and hence higher income for the Government and the nation. This then means that economic activity is enhance while the 'reach' of the Government is also extended with subsequent benefit to the population. A climate for private sector growth leads to enhanced industrialisation and the process repeats itself with subsequent enhanced economic growth. To sustain this growth the Government as custodian must have an industrialisation plan, with supporting policies, that contains a component of scenario planning as part of this so that all possible outcomes are anticipated with appropriate mitigation measures developed to safeguard economic gains. Should any particular shock hit, there must be plans on how labour can be shifted to other sectors as a 'safety net'. Those sectors not affected by the shocks can be enhanced to absorb labour from the affected sector. Investment levels in infrastructure and any other appropriate areas must be planned for. Also, importantly the population must be educated and skilled so that the human capital of the nation rises with its fortunes and enhances the ability to turn plans into reality. Having skills and not harnessing them in a systematic and planned manner will simply lead to the same old pattern of unsustainable activities which may see gains in limited areas for a limited time but ultimately the gains may be lost.

## THE ROLE OF ENGINEERS

Engineers, as part of a nation's human capital, have a vital role to play in achieving sustainable industrialisation. Some commentators have argued that due to the capital intensive nature of industrialisation activities and associated infrastructure, and because the activities must be carried out through harnessing many other diverse skilled individuals, engineers are constrained by these shortcomings from making a difference to the wider economic fortunes of a nation. This suggests that engineers cannot be proactive but simply reactive to external investment decisions around them made by others with capital. However, despite this challenge engineers must take a more optimistic approach and identify the areas in which their intellectual capital can make meaningful impact and become agents for sustainable economic development in any way large or small.

Current engineers have an opportunity to contribute to economic growth through knowledge transfers in various workplace and other settings as well as development of innovative and appropriate technology that enhances productivity and is economically practical. The attitude that engineers must approach this with is highlighted below.

Authors Blundell, *et al* (1999) in studying the returns on human capital investment differentiate between individual returns and social returns. The former refers to direct benefits derived by the individual, such as increased workplace benefits, and the latter refers to the 'spill-over' effect onto the wider economy that an individual's human capital can have. Engineers must therefore not simply look at the personal gains from acquiring the skills they possess but how they can apply these skills to ensure the 'spill-over' effect takes place and leads to the enhancement of economic growth. This is the key to maximising and leveraging the human capacity presented by engineers. The 'spill-over' effect can be applied by:

- Improving on productivity
- Growing other human capital through knowledge and skills transfer
- Input to policy formulation
- Technology assimilation and adaptation to local conditions where required
- Carrying out research that can lead to commercialisation of the outputs

This is in fact a crucial focus that all skilled individuals must have. Sustainable growth will involve increasing the human capital of a nation by each skilled individual playing their part in improving their productivity as well as allowing their skills to benefit and transfer to others around them. The focus is to develop oneself and then use that state of personal development to effect change around ones environment. The focus for the individual must not simply be to do 'just enough' to make it past the performance appraisal but a self-motivated approach to the 'spill-over' effect seeking out the five avenues outlined above and even more ways to contribute to the economic growth aspirations.

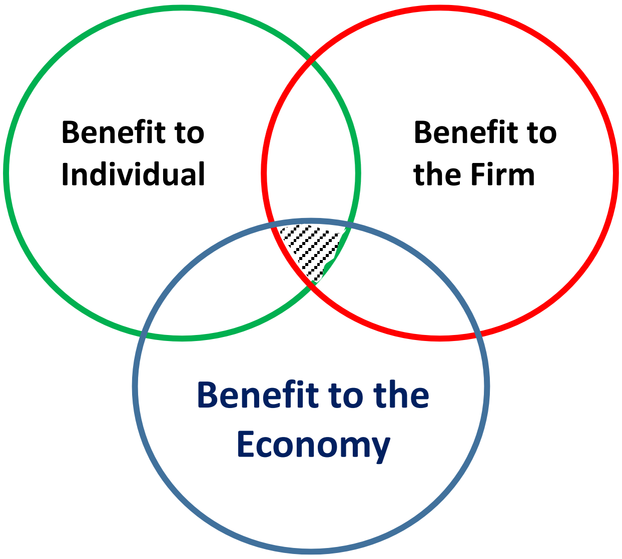


Fig.2 The benefit choice in applying ones skill set

Because engineering is a career motivated by improving the lives of societies and guided by ethics, engineers must stand ready to play their part in driving the necessary activities required for sustainable industrialisation through innovative application of their skills in a challenging environment.

## NEED FOR INNOVATION

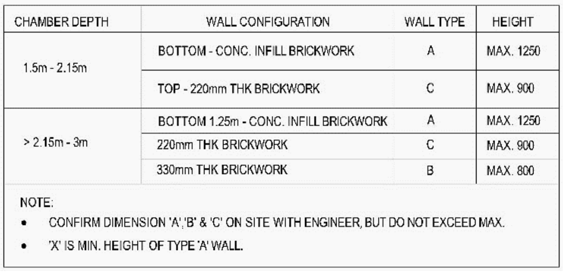
Innovation is a product of a skilled population. Innovation can either generate new technology or indeed take current technology and practise, and improve upon it. Therefore Africa needs to not only be an end user of technology but a source and innovator of technology. This ensures that when foreign investors are long gone the skills to carry out the activities that had been undertaken and also to diversify to other activities are retained in the nation. Innovation can ensure that economic activities are carried on even in the face of shocks. This therefore means that Africa must find ways to develop economically viable home-grown or at least home-nurtured technology. Technology that is leveraged in such a way that the nation has sufficient skills to drive the process at all levels from business managers to artisans. Innovations developed must not simply be isolated efforts, benefiting a privileged few, but part of a broader effort in achieving sustainable industrialisation with benefits for all. Engineers in applying themselves must constantly look to ways of using appropriate methods and materials.

Through research and client driven initiatives engineers are called upon on a daily basis to innovate solutions. This could be anything from labour intensive techniques to absorb employees in employment generation activities to green buildings that save on the carbon footprint.

## SOME PROJECT HIGHLIGHTS

### Skills diversification for a workforce:

One of the activities the author had to undertake was to design chambers for a water supply pipeline for a Municipal client in KwaZulu Natal, South Africa. Because the municipality wanted to maximise the productive time of their workforce, used mainly for pipe laying at the time, they requested for simple masonry chambers that could be built by unskilled personnel, requiring only basic training and a full time skilled supervisor, with minimal requirement for formwork and reinforcement fixing. They did not know beforehand the invert levels of all the chambers, so they requested for a generic detail showing plans for different chamber depths. The challenge was to come up with something simple to construct yet flexible to accommodate different depths. The author came up with a scheme where the chamber bases would be cast in reinforced concrete but employing the use of standard mesh, cut and bent by the supplier to suit each particular chamber prior to sending to site, thus eliminating the need for steel fixing on site. This was detailed and presented on a bending schedule. The walls for the deep chambers were designed to be concrete infill masonry walls with mesh reinforcement in the centre of the infill portion. For the shallower depths masonry walls of 330 and 230mm thickness were specified depending on the effective wall span. The cover slabs were to be reinforced concrete covers and cast on the ground as the final operation before covering the chambers. The details for the different depths and associated wall types were presented in graphical and tabular format on drawings. This option was used in-lieu of reinforced concrete chambers; both conventional and the quicker precast rings options available on the market which would have required skilled labour to build and install. The Municipality wanted to fulfil the objective of keeping its labour force productive while at the same time providing them with a new skill set that they could build on should there be a need for a labour shift through downsizing or retrenchment.



| CHAMBER DEPTH | WALL CONFIGURATION | WALL TYPE | HEIGHT |
|---|---|---|---|
| 1.5m - 2.15m | BOTTOM - CONC. INFILL BRICKWORK | A | MAX. 1250 |
| | TOP - 220mm THK BRICKWORK | C | MAX. 900 |
| > 2.15m - 3m | BOTTOM 1.25m - CONC. INFILL BRICKWORK | A | MAX. 1250 |
| | 220mm THK BRICKWORK | C | MAX. 900 |
| | 330mm THK BRICKWORK | B | MAX. 800 |

NOTE:

- CONFIRM DIMENSION 'A','B' & 'C' ON SITE WITH ENGINEER, BUT DO NOT EXCEED MAX.
- 'X' IS MIN. HEIGHT OF TYPE 'A' WALL.

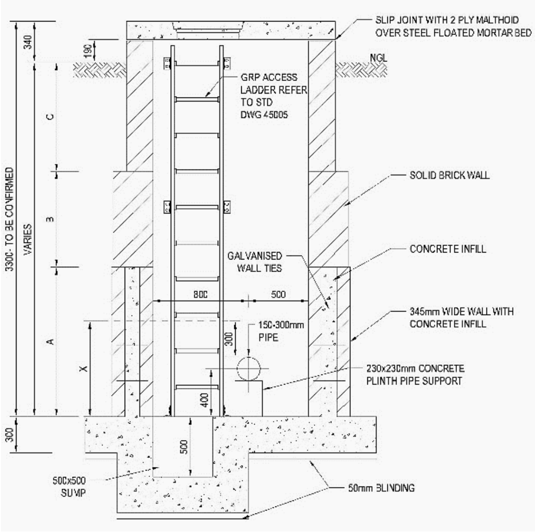


Fig.3 An example chamber details

## EXAMPLES OF CONTRIBUTIONS BY ENGINEERS & SCIENTISTS IN SOUTHERN AFRICA:

### South Africa’s Dams:

Author Vuuren (2012) highlights how from the 1930s South Africa undertook a major spend on constructing dams and canals. The construction activity was used to enhance economic growth through mass employment due to the amount of labour that was required to build these dams and associated hydraulic structures. The irrigation schemes supplied by the canals provided much needed water inland to farms for enhanced agricultural production. The impounded water was also to meet the needs of industry and urban populations. One engineer who made notable contribution during this time was Alfred Dale Lewis who served as Director of Irrigation from 1921 to 1941.

### Clean Coal Technology:

South Africa is currently building and has further proposed coal fired power stations to run on what is considered low grade coal that is largely unsuitable for export. This coal will be used in dry cooled power stations that require less process water for cooling. The use of fabric filters, low NOx burners and flue gas desulphurisation will result in release of reduced amounts of pollutants into the air leading to enhanced environmental performance Zachary (2010). This breaks away from the approach used with the older wet cooled coal fired power stations. In addition clean coal technologies for Coal beneficiation and underground coal gasification processes are now being extensively developed or employed in South Africa, Jeffrey et al (2014).

### Durability and Improved Building Life:

A lot of research is on-going and has produced many useful design and material guidelines on the durability of concrete structures in different environments. The development of durability indices by the effort of research groups such as at the University of Cape Town, Beushausen & Alexander (2008), coupled with improvements in blended cements have made it possible to batch dense concretes with good water and gas penetration resistance. This dense concrete is also critical for the acceptable performance of liquid retaining structures. Other properties such as prevention of aggregate-alkali reaction are added benefits.

### Solar Technology:

Researchers have developed and are ready to move into the commercialisation stage for innovative products that harness the suns energy for electricity generation. These are thin-film solar technology (engineeringnews.co.za, n.d.) and concentrating solar power (Helio 100, n.d.).

### Software Development:

Educational software for portable devices is being developed particularly for learners who do not have access to teachers or classrooms or printed material for their lessons or who simply need additional aids for learning. This is all based on appropriate local curriculum content that will benefit the learners. One such product is mathemagics (mathemagicsa.co.za, n.d.).

### Training and skills development:

Many courses are now offered by qualified and skilled practitioners to impart knowledge on the next generation of engineers and keep the current engineers updated with industry best practice through continuing professional development (CPD) courses.

## CONCLUSION

The need for sustainable industrialisation is without doubt one of Africa’s greatest needs in order to accelerate its path to developed nation status. In order to achieve this Africa needs to sustain all its short term gains in order to achieve sustainable economic growth. One of the ways it can achieve this is through development of its human capital by increasing skills, and hence competencies, and making use of the current skilled population. Africa needs industrial policies geared towards optimum use of its skilled human capital to maximise its gains from this skill pool while all the while growing it.

Engineers are an important skill pool in fostering sustainable industrialisation through the skills they possess and the innovation of solutions they are able to produce given any set of resources and constraints. Because they are guided by ethics and motivated by improving livelihoods engineers are well placed to produce sustainable solutions that can move industrialisation forward to the sustainable levels that Africa requires it to be. This requires a deliberate effort on the part of engineers to apply their skills sets to maximise social returns on their human and intellectual capital by looking at these through a 'spill-over' effect lens.

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# Master of Engineering Degree in Renewable Energy Engineering at the University of Zambia

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## Abstract

*Zambia is vastly endowed with natural resources including land, vegetation, water, sunshine and wind. To date Zambia has not fully exploited its potential in renewable energy utilization. The largest source of electricity energy is from large hydro power stations which constitutes only a third of the total national hydro power potential. Solar power is virtually untapped. Policies and other measures have now been put in place to encourage the development of other renewable energies. However this has been hampered by lack of skills starting at policy level up to implementation level. To address this gap the University of Zambia, School of Engineering with funding from NUFFIC developed a Master's degree program in Renewable Energy Engineering which is hosted in the School of Engineering. The aim of this program is to train skilled human resources needed by the nation in implementing renewable energy engineering. The program is tailored to also train trainers of trainers in renewable energy engineering.*

***Key words**: Renewable Energy, Masters of Engineering, University of Zambia*

## Introduction

Zambia is well endowed with hydropower and other energy resources, which could facilitate production of electricity for both urban and rural areas of the country. The country has an installed electricity generation capacity of 1786MW and undeveloped hydropower potential of over 6000MW(Haanyika 2008).With fuel prices constantly rising and global oil reserves declining, renewable energy is being considered as the energy source of the future. The concept of renewable energy is being increasingly promoted and publicized all over the world. Fossil fuels are perishable sources of energy, whereas renewable energy sources are non-perishable and can be easily replenished. The various known forms of renewable energy sources include the following: hydro, solar, biomass, wind, geothermal, fuel cells and tidal. Most renewable energy sources do not involve the combustion of fossil fuels or other substances, which may release pollutants. Therefore, renewable energy is a clean source of energy and one that is environmentally friendly. Renewable energy sources are plentiful and are available all over the world. Renewable energies, being non-perishable energy sources are available on a sustainable basis. This paper highlights the significance of different renewable sources of energy, along with their contributions in the present Zambian energy scenario. Finally, the new Masters of Engineering program in Renewable Energy Engineering that has been developed is outlined.

## Potential in renewable energy utilisation

**Solar energy**: Zambia is situated at latitude of 8 to 18 degrees south of the equator with an average of about 8 hrs average sunshine per day. It has an average solar insulation of about 5.5 kWh/m/day and about 3,000 hours of sunshine annually. Solar radiation in winter is more than 5.0kWh/m$^2$/day, rendering it suitable for solar applications (Holm 2004). However, the country's solar energy potential has not been exploited and it is being realized that Solar energy in Zambia can be one of the cost effective ways to electrify off grid areas(Mfune and Boon, 2008).

**Biomass energy**: Woodland and forests are estimated to cover about 50 million hectares (66 %) of Zambia's total land area. Wood fuel accounted for over 70% of the total national energy consumption in 2007. Households accounted for about 66% of wood fuel consumption(Ministry of Energy and Water Development, 2008).

**Hydro energy**: Zambia has abundant hydro power resources with an estimated potential of about 6000 MW although currently on about 1700 MW has been installed, currently satisfy most of its energy needs (99.9%) (Mfune and Boon, 2008). This means that proper design of small hydro power plants can be an environmental friendly solution and represents a useful alternative renewable energy source, especially for rural areas without developed electricity grids.

**Wind energy**: The country has an ideal plateau landscape which offers some locations where there is potential for wind energy exploitation. Wind speeds in Zambia are low with an average of 2.5 meters per second at 10 meters above the ground(Mfune and Boon 2008). Based on the collected wind data, the Zambian Directorate of Energy it was shown that wind energy in Zambia does not exhibit great potential for electricity generation(Mfune and Boon 2008). Consequently it may be used for pumping water for irrigation(Ministry of Energy and Water Development, 2008).

**Geothermal energy**: Zambia has more than 80 hot springs and its geothermal energy potential has not been studied in great detail(Ministry of Energy and Water Development 2008).

**Bio energy**: Zambia is considering the exploitation of sugar cane, sweet sorghum and Jatropha as possible sources of bio-fuel. It is also considering bio-fuel as an alternative to petroleum to ensure security of supply and stabilization of fuel prices (Ministry of Energy and Water Development, 2008). So far about 341,000 biogas digesters are currently operational in the country.

## Energy policies

Zambia has had national policies on energy. The focus of these policies has been on hydro, biomass, petroleum products development and pricing. However in recent times there has been a shift in policies to renewable energies development (National Energy Policy of 2008, Fifth and Sixth National Development Plan and Public Private Partnership Act among others) in order to address areas of deficiencies in energy supply. Examples include the rural electrification program and the shift to promotion of renewable energies. It is worth stating that there has been lack of implementation of energy policies due to lack of human capital with expertise in renewable energies (Haanyika, 2008).

## Renewable Energy Education

Many of the engineering and technical courses that are currently taught at universities and colleges in Africa provide little exposure to energy technologies. Modest changes in the curricula of existing colleges and universities could significantly increase the supply of skilled renewable energy engineers, policy analysts and technicians(Karekezi, 2002).

In order to achieve a large-scale deployment of renewable energy (RE), a skilled and educated workforce needs to be in place as well as awareness within the population about the benefits of RE. However, teachers and professors with RE knowledge and understanding are still rare (Islam and Amin, 2012). Secondly there are a lot of gaps in information in terms of actualizing the exact figures in terms of potential renewable energy and its geographical location. This means there is need in renewable technologies and potential sources and experts who can do this work.

In light of this need for skilled technical manpower, the University of Zambia School of Engineering, with some funding from the Netherlands Government under NUFFIC developed a 2 year Master of Engineering program in Renewable Energy Engineering. This programme is designed for people who have the ambition to strengthen, lead and transform renewable energy industry. It is suitable for students following on from BSc/BEng programmes on a variety of scientific and engineering related subjects, such as agricultural engineering, mechanical engineering, manufacturing engineering, electrical engineering, electronics engineering, energy engineering, control engineering and system engineering, and physics.

MEng Renewable Energy Engineering programme offers the opportunity to combine technical depth in renewable energy system design and integration, modelling and simulation, project development and implementation, with business expertise in teamwork, leadership and entrepreneurship to successfully lead local and international companies in the future. This course brings together the rigor, engineering expertise, research and knowledge transfer experience of the School of Engineering to provide an integrated renewable energy engineering programme.

### *Masters of Engineering Renewable Energy*

This section gives the methodology that was used to develop the programme, the aims, the goals, the course map and the content of the course.

## Methodology

The methodology that was used involved first ascertaining the need for the renewable energy program by getting information from experts, government and private agencies in the need for experts in the renewable area. This was followed by an analysis of renewable energy programmes offered by other universities. Then aims and the goals of the programme were drawn. Finally the aims of the courses were also drawn up and analysed using the revised

Blooms Taxonomy as explained by Krathwohl (2002) to ensure that the courses had enough complexity for a high level course.

## Aim of the Programme

The aim of the MEng programme is to provide professionals with technical and managerial knowledge and expertise in the renewable energy engineering sector. There is already a substantial demand for engineers with expertise in this area. The purpose of this programme is to help meet this demand. Our graduates are expected to take up leadership positions in the energy sector and work effectively in the framework of national and international cooperation.

## Goals of the Programme

The goals of this programme are to:

1. Provide a thorough training in the principles of renewable energy systems;
2. Introduce students to practical aspects of system design, monitoring and development of renewable energy systems;
3. Train engineers, scientists, environmental scientists and policy analysts to participate in the development of the renewable energy industry in Zambia and internationally;
4. Enhance the capacity to train engineers in Zambia and reduce the cost of sending personnel to train outside the country;
5. Address the social, economic and environmental issues involved with renewable energy systems; and
6. Undertake research that enhances teaching and promotes innovation in the exploitation and utilization of renewable energy technologies.

## Professional Competences

Upon completion of the MEng. Degree Program in Renewable Energy Engineering, students will have gained the following professional competence:

### *General Knowledge & Understanding*

Graduates will be able to display advanced understanding of relevant scientific theories, ideas, methodologies and the newest technologies in renewable energy science, and use this new knowledge to excel in their professional development, and gain sufficient competence to help provide solutions to our current and future energy problems.

### *Specific Type of Knowledge*

Graduates will acquire a solid foundation in the field of renewable energy science and technology, and will be equipped with the necessary theoretical and technical skills to advance its future use and potential. They will be able to demonstrate an advanced understanding of the technical and practical aspects of renewable energy utilization, methods of minimizing environmental impacts of energy use, and in energy economics and energy policies. They will also have a new appreciation for the interrelationship between the various disciplines necessary for successful execution of renewable energy projects, from the initial exploration to the stages of implementation and utilization.

### *Practical Knowledge*

Graduates will be able to use their acquired knowledge to perform detailed feasibility studies, scientific analysis, and conduct research on renewable energies and technologies, from exploration, exploitation and technical aspects of utilization to environmental, social and economic considerations. They will be able to use this practical knowledge to support local industry and community organizations in utilizing renewable energy technologies, as well as help supporting increased use of renewable energies on a national-wide level. Focus is on applying innovative technical solutions to real-world problems.

### *Theoretical Competence*

Graduates will be able to use their advanced knowledge, newly acquired methodologies, analysis and problem-solving skills to demonstrate originality and find innovative solutions to new types of problems, or problems initiated by new conditions or circumstances. They will be able to evaluate which research methodologies and theoretical analysis applies in each case.

### *Professional Cooperation, Information Evaluation, and Communication*

Graduates will have the competence to take active part in professional partnerships and research networks focusing on renewable energy technologies and promote the use of renewable energy sources in different locations, as well as the ability to arrive at joint solutions to complex energy problems with professionals representing different disciplines. They will have the required skills to evaluate complex scientific information, and access its relevance for any particular energy-related problem. They will also have the ability to effectively communicate their knowledge, understanding and research results to the broader scientific community and the general public, using different mediums.

### *Academic Competence*

Graduates will have acquired all the needed academic competence to engage in and successfully execute a Ph.D. research or teach in an institution of higher learning.

## Curriculum

Based on the above mention aims, goals and required professional competence the curriculum plan with the courses shown below was developed. It consists of two parts.

### *Part I Course Work*

Full-time students shall undergo the course work during a period of two semesters (one academic year). The course work shall consist of 8 course units. The course work is composed of lecturers, tutorials, assignments, laboratory and field work. The candidate shall, at the end of the course work, take written final examinations. The final assessment is based on the performance in the final examination as well as the assessment in tutorials, assignments, laboratory, field work and semester tests. A candidate who fails in courses equivalent to more than one full credit shall be excluded from the programme. A candidate shall, at the end of Part I, prepare his/her project proposal with the guidance of an academic supervisor.

A candidate shall take 6 core courses equivalent to 3 units. These are compulsory. The candidate shall take 2 other elective courses, equivalent to 1 unit. The curriculum is shown in Table 1.

Table 1 Masters of Renewable Energy Curriculum map

| First Semester | | | |
|---|---|---|---|
| Course Code | Course Title | Credit | Course Type |
| REE 6011 | Energy Systems and Sustainability | 0.5 | Core course |
| REE 6021 | Solar Energy | 0.5 | Core course |
| REE 6031 | Hydro Power | 0.5 | Core course |
| GES 5881 | Research Methods | 0.5 | Core course |
| Second Semester | | | |
| REE 6052 | Energy Conversion and Integration Systems | 0.5 | Core course |
| REE 6062 | Bioenergy | 0.5 | Core course |
| REE 6172 | Wind Energy | 0.5 | Elective course |
| REE 6182 | Geothermal Energy | 0.5 | Elective course |
| REE 6192 | Geomatics for Renewable Energy | 0.5 | Elective course |

***Key to course coding system***

**Letters**

REE: Represents “Renewable Energy Engineering”

**Digits**

The first digit represents the level of study, i.e. Masters level = 6.
The second digit indicates whether a course is a core course (0) or optional (1).
The third digit indicates the sequential numbering of the courses to uniquely identify each course.

The fourth digit indicates the semester in which the course is to be taught (i.e. 0: Full course; 1: First semester; 2: Second semester; 5: Either semester).

***Part II: Research Work***

Part II shall comprise research work and a dissertation in renewable energy

No candidate shall be permitted to register for Part II of the programme unless he or she satisfies the requirement of Part I.

A candidate shall, at the end of his/her research work, and prior to the submission of his or her dissertation, present the results of his/her research work at an open Seminar organized by the Directorate of Research and Graduate Studies for the purposes of discussion and comments.

The project supervisor(s) shall furnish a report on each candidate to the School of Engineering Graduate Studies Committee and the Board of Graduate Studies at least once every semester. In case of serious delay in the students’ work from any cause whatsoever, the supervisor(s) shall notify the Dean of the School of Engineering and the Board of Graduate Studies through the relevant Head of Department.

**Discussion**

Developing of the Renewable Energy course marked a new phase in development of courses as the activities were not restricted to particular departments but involved the whole school as renewable energy has cross cutting issues. During the process of development new members of staff had an opportunity to learn how to develop courses at master’s level where the role of the learners was reemphasized by the use of the revised Blooms Taxonomy. The need for experts the number of renewable projects that are being considered and the need for preparation of bankable proposal for the energy sector.

The data in renewable energy is sketchy in some areas and in some extreme case none existence. These means that studies need to be carried out to cover this knowledge gaps while at the same time generating solutions to meet the energy challenges of the country. Therefore a master's degree program in renewable energy that has been developed will not only help in imparting knowledge in renewable energy technologies but will also be a vehicle for research in finding solutions to energy problems while helping to create linkages between the university and industry. These linkages are essential in the survival of higher training institutes as this will help in keeping them focused on meeting the needs of industry and society at large. The links can benefit industry by providing local, competitive and sustainable solutions to their energy problems. The career prospects for graduates at masters' level in the renewable energy field will also be very good.

While developing the course it was also observed that there some skills missing in ICT, project management and engineering management. As a bonus from the experience got from the development the renewable energy course, the school in a mass production manner developed six new master's programs which have just been approved by the University of Zambia. This was done in a period of six months. These are MEng in Project Management, MEng in Construction Management, MEng in Engineering Management, MEng in Geo-informatics and Geodesy, MEng in Telecommunications and MEng in Wireless Communication. However collaboration is needed for all these new courses to be mounted.

## Conclusion

The development of the master's program in renewable energy is a timely intervention in meeting the gap in expertise in renewable energies and as a vehicle for conducting research. It is also a means which the university can reconnect with industry and society to provide timely solutions to energy related issues. It is also clear that graduates with a Master's degree in Renewable Energy Engineering have a special the role to play.

The skills got from the development of the course are important that it will now take less time to develop engineering programs to meet the rapidly changing needs of society as shown by six additional masters programs that have just been developed. The university needs to take measures to reconnect with industry as this is the only way that the country can harness its local manpower to solve energy issues in a sustainable manner.

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**Dr. Simon Tembo** obtained his Doctor of Engineering Degree in Electrical, Electronic and Computer Systems Engineering from Akita University, Akita, JAPAN in March 2013. His doctorate research was in cooperation with Nippon Telegraph & Telephone (NTT) Corporation in Tokyo, Japan. He received his Masters of .Engineering Degree in Information and Network Science from University of Electro-Communications, Tokyo, JAPAN, in March 2000; and received the Bachelor of Engineering Degree in Electrical and Electronic Engineering from the University of Zambia in 1995. He is currently the Assistant Dean Postgraduate in the School of Engineering at the University of Zambia. He was instrumental in the development of the Six (6) Master of Engineering postgraduate programmes in: Computer Communications; Information and Communications Technology; ICT Regulations, Policy and Management; ICT Security; Telecommunications Systems; and Wireless Communications. From 1993 to 2008, he worked for Zambia Telecommunications

Company Limited (ZAMTEL) of which from 2005 to 2008, was appointed as Managing Director of ZAMTEL. In 2009, he joined the School of Engineering at the University of Zambia as a Lecturer in the Department of Electrical and Electronic Engineering. His research interests include Power Generation Strategies of the 21st Century, Internet Routing Protocols, High Speed Networks, and Routing Algorithms for Optical Fibre technologies and ATM switching networks. He is currently serving as UNZA ICT Expert on the ICT Conformance and Interoperability (**C&I**) Type Approval Test Laboratory Project to be established by ZICTA here in Zambia. From 2005 – 2008, he served as interim Board Chairman for COMTEL LTD. He is currently a member of the IEEE/MEIZ/REng

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# Zambia Women in Engineering Section (ZWES): A Strategy to Achieving a World-Class Diverse Engineering Profession

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## Abstract

*Zambia, like many developing countries suffers from insufficient numbers of engineers graduating to meet the needs of the engineering industry. The anecdotal evidence available shows that there is a significant lack of diversity within the profession in Zambia. This insufficiency, unless it is addressed, will negatively impact Zambia's ability to become a prosperous middle-income country by 2030.*

*For many centuries, the participation of women in engineering has been slow in terms of advancement. To break this trend, especially in the twenty-first century, it is imperative to identify and embrace workable strategies to reach all key stakeholders: girls and young women, parents and teachers, guidance counsellors, employers of engineers, role models and leaders in the professional engineering body –Engineering Institution of Zambia (EIZ).*

*The objective of this paper therefore, is to outline the EIZ strategy under the Zambia Women in Engineering Section (ZWES), referred hereinafter as "the Women Section", aiming at the creation of socio-economic, cultural and educational benefits for women in engineering in Zambia. The paper also outlines the mandate that the Section has to create opportunities for inclusion and diversification of the engineering workforce in Zambia.*

*A summary of the Women Section main objectives is defined as:*
- *Broaden the participation of women in engineering in Zambia.*
- *Improve engineering culture to attract, retain, and support women in the profession.*
- *Increase number of females in the engineering workforce from the current 10% to about 30% by 2030.*
- *Develop a highly prepared, diverse engineering workforce for tomorrow by working with educational institutions.*
- *Develop and implement activities aimed at enhancing gender sensitivity and more importantly creating a strong sense of community for ZWES members.*

**Keywords:** *Zambia Women in Engineering Section (ZWES), Diversification, Mandate and Strategies.*

## Introduction

It is reported (UNESCO,2010) that for nearly three decades, governments and industries across the world have been seen to support initiatives aimed at increasing women representation in the engineering profession, identifying that there is still a large untapped pool of talent amongst women. These efforts have had quite some influence, but engineering still remains an extremely male-dominated profession in most countries world-over and

Zambia is no exception. For Zambia's case, gender issues in engineering are increasingly a focus of concern. The Government of the Republic of Zambia (GRZ) through the National Gender Policy (NGP, 2000), outlines the necessary steps and a policy framework needed to achieve gender equity. The government is committed to redress this gender imbalance and inadequacies in all sectors of the economy including engineering. Therefore, EIZ needs to provide and create an enabling environment for full participation of women in the engineering profession.

According to Hamukoma (2011), there is a current and future projected shortfall of engineers and appropriate engineering skills in Zambia. It is therefore, imperative that all available human resources are adequately trained and used to address these shortfalls. Yet, historically, women have been significantly underrepresented in engineering fields, typically making far less than 10% of the engineering work force in Zambia. Generally in Africa, the numbers are about the same, with South Africa having around 10% and Kenya about 8% representation of women engineers. There is clearly room for improvement – not only in the recruitment of women into engineering, but also in the retention and promotion of those women already in the profession.

It is also evident (UNESCO, 2013) that there is a need to encourage more young women to study engineering. However, it must be understood that women face diverse challenges when pursuing an engineering education and when deciding to apply for engineering jobs, both within the academia or private sector. Educational constraints, cultural norms and prejudices influence opportunities and choices, severely reducing the number of women engineers.

## Background/Literature Review

According to a UNESCO (2013) review of global historical data, the underrepresentation of women is significantly evident from the low percentages of the total workforce ranging from about 10 to 20% for most countries. UNESCO review also indicates that in Africa, South Africa in particular, recorded the highest percentage of around 10% of women in the engineering workforce while Kenya showed a representation of 8% by women engineers.

In terms of recruitment, UNESCO (2013) reveals that there is an increase in the uptake of women studying Science, Technology and Innovation (STI) which is positive showing that in the USA and Europe, women now make up around 30% of the engineering students enrolled at university, in India it is 35%, in South Africa the representation is 15% whereas in the Gulf region (such as Kuwait) women make up around 60% of the engineering students at university.

However, even in countries where the numbers of women studying STI have increased, UNESCO (2013) observes that it has not translated into more women in the workplace. Many students who graduate do not go into the engineering profession due to many different factors based on cultural beliefs and religion.  Therefore, it is evident that there is a need to encourage more women to study engineering and enter and stay in the engineering workforce. Despite many challenges that women face in both pursuing an engineering education and deciding to choose an engineering job, both within academia or industry, these educational constraints, cultural norms and prejudices that influence women opportunities and choices, have to be aggressively addressed. In line with the current and future huge global need for engineers, it is imperative that the woman potential resource is fully exploited.

According to Collis (2013), despite the fact there is a growing global demand for engineers, many women leave the profession. Therefore, the gender gap is ever-increasing and difficult to close. Across the world, there is an insatiable demand for engineers. It is also further reported that the profession is still a long way to overcoming this long-standing challenge of attracting and retaining female engineers.

It is also quoted (Collis, 2013) that "Women's voices are essential to the problem-solving and innovation that is at the heart of engineering. There is need to do more, as both a society and an industry, to encourage girls to engage in maths and science in school, to support women pursuing engineering degrees in university, and to provide women with opportunities to thrive in the workplaces. There is also a need to re-imagine what an engineer and a leader looks like to be able to tap into this critical half of the human talent pool."

## Rationale

The estimated current statistics of Zambian women in engineering from EIZ database clearly show that participation of women has lagged behind that of men. Also, EIZ Act No. 17 of 2010 does not reflect a gender sensitive Engineering Policy for women to effectively participate in the development and implementation of National Engineering programmes. Again, if Zambia is to attain the Republic of Zambia Vision 2030 (2006) which is quoted as “To be a prosperous middle-income country by 2030”, then EIZ needs to consider strategies to include attraction and retention of females in the engineering profession.

The 2010 National Census indicated that 50.7% of the Zambian population comprises of females (Central Statistical Office, 2012). Therefore, this is a clear indication that there is untapped human resource for engineering in the female population of Zambia. In addition, a survey conducted by Hamukoma (2011) for the Zambian Mining Industry indicates that there are shortfalls in the number of graduate engineers needed to fulfil the mining industry’s annual recruitment needs. Generally, mining industry constitutes about 50% of the engineering industry since Zambia’s industrial base depends on copper mining. Hence for Zambia to develop to Vision 2030 and beyond, it is imperative to address the insufficient number of engineering graduates needed to fill skill gaps in Zambian industry by encouraging women participation in engineering. The women participation will also strive to enhance diversity in the engineering profession in Zambia.

An attempt to review EIZ gender demographics provided unreliable results because the database has not been set up to capture this information. Therefore, the percentages reported herein are figures obtained from the trends at the Schools of Engineering and Mines at the two universities (UNZA and CBU) extrapolated to estimate the EIZ gender representation. The demographics estimate that on average, only about 7-8% of the registered engineering professionals are females. Considering individual engineering disciplines, the database also reveals that Mechanical Engineering is the least diverse with only about 3% being female, while Civil Engineering is the most diverse with about 15% females. It follows that the Zambian industry can only realize its full potential by increasing diversity in the EIZ membership substantially from the current low numbers.

## Zambia Women in Engineering Section (ZWES) Mandate

As part of the strategy to increase diversity in the engineering profession, EIZ has in accordance with Section 3.1 of the EIZ Constitution (2013), launched a Section for Zambian Women in Engineering (ZWES). The Women Section will work to transform the culture in the engineering profession to attract, retain, and support women. The Section will aim to increase the number of females registered and retained in the engineering workforce from the current 10% (this number is only anecdotal as no data on gender is available) to about 30% by 2030. The goal is to broaden the participation of women in engineering in Zambia. With a clear focus on research-based issues and solutions, Women Section will also help members develop a highly prepared, diverse engineering workforce for tomorrow. This will be achieved by working closely with engineering education institutions, schools, public and private partners who share the passion to diversify the engineering profession in Zambia. The ZWES will also organize activities and events as part of the EIZ calendar aimed at not only enhancing gender sensitivity but more importantly at creating a strong sense of community for members.

## Mission

The core purpose of ZWES is to increase the number and advance the prominence of women in engineering in Zambia. The Women Section will ensure national competitiveness by leading and supporting the EIZ effort to expand female participation and improve the quality of life for women engineering professionals.

## Vision

To be recognised as an instrument to facilitate the transformation of EIZ into a world-class gender-balanced engineering fraternity in which men and women have equal opportunities for career advancement, wellbeing and professional development.

## Values

The guiding principles for ZWES will be:

1. Knowledge of research, statistics, training, and practice relevant to women in engineering and Science Technology and Mathematics (STM) as a way to drive change;
2. Collaboration which draws on strengths from many sectors as key to advancing women in engineering;
3. Inclusion of women as a tool to improve the engineering profession; and
4. Development and influential leadership critical to press forward the success of women in engineering.

## General Roles

1. To constantly expand and share their knowledge of best practices and research-based issues that will implement best and promising interventions to promote the success of women in engineering. This will be achieved through participation in the ZWES conferences, collaborative and supportive networks working to improve retention of females in engineering.
2. To network, collaborate, and benchmark with international associations committed to women in engineering development. This should allow members to learn about promising and proven practices for recruitment, retention and support of women in engineering.

3. To conduct and support research and compile statistics about women in engineering and STEM related fields in Zambia. The Women Section will provide an essential resource among corporate partners and diversity partners.
4. To facilitate career and professional development through volunteer leadership opportunities and seminars.
5. To advocate for women in engineering on campuses, within corporations, government agencies and organizations at all levels, and high schools from grassroots up to national level.

### Roles of the Women Section with Corporate Partners

1. To encourage corporate partners to endeavour to meet the **30%** representation in all decision making positions as agreed to by the Southern Africa Development Community (SADC) Declaration on Gender and Development.
2. To work with corporate partners and engineering educators to actively engage in aligning engineering culture to support corporate needs for a diverse, globally competent workforce.
3. To work with academic leaders and corporate partners to identify, recruit, develop, retain and graduate highly diverse, excellent female engineering talent.
4. To work with corporate partners to develop robust relationships with engineering schools' diversity programs that enrich student experiences and create employment pathways.

### Overall Objectives

The five main objectives of the ZWES are outlined as:

1. Broaden the participation of Women in Engineering in Zambia;
2. Improve engineering culture to attract, retain, and support women in the profession;
3. Increase number of females in the Engineering workforce from the current 10% to about 30% by 2030;
4. Develop a highly prepared, diverse engineering workforce for tomorrow by working with educational institutions; and
5. Develop and implement activities aimed at enhancing gender sensitivity and more importantly creating a strong sense of community for ZWES members.

### Specific Goals and Objectives

The four main goals ZWES will pursue as adopted from Women in Engineering ProActive Network (WEPAN, 1990) include:

#### 1. Systemic Change

The ZWES will inspire stakeholders to create meaningful, measurable systemic change to advance diversity, capacity and prominence of women through engineering initiatives in schools and corporate settings.

#### 2. Building Excellence through Diversity

The inclusion of women will be recognized as improving the quality of engineering itself, and as a result, there will be broader access, success and equity for a gender diverse community.

### 3. Knowledge Source

The Women Section will be a primary, reliable and respected source of research-based knowledge and practice relevant to advancing women in engineering. Mechanisms that translate knowledge for practical implementation, with a particular emphasis on resources, seminars and conference sessions to address the needs of women in engineering will be developed.

### 4. Collaboration

The ZWES will work to build successful relationships with an array of partners and stakeholders interested in advancing women in engineering. The section will also establish, maintain and strengthen relationships and expand collaboration opportunities with engineering diversity societies and engage new corporate partners in its mission. Partnerships with non-governmental organisations with missions related to STEM education and women in engineering will be established.

## Methodologies

To achieve its objectives, the ZWES will capitalize on the following measures:

a. Develop and implement a policy that advocates for diversity and inclusion of women engineering professionals in Zambia;
b. Review the school and college curricula on science and technology to make it gender sensitive;
c. Advocate for special funds and scholarships to be awarded to qualified females for their education in engineering and related fields. This will expand participation of female engineering professionals;
d. Create programs with primary school, high school, and craft and diploma colleges to cultivate the next generation of female engineers. In addition, the Women Section will promote and encourage study of science and technology subjects in schools;
e. Establish and/or strengthen career counselling programmes to address problems which hinder female progression in engineering education; and
f. Provide incentives to females in engineering and STEM education.

## The 2016 -2018 Strategic Implementation Plan

The Strategic Implementation Plan (SIP) will provide guidance in effectively carrying out the ZWES roles and responsibilities aimed at advancing the mission of increasing the number and advancing the prominence of women engineering professionals in Zambia. The plan is to help realize fullest potential and to impact the nation and beyond through awareness, access, support and development. It is believed that by creating a shared vision and working together culture, the Women Section will accomplish more in moving forward the mission. It is hoped that full implementation of the SIP will result in a nation where women are highly valued and influential as leading engineers, innovators and scientists.

## Strategic Objectives

The Women Section shall endeavor to achieve the following objectives under the 2016-2018 SIP:

1. Increase EIZ membership by an increased ZWES membership from the current 10% to 20% _and increase compliance levels to 90% by 2018;
2. Contribute to raise 10% of the required K50 million to construct the new EIZ

headquarters building since we make up 10% of EIZ's membership;

3. Develop, promote, maintain and improve professionalism amongst women in engineering through mentorship schemes, workshops, CPDs, career talks and other related activities;
4. Develop and enhance ZWES representation at all levels/organs of EIZ including the EIZ secretariat;
5. Ensure Gender mainstreaming, HIV/AIDS, Safety, Health, Environment and Disability issues as related to women engineering professionals are addressed at the workplace;
6. Provide research-based advice to government through Council on matters related to women in engineering in Zambia; and
7. Contribute to the general advancement of Science, Technology, Engineering and Mathematics (STEM) by encouraging and supporting STEM Education for girls in schools.

## ZWES Initiatives and Programs

The Women Section has a clear focus on promoting strategies to advance the principal goal of **30% women** and **70% men** of the total engineering workforce by **2030**. This will be achieved by engaging in programs, projects, partnerships and relationships – all aimed at achieving the core purpose of increasing the number of women engineering professionals. Therefore, three key initiatives and programmes are proposed.

## The Advancing Culture in Engineering [ACE] Initiative

The ZWES proposes to launch the Advancing Culture in Engineering (ACE) Initiative to advance inclusive cultures in the engineering profession. The ACE Initiative adopted from WEPAN (1990) Strategic Plan, will align industry and education to create positive academic, social and workforce cultures that retain and graduate many more female engineers to meet corporate needs for a diverse, globally-competent workforce. Improved communication, negotiation, innovation and effectiveness will be needed to achieve the necessary cultural change.

The engineering profession, as reported in the Australasian Institute of Mining and Metallurgy (AusIMM) Bulletin (2002), has generally been accepted for a long time to be a conservative, male oriented work culture. This impression has created a culture where, even if harassment and discrimination did not exist, there is frequently a perception that they did exist. While it is not easy to change such a culture, it is imperative to make the organisational practice at the workplace more pleasant, efficient and inclusive. Therefore, it is critical for employers to continually review their policies and procedures and ensure that they are relevant to and effective in diversity at the engineering workplace.

EIZ and corporate partners will fund the project to support ZWES' efforts to advance diversity and build more inclusive environments. ACE will provide support for efforts in engineering institutions to create and sustain inclusive interactions and cultures that benefit all participants. This support will be in the form of intensive professional development and expert consultation to facilitate female participation. The project will be extended to include engineering faculty implementation of engineering education that is engaging and motivating to a diverse community of female students.

### Engaging Female Students in Engineering (ENGAGE) Initiative

ZWES will also launch the ENGAGE Initiative to source for mini-grants to fund faculty to implement research-based classroom strategies known to improve female student engagement and retention in engineering. These will be up to five-year projects funded by EIZ, National Science and Technology Council (NSTC) and other public or private supporters.

### Supportive Community

The Women Section is an inclusive forum focused on issues of interest to women in engineering and technical careers. To create a supportive community, ZWES will endeavour to:

1. Establish a strong network of women in engineering from academia, government and industry, corporate representatives, government officials, and other individuals supporting and advocating for the role of ZWES.
2. Establish an award and recognition program to honour outstanding accomplishments of women in the engineering profession as well as those who have contributed significantly to the advancement of women in engineering and technology.

### Professional Development Seminars, National Conference and Change Forum

ZWES shall on an annual basis hold professional development seminars on research-based topics related to underrepresentation of women in engineering and STEM. A national conference will be held annually with a specific focus on research-to-practice based advances in outreach, retention and graduation of female engineering professionals and improving culture to advance women participation in engineering. These will create opportunities to disseminate research results and thereby providing a pool of knowledge for members.

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### Universities and College Chapters

The Women Section will form ZWES Chapters at the various learning institutions offering engineering courses. The Chapters will contribute knowledge of root causes, interventions and new strategies; and gain a close view of the successes and challenges of systemic change. The Chapters will be encouraged to adopt strategies and practices that promote the success of female students in engineering at learning institutions.

### Target Groups

1. Women in engineering;
2. Program directors and staff involved with women in engineering;
3. Directors of academic diversity programs in related STEM fields;
4. Engineering faculty, heads of departments and deans;
5. Academic mentors and advisors;
6. College of engineering recruiting personnel;
7. Engineering researchers and scientists;
8. High school educators; and
9. Anyone interested in promoting and achieving improved representation of women in engineering.

## Conclusions

The paper has highlighted some strategies and ideas for improving diversity in the engineering workforce in Zambia through the ZWES. The EIZ diversity aim is to be amongst the leaders in the world and will regularly review the ZWES diversity strategies and compare with other similar professional women bodies. This should help to recruit, attract and retain the women in engineering in Zambia and maintain a strong culture of professionalism. Both EIZ and industry have a role to play in encouraging girls and women from diverse backgrounds to join the profession. In the long term, it is hoped to improve the public perception of engineering culture in industry and increase women participation in engineering.

## Recommendations and Way Forward

The following are recommended activities that EIZ through ZWES will address:

1. Update the registration process to capture information on gender.
2. Recruit more women into profession especially in the Mechanical engineering field.
3. Ensure retention of women already practicing engineering in Zambia.
4. Create a supportive environment for women throughout their engineering careers.
5. Celebrate the achievements of women in engineering.

The way forward is to get a pro-active ZWES including partners who want to make a difference. This calls for connections with relevant regional and global associations to build on ideas rather than re-inventing the wheel. ZWES will also work to strengthen the EIZ position on gender with industry and stakeholders to constantly review and align efforts to achieving a sustainable diverse engineering profession.

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# SESSION 2C

# ENGINEERING DESIGN AND MANAGEMENT

# Performance and interaction of critical elements of the chain ropeway system

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## Abstract

*In this paper the performance of a chain ropeway system designed for use in mountain orchard is determined. Use of experiments to determine the effects of the load, load speed and load spacing on power and torque requirements of the ropeway have been investigated. Design of experiments was used to minimise the number of experiments while maintaining the most important information. It has been found that the load is the most important factor that determines the power and torque requirements of a chain ropeway. Speed of the system was found to significantly affect the power requirement only. Spacing of the loads on the ropeway on the other hand was found to have some limited influence on the torque requirement and the tension in the chain. The relationship of power requirement, torque and tension in the chain to the total load carried was determined. In addition, the relationship between the chain and the support sheave and the relationship between the drive wheel and the chain were determined. This relationship may be used in the design of the chain ropeway and at the same time give an indication on the safe loads that can be carried on the ropeway as the force in the chain can now be approximated.*

***Key words:*** *Chain ropeway, mountain orchard, design of experiments*

## 1.0 Introduction

Rope transportation systems are widely used in many fields of modern technology to transport single piece loads, discretely fixed on a horizontal, vertical or inclined flexible element which represents one or several parallel ropes, chains or belts. Aerial ropeways have been found to be economical in mountainous terrain and under adverse weather conditions (Neumann, Bonasso, & Dede, 1985). The section between the supports are flexible and may carry from one to six or even more moving concentrated loads that undergo together with the flexible element longitudinal and transverse oscillations (Brownjohn, 1998; Il'in & Karyachenko, 2007).

In order to develop mechanised agriculture production system that would save time and energy thereby improving productivity and ultimately make it more attractive for labour to

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be deployed in orchards, the machinery laboratory of China Agricultural Research System at South China Agricultural University (SCAU) has developed a chain ropeway system to help move inputs and produce during farming operations in the mountain orchards of China (Hong, *et al.*, 2011; Hong, *et al.*, 2010; Mwape, Hong, & Wu, 2011; Wen, *et al.*, 2011).

In this application of the ropeway the wire rope has been replaced by a chain. The ropeway being developed is a monocable ropeway shown in Figure 1. This is a novel application of a chain replacing a wire rope. A sprocket is used to drive the chain. The carriers are woven baskets hooked on the chain which is supported by the sheaves.

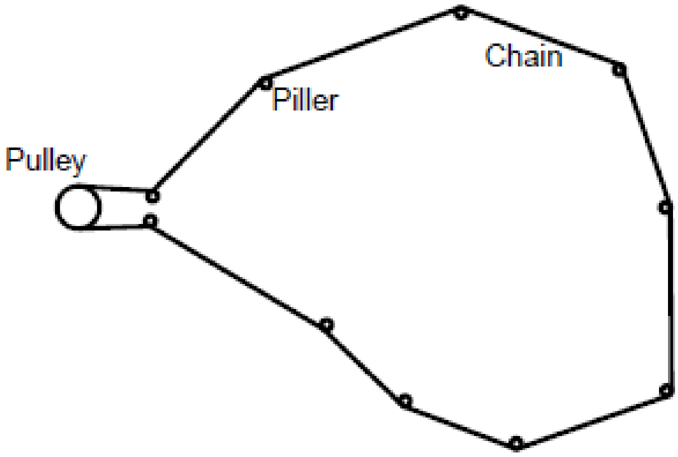


Figure 1: Chain rope way system

A model has been built as proof of the concept but more work is needed to improve its performance to a level where it can be manufactured and be used by farmers.

Safety is very important in the design of ropeway systems. In the design of a ropeway system, one of the critical areas apart from the rope itself is the drive wheel and chain interaction as this is the interface through which power is transmitted to achieve the transportation function. To be able to design the drive wheel and select the appropriate chain, it is important to know the forces that are involved in the interaction between the chain and the drive wheel and between the chain and the sprocket shown in Figure 2. Consequently the aim of this part of the study is to determine the interaction of the chain and the drive wheel and the interaction between the chain and the sheaves and the loading in the chain. Secondly, to determine the impact of the load, load speed and load spacing on the power, torque and tension in the chain ropeway system.

## 2.0 Model development

### 2.1 Determination of interaction between the chain, the support sheave and the drive wheel.

To determine the interaction between the chain and the drive wheel, similar analysis to that of a sprocket and roller chain may be done. The roller chain transmission is quite complicated and has received a lot of attention in terms of research (Burgess & Lodge, 2004). To simplify the problem, a free body diagram of the drive wheel and the chain for forces in the horizontal plane are shown in Figure 3.

Figure 2 Drive wheel and chain and support sheave

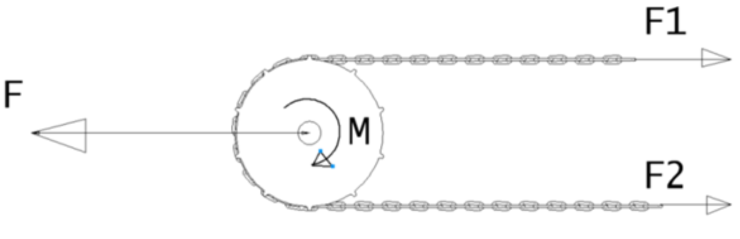


Figure 3 Free body diagram of forces on the chain and drive wheel

The force F is the drive wheel bearing force while F1 and F2 are the horizontal forces in the chain. M is the torque coming at a speed ω. Once the free body diagram is determined the problem remains in determining the values of F, F1, F2 and M. In the study the values F and M were determined experimentally. Once they were determined, the value F1 was also determined. The following equation gives the value of F1.

$$M = (F1 - F2)r \quad (1)$$

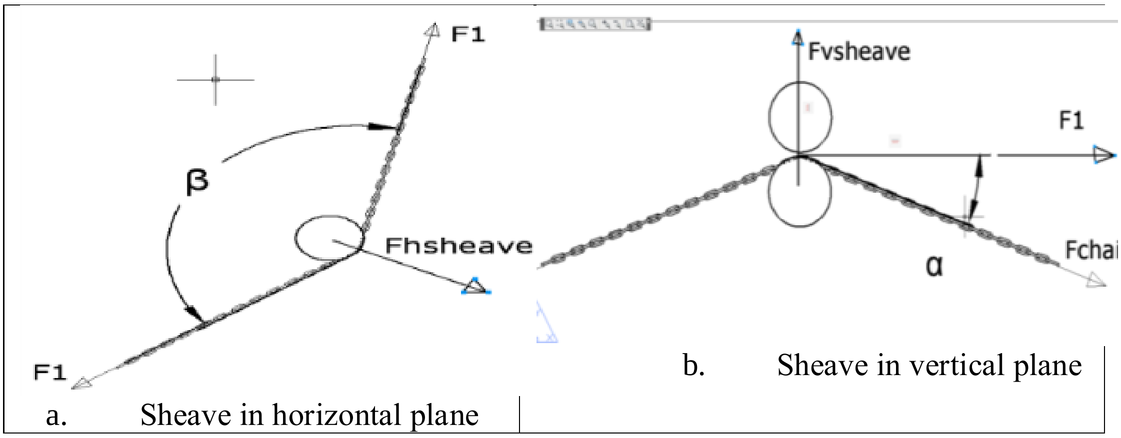
where $r$ is the radius of the drive wheel.

$$F2 = F - F1 \tag{2}$$

Simplifying the two equations results in

$$F1 = \frac{1}{2}\left(\frac{M}{r} + F\right) \tag{3}$$

For the sheave chain interaction the following free-body diagram is presented in Figure 4. There are two types of sheaves those supporting it above the ground and those that are changing the direction in the horizontal plane. However there are assumptions made with regards to the maximum angle β in the horizontal plane is set to a certain maximum for the extreme case.



a. Sheave in horizontal plane

b. Sheave in vertical plane

Figure 4 Forces acting on the chain

The horizontal and vertical the sheave forces are given as

$$F_{hsheave} = 2F_1 cos\frac{\beta}{2}\ ,\mathrm{F}_{\mathrm{chain}} = \frac{\mathrm{F}_1}{\cos\alpha},\ \mathrm{F}_{\mathrm{vsheave}} = 2\mathrm{F}_1\tan\alpha \tag{4}$$

Make the diagrams bigger for clarity and also enlarge Eq. 4.

## 2.2 Methods and materials

The experimental work is an extension of the work done by Chileshe (2011). In this experiment the main measuring instrument that was used was the GB-DTS torque sensor and a load cell used to measure the bearing load on the chain pulley mechanism. Figure 5 shows the equipment that was used in the experiment.

The first aim of the study was to determine the effect of the load, load spacing (i.e. distance between the loads) load speed on the power requirements, the torque, and the tension on the support. The second aim was to determine the relationship of the forces in the chain with the changing load as it is operating.

Water containers representing loads

GB-DTS torque sensor

Torque and tension measurement system

Loads hung on the ropeway

Figure 5 Set up for determination of the performance of chain ropeway system

## 2.3 Design of Experiments

Design of Experiments (DOE) provides a powerful means to achieve breakthrough improvements in product quality and process efficiency (Anderson & Kraber, 1999). Design of experiments is now being used in areas which traditionally were not centered on experiments. Harlow and others introduced a new methodology for the characterisation of CAD heuristics which employs well-studied design of experiments methods (Harlow III & Brglez, 2001). Kim presents a methodology to effectively determine the optimal process parameters for warm forming of lightweight materials using finite element analysis (FEA) and DOE (Kim, 2010). DOE can show how to carry out the least number of experiments while maintaining the most important information. The most important process of the DOE is determining the independent variable values at which a limited number of experiments would be conducted.

An improved DOE proposed by Taguchi approach adopts the fundamental idea of DOE, but simplifies and standardises the factorial and fractional factorial designs so that the conducted experiments can produce more consistent results (Roy, 2001). The DOE technique based on this approach makes use of these arrays to design experiments making it possible to carry out fewer fractional factorial experiments than full factorial experiments. In addition relative influence of factors and interactions on the variation of results can be identified. Through fractional experiments, optimal conditions can be determined by analysing the S/N ratio (Signal-to-Noise ratio) as a performance measure, often referred to as ANOVA (Analysis of Variance).

## 2.4 Experimental setup

The experiments were conducted on the full scale model which has been built on the top floor of the College of Engineering at South China Agricultural University. A steel chain is used in this experiment. The chain link is 43mm long, 21mm wide with 6.35 mm thickness, and mass of the cable is 0.75 kg/m. The cross sectional area and the second moment of area of the cable are 6.33e-005 $m^2$ and Ix = 1.6e-010 $m^4$ Iy = 3.56e-009 $m^4$.

The experiments were conducted using factors adjusted according to Table 1 and Table 2. However the order in which the experiment was run was generated by a random generator. The readings of torque, power and speed were taken at 5 second intervals with the aid of a phone which was used to record the video of the display. The readings from the load cell measuring the drive pulley bearing load were measured and recorded using a computer data acquisition system. The system was allowed to complete a whole cycle in each of the tests.

Table 1 Factors and levels for multiple loads

| Factors | levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A | 4x10 | 4x15 | 4x22 |
| B | 5 | 10 | 15 |
| C | 30 | 40 | 50 |

A: Load (kg); B: Load distance (m); C: Frequency (Hz),

Table 2 Experimental design for an L9 (34) orthogonal array for determining Power, Torque and Pull

| | | | Response | | |
|---|---|---|---|---|---|
| A | B | C | Power Avg. | T(Nm) Avg. | P(N) max |
| 1 | 1 | 1 | 0.0874 | 61 | 1498 |
| 1 | 2 | 2 | 0.126 | 61.6 | 1479 |
| 1 | 3 | 3 | 0.1556 | 60.6 | 1433 |
| 2 | 1 | 2 | 0.16 | 79.31 | 1859 |
| 2 | 2 | 3 | 0.2068 | 80.6 | 1830 |
| 2 | 3 | 1 | 0.0973 | 69.7 | 1717 |
| 3 | 1 | 3 | 0.23 | 93.7 | 2395 |
| 3 | 2 | 1 | 0.1207 | 94.4 | 2269 |
| 3 | 3 | 2 | 0.167 | 87.6 | 2421 |

## 3.0 Results and discussion

With reference to Figure 1 and Table 3, it is shown that frequency or rotational speed (p = 0.028) and the carried load has a big impact (p=0.008) and are statistically significant on the power consumption which is in agreement with the study by Li and Ou ( 2009). However the spacing distance though has an impact in reducing the power which is not statistically significant (p=0.163.).

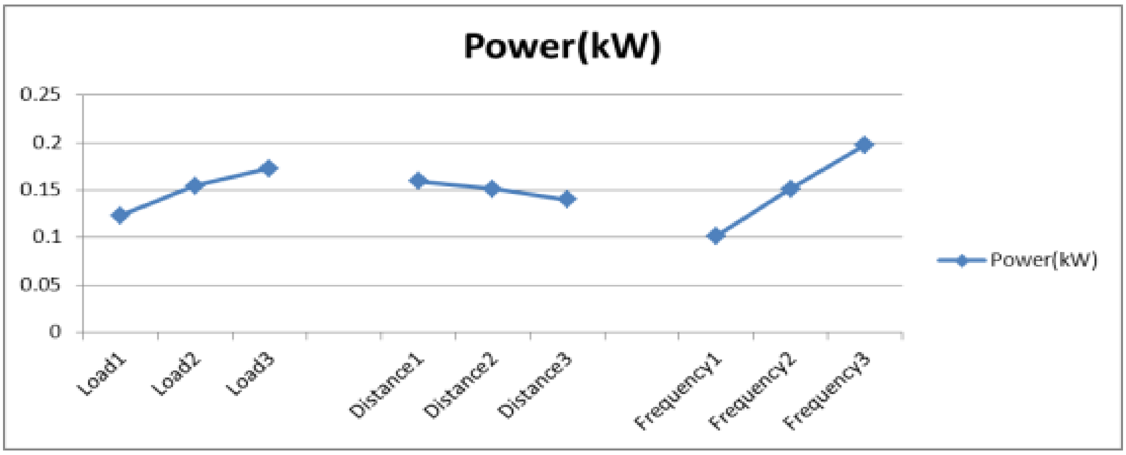


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Figure 1 S/N ratio graph for variable =power for multiple loads

Table 3 Analysis of variance with dependent variable: power for multiple loads

| Source | Type III Sum of Squares | df | Sig. | Partial Eta Squared |
|---|---|---|---|---|
| Corrected Model | 0.018a | 6 | 0.018 | 0.994 |
| Intercept | 0.203 | 1 | 0.000 | 0.999 |
| Load | 0.004 | 2 | 0.028 | 0.972 |
| Spacing | 0.001 | 2 | 0.163 | 0.837 |
| Frequency | 0.014 | 2 | 0.008 | 0.992 |
| Error | 0.000 | 2 | | |
| Total | 0.221 | 9 | | |
| Corrected Total | 0.018 | 8 | | |

a. R Squared = 0.994 (Adjusted R Squared = 0.976)

From Figure 7, and

Table 4, it is seen that the load has the biggest impact on the torque followed by spacing which shows a trend of reducing the torque requirement as the distance between the loads is increased. The frequency has the least influence. Of the three it is only the load which is statistically significant (p=0.01<0.05) showing a similar pattern as the case of carrying a single load in previous work done (Chileshe, 2011).

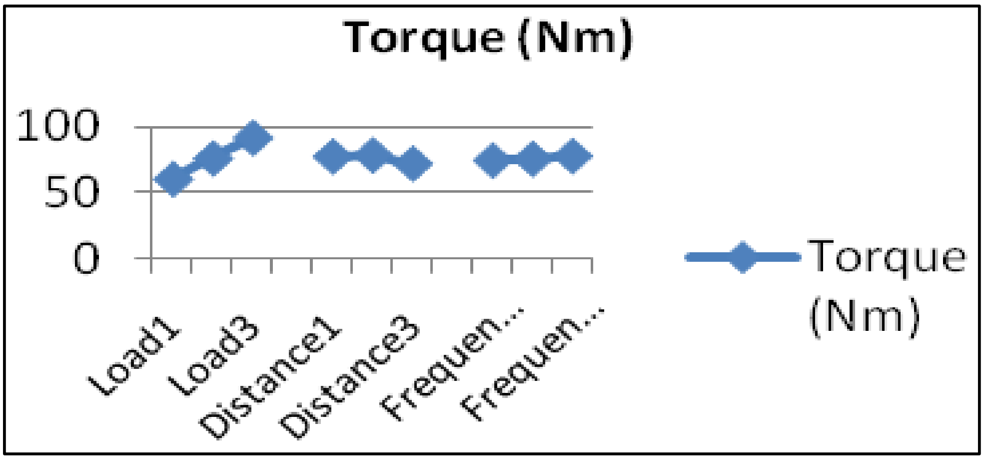

Figure 7 S/N ratio graph for variable =Torque for multiple loads

Table 4: Analysis of variance with dependent variable: torque for multiple loads

| Dependent Variable: T(N) | | | | |
|---|---|---|---|---|
| Source | Mean Square | F | Sig. | Partial Eta Squared |
| Corrected Model | 251.831 | 34.754 | 0.028 | 0.991 |
| Intercept | 52671.780 | 7269.072 | 0.000 | 1.000 |
| Load | 713.024 | 98.402 | 0.010 | 0.990 |
| Spacing | 34.218 | 4.722 | 0.175 | 0.825 |
| Frequency | 8.250 | 1.139 | 0.468 | 0.532 |
| Error | 7.246 | | | |
| Total | | | | |
| Corrected Total | | | | |
| a. R Squared = 0.991 (Adjusted R Squared = 0.962) | | | | |

With reference to Figure 8 and

Table 5 it can be seen that the load is the most influential towards the pulley bearing force and is statistically significant (p=0.006). The load spacing (p=0.49) and the frequency (p=0.345) are not statistically significant towards the pulley bearing pull.

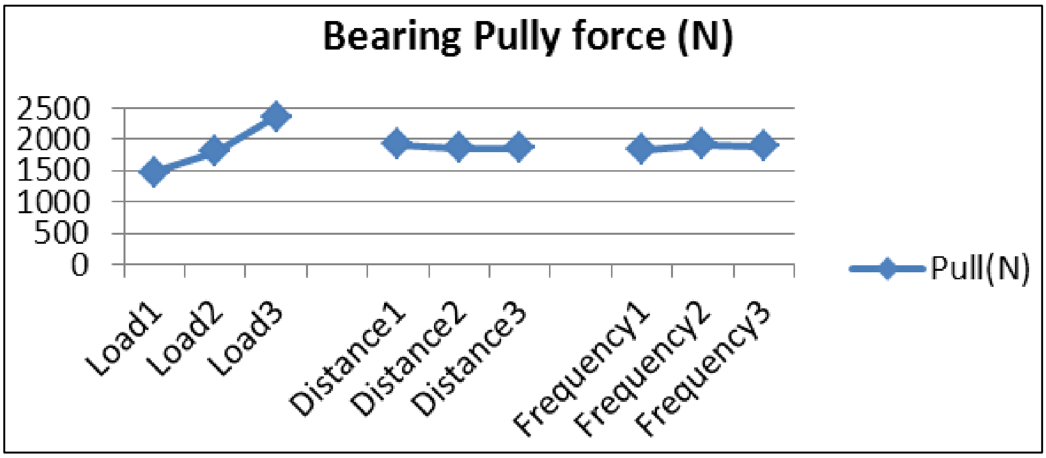

Figure 8 S/N ratio graph with dependent variable: Pulley bearing force for multiple loads

Table 5: Analysis of variance for Pulley bearing force

| Source | Sig. | Partial Eta Squared |
|---|---|---|
| Corrected Model | 0.016 | 0.995 |
| Intercept | 0.000 | 1.000 |
| Load | 0.006 | 0.994 |
| Spacing | 0.492 | 0.508 |
| Frequency | 0.345 | 0.655 |

Further investigation of the frequency with the bearing load on the chain drive was carried out with the following combinations shown in Table 6.

Table 6: Combination for investigating on influence of speed on drive bearing force

| combination | max bearing force | Torque | Speed | Power |
|---|---|---|---|---|
| 40Hz 8x20kg | 2725 | 122.2 | 15.46 | 0.194 |
| 50Hz 8x20kg | 2665 | 110.1 | 22.35 | 0.256 |

The detailed results of the bearing force were analysed comparing of means using SPSS The results show that frequency which translates to the speed of the chain does not influence the bearing force as the bearing force for 40Hz 8x20kg load is equal to 50Hz 8x20kg (p=1.00>0.05). Having established that speed of frequency did not significantly influence the drive wheel bear force, the effect of the weight and the spacing were investigated. These tests were run while keeping the frequency constant at 50Hz as this is also the operating frequency of the ropeway as shown in Table 7.

Table 7: Combination of factors at 50Hz speed on the drive wheel bearing force

| Factors | | | | | | Responses | |
|---|---|---|---|---|---|---|---|
| | Experiment label | weight | spacing (m) | No of weights | total load | Bearing force (N) | Max force |
| | fun00 | 0 | 5 | 0 | 0 | 781.45 | 866 |
| Combination 1 | fun01 | 15 | 5 | 4 | 60 | 1436.55 | 1729 |
| | fun03 | 15 | 10 | 4 | 60 | 1419.71 | 1746 |
| | fun02 | 15 | 15 | 4 | 60 | 1427.85 | 1793 |
| Combination 2 | fun55 | 15 | 5 | 6 | 90 | 1600.97 | 1923 |
| | fun04 | 15 | 10 | 6 | 90 | 1614.93 | 1890 |
| | fun06 | 15 | 10 | 6 | 90 | 1593.01 | 1820 |
| Combination 3 | fun07 | 15 | 5 | 8 | 120 | 1775.86 | 2063 |
| | fun18 | 22 | 5 | 8 | 176 | 2218.46 | 2618 |
| | fun08 | 15 | 10 | 8 | 120 | 1751.21 | 2002 |
| | fun09 | 15 | 5 | 10 | 150 | 1909.78 | 2174 |
| | fun20 | 22 | 5 | 10 | 220 | 2438.28 | 2790 |
| | fun10 | 15 | 5 | 12 | 180 | 2027.29 | 2292 |
| | fun21 | 22 | 5 | 12 | 264 | 2608.44 | 3030 |

The results for combination 1 and combination 2 were analysed using the ANOVA one way test while combination 3 was analysed using the t test.

The results show that there is no significant differences in the drive wheel bearing force due the spacing for the 4 x 15kg mass loaded (P=0.522) and the 6x 15kg(P=0.317). For the 50Hz 8x15kg loads (with 5m spacing) and 50Hz 8x15kg loads (with 10m spacing) spaced, the effect of the spacing was not statistically significant though just barely (P=0.073). Looking at the way significance measure has been decreasing as the number of weights increase it means that below a certain minimum load the spacing has no influence and in this case it can be suggested that the borderline weight beyond which the spacing starts to play a big role in the loading is 8 x 15kg for the chain ropeway that is being studied.

Regression analysis was also carried out to determine the relationship between the load and the drive wheel bearing force and a linear relationship was obtained shown in Table 8 and the plot in Figure 9.

Table 8 Linear Model of the relationship between the carried load and the drive wheel bearing force

| Coefficients | Unstandardised Coefficients | | Sig. |
|---|---|---|---|
| | B | Std. Error | |
| total_load | 6.451 | .049 | .000 |
| (Constant) | 983.294 | 6.738 | .000 |

The model is givens as

$$\text{drivewheel force} = F = 983.294 + 6.451\text{total\_load} \tag{5}$$

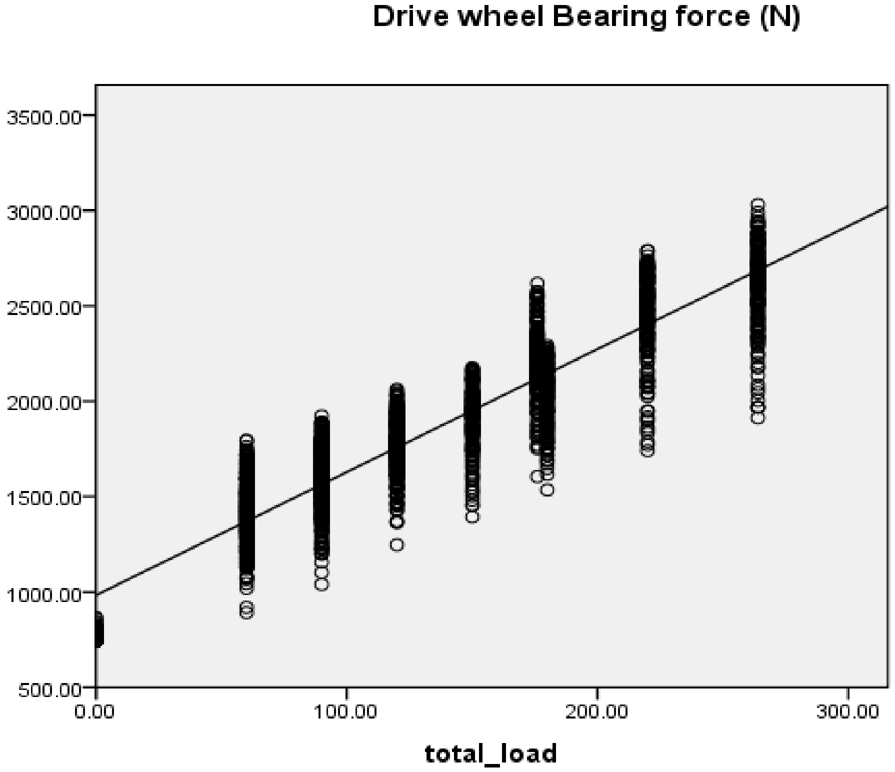

Figure 9 Relationship of the carried load to the drive wheel bearing force.

The bearing wheel force ranges from 983N with no load to just below 3000N at full load.

Next the linear regression was carried out on the total load and the torque in SPSS and the following are the results in Table 9 and plotted in Figure 10.

Table 9 Model Summary for variable Torque (M)

| R | R Square | Adjusted R Square |
|---|---|---|
| 0.793 | 0.629 | 0.628 |

The independent variable is Total load.

Then the model is given as

$$M = 41.832 + 0.341 * Totalload \tag{6}$$

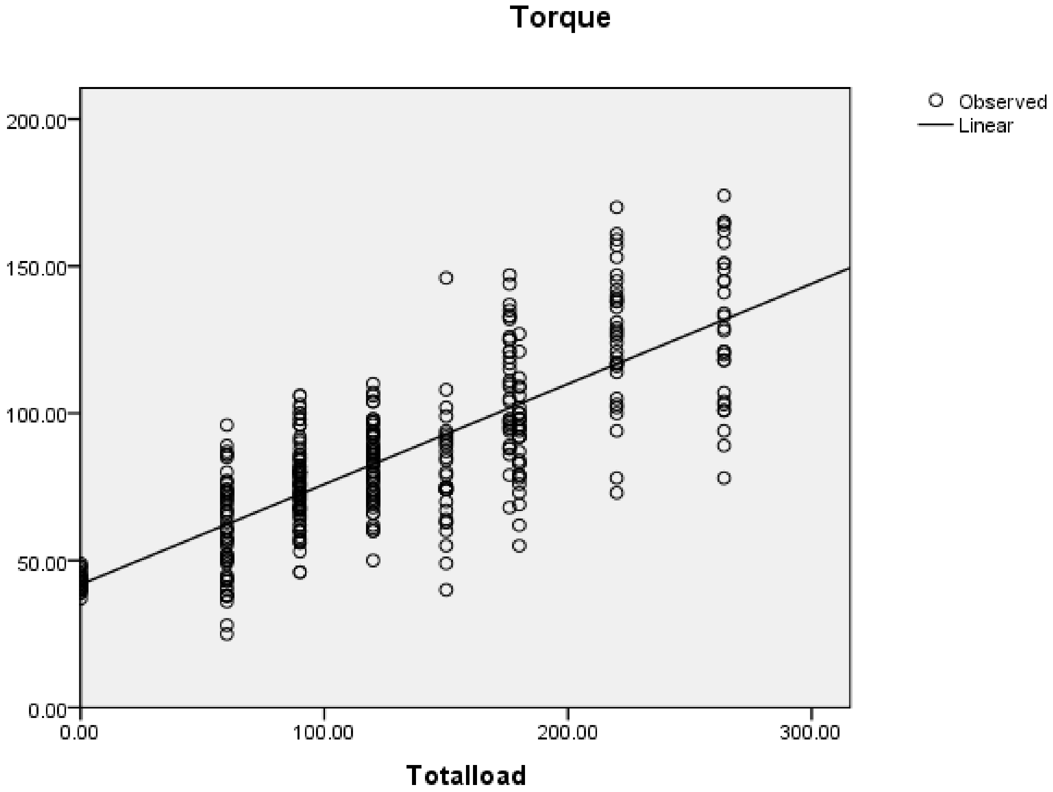

Figure 10 Relationship of the carried load to the torque.

Further looking at the relationship of the total load and power gives the following results as shown in Table 10 and plotted in Figure 11.

Table 10: Model Summary for variable Power

| R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|
| .767 | .589 | .588 | .036 |

The independent variable is Total load.

The model for power is then

$$Power = 0.130 + 0.001Totalload \quad (7)$$

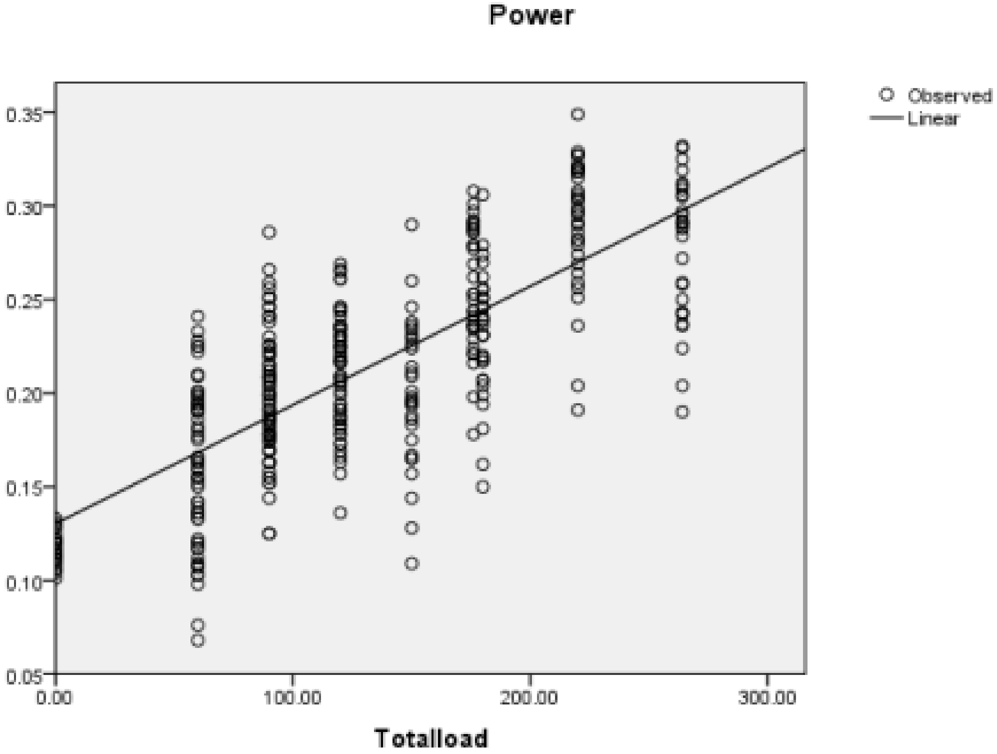

Figure 6 Relationship of the carried load to the power.

## 4.0 Conclusions

1. The load is a very important factor as it affects the drive wheel bearing force and the amount of power.

2. The frequency which is a measure of speed has a direct impact on the power but has been found to have no impact on the drive wheel bearing force.

3. The spacing has been found to influence the drive wheel bearing force slightly and a larger spacing was shown to make the ropeway system perform marginally better in terms of the maximum load that it would be able to transport.

4. At no load, and operating at 50Hz, the minimum power requirement for the ropeway is 0.130kW and the minimum torque is 41.8Nm.

5. Models for relating the drive wheel bearing force to the total load, the total load to the power required, and the torque to the total load have been determined. The models give the maximum load that can be carried for a similar configuration of length and the relationship between the load the tension in the chain and the power requirement chain ropeway of similar size. So limiting the distance supports to a maximum of 11 m for a length of chain of around 80m, it would be safe to use the above relationship for preliminary design values.

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# Correlation of SPT with DPSH Test results – A Case for some Zambian soils

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## ABSTRACT

*There are several types of field tests conducted for determining bearing capacity of foundation soils worldwide. Dynamic penetration is the oldest and quicker field technique for determining mechanical properties of foundation soils. The Standard Penetration Test (SPT) is the oldest and more popular but has some disadvantages. The Dynamic Probe Super Heavy (DPSH) is similar but does not require a trial hole or boring, as pipes are driven from the ground surface, and is quicker to conduct. The DPSH however does not allow sampling of materials, for further testing. The SPT uses a split spoon sampler at its tip whilst the DPSH uses a solid cone. Chances of clogging the SPT hollow sampler are high and the SPT may give misleading results. With the DPSH, it is possible to have a better idea about the underlying strata below the proposed foundation level without having to conduct costly drilling or coring operations, especially for shallow foundations. Both tests are empirical but the DPSH test results have to be correlated to SPT ones, to obtain the various mechanical properties. The interpretation of DPSH test results is not standard as several correlations exist but none have been established for Zambia.*

*This paper reviews various correlations between SPT and DPSH and proposes new correlations, based on data compiled from various field tests conducted in selected sites in Zambia. The analysis is qualitative and it is understood that once equivalent SPT penetration values are obtained from DPSH dynamic test, the penetration values have to be modified according to various modification factors to obtain various mechanical properties. These modifications are not part of this paper. The study established that the modification factors are a function of depth of penetration, resulting from increased friction due to lateral pressure. Further, higher correlation factors were observed for the more cohesive soils. The proposed factors have taken this into account.*

*It is highly recommended a comprehensive research be, taking into account energy dissipation and lateral pressure effects on driving rods, for various types of soils, and at deeper penetrations*

***Key words**: Dynamic Penetration Tests, SPT, DPSH, shallow foundation, bearing capacity*

## Introduction

The Standard Penetration Test (SPT) is an in-situ dynamic penetration test to provide information on the properties of soil. Disturbed soil sample may be collected from the split spoon for grain-size analysis, soil classification and chemical analysis. The SPT involves the driving of a standard sampler through a depth of 450mm into the bottom of a trial hole or a borehole using the standard mass of 63.5kg falling through 760mm. The Number of blows over the last 300mm is recorded as the SPT N value.

Like the SPT, the Dynamic Probing Super Heavy (DPSH) uses a hammer that delivers energy to a rod string by dropping a mass of 63.5kg from a height of 760mm. Unlike the SPT, a solid cone is driven instead of a split spoon sampler, from the ground surface and the test does not soil samples to be brought to the surface, thus allowing a continuous record. The International Society for Soil Mechanics and Foundation Engineering (ISSMFE) has outlined a procedure called Dynamic Probing Super Heavy (DPSH) which is designed to closely simulate the dimensions of the Standard Penetration Test (SPT).

One advantage of the Dynamic penetration testing is that it enables recognition of the lithology of the underground being penetrated, thereby permitting characterization of the lithologies that constitute the underground for their geotechnical homogeneity and recognition of granular and cohesive soil successions.

The dynamic cone penetrometer consists of five essential elements:

(a) The hammer, which generally has a free fall with more or less constant height of fall;
(b) The anvil which sometimes has a camping cushion and a fixed or friction connection with the extension rods;
(c) The driving rods which have a variety of weights and diameters;
(d) The tip of cone point, which is characterised by the apex angle, the size and the tip diameter to rod diameter ratio; and
(e) The casing tube that follows the point to remove the friction on the rods.

Generally the dynamic penetrometers are equipped with an enlarged cone and the number of blows required to drive the penetrometer a depth of 100, 200 and 300mm, may be referred tom as $N_{10}$, $N_{20}$ and $N_{30}$, respectively. Figure 1 shows the SPT equipment while Figure 2 shows parameters of a typical penetration cone.

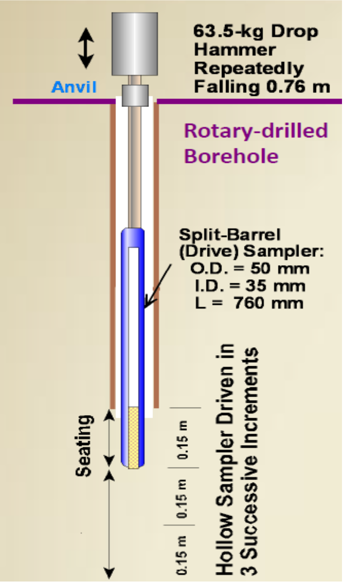
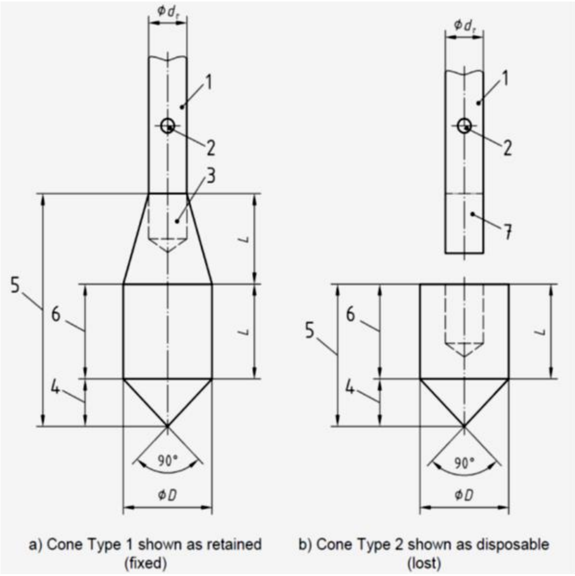


Figure 1: SPT Set up



a) Cone Type 1 shown as retained (fixed)

b) Cone Type 2 shown as disposable (lost)

Figure 2: Dynamic Penetration Cones **Types (EN ISO 22456-2005 (E))**
**(**1 Extension rod, 2 Injection opening (optional), 3 Point mounting, 4 Cone tip, 5 Cone, 6 Mantle)

There are several types of penetrometers on the market and Table 1 shows parameters for the Swedish DPSH while Table 2 shows parameters for various Dynamic Tests in Europe.

Table 1: Technical Specifications for the Swedish DPSH

| | |
|---|---|
| Hammer weight | 63.5±0.5 kg |
| Drop height | 750±20 mm |
| Energy of hammer impact | 238 kJ/m$^3$ |
| Cone apex angle | 90° |
| Cone base area | 20 mm |
| Cone base Ø | 51±0.5 mm |
| Length of cylindrical area | 51±2 mm |
| Height of cone tip | 25.3±0.4 mm |

Table 2: Characteristics of various Dynamic Penetrometers European Countries

| | Name of Penetrometer | | | | Tip Dimensions | | Rod Dimensions | | | Hammer Weight (kg) | Drop Height (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | DPL | DPM | DPS | DPSH | Diameter (mm) | Angle (°) | Ø $_{\text{Inn}}$ (mm) | Ø $_{\text{Out}}$ (mm) | Length (m) | | |
| Belgium | * | | | | 22.5 | | | | | | |
| | | | | | 25.2 | 60 | 0 | 20 | 1.0 | 10.0 | 50 |
| | | | | | 35.7 | | | | | | |
| Denmark | | | | * | 51 | 90 | 0 | 32 | 1.0-2.0 | 63.5 | 75 |
| Finland | * | | | | 35.7 | 90 | 0 | 22 | 1.0 | 10 | 50 |
| | | | | * | 45 | 90 | 0 | 32 | 1.0 | 63.5 | 50 |
| France | | | | | | | | | | 32;64;96 | |
| | | * | | * | 62 | 90 | 0 | 40 | 1.0 | 120 | 76 |
| | | * | | * | 70 | 90 | 0 | 40 | 1.0 | 30;60;90 | 40 |
| | | | | * | 45 | 90 | 0 | 32 | 1.0 | 63.5 | 50 |
| | | * | | | 35.7 | 90 | 0 | 22 | 1.0 | 30 | 20 |
| | | | * | * | 43.7 | 90 | 0 | 32 | 1.0 | 50;100 | 50 |
| Germany | * | | | | 25.2;35.7 | 90 | 6 | 22 | 1.0 | 10 | 50 |
| | | * | | | 35.7 | 90 | 6;9 | 22;32 | 1.0-2.0 | 30 | 20;50 |
| | | | * | | 35.7;43.7 | 90 | 9 | 32 | 2.0 | 50 | 50 |
| Italy | * | | | | 25.2;35.7 | 60;90 | 0;14 | 20;28 | 1.0 | 30;20 | 20 |
| | | | * | | 51 | 60 | 0 | 34 | 1.2 | 73 | 75 |
| | | | * | | 50.5 | 60 | 14;34 | 32;40 | 1.0-1.5 | 63.5 | 75 |
| Norway | | | | * | 51 | 90 | 0 | 32 | 1.0-2.0 | 63.5 | 75 |
| Spain | * | | | | 35.7 | 90 | 0 | 22 | 1.0 | 10 | 50 |
| | | | * | | 45 | 90 | 0 | 32 | 1.0 | 63.5 | 50 |
| | | | * | | 67 | 90 | | 40/32 | 1.0-2.0 | 63.5 | 75 |
| Sweden | | | | * | 51 | 90 | 0 | 32 | 1.0-2.0 | 63.5 | 75 |
| Switzerland | * | | | | 35.7 | 30-90 | 0 | 22;25 | 1.0-2.0 | 30;20 | 20;50 |
| | | * | | | 43.7 | 30 | 155 | 32 | 1.0-2.0 | 50 | 50 |
| | | | * | | 62.5-60 | 90 | 26 | 42;38 | 1.5-2.0 | 63;60 | 76;50 |

DP-Dynamic Penetration, L-Light, M-Medium; H- Heavy; SH- Super Heavy

**Source**: Adapted from ISSMFE and Giovanni Spagnoli (2011)

To ensure consistency with the Standard Penetration test results, the drop height should be checked before testing and frequency of blows should be kept within 15 to 30 blows/min. In addition, the driving rods should be rotated 1.5 times, for every 1 m of probing in order to decrease skin friction on the rods.

The SPT penetration values (N) are then correlated for various factors to determine mechanical properties such as bearing capacity of a foundation soil. The SPT is an industry standard, and the blow counts for DPSH have to be correlated to the SPT N values before determining the bearing capacity or other mechanical properties. Several correlations exist but none have been developed for Zambian soils.

This paper compares correlations from various literature, presents field test results from selected sites in Zambia and make a recommendation on correlation factors based on comprehensive data, as currently there are no standard correlation factors for Zambian soils.

**Literature Review on use of DPSH**

The Dynamic Penetrometer Super Heavy (DPSH) made by Swedish company BORRO AB is designed for vertical geological sounding in order to obtain relative density $I_D$ of non-cohesive soils. According to PN-B-04452:2002 standard, the relation between number of blows for each 200mm penetration ($N_K$) and relative density ($I_D$) of sands with a coefficient of uniformity U>3 is described by the formula:

$I_D = 0.441 \log N_{20} + 0.196.$ Equation 1

According to Waschkowski (1982), the dynamic resistance in clean dense sands or in gravels is not influenced by the kind of cone tip except for the heterogeneity. This is due to the fact that during the impact, the relative displacement between the rods and the soil is very small, and the transmission of the compression wave down to the rods causes vibration in the sands and in gravels which support the drive rods. In soft soils the skin friction along the rods battery has a great influence on the penetration resistance. Tables 3 shows some correlation of Dynamic Penetration over a 300mm penetration (DP $N_{300}$) and SPT. The specific tests upon which each correlation is based are indicated for each correlation in the brackets.

Table 3: Correlation between SPT and DPSH for 300mm penetration

| **Deposit** | **Correlation** | **Correlation Coefficient, R** | **Proportionality Coefficient, $K_1$** |
|---|---|---|---|
| Chalk in UK (1990) | DP $N_{300}$= 1.4 SPT $N_{300}$ (DPH versus SPT) | 0.78 | 1.4 |
| Reading Beds: sand in UK (1990) | DP $N_{300}$= 1.4 SPT $N_{300}$ (DPH versus SPT) | 0.75 | 1.4 |
| Alluvial Gravel in UK (1990) | DP $N_{300}$= 1.0 SPT $N_{300}$ (DPH versus SPT) | 0.31 | 1.4 |
| Flood Plain Gravel in UK (1990) | DP $N_{300}$= 1.1 SPT $N_{300}$ (DPH versus SPT) | 0.80 | 1.1 |
| Gravel and Sand in Germany (2008) | DP $N_{300}$= 1.15 SPT $N_{300}$ (DPSH versus SPT) | - | 1.15 |
| Highly Weathered Limestone in Sudan (2011) | DP $N_{300}$= 2.44 SPT $N_{300}$ (DPL $_{\text{Modified}}$ versus SPT) | 0.86 | 2.44 |

$N_i$ = Number of blows for i penetration in mm
**Source:** Kassim and Ahmed (2011)

It has been indicated that for cohesive soils, and in tests executed at appreciable depth, care should be exercised because with some equipment the skin friction on the rods contributes significantly to the measured resistance. However no conclusive factors have been derived.

The penetration resistance increases more than linearly with increasing soil Density Index (DI); change in density index, for instance as a result of deep compaction, can be detected by dynamic probing, as shown in Figure 3.

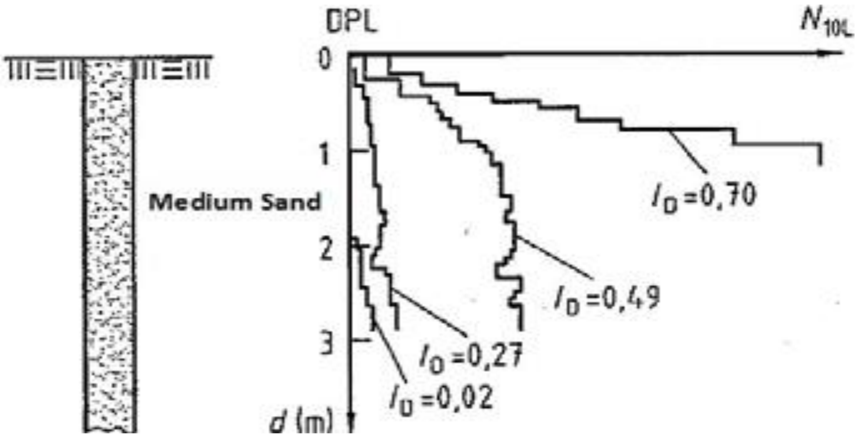


Figure 3: Change in penetration resistance with Density Index (ID) in a homogeneous backfilled soil (DIN, 2002)

Figure 4 shows that the penetration resistance fluctuates more sharply in coarse-grained soils than in finer-grained soils. The fluctuation is more pronounced in gravels than in sands. Further, for shallower penetration below the critical depth (1 or 2 m,) the penetration resistance remains almost constant for the same conditions.

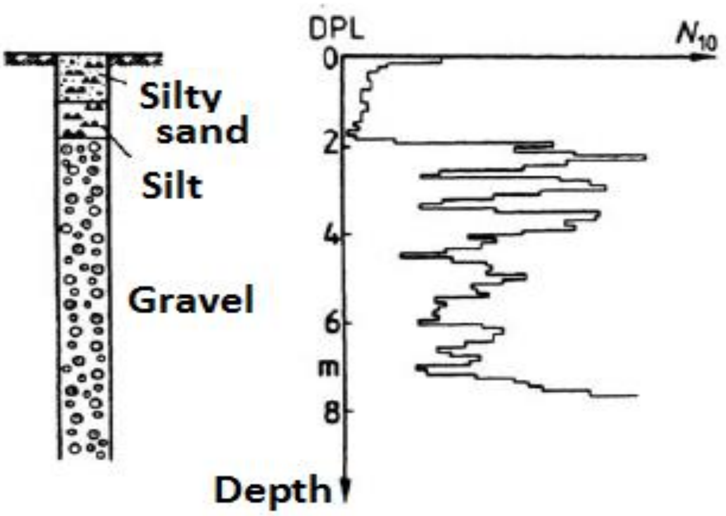


Figure 4: Variations in penetration resistance in fine-grained and coarse-grained soil (DIN, 2002)

Soils with sharp-edged or rough particles have a higher penetration resistance than those with round and smooth particles, due to better packing effect in the latter.

Most of the correlations have taken the form of a linear relationship, passing through the origin, as summarised in Table 3. Thus the linear relationship is of the form:

$$DP\ N_{300} = K\ SPT\ N_{300} \qquad \text{Equation 2}$$

where K is the constant of proportionality and subscript 300 refers to 300mm penetration.

Other colorations have been based on a 100mm depth of penetration using the DPSH. The relationships are summarised in Table 4.

Table 4 Correlation between SPT and DPSH for 100mm penetration

| **Deposit** | **Correlation** | **Correlation Coefficient, R** |
|---|---|---|
| Stiff Clay in UK and Norway (1996) | $N' = 8N_{10} - 6$ | 0.89 |
| Slightly Plastic Clay above Groundwater in Germany (2011) | SPT $N_{300} = 1.0$ DP $N_{10} +3$ (DPH versus SPT) | - |
| Highly Weathered Limestone in Sudan (2011) | SPT $N_{300}= 1.43$ DP $N_{100}$ (DPL $_{\text{Modified}}$ versus SPT) | 0.92 |

**Source**: Kassim and Ahmed (2011)

In a case study of highly weathered limestone in Eastern Sudan by Kassim and Ahmed (2011), using a modified light weight $DPL_{modified}$, a statistical analysis was used to produce the $DPL_{mod}$ *versus* SPT correlations. The analysis indicated a linear trend line as follows:

DP $N_{300}$ = 2.44 SPT $N_{300}$ Equation 3a
SPT $N_{300}$ = 1.43 DP $N_{100}$ Equation 3b

MacRobert et al (2011) conducted statistical analysis of SPT and DPSH resistance values from different geological depositional and weathering environments in Southern Africa; Matola in Mozambique, Gope in Botswana, Umdloti and Cape Town in South Africa, and Illha de Luanda in Angola. Their study revealed that energy losses were greater in the DPSH test than in the SPT, leading to higher penetration N values in the former. The dynamic force applied to the DPSH rods causes soil to fill the small air annulus around the rods, exerting a frictional resistance. The different geological settings of the test sites revealed that, although different factors cause the friction, the equivalence varied in a similar manner. In the SPT there is no such resistance. Hence a single correlation formula was suggested:

Equivalent SPT, $N = N_{30SB}/(0.2N_{30SB} +0.8)$ Equation 4
where SPT N=Number of Blows from Standard SPT
$N_{30SB}$=Number of Blows from DPSH for 30cm penetration`

This shows that for $N_{30SB}$ as low as 10, the modification factor to get SPT N is as high as 2.8.

## SPT and DPSH field Tests carried out in Zambia

A number of geotechnical investigations were conducted in selected towns of Zambia, namely Livingstone, Lusaka, Nampundwe and Ndola. The SPT was conducted in trial holes of maximum depth 3.0m. This is because for shallow foundations, the maximum depth for hand excavation of trial pits ranges from 1.5m to 3.0m. Beyond 3m, the excavation does not only become difficult but there are also chances of wall carving, which can result in loss of life if the walls are not supported, or where they are not able to withstand lateral pressure.

## Correlation between SPT and DPSH for some Zambian soils based on Test Data

Data on penetration values and classification of the soils based on the Unified Classification system, at various depths for each site are presented in the Tables 5 to 8. Figures 5 to 8 show the corresponding penetration ratios, $DPSHN_{300}/SPTN_{300}$, for each site.

Table 5a presents data for a Livingstone site, which generally consisted of an upper layer of up to 0.5m of silty-sand and the rest was fine sand of less uniform texture, at a depth of 3.0m.

Table 5a: Series ESCI LV in Livingstone at 3.0m depth

| S/N | Depth (m) | $SPTN_{300}$ | $DPSHN_{300}$ | Soil Description |
|---|---|---|---|---|
| ESCI LV-1 | 3.0 | 11 | 16 | Coarse Grained |
| ESCI LV-2 | 3.0 | 11 | 15 | Coarse Grained |
| ESCI LV-3 | 3.0 | 13 | 18 | Coarse Grained |

Figure 5a shows that for Series ESCI LV there was a consistent ratio between SPT blows and DPSH ones. Thus at a depth of 3.0m the ratio averaged about 1.4.

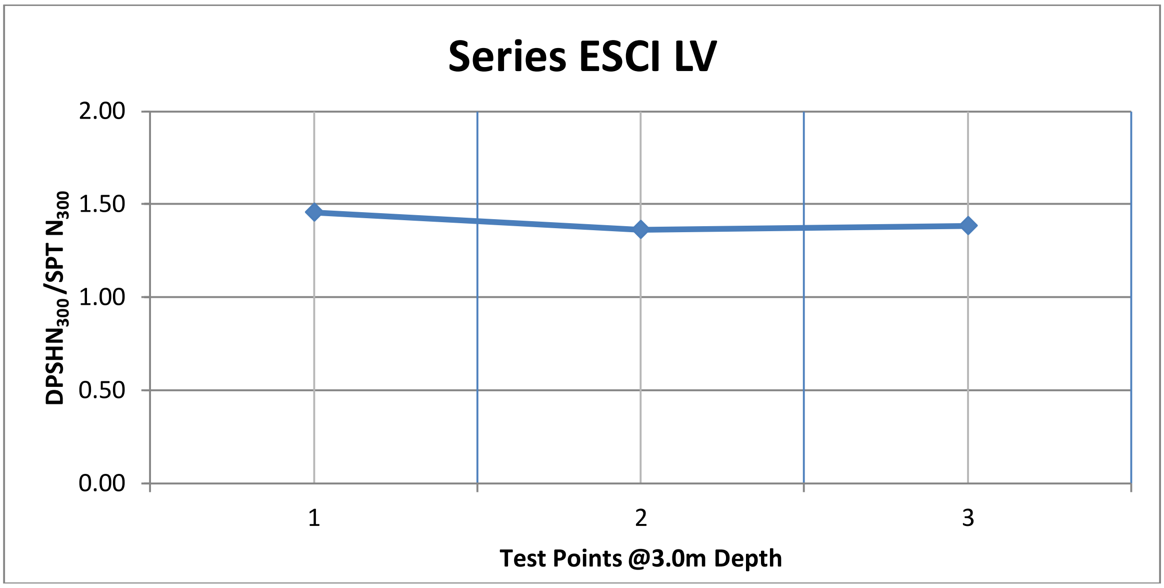


Figure 5a Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series ESCI LV

For Series BVUS LV there was more variation but the average ratio was about 2.50, as shown in Figure 5b.

Table 5b Series BUS LV in Livingstone at 2.0m depth

| S/N | Depth (m) | $SPTN_{300}$ | $DPSHN_{300}$ | Soil Description |
|---|---|---|---|---|
| BUS LV-1 | 2.0 | 12 | 29 | Coarse Grained |
| BUS LV-2 | 2.0 | 13 | 22 | Coarse Grained |
| BUS LV-3 | 2.0 | 8 | 28 | Coarse Grained |

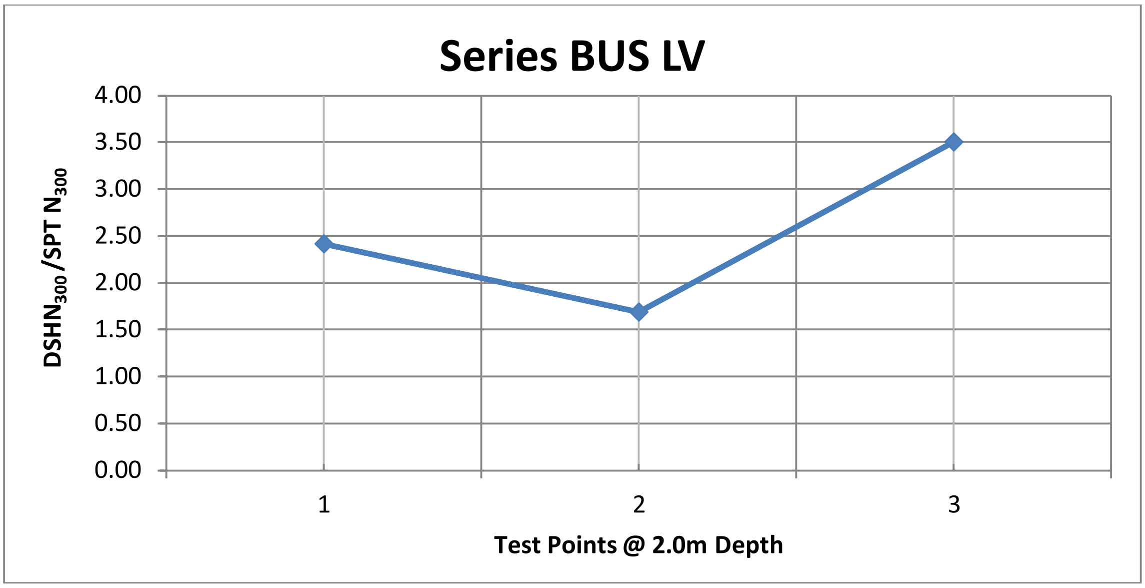


Figure 5b: Ratio DPSHN$_{300}$/ SPTN$_{300}$ for series BUS LV

For series HOS LV the data and ratios are presented in Table 5c and Figure 5c, respectively. The ratios varied from 0.5 to 1.75 but averaged about 1.0 at a depth of 2.0m.

Table 5c: Series HOS LV in Livingstone at 2.0m depth

| **S/N** | **Depth (m)** | **SPTN$_{300}$** | **DPSHN$_{300}$** | **Soil Description** |
|---|---|---|---|---|
| HOS LV-1 | 2.0 | 10 | 6 | Coarse Grained |
| HOS LV-2 | 2.0 | 8 | 7 | Coarse Grained |
| HOS LV-3 | 2.0 | 5 | 6 | Coarse Grained |
| HOS LV-4 | 2.0 | 10 | 13 | Coarse Grained |
| HOS LV-5 | 2.0 | 12 | 12 | Coarse Grained |
| HOS LV-6 | 2.0 | 7 | 12 | Coarse Grained |
| HOS LV-7 | 2.0 | 13 | 16 | Coarse Grained |
| HOS LV-8 | 2.0 | 4 | 3 | Coarse Grained |
| HOS LV-9 | 2.0 | 9 | 5 | Coarse Grained |
| HOS LV-10 | 2.0 | 8 | 5 | Coarse Grained |

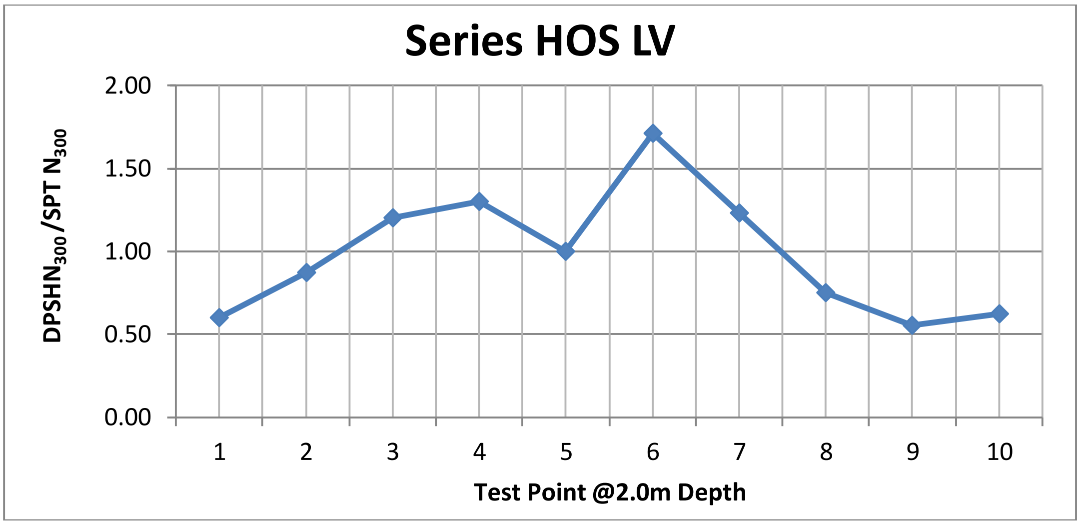


Figure 5c: Ratio DPSHN$_{300}$/ SPTN$_{300}$ for series HOS LV

Tables 6 indicate the characteristics for Lusaka soils. Table 6a shows characteristics for Series ESCI LS whilst Figure 6a indicates ratios at 3.0m. The average ratio was about 1.25. The high penetration values for Test Point 1 was due to rocky formation at that depth.

Table 6a: ESCI LS Series Lusaka at 3.0m depth

| S/N | Depth (m) | SPTN300 | DPSHN300 | Soil Description |
|---|---|---|---|---|
| ESCI LS-1 | 3.0 | 55 | 55 | CL-ML Silty-clay of Low Plasticity |
| ESCI LS-2 | 3.0 | 4 | 5 | CL-ML Silty-clay of Low Plasticity |
| ESCI LS-3 | 3.0 | 7 | 9 | CL-ML Silty-clay of Low Plasticity |

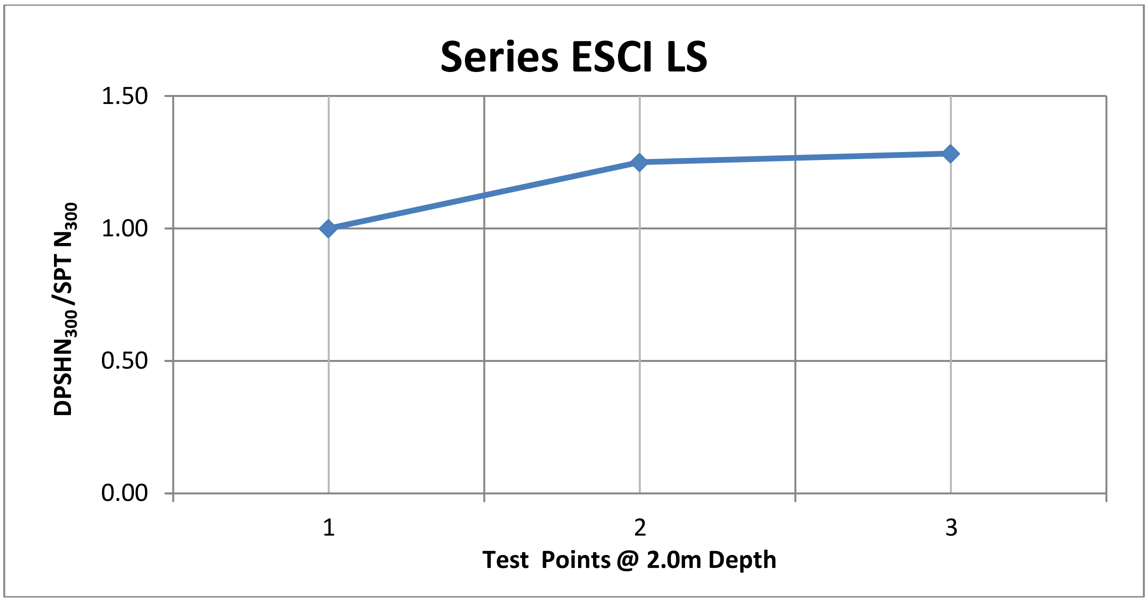


Figure 6a: Ratio DPSHN300/ SPTN300 for series ESCI LS

For Series MP LS, Table 6b shows the characteristics of the soil whilst Figure 6a shows the penetration ratios at depths 1.5m and 3.0m, respectively. In general, at 1.5m the penetration, the ratio was about 1.5 and about 1.35 at 3.0m depth.

Table 6b: Series MP LS in Lusaka

| S/N | Depth (m) | SPTN300 | DPSHN300 | Soil Description |
|---|---|---|---|---|
| MP LS3-1.5m | 1.5 | 10 | 2 | CL- Poorly graded Gravelly Sand-Clay mixture. |
| MP LS3-3.0m | 3.0 | 16 | 12 | CL- Poorly graded Gravelly Sand-Clay mixture. |
| MP LS4-1.5m | 1.5 | 6 | 9 | CL- Poorly graded Gravelly Sand-Clay mixture. |
| MP LS4-3.0m | 3.0 | 12 | 13 | CL- Poorly graded Gravelly Sand-Clay mixture. |
| MP LS5-1.5m | 1.5 | 6 | 9 | CL- Poorly graded Gravelly Sand-Clay mixture. |
| MP LS5-3.0m | 3.0 | 37 | 50 | CL- Poorly graded Gravelly Sand-Clay mixture. |

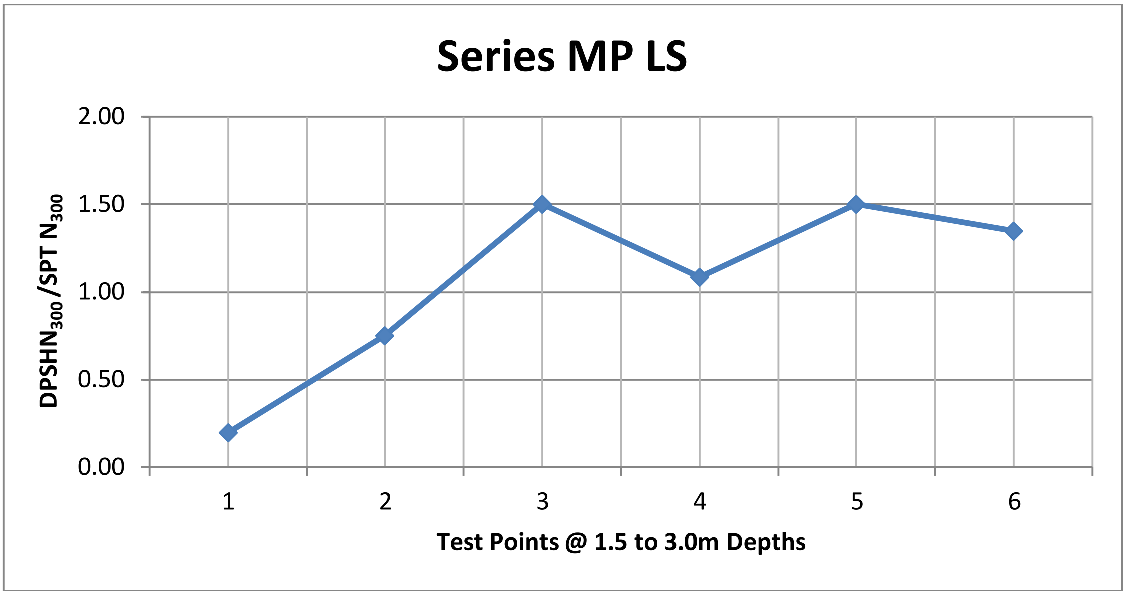


Figure 6b: Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series MP LS

Table 6c and Figure 6c show characteristics for Series MS LS. At 1.5m depth, the ratios averaged about 1.0. For 3.0m depth, the ratio was above 1.5. The peaks of 4.0 and 5.0 are due to rock intrusions. Some relatively low penetration values were recorded at depths of about 3.0m due to a schist at this level, at some locations.

Table 6c: Series MS LS

| **S/N** | **Depth (m)** | **$SPTN_{300}$** | **$DPSHN_{300}$** | **Soil Description** |
|---|---|---|---|---|
| MS LS1-1.5m | 1.5 | 17 | 8 | OL or ML |
| MS LS1-3.0m | 3.0 | 18 | 50 | OL or ML |
| MS LS2-1.5m | 1.5 | 10 | 9 | CL |
| MS LS2-3.0m | 3.0 | 12 | 11 | OL or ML |
| MS LS3-1.5m | 1.5 | 10 | 12 | CL |
| MS LS 3-3.0m | 3.0 | 36 | 15 | CL |
| MS LS 4-1.5m | 1.5 | 12 | 18 | CL |
| MS LS 4-3.0m | 3.0 | 50 | 9 | OL or ML |
| MS LS 5-1.5m | 1.5 | 8 | 31 | OL or ML |
| MS LS 5-3.0m | 3.0 | 15 | 32 | CL |
| MS LS 6-1.5m | 1.5 | 13 | 33 | OL or ML |
| MS LS 6-3.0m | 3.0 | 10 | 50 | OL or ML |
| MS LS 7-1.5m | 1.5 | 30 | 50 | OL or ML |
| MS LS 7-3.0m | 3.0 | 23 | 30 | Could not be classified |
| MS LS 8-1.5m | 1.5 | 10 | 15 | CL |
| MS LS 8-3.0m | 3.0 | 14 | 6 | CL |
| MS LS 9-1.5m | 1.5 | 18 | 14 | CL |
| MS LS 9-3.0m | 3.0 | 11 | 7 | OL or ML |
| MS LS 10-1.5m | 1.5 | 11 | 14 | OL or ML |
| MS LS 10-3.0m | 3.0 | 20 | 7 | OL or ML |

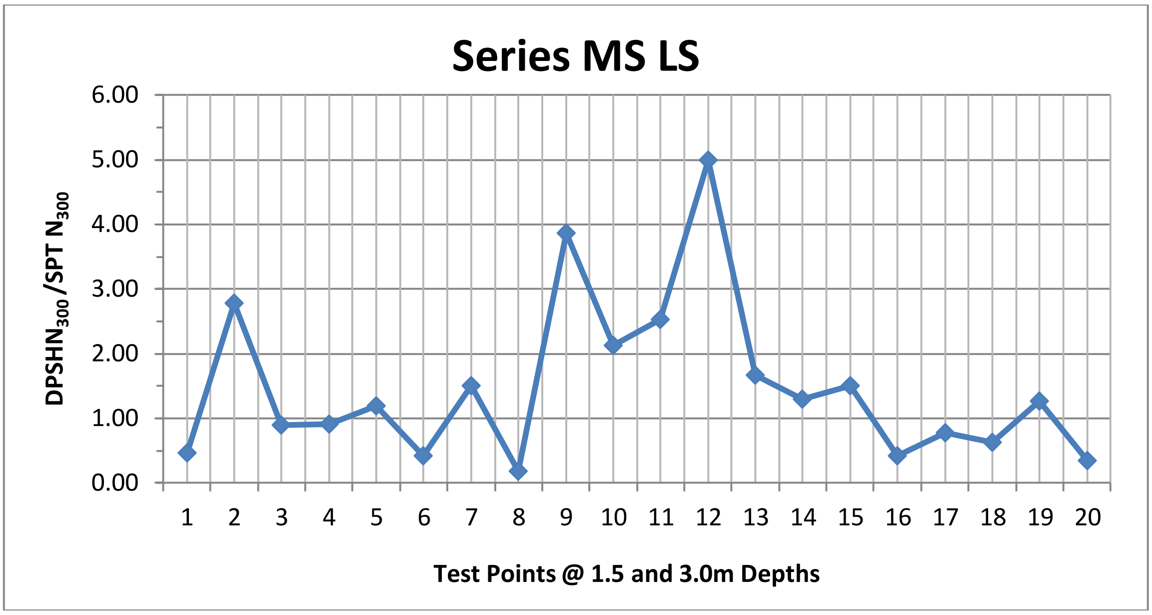


Figure 6c: Ratio DPSHN$_{300}$/ SPTN$_{300}$ for series MS LS

For series MTC LS, higher ratios of about 2.0 were recorded at 1.5m depth and lower ones, of about 1.5 at 3.0m. The ratios averaged about 1.25. In general lower strength material, in form of a schist was found at about 3.0m depth.

Table 6d: MTC Series

| S/N | Depth (m) | SPTN$_{300}$ | DPSHN$_{300}$ | Soil Description |
|---|---|---|---|---|
| MTC LS1-1.5m | 1.5 | 19 | 24 | CL- Inorganic Sandy-Clays of Medium plasticity |
| MTC LS1-3.0m | 3.0 | 16 | 5 | Could not be classified |
| MTC LS2-1.5m | 1.5 | 12 | 6 | CL- Inorganic Sandy-Clays of Low plasticity |
| MTC LS2-3.0m | 3.0 | 16 | 27 | Could not be classified |
| MTC LS3-1.5m | 1.5 | 23 | 45 | OL or ML Inorganic or Organic Silty-Clays of Low plasticity |
| MTC LS3-3.0m | 3.0 | 18 | 38 | Could not be classified |
| MTC LS4-1.5m | 1.5 | 13 | 25 | CL- Inorganic Sandy-Clays of Low plasticity |
| MTC LS4-3.0m | 3.0 | 26 | 25 | Could not be classified |
| MTC LS5-1.5m | 1.5 | 19 | 16 | CL- Inorganic Sandy-Clays of Low plasticity |
| MTC LS5-3.0m | 3.0 | 12 | 3 | Could not be classified |
| MTC LS6-1.5m | 1.5 | 10 | 26 | OL or ML Inorganic or Organic Silty-Clays of Low plasticity |
| MTC LS6-3.0m | 3.0 | 19 | 7 | Could not be classified |
| MTC LS7-1.5m | 1.5 | 19 | 44 | OL or ML Inorganic or Organic Silty-Clays of Low plasticity |
| MTC LS7-3.0m | 3.0 | 34 | 6 | Could not be classified |
| MTC LS8-1.5m | 1.5 | 26 | 26 | CL- Inorganic Sandy-Clays of Medium plasticity |
| MTC LS8-3.0m | 3.0 | 50 | 60 | Could not be classified |

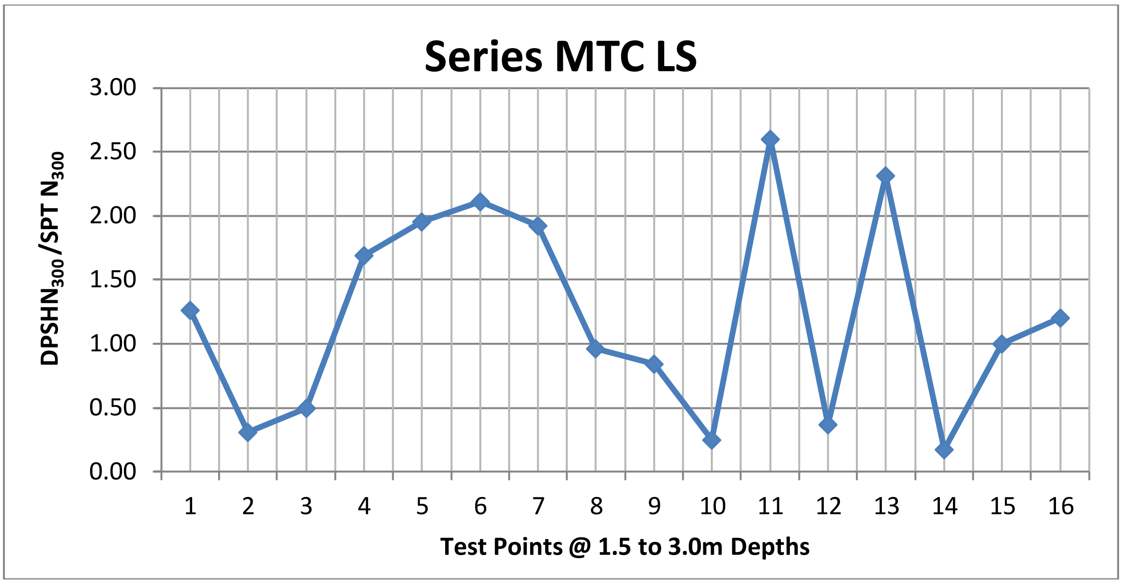


Figure 6d: Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series MTC LS

Table 6e and Figure 6e show the characteristics for series PYB LS. Rock was encountered at penetration points 1 and 5, hence the high penetration values indicating refusal at these points. The ratio generally averaged about 1.0 at this site.

Table 6e: PYB LS Series

| **S/N** | **Depth (m)** | **$SPTN_{300}$** | **$DPSHN_{300}$** | **Soil Description** |
|---|---|---|---|---|
| PYB1-1.0m | 1.0 | 55 | 55 | Gravelly sandy-clay of Low Plasticity |
| PYB2-2.0m | 2.0 | 19 | 11 | Gravelly sandy-clay of Low Plasticity |
| PYB3-2.0m | 2.0 | 14 | 7 | Gravelly sandy-clay of Low Plasticity |
| PYB4-2.0m | 2.0 | 14 | 50 | Gravelly sandy-clay of Low Plasticity |
| PYB5-1.5m | 1.5 | 55 | 55 | Gravelly sandy-clay of Low Plasticity |

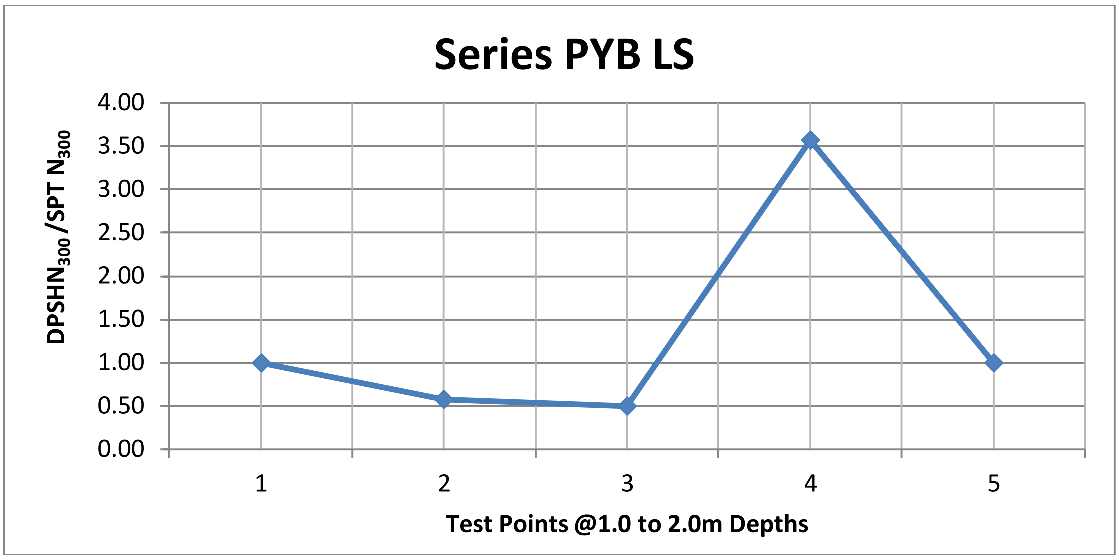


Figure 6e: Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series PYB LS

Table 6f and Figure 6f show the characteristics of series UM LS in Nampundwe, Lusaka Province. Figure 6f shows a general variation of 0.7 to 1.5, averaging about 1.0 at depths of 1.5m to 3.0m.

Table 6f: Series UM LS Series

| S/N | Depth (m) | $SPTN_{300}$ | $DPSHN_{300}$ | Soil Description |
|---|---|---|---|---|
| UM LS1-2.0m | 2.00 | 19 | 13 | SC- Clayey-Sands of Medium plasticity |
| UM LS2-2.0m | 2.00 | 18 | 18 | SC- Clayey-Sands of Medium plasticity |
| UM LS3-2.0m | 2.00 | 16 | 14 | SC- Clayey-Sands of Medium plasticity |
| UM LS4-2.0m | 2.00 | 18 | 14 | SC- Clayey-Sands of Medium plasticity |
| UM LS5-1.5m | 1.50 | 17 | 19 | SC- Clayey-Sands of Medium plasticity |
| UM LS6-1.5m | 3.00 | 15 | 14 | SC- Clayey-Sands of Medium plasticity |
| UM LS6-3.0m | 1.50 | 15 | 24 | SC- Clayey-Sands of Medium plasticity |
| UM LS6-3.0m | 3.00 | 16 | 20 | SC- Clayey-Sands of Medium plasticity |
| UM LS7-1.5m | 1.50 | 30 | 27 | SC- Clayey-Sands of Medium plasticity |
| UM LS7-3.0m | 3.00 | 32 | 50 | SC- Clayey-Sands of Medium plasticity |
| UM LS8-2.0m | 2.00 | 21 | 17 | SC- Clayey-Sands of Medium plasticity |

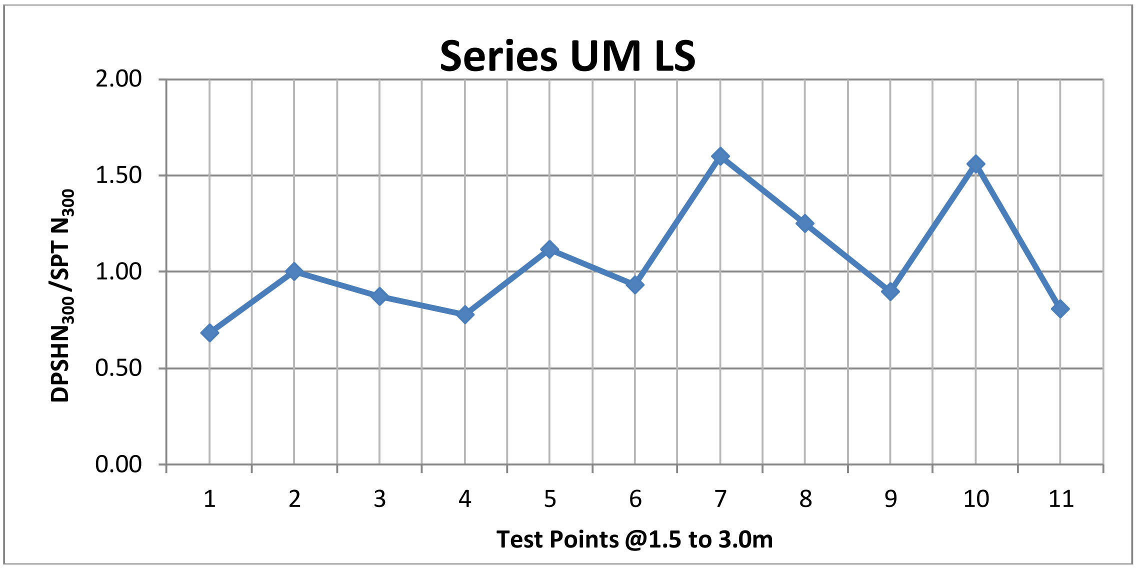


Figure 6f: Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series UM LS

Table 7 and Figure 7 show the characteristics for series NP ND in Ndola on the Copperbelt Province. The ratio averaged about 1.75 for depths of 1.0 to 2.0m.

Table 7: Series NP ND

| **S/N** | **Depth (m)** | **$SPTN_{300}$** | **$DPSHN_{300}$** | **Soil Description** |
|---|---|---|---|---|
| NP ND1-1.0 | 1.0 | 11 | 29 | ML-Silty-Clays of Medium Plasticity |
| NP ND1-2.0 | 2.0 | 31 | 52 | CH-Inorganic Silty-Clays of Medium Plasticity |
| NP ND2-1.0 | 1.0 | 13 | 12 | CH-Inorganic Silty-Clays of Medium Plasticity |
| NP ND2-2.0 | 2.0 | 19 | 26 | ML-Silty-Clays of Medium Plasticity |

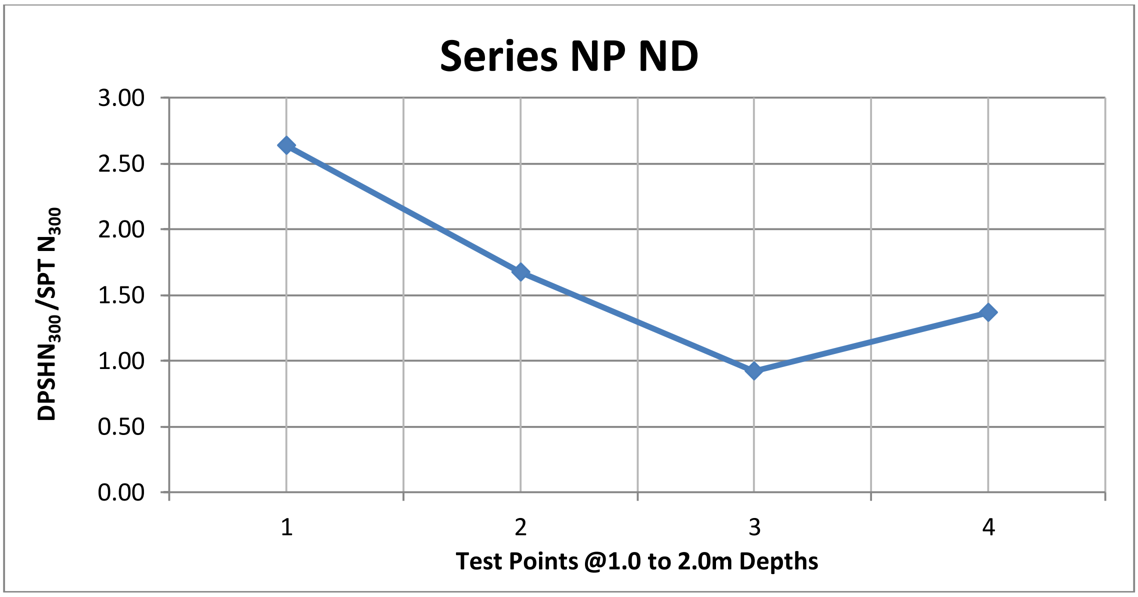


Figure 7: Ratio $DPSHN_{300}$/ $SPTN_{300}$ for series NP ND

## Discussion

For the sandy terrain of Livingstone, it can generally be seen that the penetration ratios varied from as low as 0.5 to about 1.50, averaging about 1.0. For the gravelly Lusaka soils, higher penetration ratios were recorded for finer material, but the penetration ratios generally ranged from 1.0 to 1.5. For the more cohesive site in Ndola, the ratios ranged from 1.0 to 2.5. It is observed that there is a general increase in the ratio $DPSH_{300}/SPT_{300}$ with depth, for depths of 1.0 to 3.0m. The ratios are greater for cohesive materials, resulting from increased lateral pressure on the driving rods for the DPSH test, as has been indicated by other authors.

From above, a minimum penetration ratio of 1.0 for both coarse grained and cohesive soils, and maximum values of 1.33 and 2.0, respectively, for coarse grained and cohesive soils are being recommended, in Equations 5 and 6. The ratios are a function of depth, a major parameter for lateral pressure on the driving pipes. The range of application is up to 3.0m depth.

$DPSHN_{300}/\ SPTN_{300} = 1.0 + (\text{Depth}/3.0^2)$ (Coarse Grained Material) Equation 5

$DPSHN_{300}/\ SPTN_{300} = 1.0 + (\text{Depth}/3.0)$ (Cohesive Material) Equation 6

The results based on this formula are within the proposals made by other authors (Table 3).

## Conclusion and Recommendations

It has been demonstrated that there is general increase in the ratio $DPSHN_{300}/\ SPTN_{300}$ with depth, for depths range 1.0 to 3.0m, resulting from increased friction on the driving rods for the DPSH, which is significant in the case of the SPT. The ratios are greater for cohesive materials. The proposed correlation factors range from 1.00 to maximum values of 1.33 and 2.00 for coarser and cohesive materials, respectively. These factors compare well with factors suggested by other researchers. The derived SPT $N_{300}$ values from DPSH300 have to be subjected to various correction factors, to obtain the required mechanical properties.

It is being recommended that further research be conducted, taking into account energy dissipation and lateral pressure effects on driving rods, for various types of soils, and at deeper penetrations in Zambia, to arrive at more standard correlation factors.

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# Construction Accidents in Zambia: Causes and Remedial Measures

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## Abstract

*As Zambia develops its infrastructure such as roads, hospitals and schools among others, incidences of on-site accidents detrimental to workers, projects and the nation are likely to increase. Despite the use of the Factories Act 1994 and company safety and health regulations, accidents are still prevalent in the construction industry as evidenced in the media reports.Construction accidents have devastating effects on the labour force and the entire industry.Reported and other unreported accidents could be prevented or their effects mitigated. This research attempts to highlight types, causes and preventive measures of construction accidents in Zambia.*

*Interviews were conducted prior to a questionnaire survey. Three sites were used for the purpose of triangulation and verification of interview and questionnaire results. Interviewees and respondents to the questionnaires were construction stakeholders who included clients, consultants, contractors, and government organisations. The population size was 90 respondents from 50 companies. Contractors were sampled from 3,887 companies registered by National Council for Construction in 2012. Some organisations were purposively sampled because of their direct link with the construction industry.*

*The results showed that falling from a height, hit by falling objects and the collapse of earth were the most common types of accidents. Causes of accidents were identified to result from poor attitude to safety, not providing safety equipment, deficient enforcement of safety and health regulations, lack of safety training, and inclement weather. Common effects of accidents identified included unnecessary costs, disabilities, reduced production, reduced productivity, job schedule delays, and fatalities.*

*Preventive measures to causes of identified construction accidents included improved attitude to safety and health by all stakeholders, enhanced enforcement of the Factories Act, inclusion of safety and health as an item in all Bills of Quantities, provision of adequate personal protective equipment, training of project teams in Occupational Safety and Health, and the introduction of Occupational Safety and Health subjects in curricula of universities and colleges for students pursuing construction related qualifications.*

*All construction stakeholders have to be fully participate in issues of safety and health if construction accidents have to be prevented and their effects mitigated.*

***Keywords:*** *Accidents, Construction, Safety, Zambia*

## Introduction

The construction industry involves many other types of work aside from the building process, such as painting, landscaping, electrical, supply, telecommunications, plastering and paving (Alazab, 2004). According to the United Nations Environment Programme (UNEP, 2003), developing countries account for 23 per cent of global construction activities. The UNEP, 2003 also noted that the construction industry in poorer countries is more labour intensive.In Zambia, like in other developing countries, construction is not only labor intensive but workers are also unskilled, migrate within and emigrate outside the country.Construction has been observed to be an industry with a high rate of occupational accidents and use of multiple contractors and sub-contractors on single sites is the rule (ILO, 2011).The industry has also been said to be dirty and involves difficult work. The work is often dangerous and present safety hazards which if not managed and prevented may maim, injure or make workers sick (Tam *et al.*, 2004).

The construction work site and its environment changes daily, making safety and health management in the construction sector difficult (Muya *et al.,* 2008). Some accidents that occur in the construction industry involve contact with moving machinery or materials, being struck by moving, flying or falling objects, being hit by a moving vehicle,being struck against fixed or stationary objects, injuries resulting from handling, lifting or carrying objects, slips, trips and falls on the same level, falls from a height, being trapped by collapsing earth, being drowned or asphyxiated, exposure to, or in contact, with harmful substances, exposure to fire, exposure to explosions or contact with electricity or electrical discharges (Hughes and Ferrett, 2007).

Studies by Health and Safety Executive (HSE, 2006) and Mukhalipi (2004) suggest that in most cases, accidents are due to decisions by management and failure by supervisors to follow laid down safety procedures. The root causes of accidents include: lack of proper training; deficient enforcement of safety and lack of safety equipment; unsafe methods or sequencing; unsafe site conditions; not using provided safety equipment and poor attitude towards safety (Arbolela *et al.*, 2004). According to Gibb *et al* (2001) the causes of accidents include: unsafe working conditions at height; stepping on, striking against or tripping over objects; poor lighting; collapse of earth during excavations; collapse of scaffolding and working platforms; hazards in lifting operations; electrocution; fire hazards; lack of proper access and inadequate education and training. Lack of knowledge and information could also lead to accidents as employees may not necessarily be aware of the risks they face (Antonson, 1997: Gardener *et al.*, 1999).

Contractors mostly focus on achieving objectives such as meeting the production schedule, cost targets and quality requirement before considering safety (Tam *et al*, 2001). It is quite common for employers to blame the “feckless" victims for the accidents that kill or injure them at work. However, it is the project's management who push for the speed of work to be tripled (Snalshall, 1990).Workers are forced to do short cuts or unsafe practices which often become norms (Wright, 1986). Unfortunately, these unsafe practices allow workers to complete the work much more quickly (Slappender *et al.*, 1993).Asking workers to do more than they can handle may result in them developing high stress levels, especially when deadline pressures are put on them. Supervisors' pressure may cause subordinates to work unsafely while trying to satisfy objectives, such as completing the work within unreasonable time schedule (Slappender *et al.*, 1993).

Employees’ poor Occupational Safety and Health (OSH) behavior is common in Small Scale Enterprises (SSEs) where workers are left to be responsible for their own workplace safety and health (Aksom and Hadikusumo, 2007: Holmes *et al.,*1997 and akin, 1992).Additionally, poor behavior of individual employee could often be the primary cause of accidents (O Toole, 2002). Poor behavior and attitude have been attributed to most workers not putting on their Personal Protective Equipment (PPE) while working on site (Dedobbeler and Beland, 1991). Furthermore, stress at work may cause strain and affect the capacity to cope with risk (Rundmo and Hale, 2003). Atmospheric conditions such as working in the cold if there is lack of regular warmth, make hands numb and fumble, and also the mind is less alert than usual (Silavwe, 1995). Factors that contribute to accidents include: severe weather; hazardous substances used or generated during construction; site conditions; unsafe practices; inadequate training; poor supervision and monitoring; lack of safety and health facilities; and human errors (Anumba and Bishop, 1997).

Poor safety and health does not only hurt workers but also the companies that hire them and the community where they originate from (Arbolela *et al.*, 2004). OSH incidences are often fatal to individuals, cost organisations and national economies through compensation to affected employees, damage equipment and materials or facilities, and disrupt production processes (Muya *et al.*, 2008).Injuries, accidents and work related illnesses reported on construction sites contribute to additional costs and delays on projects (Elbeltagi and Hegazy, 2001). There is a high cost associated with work-related injuries, including workers' compensation via insurance claims, indirect costs of injuries and increased liability suits. Other significant impacts of site accidents are interrupted construction schedules, impairment of firms and psychological burden on workers (Levitt *et al.*, 1993).

Priority must be given to measures that eliminate or reduce the hazard at source and provide collective protection (EASHW, 2003).A risk assessment of hazards to which workers are exposed is vital as control for prevention. The risk assessment reveals three requirements: risks identification; evaluation of the risks; and controlling of risks associated with a particular workplace (Ligard and Rewlinson, 2005).Employers have to provide, without charge, PPE which workers are required to use without fail. Moreover, construction sites, at all times have to be kept free from accumulation of waste materials or rubbish caused by operations throughout the construction period to permit safe and convenient access (University of Michigan, 2010). Additionally, more safety training and inspections have to be conducted (Kitumbo and Kirenga, 2001).

To abate causes and effects of construction related occupation safety and health problems, many countries have National Occupational Safety and Health (NOSH) policies, construction specific laws and regulations. Zambia, however, has no NOSH policy (ILO, 2012). The construction industry uses the Safety and Health Regulations in the Factories Act Cap 441 of the Laws of Zambia. The Ministry of Labour and Social Security, through the Occupational Safety and Health Services (MLSS-OSHS) is responsible for enforcing the Factories Act at places of work. The basic requirements of the Factories Act include: a clean working environment; safety clothing; head gear and footwear; adequate ventilation; prevention of overcrowding; availability of first aid; sufficient lighting; availability of sanitary facilities; basic training on safety and health; and presence of fire extinguishers and hydrants (Jere, 2011). However, contractors are allowed to have company safety and health regulations provided they are better than provisions of the Factories Act. In 2010, the Occupational Health and Safety Act (OHSA) was enacted but is not in use because it is regarded as not comprehensive by construction stakeholders. Many stakeholders were left out in its drafting and development process. It was done by stakeholders in the Ministry of Health and emphasised more on health.

Despite the implementation of safety strategies, occupational accidents and incidents have been on the increase in developing countries and have unpleasant consequences (Song *et al*, 2011). In Zambia, regardless of the use of the provisions of the Factories Act and the company safety and health regulations, accidents are still prevalent in the construction industry. The construction industry recorded 487 accidents of which 58 were fatal, 281 resulted in permanent disability and 148 were temporally disability between 2003 and 2007 (ILO, 2011). Some of the media reported accidents recorded during the study period (2010 – 2013) are listed in Table 1. The print media was quoted because there were no official construction accident reports.

**Table 1: Media Reported Accidents - Causes and Effects**

| **S/N** | **Site and Media Institution** | **Type** | **Causes** | **Effects** |
|---|---|---|---|---|
| 1. | Nkana Mall-Kitwe (Times of Zambia, 06/05/ 2013) | Collapse of earth | Unsafe site and unsafe methods | One open depressed skull fracture and brain coma and the other leg injuries, work suspended |
| 2. | Ibex Hill Lusaka (Lusaka Times, 29/10/2012) | Collapse of earth | Poor attitude to safety, safety equipment not provided, deficient enforcement of safety, lack of safety training and unsafe methods | Five deaths, unnecessary costs - funeral costs and compensation |
| 3. | Kafue Steel Plant (The Post, 01/01/ 2012) | Explosion of Oxygen cylinder | Poor attitude to safety, deficient enforcement of safety, lack of safety training | Ten injured, One leg amputated, unnecessary cost in damage |
| 4. | Konkola Copper Mines (Chingola) civil works (The Post, 27/03/ 2011) | Collapse of earth | Poor attitude to safety, unsafe methods | Four deaths, unnecessary cost-funeral cost and compensation, disruption of production, poor corporate image for the sub- contractor |
| 5. | Kitwe (The Post, 24/02/2011) | Hit by falling object (piece of metal, pierced the neck | Poor attitude to safety, safety equipment not provided, deficient enforcement of safety | One death, disruption of production |
| 6. | Manda Hill - Lusaka (The Post, 27/03/ 2010) | Hit by falling object (pile of glasses carried on wheelbarrow) | Poor altitude to safety, safety equipment not provided, deficient enforcement of safety | One life was lost (death), temporary closure of site (disruption of production and job schedule delays) |

As Zambia moves from low to a middle income country, there is an increase in construction projects aimed at modernising both new and existing infrastructure. The construction industry equally is becoming more mechanised with latest machinery unfamiliar to untrained workers. Client expectations for faster construction, prioritizing completion dates and not worker's safety seem to be the trend. These factors are likely to bring about an increase in incidences of on-site accidents as well as ill-health detrimental to workers, projects and the nation as a whole. The aim of this paper is to present results of the study that investigated construction accidents experienced in Zambia**.**

## Materials and Methods

The study was conducted in five provinces of Zambia where construction projects were concentrated during the study period. The provinces sampled were Lusaka, Copperbelt, Northern, Western and North Western provinces. The provinces were chosen because construction activities were concentrated there during the study period. Most of the companies sampled had projects in other provinces in the country and thus were national in character. Primary data was collected through interviews and a questionnaire survey. Interviews were carried out prior to the administration of questionnaires. Fifteen individuals were targeted during interviews. Only 12 were interviewed as the other two were absent during the time of appointment. The interviews were used as a pilot for the study.The questions in the questionnaire were driven from the structured interviews. To improve the quality and reliability of the questionnaires, pre-tests were done to detect any interpretation difficulties. The pre-tests were carried out with seven respondents. The results of the pre-tests were used to re-phrase questions that were not clear to respondents.

The study focused its findings on the experience of respondents and used three construction sites as case studies for triangulation. The respondents' experiences were used because there were no safety or accident reports in sampled companies and sites. The questions in the questionnaires addressed: gender; age; position in the company; years of experience; class of construction of the company such as clientele, consultancy; safety policies used in the company or at their sites; whether a company had a safety officer or not; whether or not respondents were familiar with the Factories Act; provision of PPE; and type, causes and effects of accidents experienced/witnessed. The total number of questionnaires were ninety of which 80 were distributed by hand and 10 were sent by e-mail. Completed and returned questionnaires were 78 giving a response rate of 87%.

The targeted construction stakeholders included: contractors; construction industry consultants; public safety and health inspectors from the MLSS-OSHS; National Council for Construction (NCC); Workers Compensation Fund Control Board (WCFCB); and government organisations such as the Road Development Agency (RDA) and Ministry of Works and Supply- Buildings Department (MWSBD).

The primary data was collected through interviews and questionnaire survey. The semi-structured questions were used in the interviews and questionnaire survey. The targeted respondents were stakeholders in the construction industry. The population was selected from the companies registered with NCC in 2012. The total number of companies which registered was 3,887 (NCC, 2012). The companies were stratified in their respective grades and towns of operation then randomly selected.

Consultants and clients were purposely sampled because they were linked to projects which were undertaken by the contractors selected for the study. The public safety and health inspectors from the MLSS-OSHS; NCC; Workers Compensation Fund Control Board (WCFCB); The Road Development Agency (RDA) and Ministry of Works and Supply (MWS) were purposely sampled because they worked directly with contractors. The targeted population was 90 out of which only 79 responded. Both interviews and questionnaires addressed participants' experiences of accidents and their views on the status of safety in the construction industry in Zambia. Three construction sites: a road; a bridge; and an office block construction in Senanga in Western Province, Solwezi in North Western Province and Kasama in Northern Province respectively were purposively selected as case studies. The case study sites served the purpose of triangulation and verification of interview and questionnaire survey results. Non-quantifiable data was analysed qualitatively from themes that emerged. Quantifiable data was analysed using excel spread sheets.

## Results

The interviews were conducted in February 2012 and were used in the preparation of questionnaires. The questionnaire survey was undertaken between March and June, 2012. Respondents who took part in the questionnaire survey were 78 out of 90 giving a response rate of 87%.Construction stakeholders who participated in the questionnaire survey are illustrated in Figure 1. For the purpose of this study, contractors were classified according to their specialisation, whether in roads, building or both. The class of ‘Others’ comprised of NCC and MLSS-OSHS as regulators in the industry.

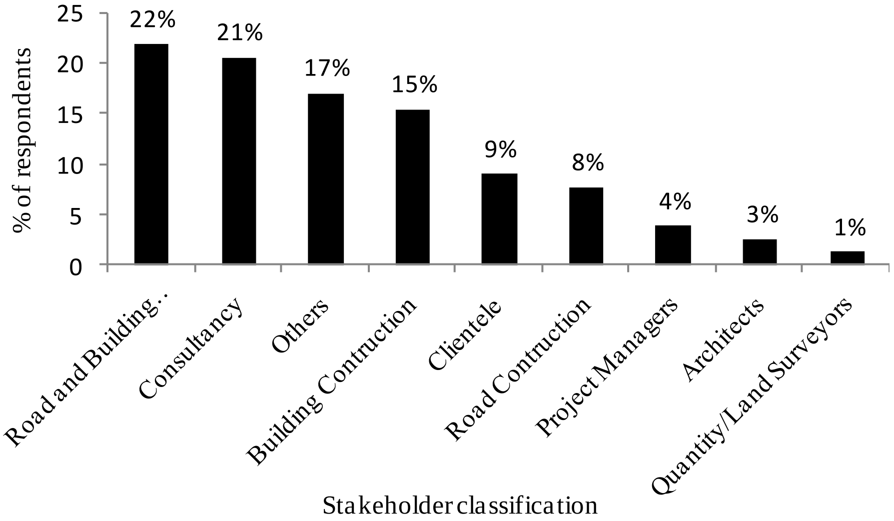

**Figure 1: Stakeholder classifications of respondents**

Figure 2 shows the job description of respondents to the questionnaire survey.The majority of the respondents were directors and the minority were architects.

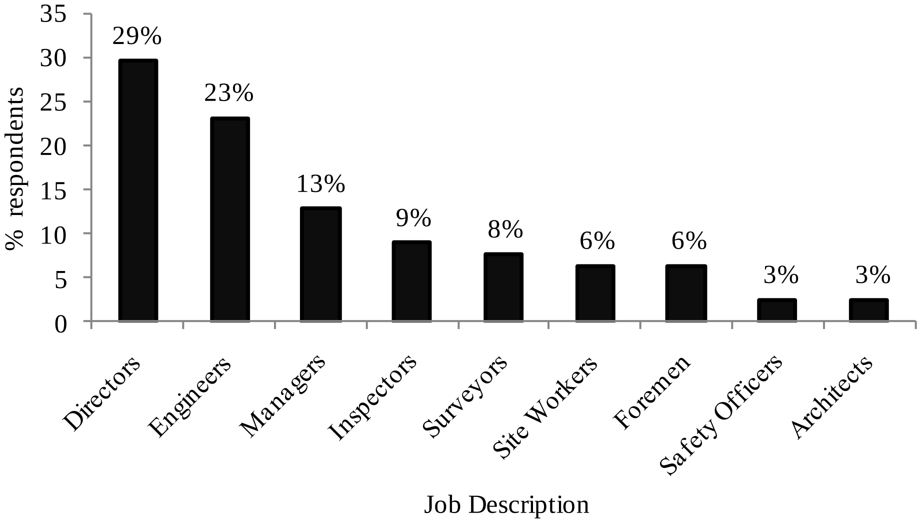

**Figure 2: Job description of respondents**

Respondents had various years of experience in the construction industry as presented in

Figure 3.

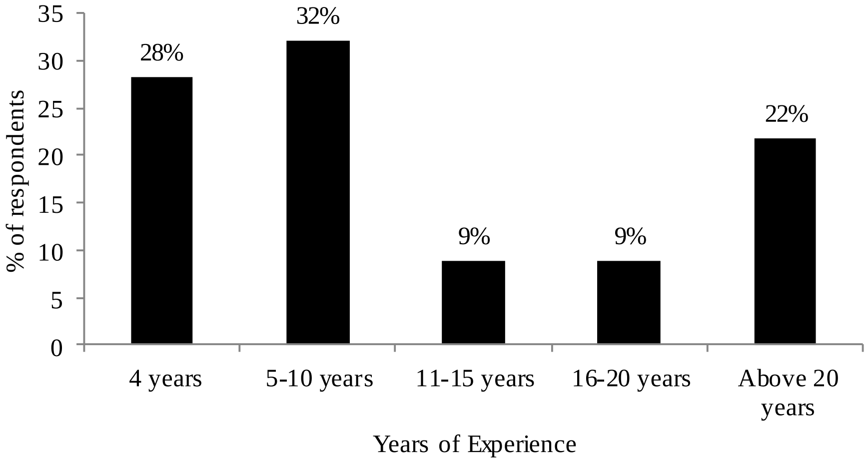

**Figure 3: Respondent's years of experience in construction**

The majority of respondents identified falling from heights as the main accident experienced on site as shown in Figure 4.

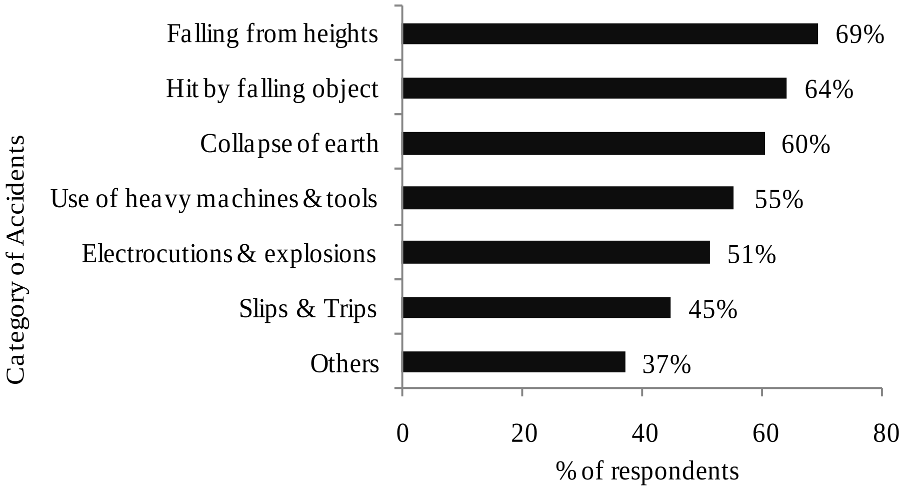

**Figure 4: Category of accidents experienced on sites**

Based on the questionnaire survey findings, the common causes of accidents in construction are presented in Figure 5. All the causes were qualified to be common as the percentage occurrence was above 45. The figure details the frequency of the causes every timeaccidents were analysed after an incident. The most common cause was poor attitude to safety and the least common was stress.

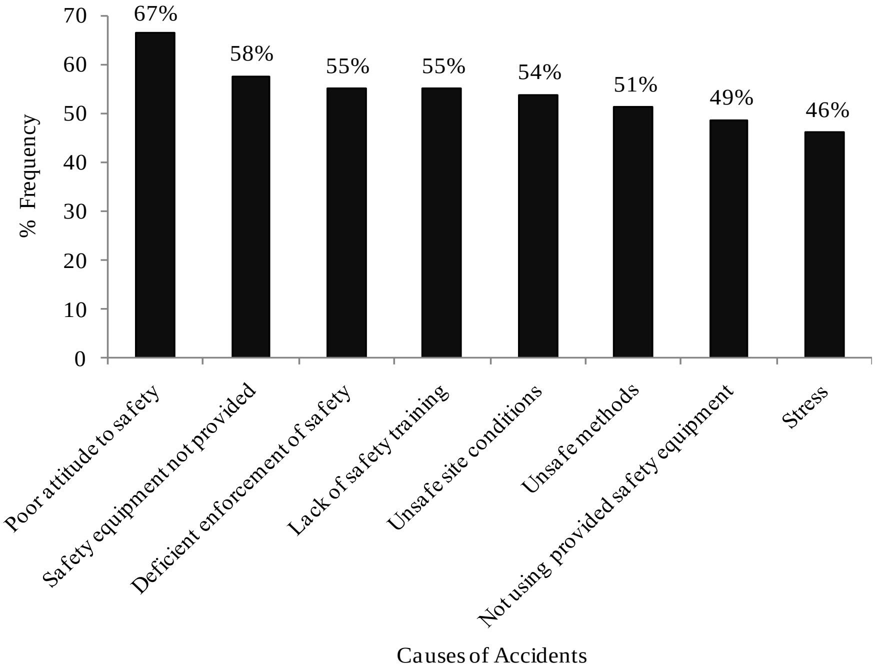

**Figure 5: Common causes of accident**

Figure 6 presents the results on the status of PPE on construction sites. The results are according to the respondents' views and experiences.

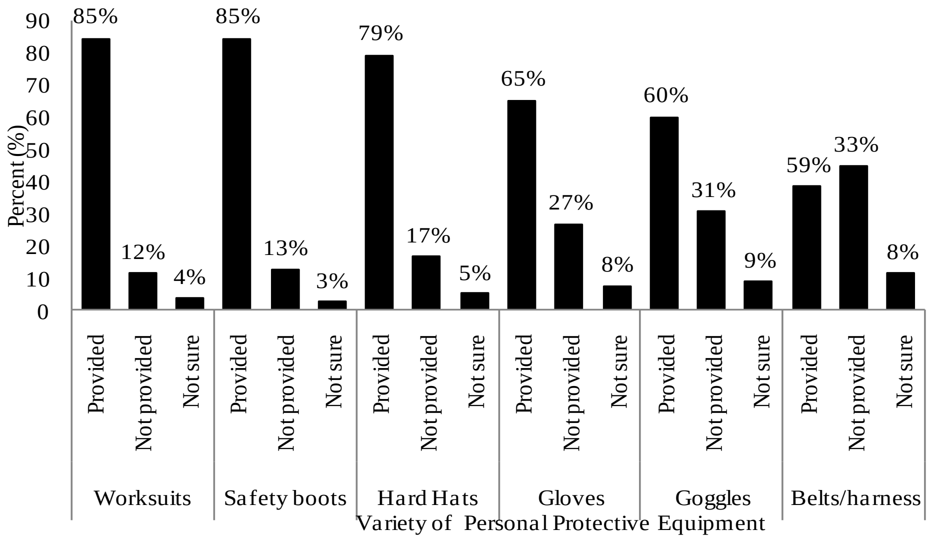

**Figure 6: Personal Protective Equipment on sites**

Most of the respondentsto the questionnaire survey indicated that accidents were prominent in the rainy season as illustrated in Figure 7. Zambia has three seasons namely: cool and dry (May to August); hot and dry (September to November); and warm and wet (December to April). In this study, the seasons were summarised as cold, hot and rainy seasons to simplify the questionsfor easier understanding by participants. Floods and slippery grounds makes the conditions unsafe for construction. Visibility is also challenging during the rainy season. There was a lot of 'down time' due to the rains which made workers to slack off when restarting work making them prone to accidents.

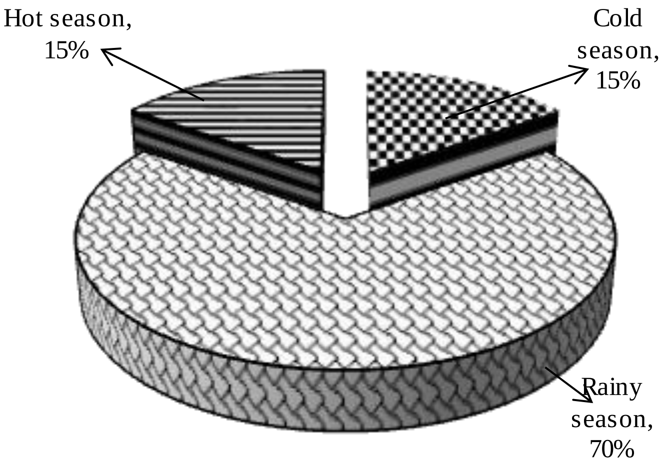

**Figure 7:** Incidence of accident and ill health by season

The effects of accidents were as shown in Figure 8. The most cited effect of accidents was unnecessary costs. In the 'Other' category, there were effects such as poverty and depression of victims or family members.

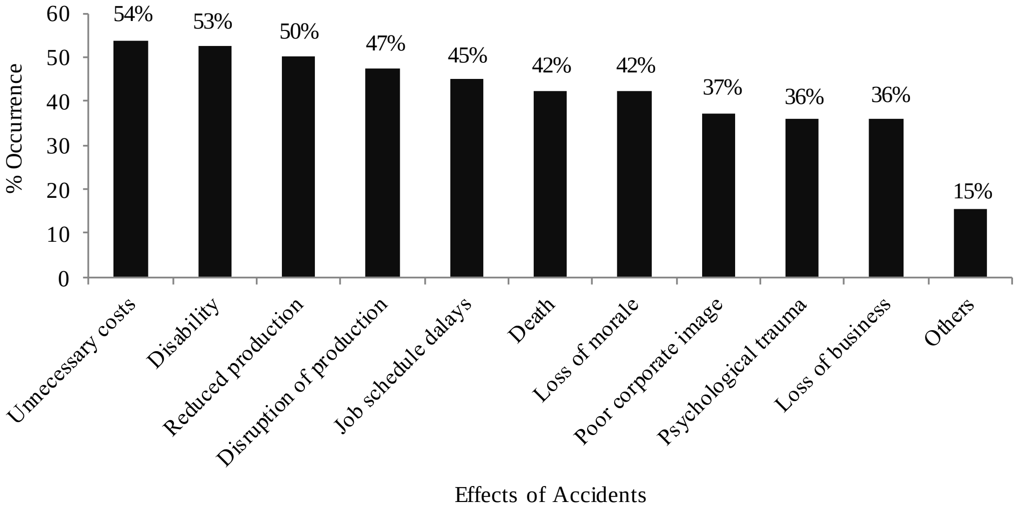

**Figure 8: Effects of accidents**

## Discussion of results

Respondents were 90% males and 10% females. The reason for few female participantscould be attributed to a small number of females in the industry who are taking up 'maledominated'careers such as engineering in Zambia and may be the case in Africa.In South Africa, women represent 8% of the building and construction management profile in the formal sector (CIDB, 2004).

Falling from height was the most common type of accident.The reasons could have been lack of safety harness and adequate safe scaffolds which were rarely provided or even absent on some sites. There was no safety harness on the visited sites. This is similar to the findings of (Larsson and Field, 2002). Hit by falling objects was second to falling from height followed by collapse of earth.Hit by falling object cause could have been due to unsafe methods which were preferred by some workers and considered to be faster. Collapse of earth was common in the rainy season because of wet soils and in places where the groundwasunstable.Furthermore, it was associated with unsafe methods of excavating and the use of unsafe or substandard ladders.

Poor attitude to safety by stakeholders in the industry was established as the most common cause of accidents.This could be linked towhy the NOSH policy and the construction tailor-made safety and health regulationswere not established. Respondents suggestedthat safety and health was not a priority to some contractors and the workers. Some contractors concentrated on achieving work targets regardless of how it was done. Most casual workers used ‘short cuts’ which were usuallyunsafe, tocomplete theirwork while ignoring safety. This is similar to findings of the studies by Tam, *et al.* (2001) and Mukhalipi (2004). Poor attitude to safety led to other causes such as not providing safety equipment, deficient enforcement of safety and lack of training.

Causes of accidents such aslack of safety equipment, deficient enforcement of safety and lack of safety training, seemed to be the responsibility of the contractors. Some contractors did not provide safety training and equipment hence putting workers at a high risk of accidents.Results revealed that despite some contractors providing PPE, it was not adequate.Manyworkers had the basic PPE which included:work suits;safety boots or gumboots;and hard hats.Safety belts, dust masks and ear plugs were rarely provided as they were considered as unnecessary expense. Some contactors alleged that workers were in the habit of losing the few ‘rare PPE’ that was provided. However, the ‘rare PPE’was provided byfew well established contractors who prioritized safety and health and appreciatedits benefits.

Deficient enforcement of safety was observed during the case study as somesupervisors and workers were not aware of the Factories Act or any other safety and health regulation.Those who had the knowledge of the Factories Act 1994 argued that it was general and descriptivein nature.They suggested that the Factories Act 1994 should be replaced by use of the NOSH policy andaconstruction tailor made OSH legislation.The NOSH policy would be an umbrella for all industries. Moreover, deficient enforcement could be attributed to the shortage of OSH inspectors in charge of the construction sector. The MLSS-OSHS construction inspectorate at the time of the study comprised of three inspectors. The inspectors were overwhelmed by the increase in the construction projects hence did not manage to inspect all project sites.

Clients were less involved in safety issues on many projects; they were more concerned with quality and the project completion time. Similarly, consultants were less interested in safety and health so long as the contractor was on schedule and works were of good quality.Large and medium contractors adhered more to safety and health than small scale contractors because they had resources and safety and health was one of their priorities. Furthermore, Large and medium contractors had qualified human resource in charge of safety and health such as safety managers and safety officers. Moreover, large and medium contractors cared about their reputation and corporate image.The few small scale contractors, who adhered to safety and health, were subcontractors. It was a contractual requirement by the main contractors. In addition, their managers or supervisors had worked for large and medium scale contractors. None of the small scale contractors sampled, had qualified safety personnel. This confirms the findings of (Champoux and Brun, 2003). Respondents suggested that small scale contractors were financially fragile and this was comparable to Antonson (1997) and Lammn *et al* (1997). Some of the reasons for non-adherence of small scale contractors were: poor management; maximization of profit; and that safety and health was expensive. Furthermore, some respondents attributed poor adherence and enforcement to the absence of safety and health as an item in the Bills of Quantities (BOQ). They argued that if safety and health was included in the BOQ as an item, adherence and enforcement would improve. Theycited the improvement of HIV/AIDS programmes on all construction projects which was an item in the BOQ.

The fourth cause of accidents was inclement weather. According to respondents, the rainy season recorded more accidents than cold and hot seasons. The respondents attributed more accidents in the rainy season to wet and slippery grounds and visibility challenges, making the season unsafe for construction works. In addition, there are more work stoppages because of the rains. To beat the work targets; workers are likely to use unsafe methods in the rainy season.

The last three causes: unsafe methods, not using provided safety equipment and stress were associated with the workers. Unsafe methods included the use of sub-standard scaffolds and excavating deep trenches without a ladder. Some contractors provided PPE but some workers did not use it especially the safety belts, hardhats and gum boots thatthey made them uncomfortable as suggested by Dedobbeler and Beland (1991). The respondents revealed that some workers hoped to work over time to get incentives. This encouraged stress which made them less vigilant to accidents as was in the case of Rundmo and Hale (2003) and Fellows *et al* (2002).

Unnecessary cost was the mostcommon effect because every time an accident occurred, the end result attracted a cost. The cost was either in form of hospital bills, funeral expenses or loss of production. The well established companies, usually large and medium scale contractors, who were registered with WCFCB, were relieved of some costs like compensation when an accident resulted in a disability or fatality. Nevertheless, costs like hospital bills and funeral expenses were met by the contractors. Fatalities and disability led to other effects such as disruption of production when work activities were halted or temporary closure of sites for accident investigations. The co-workers to the victims lost morale and were psychologically traumatised which led to reduced production and job schedule delays. Contractors who recorded poor safety and health practices on their project sites, experienced poor corporate image and lost business when dealing with clients who prioritize safety for instance Lafarge Zambia and the mining companies.

Some effects were long term and extended to family members of victims of accidents. The long term effects were poverty and increase in the number of street kids. Most victims of accidents were breadwinners and their deaths or disabilities led to less or no income thus increasing poverty in their families. Lack of sponsorship towards their children's education and welfare eventually forced the children into the streets. The findings on the effects of accidents from the study were similar to Muya, *et al* (2008), Levitt, *et al* (1993) and Arbolela, *et al* (2004).The most predominant effect of accidents was unnecessary costs contrary to Tam *et al.* (2004). The difference could have been that Tam's study was conducted in a developed country while this study was done in Zambia which is a developing country.

Preventing occupational accidents is an important task of human resource management (Rahmani, 2013). Improved attitude to safety and health by all stakeholders and enhanced enforcement of the Factories Act 1994 would improve adherence. Improved adherence would result in accident prevention thereby protecting human resource. Since the Factories

Act was considered to be general and descriptive, establishment of NOSH policy and introduction of a straight forward construction tailor- made safety and health legislation would help in reinforcing the Factories Act 1994. In addition, inclusion of safety and health as a priced item in all BOQ would encourage safe and healthy practices such as provision of adequate PPE, enhanced enforcement, training of the project team in OSH and the use of safe methods in the industry. Furthermore, it would encourage clients and consultants to actively get involved in the matters of safety and health of construction projects. Another intervention would be to introduce OSH in the curricula of Universities and colleges for students pursuing construction related qualifications. This would help increase awareness of safety and health in Zambia. This empowerment, to some extent, would address the problem of lack of safety and health training. It would also encourage the actively consideration of safety and health at all stages in the project cycle where construction personnel are involved.

## Conclusion

Falling from heights, hit by falling objects and collapse of earth were the most common type of accidents cited in Zambia's construction industry. This was due to poor attitude to safety and health by stakeholders, not providing safety equipment, deficient enforcement of the Factories Act 1994 and inclement weather. Inclement weather is an 'Act of God', therefore, to mitigate accidents in the rainy season; there should be stoppage of work on the rainy days depending on the intensity of the rains. Resuming of works may only be allowed after assessing that the area is safe to work. Also, shoring up the excavations would mitigate collapse of earthaccidents especially in weak soils. The constructionaccidents led to effects such as unnecessary costs, disability, reduced and disruption of production, job schedule delays and death.

## Study Limitation

There were no accidents or near misses reports on construction sites and companies hence respondents' experience was used. The accident or near miss reports could have given the adequate information on the types, causes and effects of accidents. The absence of accident reports could have limited the study. More research is recommended to substantially mitigate effects of accidents by using accident reports and focusing on topics such as control measures of accident prevention. Moreover, project site teams should be targeted because they are on site all the time to witness near misses and accidents. In this research despite distributing questionnaires to the worksites, more managers responded to the questionnaires. This could have made responses biased.

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# The National Kaizen Deployment in Zambia: What is the Role for EIZ and the Engineer?

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## ABSTRACT

*KAIZEN, a Japanese word; "KAI" and "ZEN" translated to mean; "Change for Better" or "Continuous Improvement". The KAIZEN Concept is the secret behind improved Products' Quality from Japan and the economic expansion from 1950. Zambia has adopted KAIZEN as a philosophy to improve Quality and productivity. This is an awareness message to Engineering Professionals through the Engineering institution of Zambia (EIZ), on the National KAIZEN program. It is hoped that it will inspire Engineers' to know more and participation in the KAIZEN implementation in industry and indeed, at personal level.*

*In this paper, The KAIZEN concept shall be discussed from the Broad National policy view and narrow down to focus at individual level and why the Engineer is essential in the National implementation. The assumption is that, the KAIZEN Concept is not new to Engineers at all because it draws its principles from well-known Quality management principles and scientific management, which are part of the Engineering training programs and Business approaches in industry such as ISO certification processes. The Zambian Government with the support from Japanese Government through Japanese International Corporation Agency (JICA), established the KAIZEN Institute of Zambia (KIZ) in 2014 to promote Quality and Productivity improvement. KIZ embarked on a capacity building program and National awareness campaign. EIZ as a professional Institution is expected to play a role of a conduit for KIZ to reach out to Engineering units or organisations in industry and the practicing Engineers, to consider adopting KAIZEN in their work place (Gemba in Japanese) for Business Excellence.*

*It is strongly felt that the engagement of Engineers and Organisations through EIZ into KAIZEN implementation, will create national unique philosophical ownership and engender domestication of the concept, in each sector in Zambia. As EIZ conducts routine monitoring, a deliberate evaluation on Quality and Productivity improvement practices (KAIZEN) would provide essential impact for organisations customer satisfaction (business).*

*Is the engineering profession essential? In my own view, the Engineer is essential in the National KAIZEN implementation because almost all sectors require the input of an Engineer today: Agriculture, mining, Information and Communication, Construction, Transport, Medical etc. To improve the economy through KAIZEN principles, the Nation needs the full participation of the Engineering professions.*

***Keywords**:*

## INTRODUCTION

This paper discusses the strategies to introduce KAIZEN a Japanese philosophy and to bring in the establishment of the KAIZEN Institute of Zambia (KIZ). It briefly outlines the activities that have been under taken by the Zambian Government to address the cultural transformation.It identifies various Institutions that are engaged and those that are yet to be engaged. In this view, this paper points at a general view on how Professional Institution and the members (in this case EIZ) are expected to participate in the National KAIZEN program deployment.

A focus on what is expected of Engineering Institution of Zambia and the Engineering profession shall be discussed with proposals and questions, but not to limit what EIZ or Engineers are able to do to contribute to the KAIZEN deployment. The need to realign all engineering practice for a reward, skill and also for social responsibility. The necessity to use the existing plateform to advise the government of the day on the best approaches to improve Product Quality and Service. Further, an "eagle's Eye" to ensure cost reduction in specific terms that answer to the nation needs and contribute to the Zambia vision 2030.

Some challenges in the implementation shall be shared in a polite manner but prudent enough to deliver the correct message and to equip all our target groups for sufficient contribution to KAIZEN implementation.

In as much as it may be envisaged that KAIZEN is a new concept and faces resistance, a number of milestones have been reached. Therefore the paper shall bring out some progress and success story famously known as "KAIZEN story". The paper shall give the humble benefits of applying KAIZEN from the Zambia experience to dispel misgivings that come with professional politics emanating from professionals' different back grounds.

The paper ends with a "rolling" conclusion providing a platform for an intelligent mind to make a responsible and patriotic choice for mother Zambia. It also invites EIZ council and management to seriously take their place on this National wide KAIZEN deployment embarked on by the Zambian government without hesitation because Quality and Productivity belongs to Engineering.

## THE GENESIS OF THE KAIZEN

KAIZEN a combination of two (2) Japanese words; "KAI" and "ZEN" is equivalent to "Change" and "Better" respectively, or taken rationally, "Continuous Improvement"; thus Change for the better. A simple principle that "TODAY MUST BE BETTER THAN YESTERDAY". It is with this that KAIZEN, taken as a philosophy, is capable of providing the necessary improvement for Zambia, based on the testimonies from the source, Japan.

Japan built her economy by renouncing a status quo after World War II, and took to always improve on Quality and Productivity. This success story has help many nations and as such, it is important to broadly appreciate that many nations have applied the KAIZEN principles, though using contemporary quality Management systems models such as Lean Manufacturing by the Western World, like the American Standards for Quality (ASQ). The European Foundation for Quality management (EFQM) founded in 1989 was also established by reputable European manufacturing companies, who have employees Total Quality Management (TQM) to enhance Continuous improvement and customer satisfaction by companies like BMW, Bosch, Benz etc.

Zambia appreciated KAIZEN following the lessons and experiences from Japanese economic success, through international Business collaboration and fora. In 2008, Japan made a commitment to support trade promotion between Asia and Africa through what was known as the triangle of hope in 2009, where Zambia was a beneficiary. The support included capacity building for Zambia Development agency (ZDA) in which KAIZEN was identified as a necessity to promote Quality and Productivity for enterprise. The Zambia Development Agency Act No. 2006 Section 5(3) (c) provides for the promotion of the development and growth of Zambian industries that are efficient in their use of resources, enterprising, innovative and internationally competitive. To answer to this policy direction KAIZEN principles fitted in very well such that it prompted ZDA management to engage JICA using experts from JUSE for a KAIZEN pilot project.

The project started with nine organisations in 2009 and by 2011, thirty organisations had implemented KAIZEN successfully in Public and Private sector. ZDA in collaboration with Zambia Association of Manufacturers (ZAM) promoted these activities and provided guidance to organisations. The implementation activities were supported by JICA. The pilot organisations increased above a hundred by July 2013, at this point, when they were invited to attend the third (from 2010) consecutive Annual National KAIZEN Conference held, to show case their KAIZEN Story, at Mulungushi International Conference in Lusaka. Remarkable cases included improvement time managements from local authorities, elimination of waste in manufacturing, mind set change through 5S practice and suggestion schemes from Quality control Circles (small group activities).

## KAIZEN IMPLEMENTATION IN ZAMBIA

KAIZEN was fully fledged in April 2014, as a Government driven project to support the National Quality Policy (NQP) under Ministry of Commerce Trade and Industry (MCTI) with the technical support from JICA. In order to establish fervent Quality and promote existing quality aspects, the KAIZEN Institute of Zambia was established, and registered as Public Institution; KAIZEN Institute of Zambia Ltd. The Institute is a non-profit organisation located at Kwacha House annex Cairo Road, Lusaka.

As core in the implementation of the KAIZEN in 2014,KIZ embarked on capacity building, to train KAIZEN Consultants and KAIZEN Coordinators to promote and provide guidance to organisations. The training is designed to provide an in-depth Theory and Practical through “On the Job Training” (OJT). Further, JICA agreed to support KIZ in the establishment of systems and organisation structures, most suitable for the Zambian environment.

KIZ’s main objective is to deliver Quality and Productivity improvement, through techniques and guidance to enable organizations to identify, analyse and challenge the “bottlenecks” in their work. Maasaki Imai referred to Dr. Demings’ famous wheel (PDCA), that all work is a process and it must therefore be measured, if it is to be improved. (Imai M, 1989:10) KAIZEN thrives largely on data and evidence based decision making. Data also enables front line staff to contribute to quality improvement effectively through performance measurements and target setting.

The application of PDCA cycle, may not be novel to most Engineering professions because Deming constructed it from the actual engineering process, premised on Design, production, delivery and evaluation. Hence, Plan, Do, Check and Act in appreciation or take corrective measures. KAIZEN principles operates on redefining a production process through process value stream mapping. In this way, the Engineer has an opportunity to continuously improve the Product or service Quality by using only needed inputs and avoid unnecessary cost, delay, or non-value addition activities in a process. These are the same attributes emphasised by ISO 9001:2015 series through the ten (10) QMS principles.

In order to promote business excellence at organisational level in three (3) sectors; Manufacturing, Service and Public, KAIZEN puts emphasis in refining an organisation vision and to align the Mission and objectives, for employee effective participation, the Japanese refer to this as "Hoshin Kanri"(Compass direction). Many organisation have developed Mission statements which are difficulty to interpret, even by the originators. KAIZEN brings a simplified approach for a mission that simply answers "why the organisation exists?" What is the mission statement for EIZ? What is the purpose of engineering professions?

In 2014 and 2015, thirty seven (37) organisations were engaged to pilot KAIZEN where business process were studies and benchmarking for Quality and Productivity improvement. This was phase one of the KAIZEN project in Zambia which was planned for three phases of two years each.

The Zambian Government has called on all Government Institutions to ensure rational and effective use of resources through a cultural transformation and embrace the KAIZEN principles to attain a SMART Zambia. According to the President His Excellence E. C Lungu in his address to parliament, on 18th September 2015, our people's attitude must improve their work culture in institutions by rational use of resources. Typical cases are; to save time through punctuality, effective communication to avoid mistakes, planned trips to save on fuel, maximise use of office space, schedule maintenance of equipment and standardize processes to avoid non conformity.

Meaning that, we must institutionalize KAIZEN both public and Private sector to enhance Quality.

**What is expected from Engineers for National KAIZEN deployment?**

It is important to consider the historical reflection on the Engineer's contributions to the birth of KAIZEN. After World War II, America dispatched American Electrical Engineers to help improve telecommunication in Japan. This is a clear indication of the leading role for Engineers in the industry; designing and implementing effective production. Other professions came in as support service whose performance greatly depends on the outlined work process for operations.

In the Japanese KAIZEN deployment model, private sector took the lead with a focus on Quality improvement based on ideas from America, through Dr Edward Deming and Mr. Joseph Juran. It is important to note that these two Quality Gurus and many others, were Engineers who specifically applied problem solving in industry through Statistical Quality Control (SQC). Deming's first encounter was with the Union of Japanese Scientist and Engineers (JUSE). They applied Quality Control to achieve Productivity in three progressive phases: Time when quality was held by inspection, then times when Quality was produced in the process and a time when quality was held at the source. (Takatori K, 2014:38) Quality through KAIZEN is inherent in the process through specifications and standardization of all work processes which eventually leads to productivity.

In Zambia the National Quality policy (NQP) was developed to essentially provide a direction to address the Quality of the products and services amid stiff competition on local and external markets. The Policy directs a focus on the efficiency and effective process orientation. This was to support the MCTI objective to enable the manufacturing sector to contribute 20% to GDP by 2015.

A close look at the Japanese government support, reveals that standardization of processes to prevent product non conformity, is held by engaging institutions such as JUSE. While the Japanese KAIZEN has its roots from the western Quality Control systems, it was domesticated with underlying principles inclined to scientific and statistical quality control. Later, more institutions were formed such as; The Japanese Productivity Centre (JPC) and Japanese Industrial Standards (JIS), Japanese Management Agency (JMA). The development of the model took a simplified and easy to understand by all, with an aggressive approach to inspire National participation.

## NATIONAL AGENDA FOR ZAMBIA

The National vision for Zambia is to be a Prosperous Country by the year 2030. By implication, it means that Zambians will be wealthy. How can this dream be realised?

Zambia has a number of problems to tackle, ranging from Historic challenges, to neglect of available resources affecting Quality and Productivity. After liberalisation of the economy, the local market has been subjected to stiff competition from foreign goods and service: our failure has been mostly on low Quality and pricing too high, there by losing market share.

As a nation, we need to devise rational approaches to address Customer satisfaction: Quality up, Cost down, timely delivery and safe process. Above all, we need to be consistence on the goods and services, the need for standardization. To achieve this, product specification must be adhered to after design, this is the enabling environment which Zambia Bureau of Standards (ZABS) is diligently promoting. Our as concern as Zambians on quality must be extended to the supplier because the product results are dependent on inputs. This important aspect is also emphasised by ISO 9001:2015 for control of external supplies and processes.

The Nation is endowed with enormous resources, albeit, society was historically only prepare for formal employment other than entrepreneurial abilities for too long (including Engineers). This has to do with the way we are socialised and the school curriculum which emphasis academic dispensations other than Entrepreneurship.

The SMART Zambia pronounced by the President in his address to parliament September 2015, puts emphasis on embracing innovation and entrepreneurship, which Engineers must reflect on today and embrace for their benefit, and National development.

The Nation has suffered serious neglect on utilisation of resources ranging from Human Capital (including Engineers), Raw Materials, water bodies, land & mineral deposits and in some cases Machinery & infrastructure e.g. Mulungushi Textiles in Kabwe.

According to Central Statistics office, Zambia has 752, 000 km$^2$ with about 40% of water in the region. Approximately 2,750,000 hectares of land is suitable for irrigation in Zambia but only 200,000 hectares are under active irrigation, representing less than 10% irritable land utilisation. However, the utilization of this arable land is mostly seasonal, confined to the rain season dominated by maize, even when our soils are suitable for many crops. The agro sector is faced with a problem of limited mechanisation for tillage, growth and harvest for the farmer, lowering productivity. What is the Engineers' response? What policies would help alleviate the situation?

## WHAT IS EIZ'S ROLE ON THE KAIZEN PROGRAM?

The Transformation Culture for a SMART Zambia requires a mind-set change and problem solving approaches to enhance Quality and Productivity. The main objectives of EIZ according to its legal mandate is to register Engineers and regulate the Engineering practice in Zambia. In line with this mandate, EIZ has done well to provide for continuous professional development for its members. But what about a provision for performance improvement for Practicing organizations or Units?

1. Provide a platform for KAIZEN awareness and dissemination for Engineering Organisation and Engineering professionals.
2. EIZ must consider KAIZEN implementation within its systems by developing a quality policy and align all process to achieve efficiency and effective service delivery.
3. The long term action for EIZ is to ensure continuous improvement for all Engineering processes, to include;
    - Training programs in Universities and TEVET sectors through proactive participation in timely curricula update to emphasis international quality best practices.
    - Engineering organisation or units to implement quality management system to address regulatory requirements and product conformity.

### The mind-set change through KAIZEN

The transformation needed for mind-set change in Zambia, is simply to shift from traditional approach, termed "Business as usual" to create an organised business environment which promotes efficiency and effective service delivery at minimum cost considering quality first, lower cost, efficient delivery and safety. KAIZEN provides practical orientation for work place organization

Quality is with certainty achieved by a Quality enterprise, with Quality people and Quality service. There is need to be mindful of the basic business organisation, the fact that order (classification, proper layout, visual control & cleanliness) in any under taking, be it; a workplace, public facility or indeed a home, is the foundation of success. The order will promote standardised best practices and prevents mistakes and reduce long searching time for utensils in production processes. This calls for specialised KAIZEN tools to drill people and sustain the philosophy. In Malaysia it is referred to as the Quality Environment (QE). KAIZEN provides 5S, 3MUs, Quality Control Circles (QCC), Standard Operating Procedures (SOPs) and Suggestion schemes. (QCC Koryo: 2008).

## IMMEDIATE ACTION FOR EIZ

### Engage focal persons for adoption of the philosophy

It is strongly recommended here that EIZ considers to create a frame work for KAIZEN institutionalisation and national wide deployment to all the members and key sector. Engage or assign focal persons for KAIZEN who could be trained by KIZ as Coordinators implementation at EIZ.

**Mind set Change:**

EIZ should consider KAIZEN on the annual calendar for conferences and forum to include awareness seminars for EIZ members and Engineering Units with focus on positive attitudes KAIZEN principles orientation, such as 5S, 7 wastes elimination, Quality Control Circles and standardization.

## CONCLUSIONS

The need to recognise and implement Quality/Productivity improvement is the main objective of the KAIZEN project in Zambia and to define common approaches across sectors for business excellence. This requires the involvement of government ministries and stakeholders for effective deployment. The National wide campaign targets key institution, such as EIZ for the required impact.

The Engineering Institution of Zambia is a well-placed institution for National outreach to all their members and organisations. The KAIZEN project is set to address issues affected by serious neglect of housekeeping principles leading to; poor inventory management, indiscriminate waste disposal, uncleaned work place, and above all safety hazards. This reflects from the bad habit of litter in public facilities and communities.

EIZ must open up for KAIZEN to conduct awareness seminars for its members and key sectors using for a cultural transformation to improve and sustain engineering professional performance and the general conduct. This will be an EIZ contribution to the national wide KAIZEN deployment through key institutions.

## THE AUTHOR

The Zambian concern on Quality and Productivity has over the years grown and brought many issues on board in Public and Private sector. The majority of Quality practitioners have attained high level of knowledge and skills through their employment engagement or in their quest to attain University studies at various levels and disciplines. The pursuit of Product and Service excellence by organisations through ISO certification has provided opportunities for mangers to undertake deep study of Quality Management Systems.

Among many Zambians who have had an opportunity to learn and practice Quality and Productivity management, is Bernard Wamundila an accredited KAIZEN Deployment Consultant and KAIZEN Trainer under the KAIZEN Institute of Zambia.

Through the Japanese International Corporation agency (JICA) and Japanese Productivity Centre, in Japan, he successfully completed a KAIZEN Consultancy course in 2014.

Earlier, He was the Quality Assurance Manager at Northern Technical College (NORTEC) after pursuing BA in Development Studies. He pursued a Diploma in Technical Education from University of Zambia after working for fifteen years (15) as Artisan for the then Chilanga Cement Plc, now Lafarge Cement Plc. He was employed by Northern Technical College (NORTEC) as lecturer in the Mechanical Department in 2002.

Mission: ‘To contribute to the Zambian Culture transformation through KAIZEN’.

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# SESSION 3A

# INFRASTRUCTURE MAINTENANCE

# PRIORITIZING REPAIR AND MAINTENANCE PROJECTS OF AIR TRAFFIC MANAGEMENT (ATM) SYSTEMS IN ZAMBIA

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## ABSTRACT

*In the recent past, the aviation industry has seen a tremendous increase in the growth and demand for air transport services. This has resulted in an increased demand for quality of the service provided by the Air Navigation Service Providers (ANSP). For this reason, there is need to develop new methods of evaluating risk and safety in civil aviation. ATM systems represent essential infrastructure in the provision of quality air navigation services and in extreme cases failure of the ATM system can result in loss of life. Consequently, it is of utmost importance to make all possible effort to make sure repair and maintenance projects are carried out in a systematic way to ensure quality service.*

*Zambia Airports Corporation Limited (ZACL) is the ANSP responsible for providing air navigation services in Zambia. The ability to provide safe and efficient air navigation services is highly dependent on the ground based ATM equipment. This study is focused on repair and maintenance projects of ATM systems in Zambia.*

*Multi criteria decision making (MCDM) tools will be used for risk assessment and for planning the repair and maintenance projects of air traffic management systems. For this purpose, at first, risks that influence ATM systems have been recognized and have been classified in five groups as risks arising from equipment aging, environmental conditions of the equipment, changes in technology, availability of spare parts, and maintenance challenges. This was achieved through interviews and meetings with decision makers at ZACL. The risks have been assessed based on their consequence on four criteria as cost of maintenance, performance, safety and quality of service delivery. Finally, a method has been proposed for planning the ATM repair and maintenance projects using multi criteria decision making tools. In a case study, air traffic management systems have been ranked based on the intensity of recognized risks using fuzzy TOPSIS method.*

**Keywords:** *ATM systems, risk assessment, repair and maintenance, MCDM, Fuzzy TOPSIS.*

## 1. INTRODUCTION

Aviation industry as one of the most important substructures for developing economic, political and social aspects of societies has a fundamental role in developing countries, and provision of quality and safe Air Navigation Services (ANS) is one of the most important parts of aviation. Air Navigation Services (ANS) includes five broad categories of services provided to air traffic during all phases of operation (area control, approach control and aerodrome control). These services are: Air Traffic Management (ATM), Communication, Navigation and Surveillance services (CNS), Meteorological services for air navigation (MET), Aeronautical Information Services (AIS) and Search and Rescue (SAR) (ICAO, 2001). Further division of these services is shown in Figure 1.

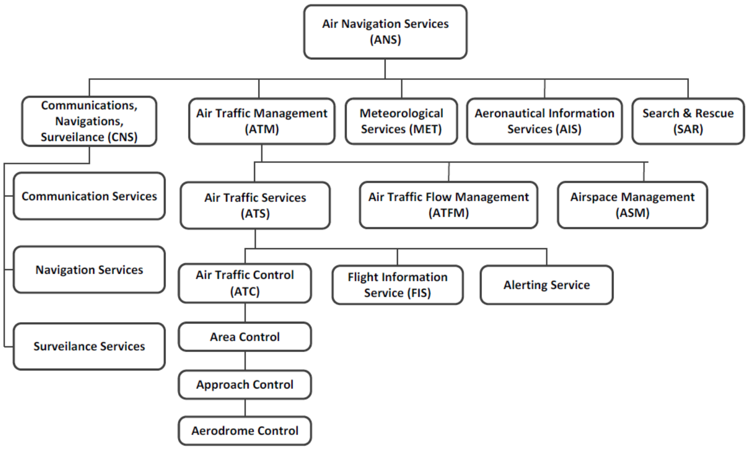

**Figure 1: The structure of Air Navigation Services. (Source: Eurocontrol 2008)**

Air traffic management (ATM) is the process, procedures and resources used to ensure the safe guidance of aircraft in the ground and in air (EUROCONTROL, 2012) and ATM systems are part of this process. ATM systems consist of a large number of interconnected subsystems with different types of technical equipment and processes. The subsystems include functions such as communications, navigation and surveillance systems in addition to the data processing and display systems in various air traffic control centers. CNS systems are critical to flight safety and any downtime is typically very costly in terms of economic penalties. These are used to receive, process, store and display information about aircraft in the ATM system. The subsystems also generate, transmit and receive flight data, requests, commands, directives and all types of safety related information that is needed to provide efficient and effective air traffic service thus ensuring the safety of air traffic and aircraft. In extreme cases failure of ATM system can result in loss of life (United States Army, 2007). Repair and maintenance of ATM systems is therefore very critical and costliest projects of aviation and a large amount of this cost is allocated for systems like navigation aids. Navigation aids are systems that help the smooth navigation of the aircraft from one place to the other. They are an important element of the ATM system and their destruction or old age lead to problems in air safety and may lead to loses not only to aircraft but loss of life as well. Furthermore, the failure to maintain the equipment due to maintenance or lack of spare parts may cause operations hard and may pause a high risk to safety of people. Recognizing the problems of ATM systems and implementation of appropriate and opportune repair and maintenance programs is fundamental step for maintaining a safe air space and preventing the dangers that may rise from it.

In this study, factors that influence the operation of Air traffic management systems and their risks have been recognized and an appropriate method has been proposed for the ranking the investigation, fund allocation programs and prioritization repair and maintenance projects of ATM systems.

In recent years, a number of researches have been done in ATM systems. For example, in a research done on Reliability Analysis of the Reykjavik Area Control Center (RACC) Air Traffic Management, Failure Mode Effect and Criticality Analysis (FMECA) and Reliability Block Diagram (RBD) were employed along with a software tool, BlockSim, in order to develop a quantitative model that is used to determine the effect of RACC electrical power system failures on the reliability of the ATM system. The model computed the reliability of the ATM system to determine the effect of electrical failures in various modes of operation (Unnur, 2013). In another research, Hulda (2013) analyzed and evaluated the metrics that are currently used to evaluate the performance of Air Navigation Service Providers (ANSP) in managing, developing and operating their services. He developed a system of performance metrics suitable for the Icelandic Air Traffic Management (ATM) System operated by Isavia, based on an analysis and modelling of the ATM System. From the literature review, we see that from a strategic point of view, little attention has been given to repair and maintenance projects of ATM systems which can be considered as internal projects from an ANSP point of view.

In a case were an ANSP is faced with the challenge of prioritizing repair and maintenance projects of ATM systems, Multi attribute or criteria decision making (MADM) tools can be used. MCDM techniques deal with the problem of choosing an option from a set of alternatives which are characterized in terms of their attributes (Hwang & Yoon, 1981a). MCDM is the most well-known branch of decision making. It is a branch of a general class of operation research models that deal with decision problems under the presence of a number of decision criteria. Many efforts have been made and several methods have been effectively developed for (MCDM) problems, which in literature, have been in very successful application of these methods (Stewart *et al*, 1992). One of the commonly used methods in this regard is the technique for order preference by similarity to ideal solution, Fuzzy TOPSIS method.

The remainder of this paper is organized as follows. Section 2 briefly introduces the Fuzzy TOPSIS method. Section 3 presents the method to recognizing, assessment and modeling ATM risks using a case study including the application of the proposed model for prioritization of repair and maintenance of ATM systems and the paper is concluded in Section 4.

## 2. THE FUZZY TOPSIS METHOD

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is an analysis method that is one of the best methods for multi criteria decision making. TOPSIS was developed by Hwang and Yoon in 1981.

TOPSIS method is based on two main solutions; the positive ideal solution which has the best attribute values; and the negative ideal solution which has the worst attribute values.
TOPSIS measures the geometric distance between all alternatives, positive and negative ideal solutions and selects the best one. The best alternative is an alternative which has the shortest

distance from positive ideal solution and also the furthest distance from the negative ideal solution (Hwang & Yoon, 1995b). TOPSIS ranks the alternatives according to these two distance measures.

This method and other classic multi criteria decision making methods don't handle the uncertainty of issues. By using fuzzy theory and assimilate it with multi criteria decision making tools, uncertainty in problem is modeled in fuzzy environment and produce more accurate answers. A decision matrix is often employed in MCDM to start the evaluation process (Li & Yang, 2004). The evaluation of alternatives $A_1$, $A_2$, …, $A_m$ are performed according to criteria $C_1$, $C_2$, …, $C_n$ and can be viewed as a geometric system with $m$ points in $n$-dimensional space.

Numbers in fuzzy MCDM problems are fuzzy numbers. Triangular fuzzy numbers are used to express linguistic variables. It can be defined by a triplet (a, b, c) where $0 \leq a < b < c \leq 1$. For a simpler comparison and evaluation, based on all the criteria in a dimensionless units, values are normalized (Chen, 1987) which also help to avoid computational complexity, resulting from different measures in decision matrix.

A detailed description and treatment of TOPSIS is discussed by (Saghafian & Hejazi, 2005) and (Jian *et al*, 2008) and we have adapted the relevant steps of fuzzy TOPSIS as presented below:

**Step 1:** Choose the linguistic ratings for consequence and likelihood to assess risk under fuzzy environment as shown in Table 1 and Table 2.

Table 1: Consequence ratings

| | Symbol | Fuzzy number |
|---|---|---|
| Very High | VH | (0.85, 1, 1) |
| High | H | (0.5, 0.85, 1) |
| Medium | M | (0.15, 0.5, 0.85) |
| Low | L | 0.0, 0.15, 0.5) |
| Very Low | VL | (0.0, 0.0, 0.15) |
| None | N | (0.0, 0.0, 0.0) |

Table 2: Likelihood ratings

| | Symbol | Fuzzy number |
|---|---|---|
| Certain | C | (1,1,1) |
| Very High | VH | (0.85, 1, 1) |
| High | H | (0.7, 0.85, 1) |
| Slightly High | SH | (0.5, 0.7, 0.85) |
| Medium | M | (0.3, 0.5, 0.7) |
| Slightly Low | SL | (0.15, 0.3, 0.5) |
| Low | L | (0, 0.15, 0.3) |
| Very Low | VL | (0, 0, 0.15) |
| Impossible | N | (0, 0, 0) |

**Step 2:** construct a decision matrix from *m* alternatives and *n* criteria.

$$\tilde{D} = \begin{array}{c} \\ \\ \\ \\ \\ \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \left[\begin{array}{cccc} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & & \tilde{x}_{mn} \end{array}\right] \end{array} \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \tag{1}$$

And criteria are constructed as follows:

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_1 \ldots\ldots\ldots\ldots\ldots\ldots \tilde{w}_n) \quad , \tag{2}$$

**Step 3:** Normalize the fuzzy decision matrix. This is accomplished using linear scale transformation. The calculations are done using formulae (3) and (4) to convert the different criteria scales into a comparable scale.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j{}^+}, \frac{b_{ij}}{c_j{}^+}, \frac{c_{ij}}{c_j{}^+}\right) \; and \; c_j{}^+ = max_i \, c_{ij} \quad for \; benefit \; criteria \tag{3}$$

$$\tilde{r}_{ij} = \left(\frac{a_j{}^-}{c_{ij}}, \frac{a_j{}^-}{b_{ij}}, \frac{a_j{}^-}{a_{ij}}\right) \; and \; a_j{}^- = min_i \, a_{ij} \quad for \;\; cost \; criteria \tag{4}$$

The normalized fuzzy decision matrix can be represented by Eq. (5):

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, \qquad i = 1, \ldots \ldots, m; \quad j = 1, \ldots \ldots, n \tag{5}$$

Where the $\tilde{r}_{ij}$ is the normalized value of $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$

**Step 4:** Calculate the weighted normalized fuzzy decision matrix. The weighted normalized value $\tilde{v}_{ij}$ is calculated by multiplying the weights $(\tilde{w}_j)$ of criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$ . The weighted normalized decision matrix $\tilde{V}$ for each criterion is calculated through the following relations:

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times j}, \qquad i = 1, \ldots \ldots, n; \quad j = 1, \ldots \ldots, j \tag{6}$$

Where $\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_j$

**Step 5:** Determine the positive ideal solution (A$^+$) and negative ideal solution (A$^-$) as described below:

$$A^+ = (v^+{}_1, \ldots\ldots\ldots, v^+{}_i, \ldots\ldots\ldots, v^+{}_n) = \{(max_i \;\; v_{ij} \;\; \big| \;\; (i = 1, \ldots\ldots, n)\} \tag{7}$$

$$A^- = (v^-{}_1, \dots\dots\dots, v^-{}_i, \dots\dots\dots, v^-{}_n) = \{(min_i \quad v_{ij} \mid (i = 1, \dots\dots., n)\} \tag{8}$$

**Step 6:** calculate the distance of each alternative from ($A^+$) and ($A^-$).

$$d^+{}_i = \left(\sum_{j=1}^{n} (\tilde{v}_{ij}, \tilde{v}^+{}_j)^2\right)^{\frac{1}{2}} \qquad , = 1, \dots\dots., m \tag{9}$$

$$d^-{}_i = \left(\sum_{j=1}^{n} (\tilde{v}_{ij}, \tilde{v}^-{}_j)^2\right)^{\frac{1}{2}} \qquad , i = 1, \dots\dots., m \tag{10}$$

The distance between two triangular fuzzy numbers $A_1 = (a_1, b_1, c_1)$ $and$ $A_2 = (a_2, b_2, c_2)$ is calculated as:

$$d(A_1, A_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \tag{11}$$

**Step 7**: calculate the closeness coefficient through equation:

$$CC_i = \frac{d_i{}^-}{d_i{}^+ + d_i{}^-} \qquad , i = 1, \dots\dots., m \ and \quad 0 \le CC_i \le 1 \tag{12}$$

**Step 8:** Rank preference order according to the closeness coefficient in descending order.

## 3. RISKS IN AIR TRAFFIC MANAGEMENT SYSTEMS

There are different types of ATM systems. We selected five main ATMs in our case study and the general model of the problem is as indicated in Figure 2.

In this study, based on the interviews done at Zambia Airports Corporation Limited, the most important risks which influence ATM systems have been recognized and classified in five main groups. These risks may arise from equipment aging, environmental conditions of the equipment, changes in technology, availability of spare parts, and maintenance challenges. Table 3 shows the recognized risks.

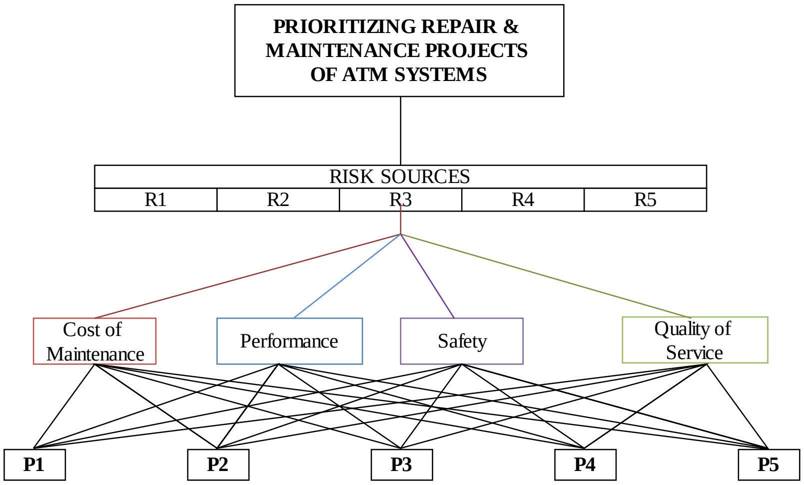

Figure 2: Modelling ATM risks

Table 3: Recognized risks

| | Sources of Risks |
|---|---|
| R1 | Risks arising from equipment aging |
| R2 | Risks arising from environmental conditions of the equipment |
| R3 | Risks arising from changes in technology |
| R4 | Risks arising from availability of spare parts |
| R5 | Risks arising from maintenance challenges |

A team of ATM experts (DMs) were interviewed and the consequences of each defined risk event on cost of maintenance, performance, safety and quality of service delivery of ATM systems by linguistic terms were expressed as indicated in Table 4.

Table 4: Consequences rating assessed by four DMs

| | | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|---|
| DM1 | C1 | L | M | VH | VH | M |
| | C2 | H | VH | L | VH | H |
| | C3 | VH | VH | L | VH | M |
| | C4 | M | VH | L | VH | M |
| DM2 | C1 | L | L | H | VH | H |
| | C2 | M | M | M | M | VH |
| | C3 | M | H | M | H | M |
| | C4 | M | H | L | H | L |
| DM3 | C1 | M | L | VH | VH | H |
| | C2 | VL | H | H | VH | M |
| | C3 | VL | M | M | H | H |
| | C4 | VL | M | H | VH | H |
| DM4 | C1 | VL | M | L | H | M |
| | C2 | VL | H | H | H | M |
| | C3 | VL | L | L | H | M |
| | C4 | L | M | L | H | M |

According to fuzzy numbers in Table 1 and consequences rating in Table 4, relative importance of risk events and criteria have been calculated by averaging of four DMs assessment. They are indicated in Tables 5 and 6.

Table 5: The relative importance weights of risk events for each criterion

| | **C1** | **C2** | **C3** | **C4** |
|---|---|---|---|---|
| **R1** | (0.037, 0.2, 0.5) | (0.16, 0.34, 0.54) | (0.25, 0.37, 0.54) | (0.075, 0.29, 0.59) |
| **R2** | (0.075, 0.32, 0.67) | (0.5, 0.8, 0.96) | (0.37, 0.62, 0.84) | (0.41, 0.71, 0.92) |
| **R3** | (0.55, 0.75, 0.87) | (0.29, 0.59, 0.84) | (0.075, 0.32, 0.67) | (0.12, 0.32, 0.62) |
| **R4** | (0.76, 0.96, 1) | (0.59, 0.84, 0.96) | (0.59, 0.89, 1) | (0.67, 0.92, 1) |
| **R5** | (0.32, 0.67, 0.92) | (0.41, 0.71, 0.92) | (0.24, 0.59, 0.89) | (0.2, 0.5, 0.8) |

Table 6: Fuzzy weights of criteria

| Criteria | Fuzzy weights |
|---|---|
| C1 | (0.35, 0.58, 0.79) |
| C2 | (0.39, 0.66, 0.84) |
| C3 | (0.30, 0.56, 0.79) |
| C4 | (0.29, 0.55, 0.79) |

A risk is defined as a product of likelihood and consequence. Thus ATMs risks were assessed based on the formula below and using likelihood fuzzy numbers as indicated in Table 2.

$$Risk = Likelihood \ \times Consequences,$$

$$R_i = L_i \times C_j, \ \ where\ L_i\ and\ C_j\ are\ respectively\ Likelihood\ and\ Consequence\ of\ risk\ event\ R_i\ for\ each\ criterion$$

For all ATM systems and all criteria intensity of risks were calculated. Calculated risks for ATM system P1 are indicated in Table 7 as an example.

Table 7: Intensity of risk events for P1

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| R1 | (0.5, 0.85, 1) | (0.5, 0.85, 1) | (0.5, 0.85, 1) | (0.5, 0.85, 1) |
| R2 | (0, 0, 0.13) | (0, 0, 1) | (0, 0, 1) | (0, 0, 1) |
| R3 | (0.42, 0.7, 0.85) | (0, 0.10, 0.42) | (0, 0.10, 0.42) | (0, 0.10, 0.42) |
| R4 | (0.85, 1, 1) | (0.85, 1, 1) | (0.85, 1, 1) | (0.85, 1, 1) |
| R5 | (0.42, 0.85, 1) | (0.42, 0.85, 1) | (0.42, 0.85, 1) | (0.42, 0.85, 1) |

In order to define the decision matrix, the total risk of each ATM system for each criterion is calculated from additive weighting of five risk events. For example, total risk for P1 and criterion C1 has been calculated using as follows:

$$\tilde{x}_{11} = W_{11} * R_1 + W_{21} * R_2 + W_{31} * R_3 + W_{41} * R_4 + W_{51} * R_5$$

$$\begin{aligned}\tilde{x}_{11} = {} & (0.037, 0.2, 0.5) * (0.5, 0.85, 1) + (0.075, 0.32, 0.67) * (0, 0, 0.13) \\ & + (0.55, 0.75, 0.87) * (0.42, 0.7, 0.85) + (0.76, 0.96, 1) * (0.85, 1, 1) \\ & + (0.32, 0.67, 0.92) * (0.42, 0.85, 1) = (1.03, 2.22, 4.03)\end{aligned}$$

Where $\tilde{x}_{11}$ is total risk of first ATM system (P1) for first criterion (C1). Other elements of the decision matrix have been calculated in a similar manner. The resulting decision matrix is as shown in Table 8 and normalized using (2) as shown in Table 9.

Table 8: Fuzzy decision matrix

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| P1 | (1.03, 2.22, 4.03) | (0.75, 1.79, 3.73) | (0.72, 1.73, 3.55) | (0.69, 1.62, 3.57) |
| P2 | (0.27, 1.22, 2.57) | (0.52, 1.61, 2.89) | (0.45, 1.42, 2.72) | (0.70, 1.30, 3.62) |
| P3 | (0.14, 0.47, 1.11) | (0.00, 0.12, 1.72) | (0.26, 0.26, 1.33) | (0, 0.13, 0.93) |
| P4 | (0.33, 1.01, 2.05) | (0.098, 0.5, 1.22) | (0.14, 0.59, 1.68) | (0, 0.089, 0.85) |
| P5 | (0.032, 0.31, 1.22) | (0.24, 0.63, 1.35) | (0.084, 0.44, 1.76) | (0.02, 0.33, 1.18) |

Table 9: Fuzzy normalized decision matrix

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| P1 | (0.008, 0.014, 0.031) | (0.201, 0.480, 1.000) | (0.203, 0.487, 1.000) | (0.191, 0.447, 0.986) |
| P2 | (0.012, 0.026, 0.118) | (0.139, 0.432, 0.775) | (0.127, 0.400, 0.766) | (0.193, 0.359, 1.000) |
| P3 | (0.029, 0.068, 0.228) | (0.000, 0.032, 0.461) | (0.073, 0.073, 0.375) | (0.000, 0.036, 0.257) |
| P4 | (0.016, 0.032, 0.097) | (0.026, 0.134, 0.327) | (0.039, 0.166, 0.473) | (0.000, 0.024, 0.235) |
| P5 | (0.026, 0.103,1.000) | (0.064, 0.169, 0.362) | (0.024, 0.124, 0.496) | (0.005, 0.091, 0.326) |

The weighted fuzzy normalized decision matrix in Table 10 has been calculated by multiplication of weights of criteria in Table 6 and normalized decision matrix in Table 9 as described in (6). This matrix will be the basis of ranking ATM systems projects.

Table 10: Weighted fuzzy normalized decision matrix

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| P1 | (0.003, 0.008, 0.024) | (0.078, 0.317, 0.840) | (0.061, 0.273, 0.790) | (0.055, 0.246, 0.779) |
| P2 | (0.004, 0.015, 0.093) | (0.054, 0.285, 0.651) | (0.038, 0.224, 0.605) | (0.056, 0.197, 0.790) |
| P3 | (0.010, 0.039, 0.180) | (0.000, 0.021, 0.387) | (0.022, 0.041, 0.296) | (0.000, 0.020, 0.203) |
| P4 | (0.006, 0.018, 0.077) | (0.010, 0.088, 0.275) | (0.012, 0.093, 0.374) | (0.000, 0.013, 0.186) |
| P5 | (0.009, 0.060, 0.790) | (0.025, 0.111, 0.304) | (0.007, 0.069, 0.392) | (0.001, 0.050, 0.257) |

Positive ideal solution and Negative ideal solution are determined by (7) and (8) on the basis of weighted fuzzy normalized decision matrix in Table 10 as follows:

$$A^{+} = \{(0.003, 0.008, 0.024), (0.078, 0.317, 0.840), (0.061, 0.273, 0.790), (0.056, 0.197, 0.790)\}$$
$$A^{-} = \{(0.009, 0.060, 0.790), (0.010, 0.088, 0.275), (0.022, 0.041, 0.296), (0.000, 0.013, 0.186)\}$$

The distance from the positive ideal solution and the negative ideal solution for each alternative have been calculated from (9), (10), (11) and they are indicated in Table11.

Table 11: The distance of alternatives from positive and negative ideal solution

| Criteria | C1 | | C2 | | C3 | | C4 | | D | |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance | $d^{+}$ | $d^{-}$ | $d^{+}$ | $d^{-}$ | $d^{+}$ | $d^{-}$ | $d^{+}$ | $d^{-}$ | $D^{+}$ | $D^{-}$ |
| P1 | 0.000 | 0.443 | 0.000 | 0.354 | 0.000 | 0.316 | 0.067 | 0.369 | 0.067 | 1.180 |
| P2 | 0.040 | 0.403 | 0.111 | 0.246 | 0.111 | 0.207 | 0.000 | 0.366 | 0.262 | 1.222 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| P3 | 0.092 | 0.352 | 0.316 | 0.075 | 0.316 | 0.000 | 0.355 | 0.011 | 1.079 | 0.438 |
| P4 | 0.031 | 0.412 | 0.354 | 0.000 | 0.263 | 0.054 | 0.366 | 0.000 | 1.014 | 0.466 |
| P5 | 0.443 | 0.000 | 0.333 | 0.023 | 0.260 | 0.058 | 0.321 | 0.046 | 1.357 | 0.127 |

Table 11 shows the closeness coefficient (CC) each alternative which has been calculated from (12) and they are ranked in descending order as shown in Table 12:

Table 12: Closeness Coefficient and project ranking

| Project | CC | Ranking |
|---|---|---|
| P1 | 0.946 | 1 |
| P2 | 0.823 | 2 |
| P3 | 0.289 | 4 |
| P4 | 0.315 | 3 |
| P5 | 0.085 | 5 |

Project P1 is at the first in prioritization and project P5 is the last one according to the ranking indicated in Table 12. The repair and maintenance projects should be planned considering this ranking, and it helps to do appropriate and opportune operations and prevents the destruction of ATM systems.

## 4. CONCLUSION

In this paper, a method for planning the repair and maintenance projects of ATM systems has been proposed according to risks that influence them. The first thing was to have the main risks recognized and classified into five groups. These are risks arising from equipment aging, environmental conditions of the equipment, changes in technology, availability of spare parts, and maintenance challenges. Then the risks were assessed based on a multiple criteria decision making (MCDM) method known as TOPSIS in fuzzy environment. So the fuzzy weights of these risks have been determined based on their impact on four criteria: cost of maintenance, performance, safety and quality of service delivery. Further in a case study, repair and maintenance projects of ATM systems have been prioritized using the proposed method. Analyzing the results shows that the proposed method is efficiently applicable for prioritizing the repair and maintenance projects of air traffic management systems and decision making about allocation of funds and performing maintenance projects. There is no limitation for number of systems or risks in the proposed method and it can be applied in different conditions or regions.

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# EFFECTS OF VEHICLE OVERLOAD ON MAINTENANCE MANAGEMENT OF TRUNK ROADS IN ZAMBIA

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## ABSTRACT

*Road networks are among the most important public assets in many countries and form Sub-Saharan Africa's largest assets and the value of the Zambian road network is estimated at US$ 8.3billion, representing 31% of the country's gross domestic product for 2014. The classified Zambian road network of 67,671 km falls into Trunk, Main, District, Urban and Primary Feeder Roads out of which 40,454 km is the core road network. Overloading of Heavy Goods Vehicles (HGVs) is negatively affecting maintenance management of Trunk roads. The vehicle population in Zambia increased from 183,701 in 2006 to 605,635 in 2014 and a vehicle population growth rate of 45,000 per year was reported by the Road Transport and Safety Agency (RTSA) in 2015. The proportion of overloaded Heavy Goods Vehicles (HGVs) in Zambia has typically been in the range of 20 to 40 per cent.*

*Overloading accelerates the deterioration of road pavement resulting in premature failure and increased cost of maintenance, and Zambia has an Axle Load Control Programme administered by RDA. Overloading in Zambia has reduced from 20% to 40% to less than 5% due to intensified enforcement. However, this low percentage of has not captured some of the heavily trafficked sections on trunk roads have no fixed weighbridges. Mobile weighbridges have been introduced, although they have their own limitations. RDA carries out road maintenance management activities with funding from NRFA, however, axle load data is not utilized in determining the maintenance needs of Trunk Roads and Maintenance Management is to some extent influenced by social and political decisions.*

*This paper assesses the effect of vehicle overload on maintenance management of trunk roads in Zambia and makes recommendations for an effective and efficient overload control management system. The paper is based on literature, from various Road agencies and other sources, which forms part of an on-going research. It has been established that although the ALCP has managed to reduced overloading to below 5%, weighbridge data is hardly being used for design, maintenance and management of the road network in Zambia. To enhance road maintenance, the RDA should make use weigh bridge data, should introduce self-regulation, and utilize Road Maintenance Management Systems to supplement the existing methods of maintenance management, which are subject to manipulation.*

***Key words:*** *Vehicle overload, Axle load, Gross Vehicle Mass, Pavement, Road Maintenance Management*

# 1. INTRODUCTION

## 1.1 Background

A good road network is key to economic development of any country as most of the essential goods are transported by road. The public road network has been identified as the largest public infrastructural asset (Heggie and Vickers, 1998). The National Road Fund Agency [NRFA] (2015) estimated the value of the road network in Zambia to be US$ 8.3 billion representing 31 per cent of the country's Gross Domestic Product (GDP) as of 2014. The value of the road asset has kept on increasing due to the numerous road projects the government has embarked on in the recent past inter alia the Link Zambia 8000, Pave Zambia 2000 and L400.

The Zambian Road Development Agency's (RDA's) Maintenance Strategy of 2014 reported that the total gazetted road network in Zambia measures 67,671 km of which 40,454 km is the Core Road Network (CRN) with 3,116km being Trunk Roads. The Road Sector Investment Programme (ROADSIP) II bankable document defined CRN as the bare minimum network that required to be maintained continuously and on a sustainable basis in order to realize its social and economic potential (RDA, 2014). It further states that, the road network in Zambia with over 5000 river crossings i.e. bridges and culverts constitute the single largest asset owned by the government. Trunk Roads refers to roads that connect Zambia to neighbouring countries and there are currently six Trunk Roads in Zambia i.e. T1 (Fallsway-Kafue Turnpike), T2 (Chirundu-Nakonde), T3 (Kapiri Mposhi-Kasumbalesa), T4 (Lusaka- Mwami), T5 (Chingola-Jimbe) and T6 (Katete-Chanida).

The vehicle population in Zambia increased from 183,701 in 2006 to 605,635 in 2014 and the Road Transport and Safety Agency (RTSA) reported a vehicle population growth rate 45,000 vehicles per year in the first quarter of 2015. The inadequacies in other modes of transport and the recovery of copper production on the Copperbelt Province with increased mining activities in the North Western Province has seen an upsurge demand for road transport. At present roads are a predominant mode of travel, generally carrying over 80 per cent passenger and more than 75 per cent of freight traffic in Sub-Saharan Africa (Runji, 2015). Going by the current situation, some unscrupulous transporters have resorted to overloading in order to increase on their profit margins.

The proportion of overloaded Heavy Goods Vehicles (HGVs) in Zambia had typically been in the range of 20 to 40 per cent depending on the district and the season of the year ( Sub-Saharan Africa Transport Policy Program, 2011). The Axle Load Control Programme (ALCP) which was launched in April 2004 had the target of reducing the rate of overloaded HGVs from greater than 20 per cent to five per cent or less, for the axles or in relation to the Gross Vehicle Mass (GVM) from greater than 55 per cent to less than five per cent (Bouveyron, *et al.*, 2006). According to the RDA (2015), this target has been achieved with the latest figures for 2014 indicating that the average overload on both axles and GVM was about two per cent of a total number of 780,690 Heavy Goods Vehicles (HGV) weighed at the eight fixed weighbridges.

The ALCP in Zambia is the Public Roads Act No. 12 of 2002 and Statutory Instrument (SI) No. 28 of 2007. Part I, Section 3 of SI No. 28 of 2007 states that the regulation applies to vehicles with a GVM of 6.5 tonnes and above. The SI 28 of 2007, Part V, Section 35 subsection 1 and 2 provides that *"An overload shall be determined by comparing weights* *found by weighing axles, combination of axles or GVM to the defined authorised limits."*

Overloading is therefore a phenomenon resulting from either exceeding the permissible or authorised axle load limit or the GVM limit. Load limits take into account the road design capacity and vehicle tyre ratings among other things. Overloading results in rapid deterioration of the pavement structures (Nordengen and Naidoo, 2014). A study by the International Road Dynamics Inc., cited by Kishore and Klashinski (2000), found that a 10 per cent increase in weight can accelerate pavement damage by over 40 per cent (Karim, *et al*., 2013). Therefore, the damage caused by overloading rises exponentially with each additional tonne of axle load, and this reduces the life of a road network substantially (African Development Bank Group [ADBG], 2014). Karim, et al., (2014) added that besides gaining more profit through the increasing delivery, overloaded HGVs can cause damage to the road surface hence reducing the pavement service life and overall service level of the pavement system. The cost of transporting a particular tonnage of load decreases quite rapidly as the amount of load which each vehicle carries increases. On the other hand the cost of providing and maintaining the roads increases as vehicle axle loads increases (Rolt, 1981).

Clearly, overloading results in frequent premature road failures, leading to increased maintenance requirements (Norad, 2009). However, the road maintenance interventions in Zambia are not always as planned due to factors such as; overloading, poor workmanship, environmental effects and political decisions.

Despite the aforementioned increase in levels of traffic, limited data capture and monitoring of overloading on Trunk Roads is concerned. There is basically lack of baseline information on the effects of vehicle overload on maintenance management of road infrastructure, particularly Trunk Roads. Vehicle overloading and road maintenance management are treated independent of each other in Zambia and hence the relationship that exists between them has not been established.

Road maintenance may be defined as any works of every description which are required for the preservation and upkeep of a road or its associated works or both, so as to prevent the deterioration of quality and efficiency to a noticeable extent below that which pertained immediately after construction (BRD, 2010). Road maintenance management on the other hand aims to identify the need for maintenance works and potential improvements of the network in order to achieve or maintain standards. The maintenance management Cycle consists of main tasks such as Policy, Management, Programming, Planning and so forth (TxDOT, 2013). In Zambia the problem of inadequate road maintenance was diagnosed to be not one of engineering but of policies and management (Jhala, 1998).

Currently Programming and prioritization of periodic maintenance interventions on the Trunk, Main and District (TMD) Networks are achieved through the use of the Zambia Highway Management System (ZHMS) and the Highway Development and Management tool (HDM-4). A Maintenance Needs Assessment Report indicating a priority list of roads and associated investments is generated annually by RDA (RDA, 2015).

This paper is an output of a research which is intended to provide the necessary information that will assist road authorities understand the relationship between vehicle overload and road maintenance management. The research will also provide a reference point for future research on topics related to vehicle overload and maintenance management of trunk roads.

The paper makes recommendations on how information on overloads can aid effective and efficient road maintenance management.

## 2. LITERATURE REVIEW

### 2.1 Asset Value of Road Network

Runji (2015) described that road networks as among the most important public assets in many countries and Sub-Saharan Africa's largest assets. Fakudze (2005) reported that the value of the African road network was estimated at more than US$ 150 billion. The Southern Africa Transport and Communications Commissions (SATCC) identified roads as Southern African Development Community (SADC)'s largest public sector assets with replacement costs estimated at approximately US$ 50 billion reported (Guideline on Low-volume Sealed Roads, 2003). The road asset value in Zambia stands at US$ 8.3 according to the National Road Fund Agency [NRFA] (2015).

### 2.2 Road Transport in Zambia

Current transport modal share is about 71 per cent of Zambia's trade (in volume) is carried by road, 24 per cent by rail and about five per cent accounts for oil imports by pipeline from Dar es Salaam (TAZAMA pipeline) (Raballand, *et al*., 2008). The main products transported by road are:

- Mining inputs and outputs (ores, concentrates, metals, sulphur, sulfuric acid, coal),
- Agricultural (sugar, tobacco, cotton),
- Fuels (diesel and petrol),
- Food (bulk grain)

The increase in vehicle population and the dominance of road transport has increased the pressure on the road network. Heavy goods that were initially transported by rail are now finding themselves on the roads which were not designed to carry such loads hence resulting in overloading. The tremendous increase in the carrying capacities of HGVs due to the advancement in technology is another cause of overloading. Table 1 gives traffic volumes on selected roads in Zambia.

### 2.3 Enforcement measures against of Overloading in Zambia

Laws and regulations to control/manage overloading have been in existence in Southern African countries for more than 40 years, and have been changed and updated to reflect the changing circumstances of the road transport industry (Karim, *et al*., 2013).

It has been established that effective enforcement of overload control measures is one way of reducing vehicle overloading. Vehicle overloading control in Zambia was previously enforced in terms of the Roads and Road Traffic Act, CAP. 464 which was amended several times making it difficult to obtain a high level of understanding of the legal framework (Chemonics International, 2003). The enforcement of overload control was done at weighbridges and the first eight fixed weighbridges were installed on the Zambian road network between 1970 and 1980. All the weighbridges at the time were of a mechanical type (Avery 58H 20) with a capacity of 30 tonnes but have since been transformed into electronic ones except two ( Sub-Saharan Africa Transport Policy Program, 2011).

Table 1: Traffic volumes on selected Zambian Roads
Source: RDA HMS (2014)

| **Point No.** | **Province** | **District** | **Location** | **Road No.** | **Direction** | **ADT - Traffic Class 1 Light Vehicles** | **ADT - Traffic Class 2 Buses** | **ADT - Traffic Class 3 Semi-Unit Trucks** | **ADT - Traffic Class 4 Trailer/ Semi trailer Trucks** | **2014-Total ADT** |
|---|---|---|---|---|---|---|---|---|---|---|
| 76 | Copperbelt | Kalulushi | Mukulumpe Estate | T3 | Both | 5,356 | 374 | 550 | 1,500 | **7,782** |
| 72A | Central | Kapiri Mposhi | KMP Glass Factory | T3 | Both | 2,595 | 261 | 368 | 1,491 | **4,715** |
| 72 | Central | Kapiri Mposhi | Manyumbi Check Post | T2 | Both | 2,395 | 345 | 522 | 1,430 | **4,692** |
| 66A | Southern | Mazabuka | Weigh Bridge | T2 | Both | 2,954 | 293 | 430 | 1,386 | **5,063** |
| 3 | Lusaka | Lusaka | Kabangwe | T2 | Both | 8,648 | 430 | 912 | 1,231 | **11,221** |
| 8 | Copperbelt | Ndola | Kafulafuta | T3 | Both | 1,811 | 401 | 356 | 1,135 | **3,702** |
| 4 | Central | Mkushi | Myafufi | T2 | Both | 2,153 | 126 | 776 | 941 | **3,995** |
| 71 | Central | Kabwe | Landless Corner | T2 | Both | 2,626 | 271 | 335 | 876 | **4,107** |
| 78 | Copperbelt | Chililabombwe | Checkpoint | T3 | Both | 3,379 | 224 | 201 | 837 | **4,642** |
| 72B | Central | Kapiri Mposhi | Mangala | T2 | Both | 1,291 | 154 | 271 | 728 | **2,444** |
| 33 | Southern | Mazabuka | Kaleya | T1 | Both | 2,208 | 175 | 204 | 680 | **3,267** |
| 46 | Southern | Mazabuka | Magoye | T1 | Both | 1,611 | 101 | 111 | 592 | **2,414** |
| 66B | Southern | Mazabuka | Turnpike | T2 | Both | 971 | 32 | 149 | 539 | **1,691** |
| 67 | Southern | Chirundu | Siavonga junction | T2 | Both | 804 | 35 | 46 | 513 | **1,399** |

The eight weighbridge stations were at Livingstone, Kafue, Kapiri Mposhi, Kafulafuta, Mpika, Nakonde, Mwami and Solwezi (Chemonics International, Inc., 2003). The private sector once operated weighbridges at Kafulafuta and Kafue in the 1990s with some degree of success. The Zambia National Service (ZNS) operated weighbridges up to April 2007 when the RDA took over. However, government officials indicated that ZNS officers manning weighbridges in the country were not well qualified to undertake the weighbridge operations on permanent basis (Chipenzi and Nkonge, 2005).

The Norwegian Agency for Development Cooperation (Norad) and the European Commission (EC) committed itself, in March 2004, to undertake an Axle Load Control Programme (ALCP) with the objective of "*Establishing a robust and efficient control system with capacity to protect all the core road network against illegal overloading*"(Norad, 2009). The ALCP for Zambia was launched in April 2004, with a budget of US$ 7.2 million and was an integral part of Road Sector Investment Programme (ROADSIP) II.

## 2.4 Effect of vehicle overload on pavement life

Each pavement type whether rigid or flexible has specific failure mechanisms and each failure mechanism is caused by specific factors (Langer, 2011). Example of such failure mechanisms include: fatigue damage and roughness of rigid and flexible pavements, faulting of rigid pavements, and rutting of flexible pavements. These failure mechanisms are caused by the following factors: heavy vehicle loadings, climate, drainage, topography, geotechnical and materials properties, inadequate layer thicknesses and poor construction technologies (Langer, 2011). Among these factors, heavy vehicle loads are the major source for pavement damage. The magnitude and configuration of vehicular loads, together with environmental factors, have a significant effect on induced tensile stresses within flexible pavement (Yu, *et al.*, 1998). Figure 2 shows a typical load dispersion in a road pavement.

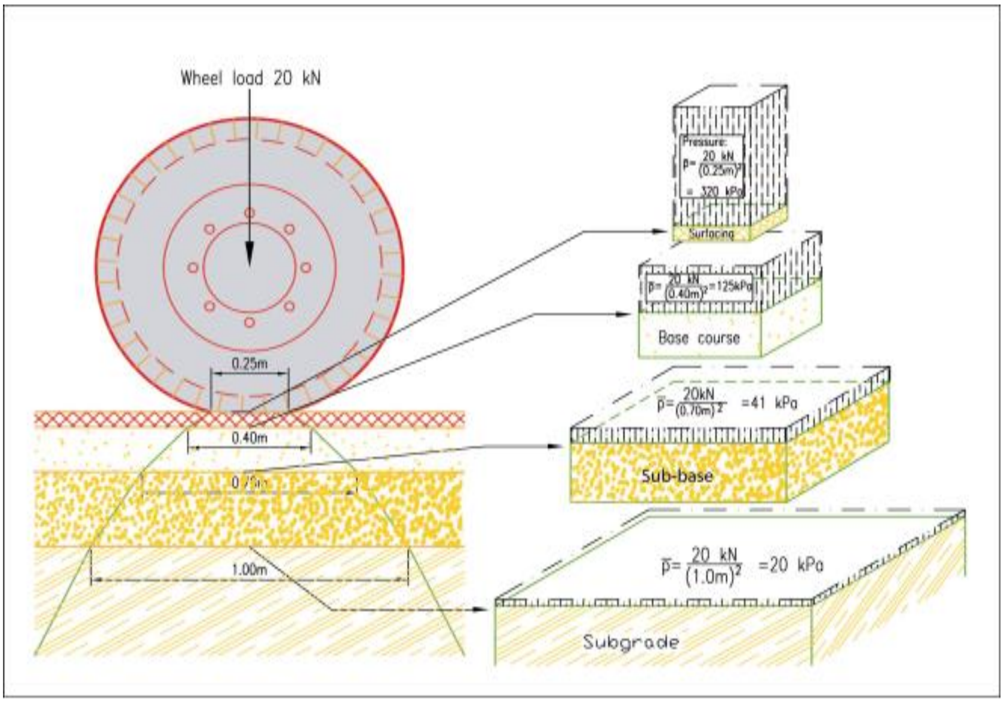

Figure 2: Typical load spreading in a flexible road pavement. Source: Botswana Roads Department (2005): Page 12

The structural damage to a pavement caused by static wheel loads is given by an empirical equation, Equation 2. This is reflected in the system used for determination of design loading, where the damaging effect of an axle loading follows an exponential function which was derived from the American Association of State Highway Officials (AASHO) Road test. This road test, carried out in Illinois, United States of America (USA) in the middle of the 1950s to the early 1960s led to the well-known Power Law (Kolo, *et al.*, 2014). This was the first systematic attempt to quantify the relationship between the axle load and the damage caused to the road.

The experiment involved allowing vehicles of various axle loads to travel along different sections of road and comparing the number of load repetitions applied to the road before a defined level of distress in the pavement was reached. This work resulted in the equivalency formula, Equation 1:

$$C = \left(P/_{80}\right)^{\alpha} \tag{1}$$

Where

C = 80 kN Equivalent Factor,
**P** = Load of a single axle in kN = Mass in kg x (9.81/1000}
**α** = Influence coefficient where,
*α = 1.0 for medium goods vehicle and buses*
*α = 2.0 for 2 axles & tandem*
*α = 6.0 for truck with drawbar trailer or articulated trucks*

The damaging power of overloads is given by Equation 2.

$$100\text{x}((1+ \text{ per cent Overload}/100)^4 - 1) \tag{2}$$

The reduction in pavement life due to overloading is given by Equation 3.

$$100\text{X}\left(\frac{\text{per cent increase in damaging power}}{100 + \text{ per cent increase in damaging power}}\right) \tag{3}$$

For an α value of 4.0 (generally used in many countries), the effect of 5 per cent overload would result in a 100 $(1.05^4 - 1)$ per cent increase in damage and 100 (22/ (100+22)) per cent reduction in pavement life, being 22 per cent and 18 per cent, respectively. Table 4 shows effects of overloads rates of 10 to 40 per cent, based on a 20 year pavement working life. This is also demonstrated in Figure 3.

Table 2: Overloading Vs Pavement Life

| S/N | Per cent Overload on Standard Axle | Per cent Increase in Damage | Working Life of Twenty Year Pavement Reduced to (years) |
|---|---|---|---|
| 1 | 10 | 45 | 13.8 |
| 2 | 20 | 105 | 9.8 |
| 3 | 30 | 185 | 7.0 |
| 4 | 40 | 285 | 5.2 |

Source: Author (2015)

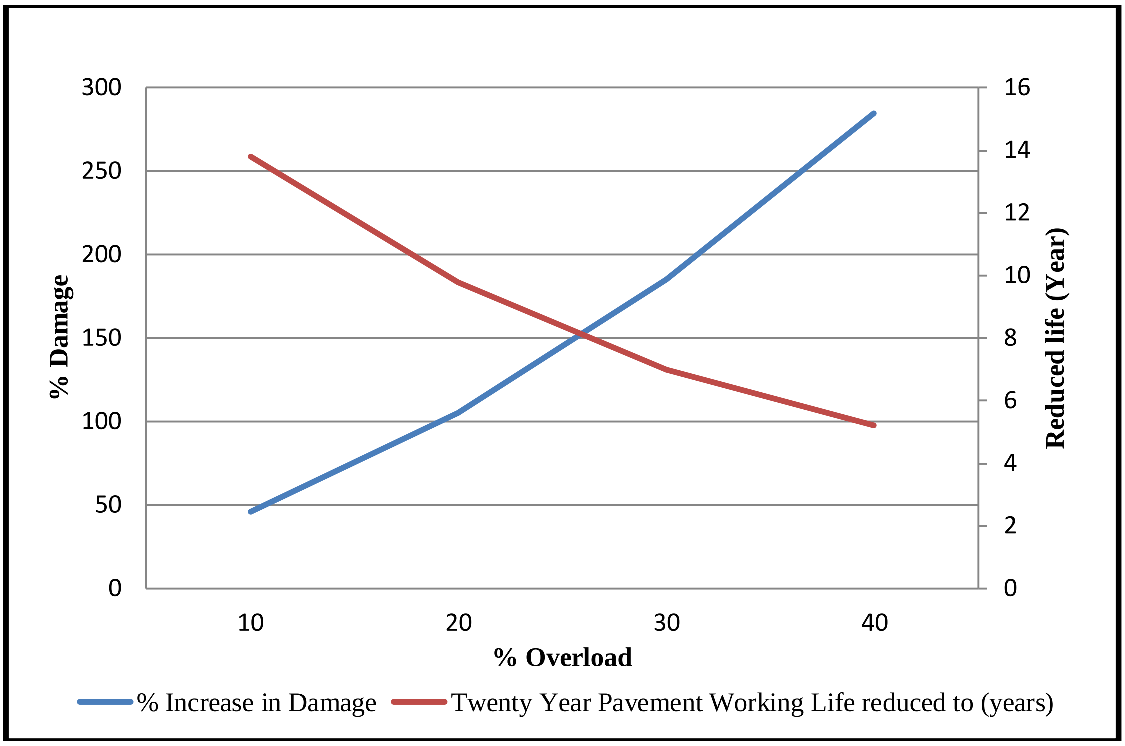

Figure 3: Damaging effect of overloading. Source: Author (2015)

The above findings are in agreement with the results of a study by the International Road Dynamics Inc. that established that 10 percent increase in weight can accelerate pavement damage by over 40 per cent (Karim, *et al.*, 2013). Therefore, the damage caused by overloading rises exponentially with each additional ton of axle load, and this reduces the life of a road substantially (African Development Bank Group, 2014). In fact it has been proved that damage increases sharply as the axle load exceed 1.5ton and that is the reason why vehicles of weight over that value are usually considered (Kolo, *et al.*, 2014).

The axle and axle unit loads are controlled by direct limits, while the loads on groups of axles and on vehicles (and vehicle combinations) are controlled by a bridge formula.

Bridge Formula: $P = 2100 \times L + 1800$ (4)

where:

$P$ = Permissible mass (kg)

$L$ = Distance between centres of outer axles

Pavement condition rate over a given life span is given by Equation 6

$PCR= 100-0.76 (Age)^{1.75}$ (5)

where

PCR is the Pavement Condition Rate. Figure 4 gives the variation of PCR with age for a 20 year design life span.

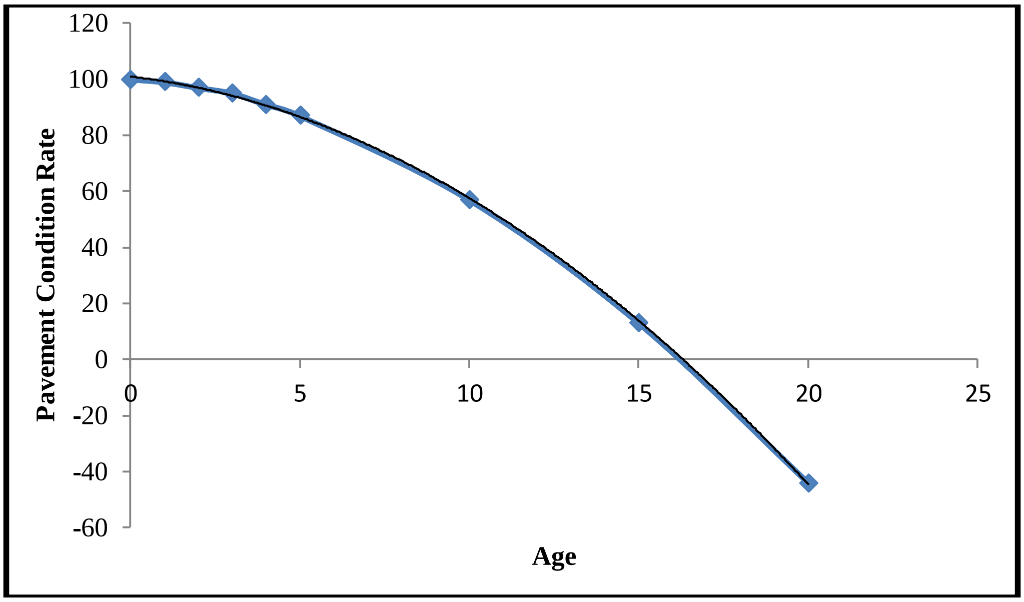

Figure 4: Variation of Pavement Condition Rate with Pavement Age. Source: Author (2015)

Figure 5 shows typical road deterioration and relative cost of intervention. The figure indicates that even without overloading, preventive maintenance should be executed over15 years from the time of construction of the road, to ensure fair condition of road.

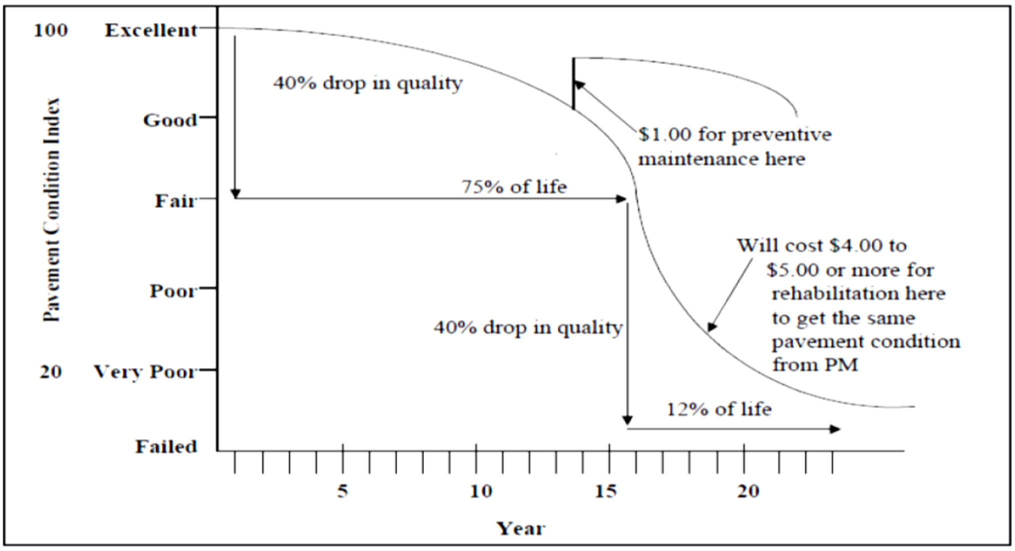

Figure 5: Typical pavement deterioration curve (Source: Hicks, et al., (2000)

## 2.5 Effect of vehicle overload on cost of road maintenance

A large portion of the road authorities' budgets are allocated to road maintenance but relatively little effort is spent on controlling the primary source of road damage - overloaded HGVs (Nordengen and Hellens, 2010). Overloaded HGVs pose serious threats to road transport operations, with increased risks for road users, deterioration of road safety, severe impacts on the durability of infrastructure (pavements and bridges), and on fair competition between transport modes and operators (Jacob and Beaumelle, 2010). The additional weight carried by overloaded trucks accelerates the deterioration of the roadway, leading to rutting, fatigue, and in some cases structural failure. In a 1990 report, illegally loaded trucks were estimated to cost USA taxpayers US$160 to US$670 million per year on the highway system (Bushman, *et al.*, 2003). Podborochynski *et al.* (2011) quantified incremental pavement damage caused by overloaded trucks in Saskatchewan, Canada and reported that accelerated damage from truck overloading had decreased the expected performance life of many of the roads and also increased maintenance and rehabilitation requirements and costs.

According to Ahmad (2002) as cited by Muhamed (2010), maintenance is always a must for any structure in order to maintain its serviceability and to prevent deterioration that may shorten the service life. The International Road Federation pointed out that many developing countries operated on tight budgets in which roads were considered low in priority. The African continent is known to invest about US$5 billion annually to build and maintain roads, which although substantial, falls way below the minimum requirement of US$20 billion per year to provide adequate road infrastructure (Tembo, 2010). According to the RDA's Maintenance Needs Report on the CRN (2012), a minimum amount of US$721 million is required annually for maintenance activities to bring the road network to maintainable condition between 2012 and 2016 in Zambia. However, Zambia's road fund receives only US$160 million a year for road maintenance (Freeman, 2014). Yet Zambia is said to be one of the few countries in the region with a road sector budget in excess of what is needed to maintain the main road network, and adequate to address the rehabilitation backlog (Foster and Dominguez, 2010).

From the above it is evident that the need for road maintenance is widely recognized, though it is still not given first priority in most developing countries. Most countries spend only about 20 to 50 per cent of what they should be spending on maintenance of their road networks (TRN- 4, 2005).

## 2.6 Road Maintenance Management

CRAB (2007) guided that an overview of maintenance management can be presented as shown in Figure 6, which includes planning, organizing, directing and controlling:

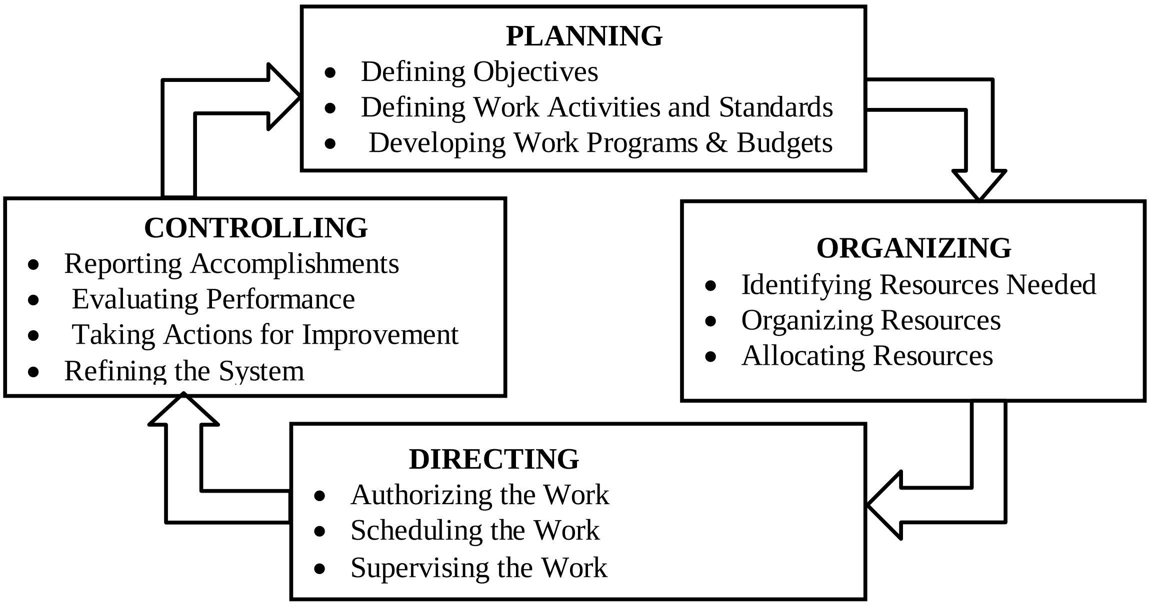

Figure 6: Overview of maintenance management. Source CRAB (2007)

They further elaborated the elements of maintenance management, as follows:

- Planning maintenance activities based upon the road features to be maintained, the resources (labour, equipment and materials) needed, and the level of service to be achieved by the maintenance. This includes preparing budgets based upon maintenance performance standards to define the specific types and amounts of maintenance work.
- Organizing the labour, equipment and material resources to ensure that planned maintenance activities can be accomplished with the budget available.
- Directing maintenance operations by authorizing, scheduling and supervising maintenance activities and preparing the annual, seasonal and short-term schedules needed for guidance.
- Controlling maintenance operations by monitoring work accomplishment and expenditures, to ensure that planned work programs are actually achieved within available resource levels.

At the moment, RDA plans, manages and coordinates the road network in Zambia whilst NRFA coordinates and manages road financing. The Committee of Ministers on Road Maintenance Initiative (RMI) oversees activities in the road sector and gives overall policy guidance. It considers "funding requests from implementing agencies" and recommends the Road Sector's Annual Work Plan to Parliament, for approval (Leiderer, *et al*., 2012).

Through a systematic method of road and bridge data inventory and data collection, the RDA will have up-to-date information for decision making on maintenance priorities for both roads and bridges including minor and major culverts (RDA, 2015).

Routine and emergency maintenance of the Core Road Network is carried are out by contractors. Although the RDA generally carries out its work by contractors, 10 per cent of its annual budget is spent on force account work, usually in areas that are not attractive to contractors or in emergencies (Leiderer, *et al*., 2012). Figure 7 shows that the budget allocations for road maintenance fall far below the maintenance needs.

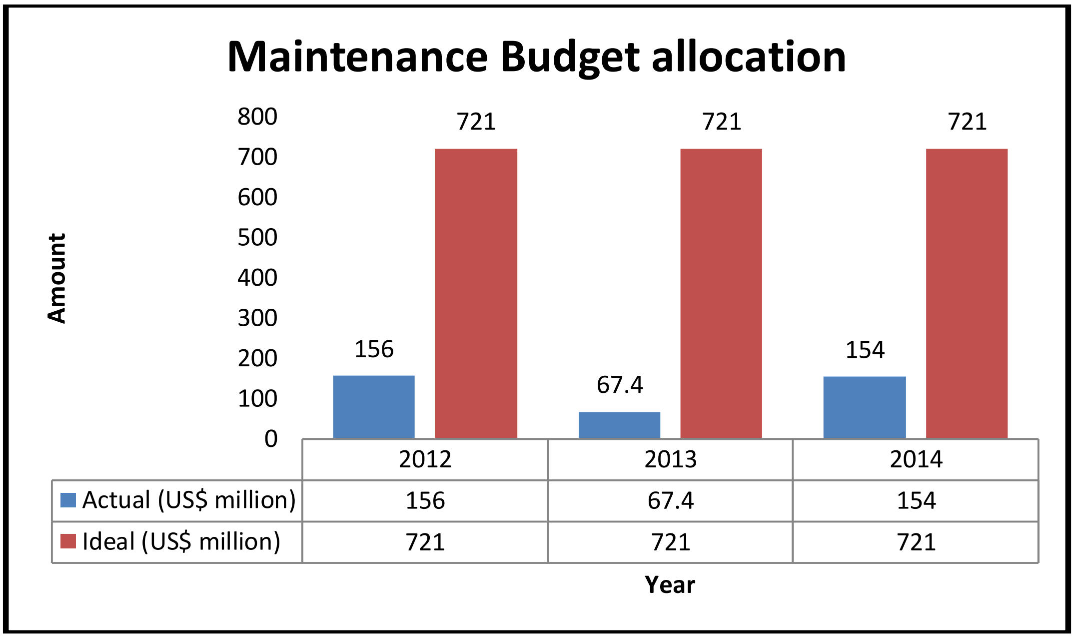

Figure 7: Maintenance Budget Vs Actual releases. Source: RDA (2014)

## 3 DATA COLLECTION

The study aimed at understanding the effect of vehicle overloading on maintenance management of Trunk Roads in Zambia. Thus, reports from RDA and NRFA and other road agencies were reviewed. In addition to reports, some of the sources of information included interviews with; Senior Management and Engineers responsible for the planning, design, road safety and maintenance of public roads in Zambia including that responsible for Axle Load Control, Weighbridge operators and Transporters who includes vehicle owners and drivers.

## 4 RESULTS

Table 3 shows that there are currently eight fixed weighbridges in Zambia.

Table 3: Weighbridge distribution across Zambia's Trunk and Main Roads

| S/N | Trunk Road Name | Number of Weighbridges | Location |  | Status | Comments |
|---|---|---|---|---|---|---|
|  |  |  | Site Name | Province |  |  |
| 1 | T1 | 01 | Livingstone | Southern | Operational | Electronic Single Deck |
| 2 | T2 | 03 | Kafue<br>Kapiri Mposhi<br>Mpika | Southern<br>Central<br>Northern | Operational | All Electronic<br>Kafue and Mpika - Single deck<br>Kapiri -Multideck |
| 3 | T3 | 01 | Kafulafuta | Copperbelt | Closed for Rehabilitation | Manual.<br>Closed since 17th December,2014 |
| 4 | T4 | 01 | Mwami Border | Eastern | Operational | Manual |
| 5 | T5 | 01 | Solwezi | North Western | Closed for Rehabilitation | Electronic, Single Deck<br>Closed since18th May 2015 |
| 6 | T6 | 0 | - |  | - | - |
| 7 | M10 | 01 | Kazungula | Southern | Operational | Electronic Single Deck |

Source: Author (2015)

## 5 DISCUSSION AND INTERPRETATION OF RESULTS

From Table 3, it can be seen that out of the eight weighbridges, only six are operational. It has further been established that Nakonde weighbridge was under private hands and was used on a commercial basis rather than for enforcement. Indications are that the RDA had plans of using the same private weighbridge for enforcement whilst in the process constructing their own.

The ALCP set the target of reducing the rate of overloaded vehicles from greater than 20 per cent to five per cent or less, for the axles or in relation to the GVM from greater than 55 per cent to less than five per cent (Bouveyron, *et al.*, 2006). According to the RDA (2015), this target has been achieved with the 2014 figures indicating that the average overload on both axles and GVM was 2.38 per cent of a total number of 780,690 HGVs weighed at the eight fixed weighbridges. This however is not so representative over the entire length of trunk roads considering non-uniform spread of weighbridges which makes it impossible to capture the entire traffic on trunk roads. Of course, overloaded vehicles that bypass the weighbridges or use alternative routes cannot be accounted for.

Construction of an additional two weighbridges at Mumbwa and Chongwe on M9 and T4, respectively is underway and several other suitable sites have been identified for construction of weighbridges along the CRN. It is important to note that weighbridges are placed where the greatest impact on reducing overloading can be achieved i.e., where heavy vehicle traffic volumes are the highest and/or the extent of overloading is the highest. However, not all roads in Zambia with the highest HGV traffic have weighbridges (Point No. 76, 66A, 3, 4, 71, 78 and 46 in the Table 3). The RDA is considering self-regulation, whereby transporters would be required to monitor their own vehicle loads, at origin and/or destination, to facilitate Axle Load Control. Further, the RDA is constructing rigid pavements at permanent check points, to reduce on pavement damage, mainly in form of rutting currently being experienced at such sections.

RDA contracts out road condition surveys, the results of which are used as a basis for prioritising maintenance of roads. In the absence of updated survey reports, the RDA prepares a priority lists of roads that require maintenance through their Engineers based at regional offices. Prioritisation of maintenance works is also influenced by political decisions. The results so far indicate that axle load data at weighbridges is not used in the analysis of damage to the pavement at particular sections. However, some consultants have been using the data for pavement design purpose. It was further discovered that ALCP activities are viewed more of a revenue raising measure rather than a preventive maintenance one.

## 6 CONCLUSION

- The effects of overloading are recognized worldwide and in Zambia
- Overload control programmes are based on Axle Load and GVM, and in Zambia the ALCP has managed to reduced overloading to below 5%
- Self-regulation can result in enhanced management of overloading on roads
- Weigh bridge data is hardly being used for design, maintenance and management of the road network in Zambia

## 7 RECOMMENDATIONS

- The government should deliberately encourage transportation of bulk cargo by other modes of transport like rail.
- Self-regulation by transporters should be encouraged, to enhance the overload control programme and Transporters should invest in in-house weighbridges.
- 
- The construction of rigid pavement on road sections where stopping of HGVs for Axle Load Control and other regulatory purposes, should be continued.
- Research efforts on optimal axle loads for Zambian and regional roads should be intensified, to reduce the cost of maintenance.
- There is a need to actively utilise weighbridge data for pavement designs, and

real-time overload control on roads, bridges and other drainage structures.

- Weighbridge data and rate of overloading, together with other factors, should be utilized in determining pavement damage and to enhance maintenance management.
- The RDA should move to the use of Road Maintenance Management Systems, to supplement the existing methods of maintenance management.

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# GLOBAL AIR NAVIGATION PLAN

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## ABSTRACT

*Over the last decade, our state Zambia, Southern Africa Region and the world at large has experienced growth of air traffic. This has resulted into operational and procedural complexities in the use of conventional air traffic navigation. This rapid growth has also negatively impacted on the environment (noise and high levels of CO2). Therefore, the need to address this challenge based on a systematic approach to ensure safety, efficiency, regularity of air transportation system and environmental protection.*

*In order to address the rapid air traffic growth and its effects, International Civil Aviation Organization (ICAO) introduced an updated Global Air Navigation Plan (GANP). The GANP describes a technology and procedure based methodology called Aviation System Block Upgrades (ASBU). This system use harnessed technological and procedural systems like the Performance Based Navigation (PBN), Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO) to handle high air traffic levels.*

*This paper will describe how the implementation of GANP can overcome the challenge of rapid air traffic growth and its negative environmental effects. The achievable results will be measured in form of qualitative key performance areas (KPA) that consist of access, capacity, efficiency, safety and environmental aspects. And PBN concept will be discussed as an important component of the GANP.*

***Keywords:*** *GANP, PBN, CCO, CDO, Air Traffic, Safety, Efficiency and Environment.*

## 1 AIR TRAFFIC GROWTH

Air transport today plays a major role in driving sustainable economic and social development. It directly and indirectly supports the employment of 56.6 million people, contributes over $2.2 trillion to global Gross Domestic Product (GDP), and carries over 2.9 billion passengers and $5.3 trillion worth of cargo annually. But even as air transport’s speed and efficiency significantly facilitate economic progress, its growth under certain circumstances can be a double-edged sword. Though a sure sign of increased living standards, social mobility and generalized prosperity on the one hand, unmanaged air traffic growth can also lead to increased safety risks in those circumstances when it outpaces the regulatory and infrastructure developments needed to support it. (International Civil Aviation Organization, 2013).

As shown in **Figure 2.1** there is a continuous and rapid growth of air traffic globally in the past decades. (Minto’o, 2014 November).

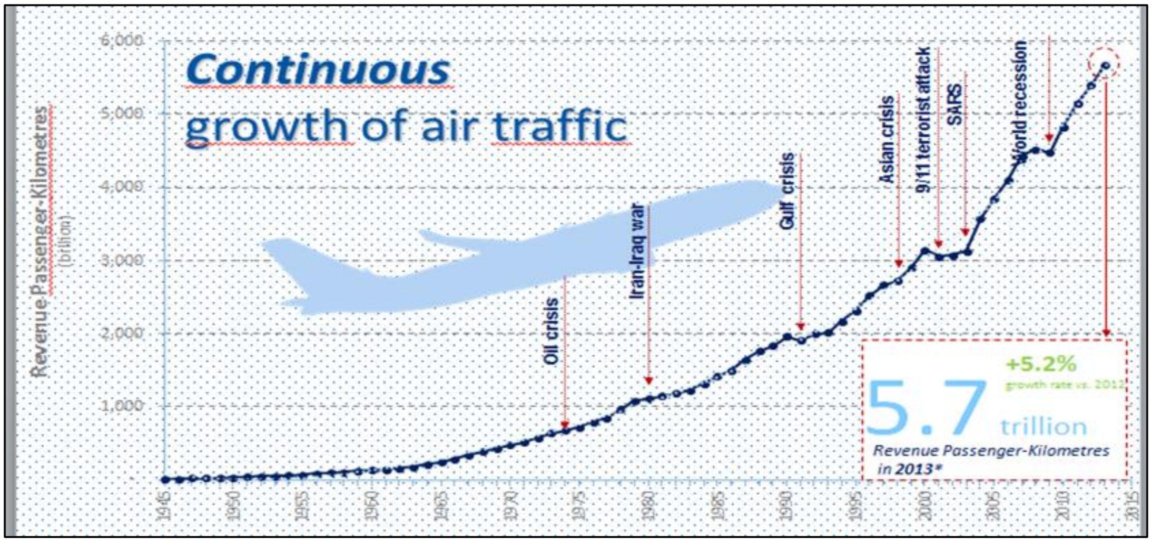


Figure 1.1 Rapid Air traffic Growth

For example in Zambia 1,086,533 passengers passed through the four international airports in 2010. And there was a sharp increase four years later, 1,575,331 passengers passed through the boarding gates of the four airports denoting an increase in the number of flights using the Zambian air space. (Zambia Airport Corporation Limited, 2015).

In order to manage such rapid air traffic growth in globally harmonized way, ICAO has developed the Global Air Navigation Plan to:

- Provide clear guidance on the operational targets and supporting technologies, avionics, procedures, standards and regulatory approvals needed to realize them.
- Establish a framework for incremental implementations based on the specific operational profiles and traffic densities of each State.

This will be accomplished through a system called Aviation System Block Upgrades (ASBUs), (Minto'o, 2014 November).

## 1.1 ASBU Methodology

An Aviation System Block Upgrade (ASBU) designates a set of improvements that can be implemented globally to enhance the performance of the Air Traffic Management (ATM) system. As shown in **Figure 2.2** there are four Performance Improvement Areas which are:

1. Airport Operations,
2. Globally Interoperable Systems and Data
3. Optimum Capacity
4. Flexible Flights and Efficient Flight Paths

Which are under blocks 0 to 3. Under these blocks there are modules that show the systems to be implemented respectively in a specified period.

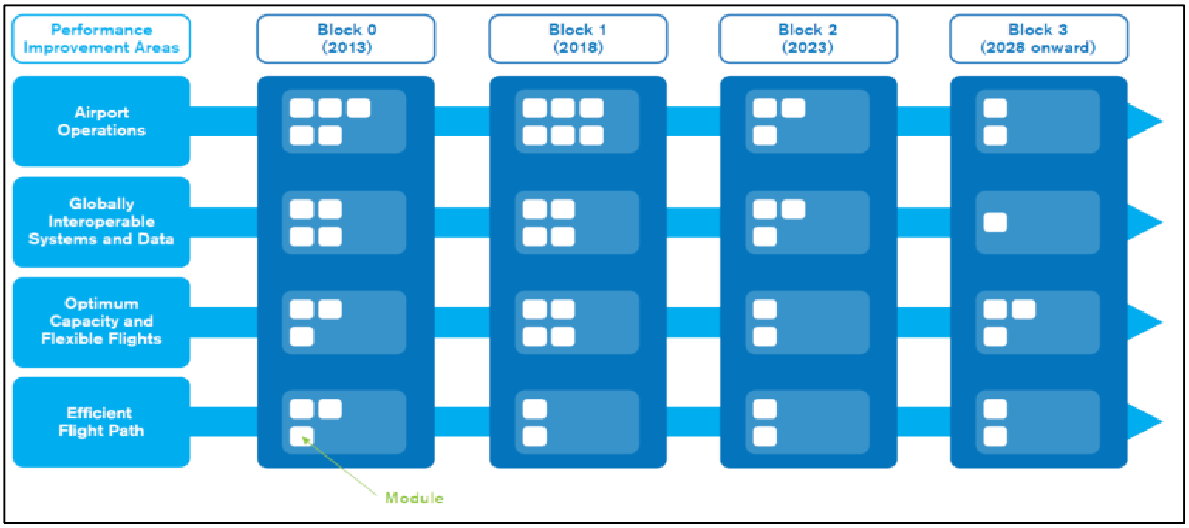


Figure 1.2 ASBU BLOCKS

The implementation process driven by the ASBU module elements will enable all States and stakeholders to realize the goals of global-harmonization, increased capacity, and environmental efficiency in a unified manner.

The Global Air Navigation Plan’s aviation system Block Upgrade methodology is a programmatic and flexible global system engineering approach that allows all Member States to advance their air navigation capacities based on their specific operational requirements. The Block Upgrades will enable aviation to realize the global harmonization, increased capacity, and improved environmental efficiency that modern air traffic growth now demands in every region around the world. (International Civil Aviation Organization, 2013)Some of the systems which are priority in the GANP are: Performance Based Navigation (PBN), Continues Descent Operations (CDO) and Continues Climb Operations (CCO). Many major airports like OR Tambo in South Africa now employ PBN procedures and, in a large number of cases, judicious design has resulted in significant increased capacity, safety and reductions in environmental impacts. This is particularly the case where the airspace design has supported continuous descent operations (CDO) and continuous climb operations (CCO).

Block Upgrade Modules will serve to assist in the effective implementation of performances like PBN. Let’s now discuss PBN concept and its benefits to Air Traffic Management, Airlines, Air Navigation Service Providers and the community in comparison to the conventional navigation.

# 2 AIR NAVIGATION

## 2.1 Conventional Navigation Procedures

Air navigation is the process of guiding an aircraft from one place to the other until it reaches its final destination safely. Currently many countries and their air spaces are using conventional navigation procedures.

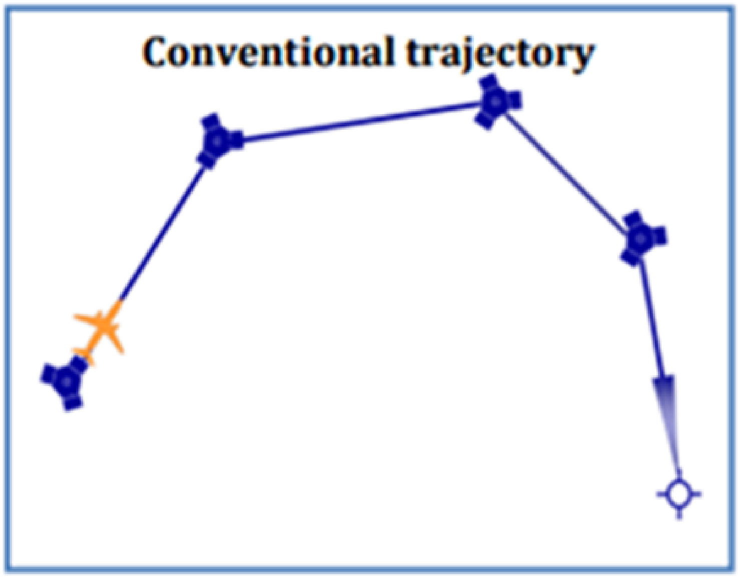


Figure 2.1 Conventional Navigation Route

In convention navigation procedures the aircraft navigates in a zigzag way from one ground air navigation site to the other as shown in **Figure 3.1**.

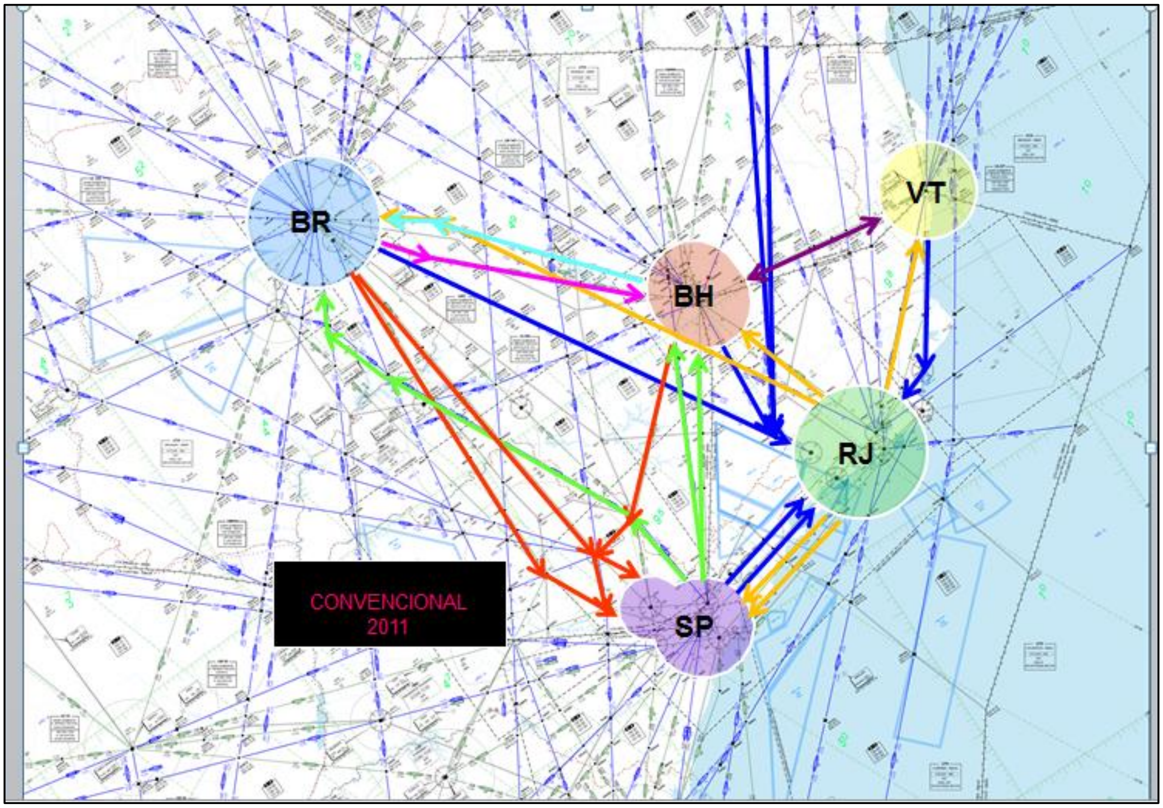


Figure 2.2 Conventional Air Navigation routes

In this type of navigation air traffic controllers provide a large amount of air space around the aircraft and routes cross each other on many points as shown in **figure 3.1**. Currently this type of navigation and its procedures has experienced a lot of complexities and challenges due to the rapid air traffic growth. This has caused air traffic controllers to work under a lot of stress hence compromising on safety. These procedures use long routes making aircraft fly prolonged hours hence increased CO2 emissions. And this has caused a lot of damage to the environment.

## 2.2 Performance Based Navigation

**PBN** is the latest concept in air navigation that provides precise, predictable and repeated satellite navigation. It is an area navigation based on performance requirements for aircraft operating along an Air Traffic Service route, on an instrument approach procedure, or in a designated airspace. Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. In this type of navigation routes are straight and are in parallel therefore increasing capacity as shown in **Figure 3.2**.

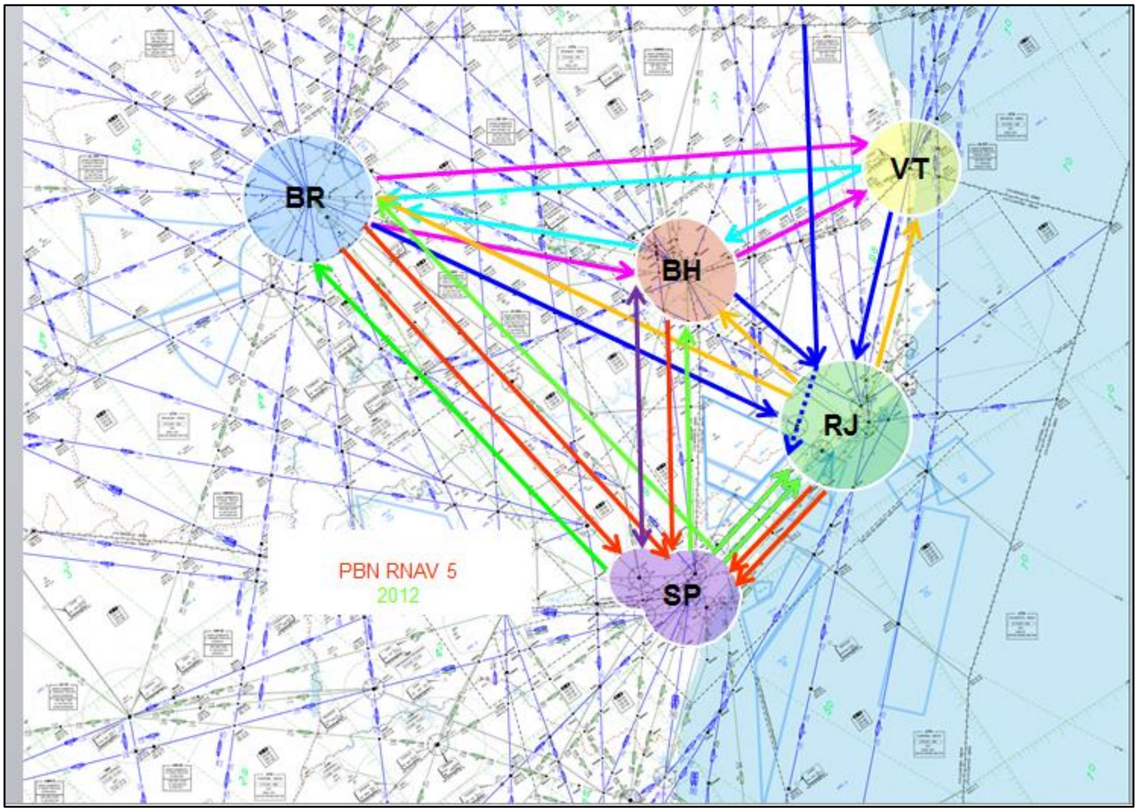


Figure2.3 Performance Based Navigation Routes

PBN is that air traffic service routes, no longer have to pass directly over ground-based NAVAIDs as shown in **Figure 3.4**. As a result, routes can be placed where they give flight efficiency benefits by avoiding conflicts between flows of traffic. Also the routes are shorter than those in conventional navigation.

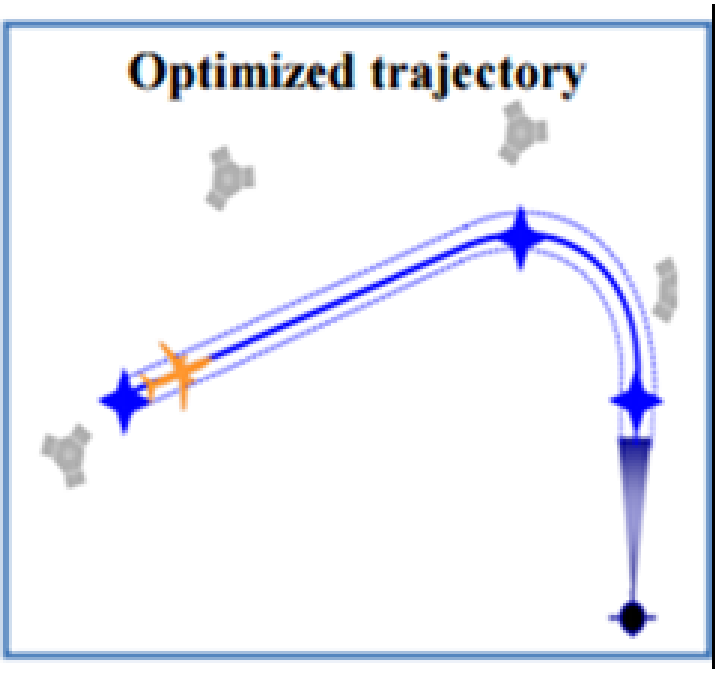


Figure 2.4 PBN Route

## 2.3 Benefits of PBN

- It allows for more **efficient** use of airspace (route placement, fuel efficiency and noise abatement.)
- Improved airspace **capacity** by used of better managed and defined shorter, more efficient routings in complex airspace.
- Parallel routes can be designed to avoid having bi-directional traffic on the same route, and to provide various options between same origin and destination airports. Most significantly, this placement benefit provided by PBN can ensure efficient connectivity between en-route and terminal routes to provide a seamless (vertical) continuum of routes. Increased **capacity** (www.canso.org)
- Narrow air space around flight paths increases air **capacity**.
- Potential introduction of flight path monitoring/alerting tools for controllers enhance **safety**.
- Reduction in complexity and variability of procedural approach control.
- The transition to a PBN environment is linked to a Global Navigation Satellite System (GNSS)-based service and a move away from traditional ground based NAVAIDS. This allows for a rationalization of infrastructure and subsequent savings in capital investment and maintenance, with savings passed onto the operators through reduced navigation services charges and a requirement to carry less equipment.
- Flexible route structures which allow for more efficient flight paths and result in reduced fuel burn and emissions

As seen PBN contributes greatly contributes to the achievement of the GNAP objectives measured by the key area performances like efficiency, capacity and safety.

Once PBN procedures are designed in a particular air space it becomes possible introduce CCO and CDO procedures.

## 2.4 CCO and CDO Procedures

CCO is an aircraft operating technique enabled by airspace design, procedure design and facilitation by Air Traffic Control (ATC), enabling the execution of a flight profile improved to the performance of the aircraft. The optimum vertical profile takes the form of a continuously climbing path. (Silva, 2012 August). Unlike the conventional navigation where an aircraft takes a step by step climb. **Figure 3.5** shows the difference between the conventional departure operation and the CCO.

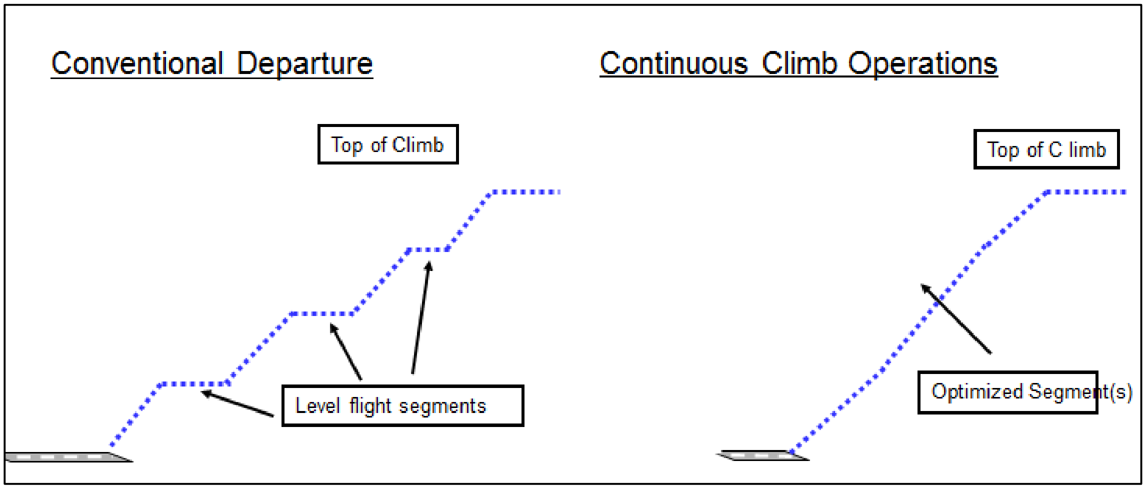


Figure 2.5 CCO compared with conventional take off

CCO does not require a specific air or ground technology, but rather is an aircraft operating technique aided by appropriate airspace and procedure design. Operating at optimum flight levels is a key driver to improve fuel efficiency and minimize carbon emissions as a large proportion of fuel burn occurs during the climb phase.

CCO enables an aircraft to reach and maintain its optimum flight level without interruption will therefore help to optimize flight fuel efficiency and reduce emissions. CCO can provide for a reduction in noise, fuel burn and emissions, while increasing flight stability and the predictability of flight paths for both controllers and pilots. (SEMINAR, 2014)

The optimum climb gradient will vary depending on:

- Type of aircraft,
- Its actual weight,
- The wind,
- Air temperature,
- Atmospheric pressure,

Departure route designed to allow the crossing of other flows of traffic to one of more runways and one or multiple airports in the Terminal system, at ranges from the runway(s) that the crossing traffic flows will be naturally separated by height when climbing or descending along their optimum profile.

Pilot’s ability to conduct a CCO depends also on the ATC clearance to be followed, either tactically or by published procedures.

CDO works exactly like CCO but in the opposite direction as shown in **Figure 3.6**.

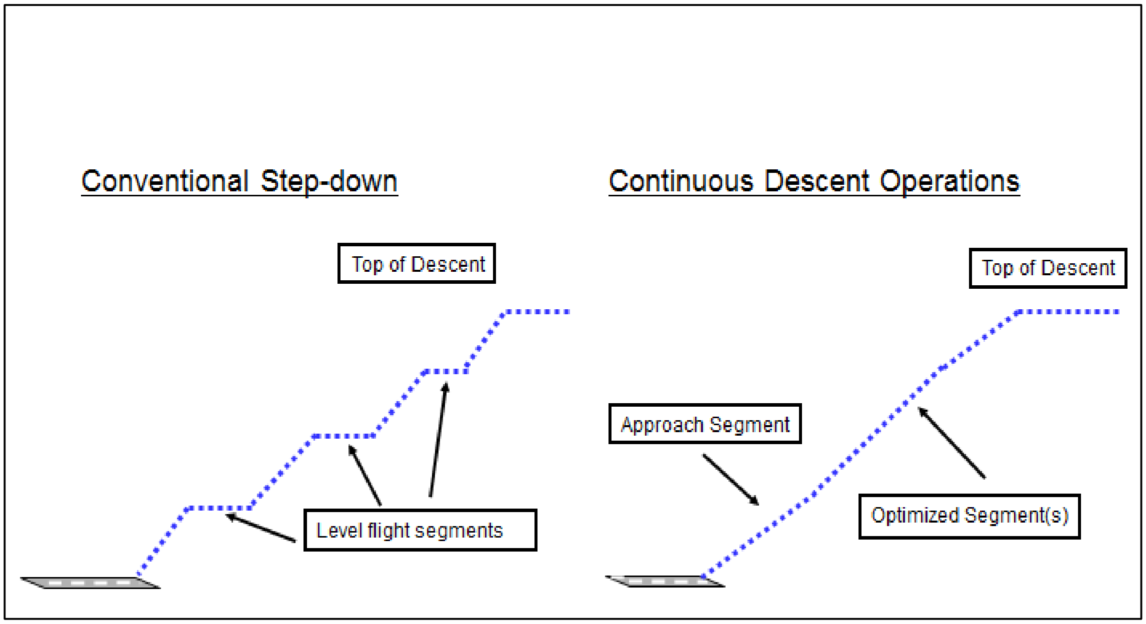


Figure 2.6 CDO compared with conventional approach

The CDO features optimized profile descents that allow aircraft to descend from the cruise to the final approach to the airport at minimum thrust settings.

CDO is enabled by airspace design, procedure design and ATC facilitation. In this procedure an aircraft descends continuously employing minimum engine thrust as compared to the conventional step- down procedure. (Silva, 2012 August) Figure 3.6 shows the comparison between the conventional step down descent and the continuous descent operation.

To quantify and measure the benefits of CCO and CDO in comparison with the conventional approach and departure, ICAO has come up with a tool called ICAO Saving Fuel Tool.

## 2.5 ICAO Saving Fuel Estimator Tool

The tool, Figure 3.7, was developed to be applicable globally with the ability to capture the difference in flight trajectory performance in terms of fuel consumption before and after implementation of operational improvements at local, regional or global level.

The tool is to assist the States to estimate and report fuel savings consistently with the models approved by ICAO’s Committee on Aviation Environmental Protection (CAEP) and aligned with the Global Air Navigation Plan. (ICAO, 2011)

**Figure 3.8** shows IFSET results on the amount of fuel saved after the implementation of PBN procedures. This result shows reduced amount of fuel consumed hence, cheaper operation and less CO2 emissions on the environment.

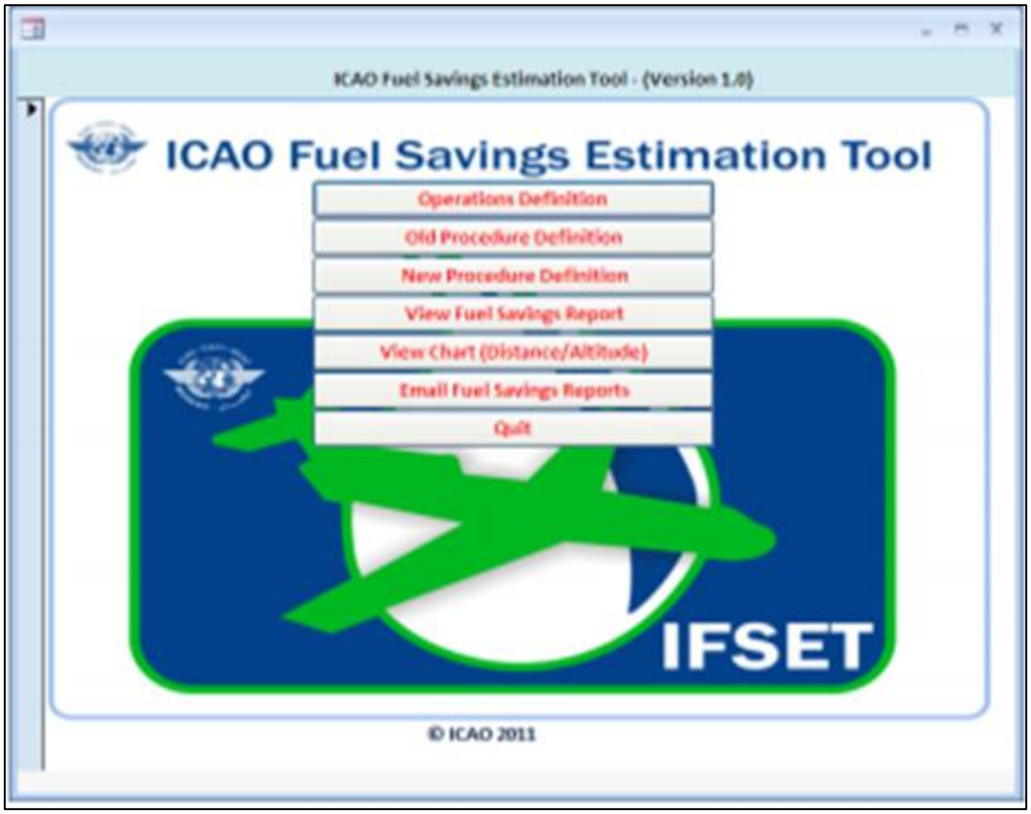
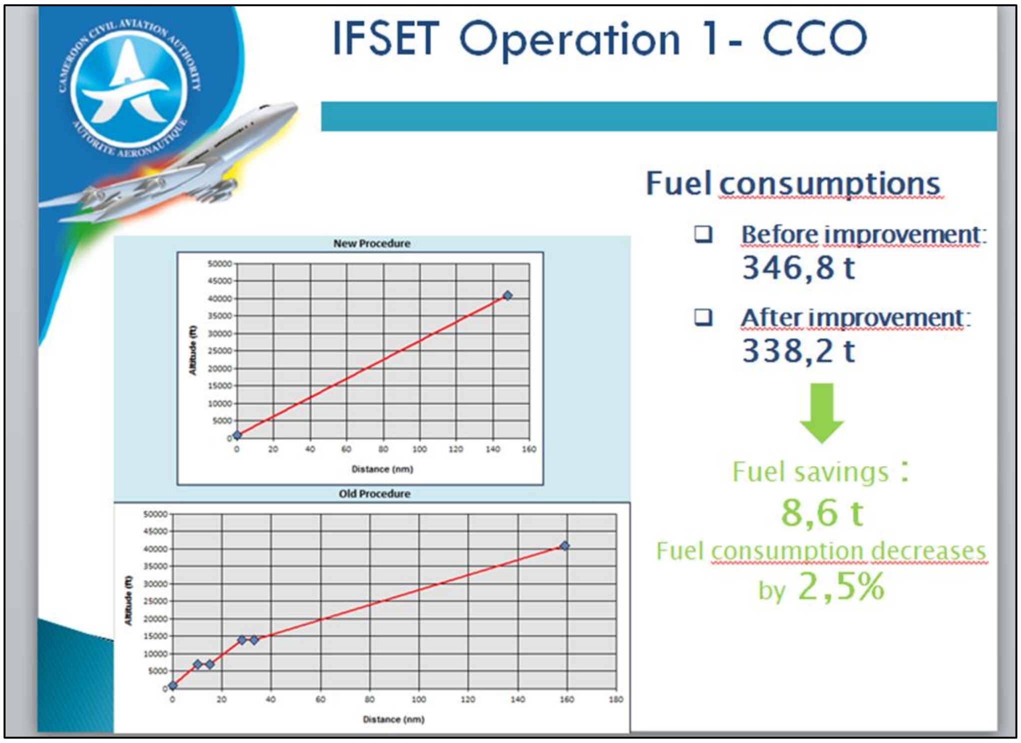


Figure 2.7 ICAO Fuel Saving Estimator Tool



IFSET Operation 1- CCO

Fuel consumptions

- ☐ Before improvement: 346,8 t
- ☐ After improvement: 338,2 t

Fuel savings : 8,6 t

Fuel consumption decreases by 2,5%

Figure 2.8 ICAO Saving Fuel Estimator Graph

Besides the significant fuel savings this achieves, CDO has the additional environmental benefit of decreasing airport/aircraft noise levels derived from less thrust employed significantly benefitting local communities

**Operating efficiency** – PBN procedures have been used to reduce track miles, fuel burn, flight time, voice communication, and pilot workload, as a result of the benefits outlined above. Communities Reduction in CO2 Emissions - The ability of PBN to provide shorter route length or vertical windows supporting CDO/CCO allows more fuel efficient profiles to be flown. The flexibility of PBN procedure design allows aircraft to fly similar profiles in instrument meteorological conditions (IMC) as they have done previously only in visual conditions. Between 2007 and 2009, Qantas Boeing 737-800s flew approximately 20,000 RNP AR approaches across Australia. During this period, they saved 59,000 track miles (up to 17.3 NM per flight), 737,000 kg of fuel; and 2.36 million kg of CO2 15 Reduced impact of aircraft noise – Continuous descent allows aircraft to keep engines near flight idle and to deploy flaps and landing gear later, reducing the noise impact. Curved 'RF' legs also allow noise sensitive areas to be avoided by placing flight paths over areas such as motorways and industrial parks, which can significantly reduce the number of people exposed to aircraft noise.(www.canso.org)

Enabling an aircraft to reach and maintain its optimum flight level without interruption will therefore help to optimize flight fuel efficiency and reduce emissions.

**Payload benefits** - Flexibility in PBN procedure design can grant significant payload benefits to airlines. As part of the original Australian PBN procedures trial, airlines increased payloads at some terrain-challenged airports by up to five tons by using a PBN procedure that takes advantage of tighter obstacle clearance criteria. Utilize aircraft capability - Some airlines maintain that although they invest significant sums of money in cutting-edge technology for new aircraft, an air traffic management (ATM) system that uses conventional navigation procedures does not allow modern flight-deck technology to be fully utilized. The PBN environment allows the airlines to harness more of their fleet's navigation capabilities, and can offer significant airspace capacity and environmental benefits. The concept of 'service priority' may add pressure on less well-equipped airlines to upgrade, or be faced with exclusion from certain routes or procedures. Smaller operators that choose to upgrade may also benefit from improved access and reduced delays, and with improved safety. (www.canso.org)

In order for this to be fully implemented, ATM tools and techniques, especially arrival and departure management tools, have to be implemented and/or updated to ensure that arrival and departure flows are smooth and appropriately sequenced.

## 3 CHALLENGES

Implementation of this determined global programme is not short of challenges. In general, challenges emanates from among the technological, operational and procedural aspects of implementation. These challenges include:

- Often inappropriate financial commitment to procure facilities, equipment and installation to facilitate ground based technologies.

- Lack of upgrade of aircraft equipage.
- Capacity for development of procedures.
- Approval of procedures.
- Initial and recurrent training of operational, technical and regulatory personnel tasked with the implementation of national air navigation plan (GNSS/RNAV procedures).

## 4 CONCLUSION

In line with the ICAO objectives if we all work towards the implementation of GANP by the use of the ASBU methodology by 2028 our skies will be well managed and the following will be achieved:
- Enhance global civil aviation safety by managing the high traffic levels.
- Increase capacity and improve efficiency of the global civil aviation system.
- Foster the development of a sound and economically-viable civil aviation system.
- Minimize the adverse environmental effects of civil aviation activities.

The GANP and its implementation involves highly advanced and sophisticated technology which shows that success of this plan entirely rests on the shoulders of engineers.

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# SESSION 3B

# INFRASTRUCTURE DEVELOPMENT

# The use of rain data derived from Remote Sensing for design of hydraulic infrastructures: A case of the Chibombe Bridge

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## Abstract

*The design of infrastructures interacting with water bodies (rivers, lakes, etc.) is directly connected with the availability of data related to hydrologic and hydrodynamic characteristics of the water body itself. For instance, the design of a bridge crossing a river needs the knowledge of the design water level of the river in the section where the bridge is located, the correlated current speed, in case of flooding the area covered by the flood, etc.*

*Usually these data are directly derived from the correlation, among rain and runoff over the catchment basin closed to the section of interest, and the flow evaluated at the section of interest. This relation is often described by equations or, in the most complex cases, by mathematical models.*

*Looking at these parameters, the basic data is rainfall, with its characteristics of intensity and duration. Usually networks of rain gauges have been established in the past; so many years of recorded data are now available and can be used for these kinds of evaluations. There are some countries in the world, including Zambia, where the density of population is very low and in the past there was no need to measure rain with high spatial resolution.*

*Nowadays some of these countries are facing an increase in development, mainly but not only in the transport infrastructure, and this obviously implies the need for new infrastructure like bridges, etc. However, there is few data available to design them in the proper and up to date way. To reduce the impact of design problems due to the lack of direct measurements, new data sources have been looked for and it was found that the one derived from the remote sensing data recorded from satellites has been found to be reliable data. One of the satellite missions mostly specialized in collecting rain data is TRMM.*

*In this article, the method applied to derive daily duration rainfall data for the country of Zambia, how it has been applied for the identification of the predictable maximum floods needed for the design of bridges and future developments to derive a more comprehensive data base is reported.*

***Keywords:*** *Rivers, hydraulic networks, Bridges, Remote sensing, NASA, Rain data processing, Rain-Runoff.*

## FOREWORDS

One of the most suitable possibilities to derive data in absence of local measurements is to derive the needed parameters from remote sensing. This technique can be applied in many observation fields like meteorology, land use, altimetric surveys, etc.

In recent years past, also rainfall measurements from satellite surveys were available. One of the spatial programs delivering rainfall data is Tropical Rainfall Measuring Mission (TRMM).

The TRMM was a joint mission between the U.S. National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA) to study rainfall for weather and climate research. It started in 1997 and officially came to an end on April 15, 2015 and produced over 17 years of valuable scientific data.

TRMM carried 5 instruments: a 3-sensor rainfall suite (PR, TMI, and VIRS) and 2 related instruments (LIS and CERES). TRMM delivered a unique 17-year dataset of global tropical rainfall and lightning. The TRMM dataset became the space standard for measuring precipitation, and led to research that improved the understanding of tropical cyclone structure and evolution, convective system properties, lightning-storm relationships, climate and weather modeling, and human impacts on rainfall. The data also supported operational applications such as flood and drought monitoring and weather forecasting.

TRMM provided some of the first space borne rain radar and microwave radiometric data that measured the vertical distribution of precipitation over the tropics in a band between 35 degrees north and south latitudes. Such information is greatly enhancing the understanding of the interactions between the sea, air and land masses which produce changes in global rainfall and climate. TRMM observations also help improve modeling of tropical rainfall processes and their influence on global circulation, leading to better predictions of rainfall and its variability at various time scales.

The TRMM observatory was launched into a near circular orbit of approximately 350 kilometers altitude with an inclination of 35 degrees and a period of 91.5 minutes (15.7 orbits per day). During August 2001, the TRMM altitude was raised to approximately 402.5 kilometers with a period of 92.5 minutes (15.6 orbits per day). In Figure 1 a picture representing the band covered by TRMM satellite is shown[1].

The Precipitation Processing System (PPS) is the data processing and science information system for TRMM and GPM.

The Earth Observing System Data and Information System (EOSDIS) serves as the long-term archive for all TRMM data products.

Data were recorded according to a grid, aligned with the planetary grid surface, with a spatial resolution of 0.25° x 0.25°.

Original daily rain data, from the web site of NASA, are available both in binary and Hierarchical Data Format (HDF) format. HDF was developed by the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign and is the selection for the common data format for EOSDIS. HDF manuals and software may be obtained via anonymous ftp at ftp.ncsa.uiuc.

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[1] The background of each picture in the present paper has been derived from **Google Earth**.

Figure 1: The band of Earth surface covered by TRMM measures (more intense the location of Zambia).

## THE GRID STRUCTURE OVER ZAMBIA

From the planetary grid structure, data recorded are referred to; a specific subset was processed to extract rain data related to Zambia (Figure 2). To simplify the management of data, the subset was extracted considering the regular area (a rectangle, in plain terms) included among minimum and maximum latitude and minimum and maximum longitude of the Zambian borders.

Figure 2: Location of the subset of the planetary grid referred to Zambia

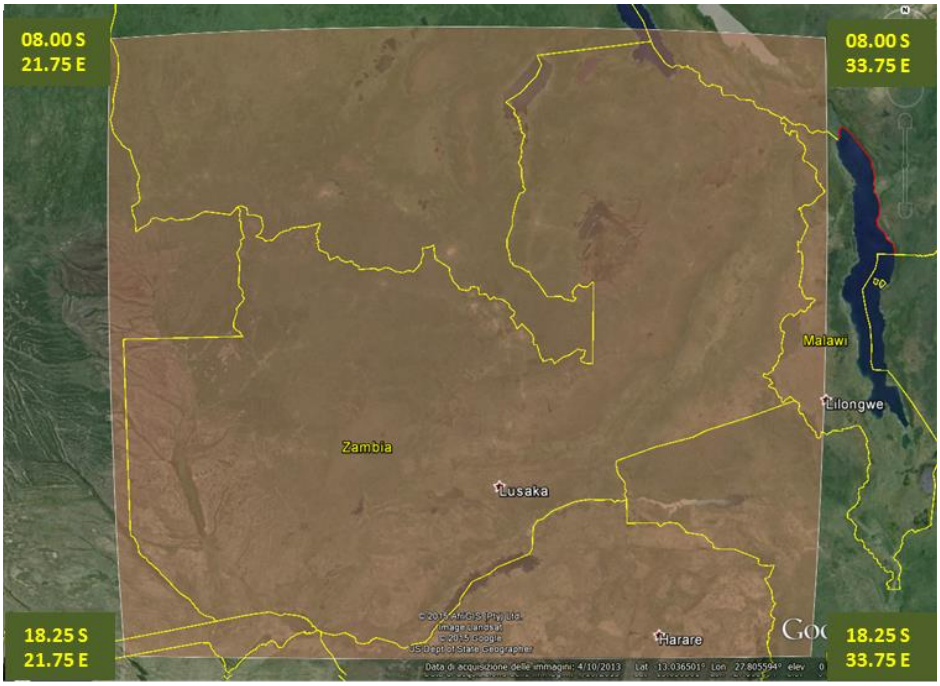


Figure 3: Detail location of the subset grid extracted from the planetary grid and covering Zambia territory.

This subset planetary grid can be represented with a georeferenced grid in spherical coordinates with cells of 0.25° of amplitude, both in latitude and longitude, covering a range from 8.000° to 18.250° South and from 21.750° to 33.750° East. The detail of this area is shown in Figure 3.

In the considered area 1968 cells were identified and, in each of them centroids were identified and used to geographically locate data of interest. Centroids are distributed over a regular grid with a spatial resolution of 0.25° x 0.25° (in longitude and latitude), moved of 0.125° in Eastern and Northern direction from the lower left corner of the related cell (Figure 4).

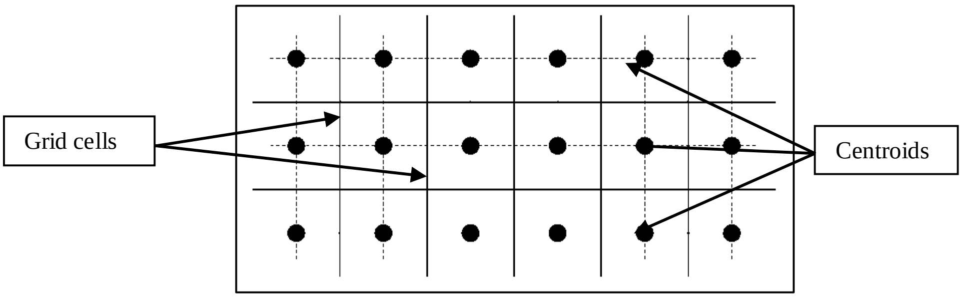


Figure 4: Schematic distribution of grid cells and related centroids

A regular distribution of 48 (in the sense of longitude) and 41 (in the sense of latitude) cells were identified. Their centroids in Figure 5 **Error! Reference source not found.**are shown.

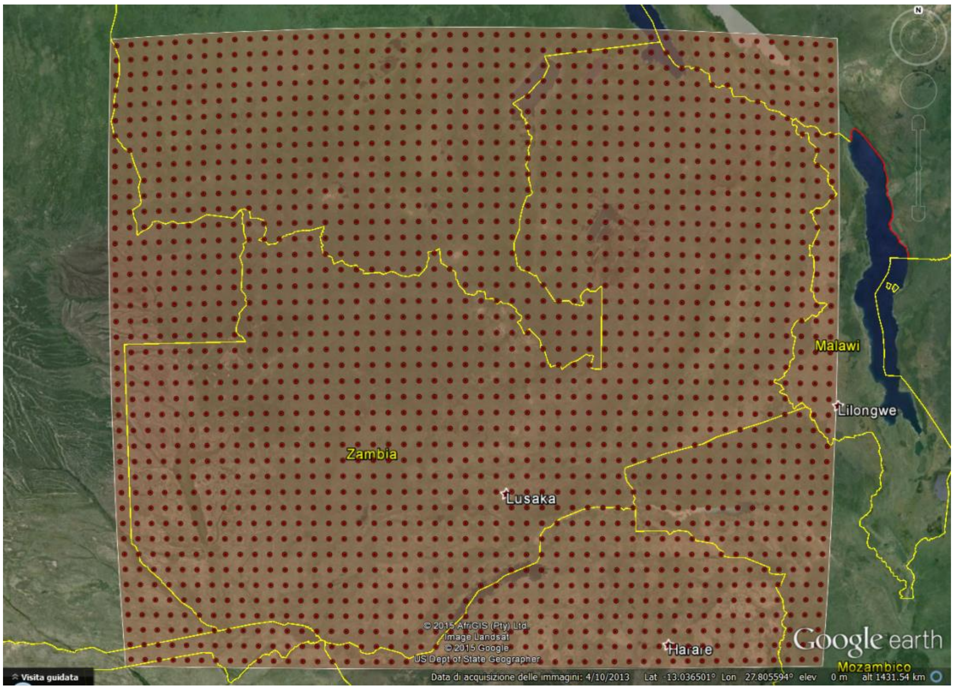


Figure 5: Visualization of centroids for the subset of Zambia grid

With reference to this spatial distribution, from the database covering the whole planetary grid, daily rainfall since January 1st, 1998 till June 30th, 2011 were extracted, creating a 3D rainfall matrix. In the first 2 dimensions, location of the centroids is addressed, while in third the rain over time is stored. For each cell 4928 rainfall data were stored, one data for each day in the considered period.

## THE USE OF THE RAIN MATRIX

The overall area described above has a dimension of about 1270 km x 1135 km, each cell covering an area of about 730 km$^2$ (27 x 27 km). For each of these cells the rainfall time history can be retrieved. An example of time series directly extracted from the Zambia global rain matrix is given in Figure 6.

In this example the daily time series of rain for the point with coordinates 24.875°E and 14.625°S is shown. Once input the coordinates of the point for which the rainfall data are required, the computer program, developed to process the rain matrix, automatically extracts the time series for this grid cell.

In the same figure a simple elaboration of data extracted is shown (lower panel) comparing the duration frequencies of daily rain (comparison of the curves achieved) taking into account the whole period (January 1st, 1998 till June 30th, 2011 – blue curve – 4928 data) or considering daily rain only for the rainy season of each year (October to April – red curve – 2879 data in the same period).

Starting from these data, it is possible to carry out many hydrological analyses. First of all, for each point, statistical analyses of rain are possible, as about 14 years of data are available for each point (Gumbel analyses, etc.). Once a catchment hydrographic basin is identified, for each return period, it is possible to evaluate the total rainfall on the basin and also any other analyses that can be derived from these parameters.

Furthermore, for hydrographic basins with concentration times greater than 1 day, these data can be used as input for rain-runoff models, after a pre-processing and optimizing of rain data to best suit geography of the catchment basin.

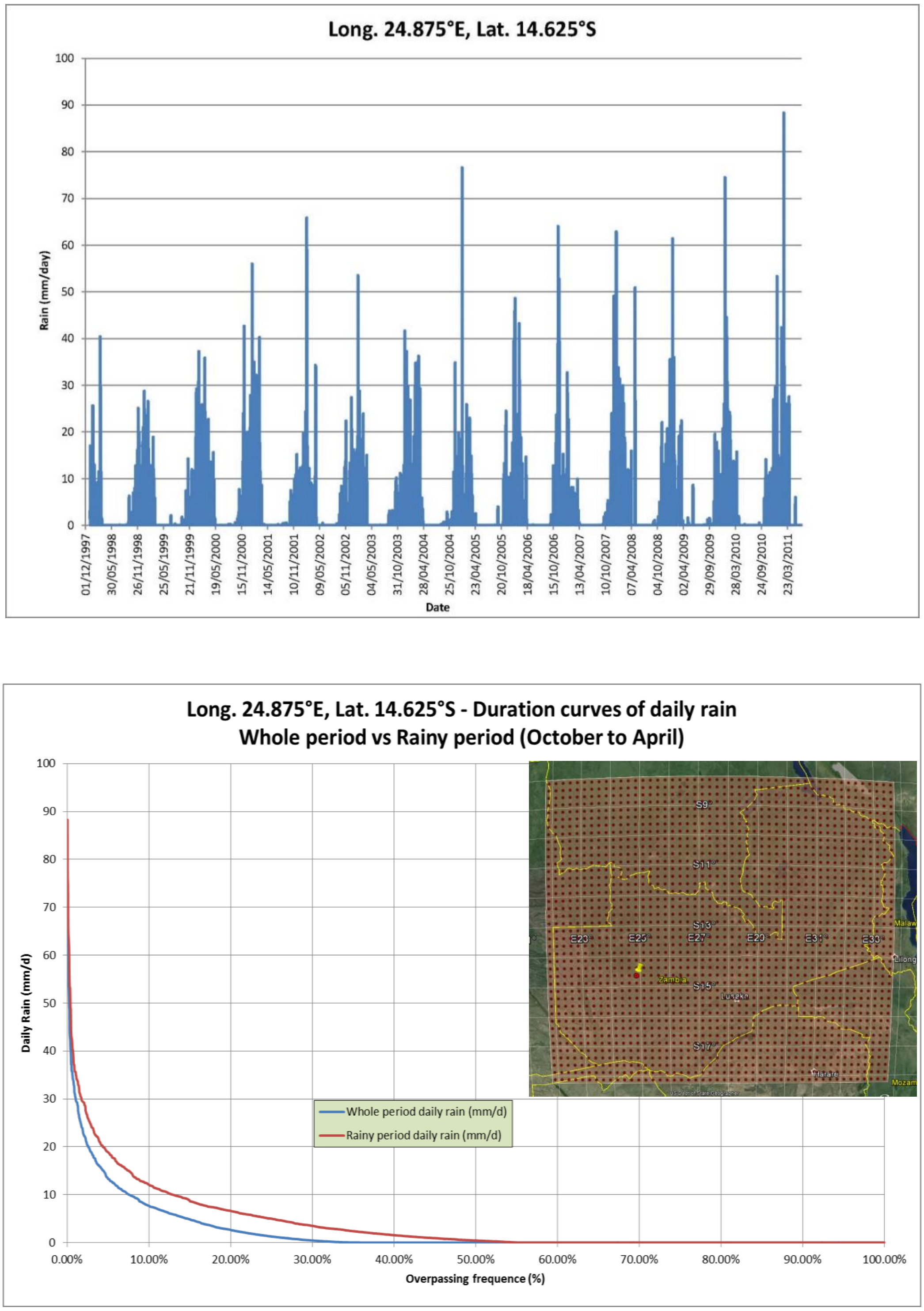


Figure 6: Rain time history of the point with coordinates 24.875°E and 14.625°S (up) and comparison of frequency curves evaluated for the whole period (blue line) and for the Rainy season (red line) (Low). The location of the point is also indicated.

## THE ADOPTION OF TRMM SATELLITE DATA FOR THE DESIGN OF BRIDGES IN THE ZAMBIA PROVINCES

Zambia as a whole has numerous water bodies; streams, rivers and lakes, in the 10 provinces which cross both major and minor roads within the country. In order for the roads to be passable, infrastructure should be properly designed, constructed and managed. For the design of such infrastructure, namely bridges, the hydrologic and hydraulic characterization of each single water body is fundamental as to define the suitable bridge elevation (i.e. freeboard on the maximum water level) and the hydraulic interventions such as the scour protection or the flooding protection (i.e. culverts).

In relation to the present consultancy activities performed by Technital Consulting Zambia Ltd., there are currently many ongoing projects related to the design of several ACROW type bridges summing up to a total of at least 91 in 5 provinces of the country. This entails at least 91 water courses, thus an equivalent number of bridge crossings. Rainfall data for all these water courses is cardinal for the hydrologic and hydraulic analyses which will lead to the most accurate and precise bridge designs. Since the areas of interest do not have any nor sufficient rainfall recordings within their catchment areas, for such projects, the application of the TRMM data for the design of the hydraulic infrastructures is preferred and resulted as the more reliable route to adopt.

Remote sensing source of rain data has been preferred to the most common pluviometric data. This is because of the following:

- Design and analysis for infrastructures scattered in the whole country, even where rain gauges are not provided for, is made possible;
- The lack of information related with the rainfall data gathered from the existing rain gauges introduces some critical aspects which will affect the accuracy of the analysis. The rain gauges are in fact located at fixed positions, far from the area of the project introducing a spatial variance of the precipitation from the measuring point to the area of study;
- The amount of the rainfall data registered by the available rain gauges is not sufficient to perform a correct probabilistic analysis;
- The satellite based information could represent a good source of data, widely used for the geo-physical analysis; and
- The application of the satellite TRMM rainfall data, once accuracy and correspondence with the effective rainfall data registered by the rain gauges is verified, allows for performance of hydrologic analysis on various locations of the Country.

For the purpose of this article, the Mount Makulu rainfall gauge data and TRMM data will be initially compared to ascertain the accuracy of rain data derived from remote sensing for the design of hydraulic infrastructures. The Mt. Makulu pluviometric station has been selected because it is the closest rain gauge station to the Chibombe Bridge proposed site, one of the bridge design currently developed by the Engineering Firm and which is described in the following paragraph as “main” application of this satellite approach. However, it should be noted that the distances of the Mt. Makulu station and many other stations from the different areas of interest for analysis are significant and thus will affect the results once considered. Figure 7 shows the aerial view of the Mt. Makulu Meteo station area and the TRMM matrix used for the comparison of the data

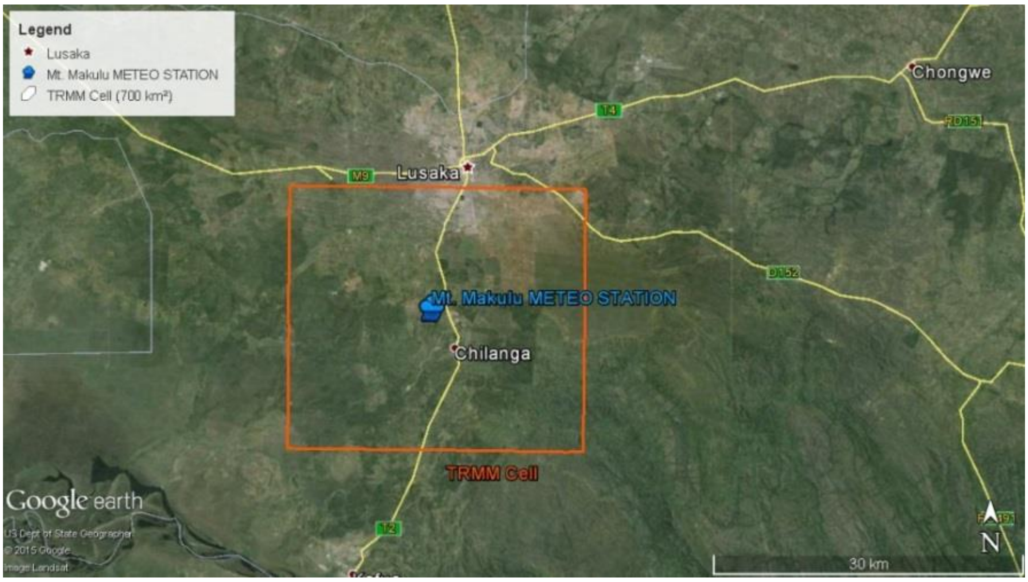


Figure 8: Aerial map indicating the Mt. Makulu Meteo station and the TRMM matrix used for the comparison of the data (source: Google Earth)

The daily rainfall data available from the Mt. Makulu rain gauge station is only for 5 years of recorded rainfall, from the year 2009 to 2013, while that from the satellite, TRMM data, is up to 14 years, from the year 1998 to 2011.

The maximum precipitation values from the collected data for each recorded year from the meteorological station are noted. These values are then used to produce the rainfall chart for the 5 years available. The values are also used for the rainfall probability (precipitation) analysis.

The same is done with the TRMM data collected. In order to extract the TRMM daily-time series data, the computer program created is used by inputting the Mt. Makulu coordinates (15°33' S and 28°15' E) into the program. Once extracted, the data is imported into Microsoft Excel and the maximum precipitation values for each year tabulated to produce the rainfall chart for all the 14 years available, Figure 8. The values are also used for the rainfall probability analysis.

The precipitation analysis procedure for both the pluviometric gauge and TRMM data is the same. Various return periods are considered for both cases, ranging for 1.001 to 1000 years.

Once the duration of independent precipitations (i.e. daily precipitation) is defined, the statistical description of the frequency of the events is usually described with the following formula:

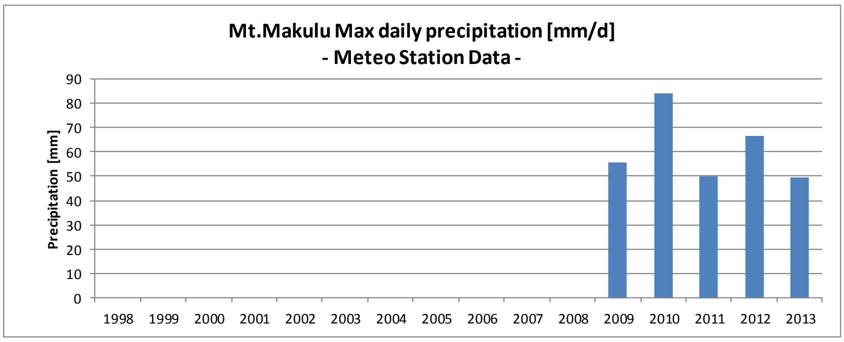
$$\mathrm{X}(\mathrm{T_r}) = \overline{\mathrm{X}} + F \cdot S_X, \qquad (3.1)$$

where:

- $\mathrm{X}(\mathrm{T_r})$ is the precipitation event (mm) associated to the design return period Tr (in the present analysis assumed equal to 50 years);
- $\overline{\mathrm{X}} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{X_i}$ is the mean precipitation height (mm) of the recorded set of data;
- $F$ is the “frequency factor”;

- $$S_X = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{X})^2}$$ is the standard deviation (mm) of the recorded set of data;

| Pluviometric Gauge Measures (Mt. Makulu Meteorolgical Station) | | YEAR | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| Max daily precipitation | H [mm] | | | | | | | | | | | | 55.80 | 84.10 | 50.00 | 66.60 | 49.40 |



| TRMM Satellite Measures (15.54°S; 28.85°E) | | YEAR | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
| Max daily precipitation | H [mm] | 67.42 | 82.76 | 80.03 | 40.60 | 42.89 | 41.48 | 31.90 | 37.35 | 46.87 | 53.87 | 56.81 | 52.19 | 44.87 | 78.51 |

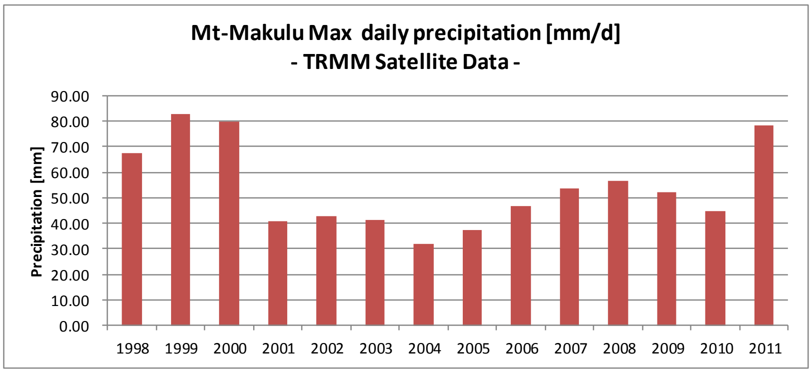


Figure 9: Rainfall charts for Mt. Makulu meteo station using Pluviometric gauge data (top) and TRMM data (bottom)

One of the most used methods for the identification of the extreme values is based on the Gumbel probabilistic approach that considers as a frequency factor *F* the following equation and it describes the "reduced" variable *Y(Tr)* with a double-exponential distribution.

$$F = \frac{Y(T_r) - \overline{Y}_N}{S_N}, \qquad (3.2)$$

where:

- $$Y(T_r) = -\ln\left(-\ln\left(\frac{T_r - 1}{T_r}\right)\right)$$ is the "reduced" variable, function of the $T_r$ described with a double-exponential distribution;
- $$\overline{Y}_N = \frac{1}{N}\sum_{i=1}^{N} Y_i$$ is the "reduced" mean;

- $S_N = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \overline{Y}_N)^2}$ is the standard deviation of the "reduced" variable;

The last two values depend only on the number of observations, equal to 14 for the TRMM data and 5 for the pluviometric gauge data. By including the eq. (3.2) in the main (3.1), the following equation is produced:

$$X(T_r) = \overline{X} - \frac{S_X}{S_N}\overline{Y}_N + \frac{S_X}{S_N}Y(T_r) \quad , \qquad (3.3)$$

The results coming from the above described approach are then plotted on a semi-logarithmic graph that defines the probabilistic curve for the daily precipitation at the considered sites, and from which it is possible to identify the most probable precipitation heights with varying return periods.

Table 1: Precipitation heights (mm) and % Difference for different return periods (yrs.) for Mt. Makulu meteo station using TRMM and Pluviometric gauge data

| **Tr (>1)** | **TRMM Data X(Tr)** | **Gauge Data X(Tr)** | **% Diff.** |
|---|---|---|---|
| 1.001 | 15.00 | 21.91 | 31.54 |
| 1.01 | 21.46 | 28.53 | 24.78 |
| 1.1 | 31.94 | 39.28 | 18.67 |
| 2 | 51.81 | 59.66 | 13.16 |
| 10 | 81.97 | 90.60 | 9.53 |
| 20 | 93.49 | 102.42 | 8.72 |
| 50 | 108.41 | 117.72 | 7.91 |
| 100 | 119.59 | 129.19 | 7.43 |
| 200 | 130.72 | 140.61 | 7.03 |
| 500 | 145.42 | 155.68 | 6.59 |
| 1000 | 156.52 | 167.07 | 6.31 |

Considering a return period of 50 years, the precipitation heights for the TRMM and pluviometric gauge data are 108.41 and 117.72 respectively from the described analysis above. The difference between the two values is 9.31 which equates to a percentage difference of less than 10. The existing differences generally in the final results are admissible because of the reduced number of data collected by the rain gauge (i.e. 5 years VS. 14 years).This validates the TRMM data for use in cases where the pluviometric data is absent or inadequate (Inadequate in the sense that there is data/recordings for various years missing as is the case with the Mount Makulu meteorological station).

**The application of the TRMM approach for the hydrologic analysis of the foreseen new bridge across the Chibombe river in the Chongwe District**

The Chibombe River lies within the main Zambezi River Basin as a tributary of the Chongwe River, as shown in Figure 9 which also shows the water streams and the catchment area of the Chibombe River, at the closure point of the proposed bridge location.

This river, similar to many rivers/streams of the Chongwe catchment, presents the drought regime during the dry season (Figure 10), but during the rainy season (from November to April) the water flow may become significant after rainfall events, resulting in flooding of the surrounding areas. This has led to the need for construction of a bridge across the river and the hydrological analysis is essential for the successful bridge design.

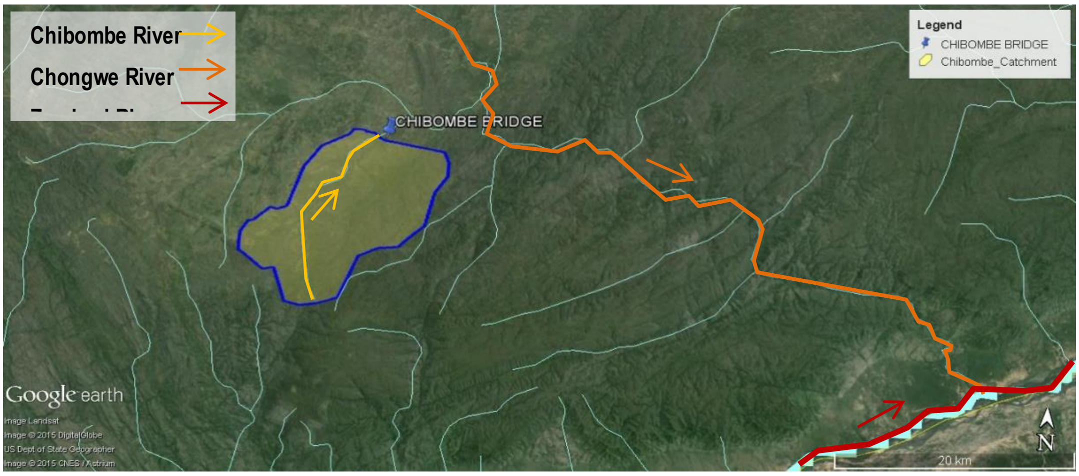


Figure 10: General map with indication of the Chibombe River and the main water streams

Figure 11: Site pictures of the existing conditions (dry season) of the Chibombe River at the proposed crossing site

For the hydrological analysis, the aim was to define the maximum flow rate design expected for a return period of 50years. The daily maximum precipitations are needed for the analysis and these were determined using the TRMM data instead of pluviometric data. This is because the closest rain gauge station to the area of the study is the Mt. Makulu station which is 70km far. This entails high spatial variation in the pluviometric data which would affect the hydrologic analysis. Therefore, a TRMM approach has been applied using the satellite rainfall data for the cell (matrix) centered in the barycenter of the catchment area. Since the same watershed resulted 147 km², the data matrix covers the entire area.

The following are the steps for the hydrologic analysis, aimed to define the reference rainfall to utilize for the definition of the PMF (Probable Maximum Flood) for the Chibombe River and hence the identification of the maximum water level reached by the same in correspondence of the proposed crossing site.

As explained previously, the TRMM data for the Chibombe River cell is extracted from the computer program developed, using a satellite rainfall matrix (TRMM Cell) centered in the barycenter of the catchment area of the Chibombe River as shown in the previous Figure 11.

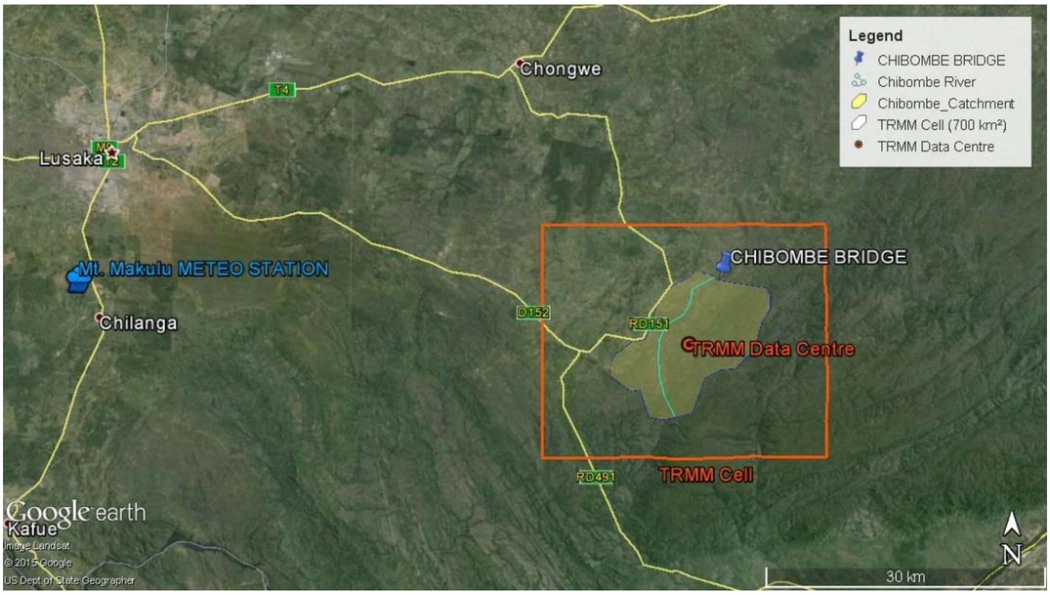


Figure 12: Aerial map indicating the Chibombe crossing site and the TRMM cell considered for the satellite rainfall data

Once extracted, the data is imported into Microsoft Excel and the maximum precipitation values for each year tabulated to produce the rainfall chart for all the years available, Figure 12. As stated earlier, the TRMM data available is from the year 1998 to 2011. The precipitation values are also used for the rainfall probability analysis using the Gumbel approach. The precipitation height for a return period of 50 years is 97.44mm according to the analysis, Figure 13.

| **Chibombe** | | **YEAR** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| **Max daily precipitation** | **H [mm]** | 45.05 | 55.06 | 31.80 | 48.42 | 47.80 | 32.49 | 45.59 | 47.71 | 29.01 | 44.52 | 48.70 | 49.32 | 90.34 | 63.38 |

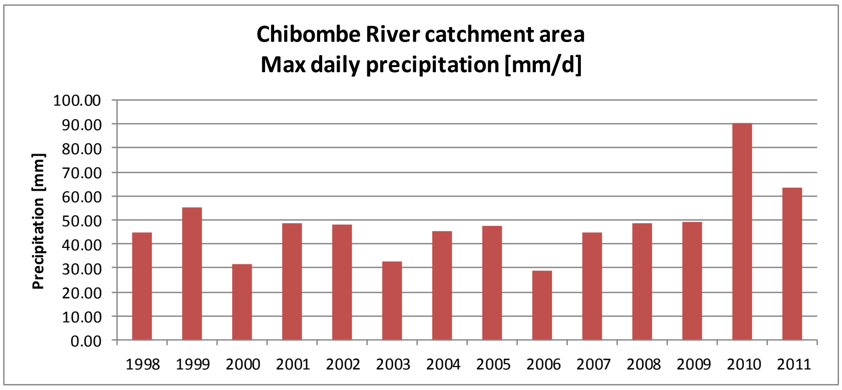


Figure 13: Rainfall charts for the Chibombe River Catchment area TRMM data

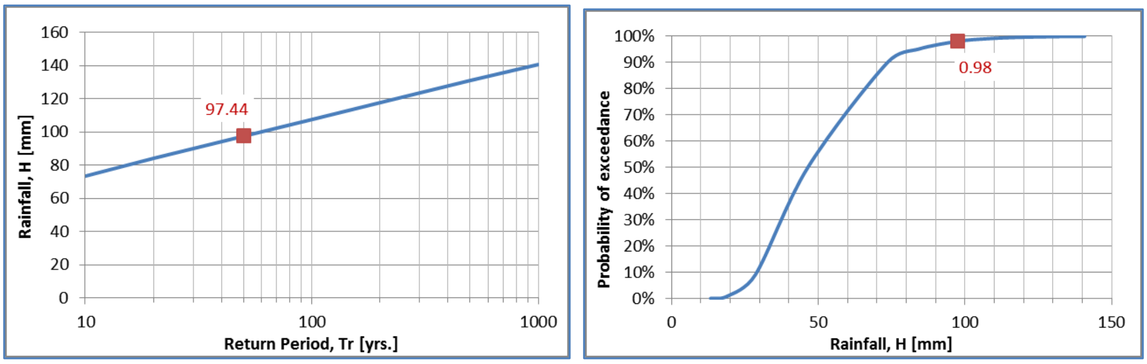
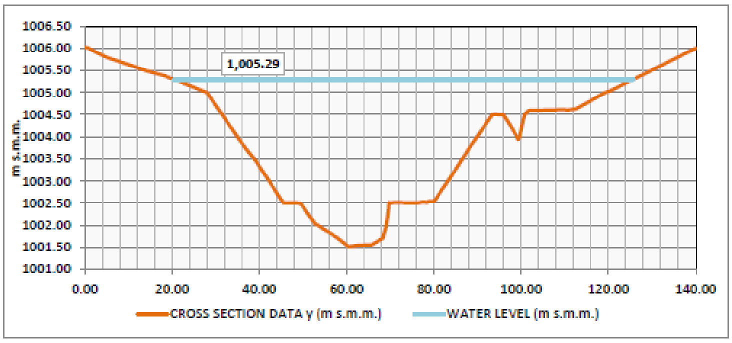


Figure 14: Daily precipitation (24h) probabilistic curves for the Chibombe River catchment area considering the TRMM rainfall data

Once identified the rainfall for an assigned design return period of 50 years, an hydrologic model has been used in the calculation of the PMF (probable maximum flood) to transform the rainfall (*afflux*) to the design flow rate (*deflux*).

The estimation of the maximum water level in correspondence to the proposed bridge has been finally performed by means of either uniform or steady-flow analysis. The results are presented in Figure 14, showing both the *ante-operam* (none crossing structure) and *post-operam* (with the new bridge and the new re-profiled cross section) conditions.

| | |
|---|---|
| **BRIDGE NAME** | ***Crossing on the Chibombe River*** |
| **River** | *Chibombe River* |
| **Scenario** | *EXISTING CONDITIONS* |



| | |
|---|---|
| **BRIDGE NAME** | ***Crossing on the Chibombe River*** |
| **River** | *Chibombe River* |
| **Scenario** | *REPROFILED CROSS SECTION* |

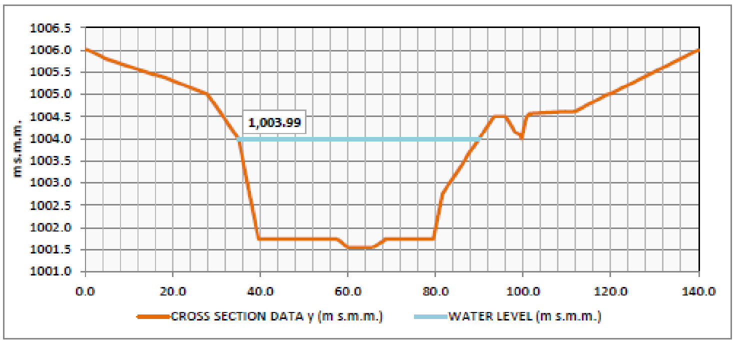


Figure 15: *Ante-operam* and *post-operam* maximum water level estimation for the Chibombe Bridge estimated using a uniform flow analysis in correspondance of the proposed crossing site

More precise evaluations (steady-flow analysis) have also been done by the utilization of HEC-RAS software, simulating the re-profiling works on the river channel and the presence of the new crossing structure, considering as input the PMF (180 m³/s) given by the design precipitation.

The output results are shown in Figures 15 and 16 referred to as 3-D general overview of the River comprehensive of the new crossing structure and cross section in correspondence of the new bridge, respectively.

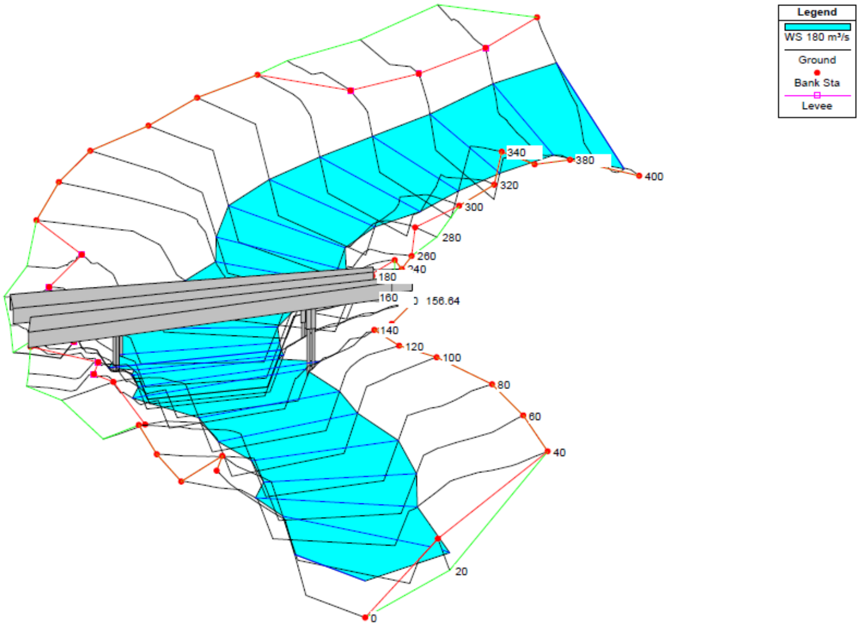


Figure 16: 3-D overview of the final (*post-operam*) conditions given by the HEC-RAS hydraulic modelling of the Chibombe River

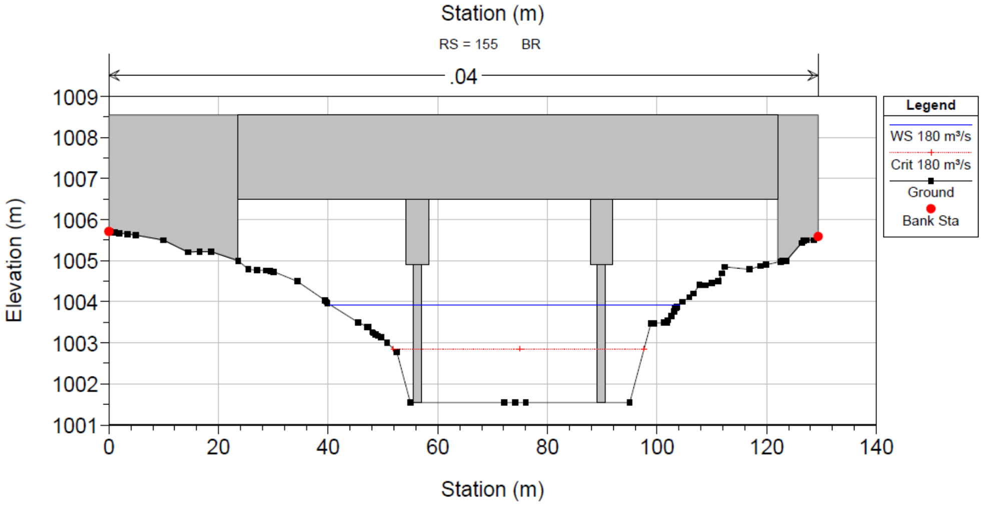


Figure 17: Cross-section in correspondence of the proposed bridge with indication of the maximum water level reached by the Chibombe River as by HEC-RAS hydraulic model

## CONCLUSIONS

The design of infrastructures interfering with rivers or other water bodies needs adequate amounts of data in order to evaluate the hydraulic security of the territory and the stability of the work in the proper way. One of the most important and useful data is rainfall. When direct measures are not available or have an insufficient spatial and time resolution, a suitable source can be rain data derived from remote sensing, like TRMM.

In previous chapters, examples about how these data can be retrieved and used have been given. It is necessary to say that this is the first application authors made in trying to evaluate design parameters like the bridge presented here above. On the other hand, these data can be used for many other purposes and other rain data can be achieved related to different precipitation times. One of these is rainfall with duration of precipitation of 3 hours. This kind of data, included in the TRMM data set and related to the same planetary grid as daily rains, could be used to calculate runoff and flows in small catchment basins or dimension rain sewage urban networks or other civil works related to intense rains with brief duration. This could be the object of future developments.

About the adoption of the TRMM data for the design of infrastructures such bridge or for hydrologic evaluations for the entire Zambian Country, it has been resulted as an optimal approach responding in the missing of local rain gauge data. Further steps will be addressed towards a deep comparison of the satellite data with the local rainfall data, recorded by means of the rain gauge stations, aimed to validate the goodness of the TRMM data, for the different time series, starting from the 3-hourly up to the monthly and yearly set. Moreover, the possibility to discretize each single catchment area in a number of data-cells will allow to identify a better and more realistic distribution of the rainfall data within the same area considered, reducing the spatial variance in considering the existing local rain gauge stations and the overestimation obtained in the adoption of a single cell rainfall data (i.e. barycenter or maximum precipitation), spread on the entire area of study.

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# Opportunities for Harmonisation of Ancillary Roadworks under Series 5000 of the SATCC Standards and Specifications

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## ABSTRACT

*The Southern African Development Community (SADC) predicts that by 2030, traffic for landlocked SADC countries will increase to 50 million tonnes. Therefore, the transformation of Zambia into a truly “land linked” country to benefit from regional road traffic is opportune. However, land linking Zambia increases the number of international road users who need to understand the local traffic signs and road markings. Traffic signs and road markings are silent speakers to the road users. The paper focuses on the need to harmonise and revise series 5000 of the Southern Africa Transport and Communications Commission (SATCC) design standards and specifications for roads and bridges. Series 5000 encompasses ancillary roadworks such as road signs and markings. The research revealed an absence of an ancillary roadworks manual in the Zambian road sector. Traffic signs regulations and manuals keep evolving to meet the needs of road users. It also revealed a high usage of modified SATCC descriptions under series 5000 indicating a need to revise the specifications. The methodology incorporated desk study followed by field visits along the North-South Corridor to obtain evidence of varying traffic road signs and markings. The results presented are from a broader study carried out on the analysis of unit rates for roadworks in Zambia. The main recommendation of this paper include; the integration of existing road traffic signs and road marking schedules, adoption of SADC road traffic signs harmonisation of SATCC series 5000, and development of an ancillary roadworks manual. The consistency of these signs and markings allow road based users to use the regional roads with confidence.*

**Keywords:** *Road traffic signs, SATCC Series 5000, Zambian road sector, Ancillary roadworks*

## INTRODUCTION

Zambia belongs to the Southern African Development Community (SADC). Of the 15 SADC member countries, six (6) are landlocked and Zambia is the largest of these. Zambia, as a centrally located country in Southern Africa, is in a position to become both a continental and regional hub and gateway for integrated, safe, secure and efficient infrastructure capacity along strategic transport and development road corridors. As industries and economies develop throughout the Southern Africa region, use of the transport network will exceed its current capacity (SADC, 2012). SADC predicts that by 2030, road haulage for landlocked SADC countries will increase to 50 million tonnes, ramping to 148 million tonnes by 2040, an 8.2 percent annual growth rate. This is phenomenal and Zambia is strategically located to benefit from regional road trunk network. All policies and efforts in the Zambian road sector are targeted towards the transformation of Zambia into a truly "*land linked*" country in the sub-region. Land linking Zambia entails increased international road users. Traffic which consists of pedestrians, animals, vehicles, and other conveyances has to be regulated to ensure road safety. Organising traffic requires the use of marked lanes, right-of-way, traffic control at intersections and signs. Traffic signs and road markings are silent speakers to the road users. For effective land linking Zambia, the traffic signs and markings should be understood by both Zambian and international road users. Unfortunately these ancillary roadworks have not been harmonised in Zambia.

The Zambian road sector has been using the Southern Africa Transport and Communications Commission (SATCC) design standards and specifications for roads and bridges which were developed and adopted in 1998. Unfortunately these standards have been in draft form since 1998. ASANRA (2013) Although South Africa updates its standards as and when required, the SATCC standards have not kept pace. The SATCC Series 5000 provides the guidelines and specification for ancillary roadwork items.

SADC was in the process of overseeing an effort aimed at harmonising road standards such as: SADC Specification for Road and Bridge works also translated into both French and Portuguese; SADC Guideline on Low-volume, Sealed Roads; SADC Geometric Design Standards; SADC Pavement Design Manual; and SADC road traffic signs, markings and signals. It was not clear how far this effort had been achieved but bilateral agreements posed a challenge regarding practical application and management of the terms and provisions.

## LITERATURE REVIEW

Series 5000 specifies ancillary roadworks under the SATCC Draft Standard Specifications for Road and Bridge Works. The document specifies the method of measurement as pay items for roadwork activities. The pay items and coding are organized into seven Level 1 SATCC categories namely: General; Drainage; Earthworks and Pavement Layers of Gravel or Crushed Stone; Asphalt Pavements and Seals; Ancillary Works; Structures; and Testing and Quality Control. The roadwork items hierarchical coding is shown in Table 1.

Table 1: Hierarchical structure of measurement items

| LEVEL 1 CATEGORY | LEVEL 2 SERIES HEADING | LEVEL 3 PAY ITEM CODE |
|---|---|---|
| SERIES 1000: GENERAL | **1100:** Definitions and terms | No pay items |
| | **1200:** General requirements and provisions | No pay items |
| | **1300:** Contractor's establishment on site and general obligations | 13.01 |
| | **1400:** Housing, offices and laboratories for the Engineers' site personnel | 14.01 – 14.16 |
| | **1500:** Accommodation of traffic | 15.01 - 15.12 |
| | **1600:** Overhaul | 16.01 – 16.02 |
| | **1700:** Clearing and grubbing | 17.01 – 17.03 |
| SERIES 2000: DRAINAGE | **2100:** Drains | 21.01 – 21.19 |
| | **2200:** Prefabricated culverts | 22.01 – 22.28 |

| LEVEL 1 CATEGORY | LEVEL 2 SERIES HEADING | LEVEL 3 PAY ITEM CODE |
|---|---|---|
|  | **2300**: Concrete kerbing, concrete channelling, chutes and downpipes, and concrete linings for open drains | 23.01 – 23.15 |
|  | **2400:** Asphalt and concrete berms | 24.01 – 24.04 |
|  | **2500:** Pitching, stonework and protection against erosion | 25.01 – 25.07 |
|  | **2600:** Gabions | 26.01 – 26.04 |
| **SERIES 3000:** EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL OR CRUSHED STONE | **3100:** Borrow materials | 31.01 – 31.03 |
|  | **3200:** Selection, stockpiling and breaking down the material from borrow pits and cuttings, and placing and compacting the gravel layers | 32.01 – 32.06 |
|  | **3300:** Mass earthworks | 33.01 – 33.13 |
|  | **3400:** Pavement layers of gravel material | 34.01 – 33.10 |
|  | **3500:** Stabilisation | 35.01 – 35.05 |
|  | **3600:** Crushed stone base | 36.01 – 36.04 |
|  | **3700:**Waterbound macadam base | 37.01 – 37.03 |
|  | **3800:** Breaking up existing pavement layers | 38.01 – 33.15 |

| LEVEL 1 CATEGORY | LEVEL 2 SERIES HEADING | LEVEL 3 PAY ITEM CODE |
|---|---|---|
| **SERIES 4000:** ASPHALT PAVEMENTS AND SEALS | **4100:** Prime coat | 41.01 – 41.03 |
|  | **4200:** Asphalt base and surfacing | 42.01 – 42.07 |
|  | **4300:** Materials and general requirements for seals | 43.01 – 43.03 |
|  | **4400:** Single seals | 44.01 – 44.07 |
|  | **4500:** Double seals | 45.01 – 45.06 |
|  | **4600:** Single seal with slurry (Cape seal) | 46.01 – 46.06 |
|  | **4700:** Sand seals | 47.01 – 47.02 |
|  | **4800:** Surfacing of bridge decks | 48.01 |
|  | **4900:** Treatment of surface defects, patching, repairing edge breaks and crack sealing | 49.01 – 49.15 |
| **SERIES 5000:** ANCILLARY ROADWORKS | **5100:** Guide blocks | 51.01 – 51.02 |
|  | **5200:** Guardrails | 52.01 – 52.12 |
|  | **5300:** Fencing | 53.01 – 53.08 |
|  | **5400:** Road signs | 54.01 – 54.09 |
|  | **5500:** Road markings | 55.01 – 55.09 |
|  | **5600:** Cattle grids | 56.01 – 56.02 |
|  | **5700:** Landscaping and planting plants | 57.01 – 57.11 |
|  | **5800:** Finishing the road and road reserve and treating old roads | 58.01 – 58.02 |
|  | **5900:** Painting | 59.01 |
| SERIES 6000: STRUCTURES | **6100:** Foundations for structures | 61.01 – 61.50 |
|  | **6200:**Falsework, formwork and concrete finish | 62.01 – 62.09 |
|  | **6300:** Steel reinforcements for structures | 63.01 – 63.03 |
|  | **6400:** Concrete for structures | 64.01 – 64.06 |
|  | **6500:**Prestressing | 65.01 – 65.03 |
|  | **6600:** No-fines concrete, joints, bearings, bolt groups for electrification, parapets and drainage for structures | 66.01 – 66.26 |
|  | **6700:** Structural steelwork | 67.01 – 67.03 |
|  | **6800:** Construction tolerances for structures | No pay items |
| **SERIES 7000:** TESTING AND QUALITY CONTROL | **7100:** Testing material and workmanship | 71.01 – 71.03 |
|  | **7200:** Quality control | No pay items |

The coding continues beyond level 3. Level 4 coding is alphabetical using lower case alphabet letters. Level 5 is numbered sequentially using roman numerals. Selection of appropriate pay items to use for each road project is critical. Pay items should facilitate contract administration for construction staff. Table 2 shows the summary of pay items per series category of works.

Table 2: Summary of pay items per series category of works

| Series Category | Description | No. of pay items |
|---|---|---|
| Series 1000: | General | 129 |
| Series 2000: | Drainage | 134 |
| Series 3000: | Earthworks And Pavement Layers of Gravel or Crushed Stone | 199 |
| Series 4000: | Asphalt Pavements And Seals | 145 |
| Series 5000: | Ancillary Roadworks | 162 |
| Series 6000: | Structures | 170 |
| Series 7000: | Testing And Quality Control | 5 |
| **Total** | | **944** |

Table 2 shows that there are 944 pay items from the SATCC Standard Specifications. Of these, 162 pay items fall under series 5000 which deals with Ancillary Roadworks. Series 5000 is further broken down into nine (9) sub categories or level 2 categories.

The paper focuses on three of the level 2 categories under series 5000: Series 5100 which describes the material, fabrication, spacing and erection of marker and kilometre posts; Series 5200 specifying guard rail fabrication; and series 5400 and 5500 describing road signs and road markings respectively. There is no reference in the SATCC document regarding traffic calming.

In the 1990's when the SATCC specifications were being prepared, the concept of traffic calming was new (Harvey, 1992). Developed in Europe, traffic calming which is a direct translation of the German word *"vekehrsberuhigung"*, is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorised street users (Lockwood, 1997). Examples of traffic calming measures include: traffic circles or roundabouts, narrowing lanes to widen sidewalks, vertical shifts in the carriageway such as road humps, speed tables and rumble strips

Harvey (1992) stated that vertical shifts in the carriageway are the most effective and reliable of the speed reduction measures currently available. This corresponds to a study carried out in Tanzania on the effects of traffic calming interventions, their long-term impact, with the aim to increase understanding of the performance of various traffic calming facilities in African road and traffic conditions, in particular: their lasting impact on traffic safety and efficiency, and their maintenance requirements. de Langen et al. (2011) stated that their major finding was the effectiveness of the raised zebra crossing. This facility had a positive permanent effect on traffic flow and low maintenance requirements if well designed and constructed (de Langen et al., 2011).

Traffic signs and road markings are critical in providing information and instructions to road users. Literature revealed that road traffic signs were generally classified under three categories:

i) Mandatory signs used to inform traffic laws and regulations to road users which they must comply such as the STOP sign or the NO-U-TURN sign. Violation of these signs is a legal offence;

ii) Cautionary signs warn the road users of the existence of certain hazardous condition either on or adjacent to the roadway, so that the motorists are cautious and take the desired action. Examples include Pedestrian or Railway crossing ahead; and

iii) Informatory signs guide road users along routes, inform them about destination and distance, identify points of geographical and historical interest and provide other information that will make the road travel easier, safe and pleasant. Examples include distances for next lay-by or bus stop.

A number of regional bodies in Africa have commenced harmonisation of road signs, traffic signals (traffic lights), and road markings to ensure safety and convenience of the public travelling on the road networks within the region whether for trade, tourism, education or other purposes. Bureau for Industrial Cooperation (2012) in the preparation of the East African transport facilitation strategy examined five countries namely Burundi, Kenya, Rwanda, Tanzania and Uganda. A review of existing practices revealed that road design practice in Burundi followed French design standards while Rwanda which used to follow French standards has of recent started to use American standards. In contrast, Kenya, Tanzania and Uganda use their own standards which were developed largely from the American and English practices. Tanzania in particular followed the SATCC standards. In cases where there were differences in practice between the countries, the study recommended adoption of a road traffic sign or marking that conformed to the SADC Road Traffic Signs Manual.

SADC (2012) stated that development in Southern Africa has traditionally occurred along routes that connect areas of industry with areas of trade. Consequently, road infrastructure has been concentrated along these routes. This formed the basis of road corridor identification in Africa. Road corridors connect manufacturing and market points to ports. SADC identified 17 corridors categorised as high, medium and low priority. There are three high priority corridors namely: the North-South Corridor; Maputo Corridor; and Dar-es-Salaam Corridor. There are seven corridors each in the medium and low priority areas. The North-South Corridor links the port of Durban to the Copperbelt in DR Congo and Zambia and has spurs linking the port of Dar-es-Salaam and the Copperbelt and Durban to Malawi (TMSA, 2014). The corridor spans 8 countries namely Botswana, Democratic Republic of Congo, Malawi, Mozambique, South Africa, Tanzania, Zambia and Zimbabwe and has a total of 10,647 km of road. Excluding South Africa the corridor spans 8,746.3 km. The Zambian part of the corridor spans 882 km from Livingstone to Chingola. 808 km from Kapiri Mposhi to Nakonde falls under the Dar-es-Salaam corridor also a high priority corridor and 136 km from Lusaka to Chirundu is under the Beira corridor in the medium priority category. The North-South corridor is the busiest in terms of both traffic and freight volumes (TMSA, 2014).

The SADC regional integration target is that there should be unimpeded road transport operations over the region (SADC, 2012). SADC now has a commonly defined, integrated and route numbered Regional Trunk Road Network (RTRN) (SADC, 2012). The need for harmonisation in road infrastructure has been further emphasised by a recommendation to develop a harmonised regional road infrastructure policy (SADC, 2012). The uniformity of these signs and markings allow road based travellers to use the regional roads with confidence.

## METHODOLOGY

The study employed mostly qualitative methods. Data was collected using desk study and field work. The research included the review of best practices documents in order to identify areas of harmonisation. Field work involved obtaining evidence of ancillary roadwork items along the Livingstone, Lusaka, Kapiri Mposhi Trunk Road Network which falls in the North-South Corridor. The North-South Corridor was selected based on its importance in the SADC region and Africa as a whole.

The paper focuses on three of the level 2 categories under series 5000: Series 5100 which describes the material, fabrication, spacing and erection of marker and kilometre posts; Series 5200 specifying guard rail fabrication; and series 5400 and 5500 describing road signs and road markings respectively.

## FINDINGS

### *Kilometre and marker posts*

Though the construction materials for the ancillary works are specified in the SATCC specifications, the dimensions and other details are referred to drawings. For instance Section 5104 specifies the material for kilometre and marker posts made up by using a mixture of four parts of concrete sand to one part of Portland cement. It further states that kilometre and marker posts shall be fabricated to the dimensions shown on the Drawings. From Section 5104, the spacing of marker posts is as shown on drawings or as directed by the Engineer. Because there are no standard dimensions of the posts, font and size of the information displayed, and spacing, the consultants on the different projects would recommend dimensions suited to their consultancies.

illustrates the varied kilometre posts along the Lusaka-Livingstone road in the North-South corridor.

| | | |
|---|---|---|
|  |  |  |
| Kilometre post on Lusaka-Kafue Road section | Kilometre post on Choma-Kalomo Road section | Kilometre post on Kalomo-Livingstone Road |

Figure 1: Varying kilometre posts along Lusaka-Livingstone road

Apart from the varied kilometre and marker posts causing confusion to road users, it becomes difficult to compare unit rates of these items on different road projects because of varied dimensions.

### *Road signs*

Another finding was the usage of modified SATCC descriptions under series 5000 also known as *B pay items*. The *B pay items* were generally introduced to match existing practice. For instance the road signs under series 5400 are measured in square metres for the sign boards and in tonnes for steel tubing and metres for timber road sign supports. However, the B item describes the complete road sign with board and support and the measurement unit indicated as number as current practice. It was also observed that the

B items were not consistent. The board sizes for some equilateral triangular traffic signs were 300mm while others were 600mm. In addition, the background colours are different. Figure 2 illustrates the non-standardised traffic signs.

Railway crossing warning along the Choma-Monze Road section

Domestic animal warning along Kalomo-Livingstone Road

Figure 2 Varied road signs along Lusaka-Livingstone road

It is not clear why the older signs were not removed but Clause 33 (7) of the Public Roads Act No.12 of 2002 could apply. It states that *'Notwithstanding any other provision of this Act, any traffic sign which was, before the commencement of this Act, lawfully erected under any written law, and which is a traffic sign which may be specified by the Minister, on the recommendation of the Agency, by statutory notice, shall continue to have effect for such period as may be specified in the notice and shall during the period be deemed to be a traffic sign lawfully erected under this Act'*. An equilateral triangle of side 90 cm are used for Territorial Roads, 60 cm for District Roads and 40 cm for Rural Roads. If the road has been upgraded then the older sign should be removed.

### *Road markings*

Series 5500 provides the specification of road marking paint. Road markings are especially critical at junctions. Therefore, there is a need for clear and unambiguous road markings at complex road junctions. The three road marking paint colours specified are white, red or yellow. The common colours used in the Zambian road sector are white and yellow. Red was intended for NO-STOPPING LINE imposing a mandatory requirement that drivers of vehicles shall not stop their vehicles adjacent to such line (except in compliance to a regulatory sign or traffic signal). However, the left or right yellow edge line used to demarcate the edge of the travel way has been painted using orange paint as shown in Figure 3.

Figure 3: Orange edgeline used instead of accepted yellow edgeline

It is not clear whether orange has now replaced yellow. Even the size of symbol markings varies on the same road. For instance, the painted arrows markings along Great East Road at Arcades Mall Entrance conform to the standard dimensions shown in Figure 4. But barely 1km away along the same road at the traffic junction at East Park Mall, the dimensions of the painted arrows are a third of the standard dimensions.

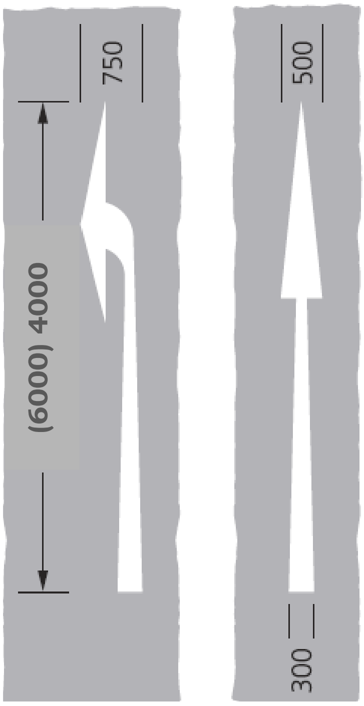

Figure 4: Standard dimensions of the turning and straight arrows road markings (after Department of Transport, 2009)

The unit of measurement for painting symbols or traffic-island markings is specified as square metre.

***Traffic calming***

Though the Zambian road sector employs a number of traffic calming techniques, there are no traffic calming standards in the SATCC specifications. Literature findings indicated vertical shifts in the carriageway were the most effective and reliable of the speed reduction measures currently available. In particular, in Tanzania, the raised zebra crossing was the most effective. Unfortunately, in Zambia, the use of raised pedestrian crossings also referred to as speed tables are confined to shopping malls. Perhaps use of speed tables in school zones could be introduced as they would be a more permanent feature on the road as opposed to a painted zebra crossing which would disappear once the paint has faded. Again there is no uniformity regarding the dimensions of the speed humps. It would be beneficial if specific speed humps applied in situation such as school zones, hospital areas, approaches to a railway crossing and major junctions.

The same applies to rumble strips. In Zambia, rumble strips are installed in a series *across* the direction of travel, and sometimes over the entire carriageway, to slowdown traffic ahead of an approaching danger spot. In other countries, rumble strips are applied along an edgeline or centreline, to alert drivers when they drift from their lane. Findings show that there is no consistency regarding the spacing of strips. When rumble strips were introduced for instance along Mazabuka – Kafue road they comprised three to five strips. These have since been replaced by speed humps. The Kafue – Lusaka road completed in 2015 incorporated ten stripped rumble strips on approaches to traffic circles. The Kamanga – Kalimba Farm road off Great East road also completed in 2015 has eight stripped rumble strips. Again these have to be standardised to provide order and the required calming effect on the roads. Bureau for Industrial Cooperation (2012) recommends the following principles when installing rumble strips:

i) rumble strips should normally be in groups of 4 strips;
ii) the height of the strips shall be no more than 10 – 15 mm;
iii) the strip width should be 0.5 m; and
iv) rumble strips should preferably have yellow thermoplastic lines across the top for better visibility

Rumble strips used in the Zambian road sector do not conform to the recommended design in all aspects including colour, as they are painted with an aluminium paint. Figure 5 illustrates the recommended design of rumble strips.

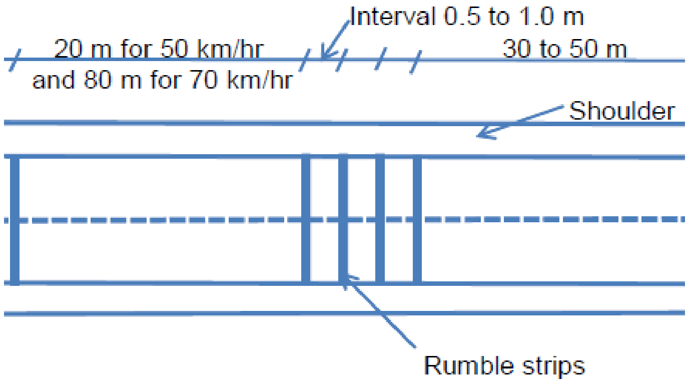

Figure 5: Recommended spacing of rumble strips (after: Bureau for Industrial Cooperation, 2012)

The effectiveness of the mini roundabouts or traffic circles introduced in 2015 along the Kafue – Lusaka road is yet to been seen. The mini roundabouts were adopted from the Federal Highway Administration (FHWA), a US agency. The inscribed circle is 51m in diameter and the circulatory road width for a double lane roundabout is 12.8m. However what was observed is that the width does not allow circulation of two semi – trailer trucks but permits one semi – trailer truck and a passenger car or SUV vehicle simultaneously.

### ***Road Traffic Act***

The 1995 Road and Road Traffic Act incorporated the Roads and Road Traffic (Traffic

Signs) Regulations which classified, described and provided an illustration of traffic signs (GRZ, 1995) in Zambia. In 2002, the Road and Road Traffic Act was repealed and replaced by two Acts namely: the Public Roads Act (GRZ, 2002a); and the Road Traffic Act (GRZ, 2002). In these Acts the classification, description and illustration of traffic signs was not included. The omission provides an opportunity for a detailed road traffic signs, markings and signals manual to be put in place. It is noted that the new traffic signs being provided do conform to the SADC Road Traffic Signs Manual as shown if

Figure 6.

It is therefore recommended that complete harmonisation of road signs, traffic signals (traffic lights), and road markings conform to the SADC Road Traffic Signs Manual as implemented by the East African transport facilitation strategy.

Figure 6: SADC Conformed traffic signs on Lusaka – Chirundu Road

***New generation traffic signs***

New generation traffic signs include illuminated or neon signs. The use of illuminated signs is not widespread in the Zambian road sector and few local authorities have installed some of these. The preferred illuminated signs are solar powered as shown in Figure 7.

Figure 7: Illuminated traffic signs

New generations of traffic signs based on electronic displays which can also change their text to provide for *'intelligent control'* linked to automated traffic sensors to provide real-time traffic incident warnings have been developed. In developed countries, real-time traffic incident warnings are conveyed directly to vehicle navigation systems using inaudible signals carried via FM radio, 3G cellular data and satellite broadcasts. But standards are yet to be developed for SADC.

## CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

The fact that the SATCC specifications that have been in use in the past 17 years in the Zambian road sector are still in draft form indicates that revision is overdue, in view of road user preferences advancement in road traffic control technology. It is not clear why it has taken so long to review the SATCC Specifications but in Zambia the public roads agency is currently in the process of procuring consultancy services to standardise the B-pay items.

The lack of a revised road traffic manual for the Zambian road sector has resulted in varied road traffic signs causing confusion to the road user. In addition, it had become increasingly difficult to ascertain the true cost of road projects as there was a notable differences in unit costs of items under series 5000. In addition, pay items that are difficult to measure in the field should be avoided and consideration of site-specific constraints should be made.

The paper therefore calls for the revision of Series 5000 of the SATCC specification to ensure that the method of measurement is responsive to the Zambian road sector. Standardising the method of measurement will provide uniformity and consistency in the Zambian road sector providing comparison of unit rates for items under series 5000 across projects and with the engineer's estimate. In addition, the revision of series 5000 and the road traffic manual would provide a platform to plan for new generation traffic signs.

Some limitations of the study include road sampling and inconclusive information regarding total number of non-standard road signs found.

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# Barriers to Implementing Forms of Systemic Innovation in the Construction Industry Departing from the Possible Adoption of Building Information Modelling in Zambia

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## ABSTRACT

*The construction industry plays a significant role in economic development; it contributes to the gross domestic product (GDP). Historically, the industry has had a number of incremental innovations, however the introduction of Building Information Modelling is a systemic change; one that requires multiple firms to change their practice. BIM is a form of systemic innovation which gives way to a modern approach to design and construction management; ideally involving a digitally collaborative environment supported by the use of a 3D model that includes information flowing through a project. This has been adopted in some developed countries such as the USA, Finland and United Kingdom.*

*The construction industry in developing countries such as Zambia can take advantage of this systemic change, as it would increase the value of investment; signified by the 20% savings by the use of BIM that the UK government claimed in 2011. In this study the barriers to the use of BIM were studied from literature, which were then analysed with respect to the findings of primary research (qualitative survey and interviews) done as a part of this study. The relevance of this comparison is to envisage barriers to developing systemic forms of innovation specific to a developing industry like that in Zambia. The need for such research is due to the lack of drivers of BIM adoption which is also relevant to several developing markets around the world.*

*From the findings it can be seen that the presumed level of digital technology used to design the questions of the survey is much higher than the actual use; only 8% of respondents had previously worked with BIM. This study further illustrates the need for further research so that theoretical frameworks can be linked to these barriers which would allow for better understanding of the core problem. Furthermore, the findings suggest that theories from sociology can be part of a valid framework due to the large number of barriers involved in people working together.*

**Keywords**: *Building Information Modelling, Construction Industry, Zambia, Barriers, Systemic Change*

# 1. INTRODUCTION

## Building Information Modelling (BIM)

According to Garber (2014), Building Information Modelling (BIM) provides the entire design and construction team with the ability to digitally coordinate complex processes of building throughout a building's life cycle. The BIM Handbook describes BIM as one or more digitally constructed accurate virtual models of a building. (Eastman, *et al.*, 2011)

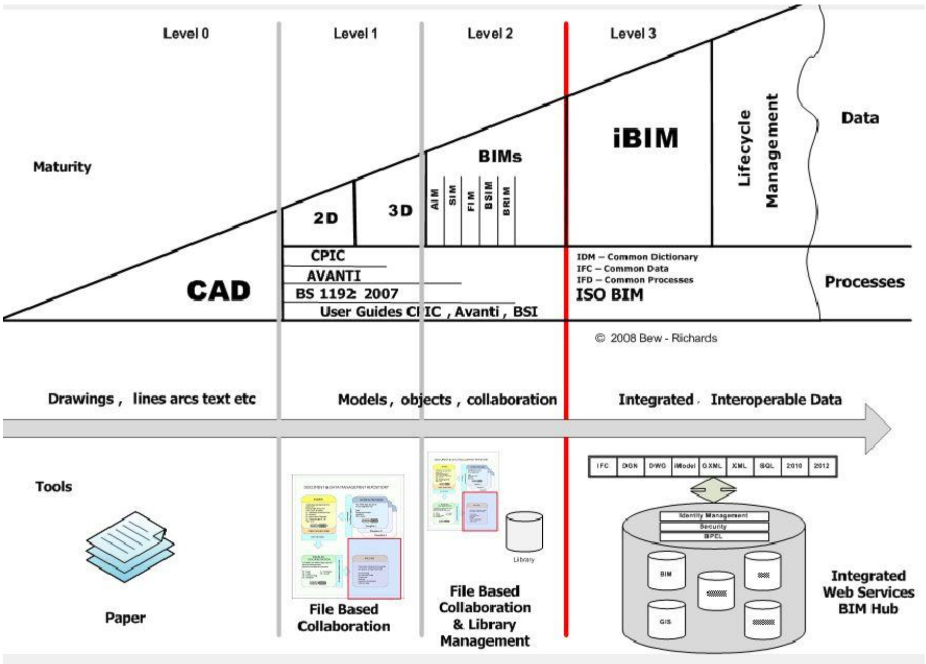


Figure 1: Levels of BIM (Bew and Richards, 2008)

The levels of BIM as shown in Figure 1 were defined to guide the maturity of digital technology, they include: (Digital Built Britain, 2015)

**Level 0** (Unmanaged CAD): A series of drawings which are relative to one another; No technology is used to manage all the resources collaboratively. This level is typical in less economically developed countries.

**Level 1** (Managed CAD in 2D or 3D): A series of models/drawings managed together by the use of a simple database

**Level 2:** Managed 3D environment with data attached but created in separate discipline models. Models controlled by a central database which predominantly sorts models and allows easy information exchange between stakeholders

**Level 3:** A comprehensive vision of the built environment as part of a smart, networked world. Multiple sub-models associated with multiple disciplines collaboratively and integrally viewed and managed.

The philosophy of BIM in the construction industry is working towards a compiled, intelligent model that contains and coordinates the following information:
Construction documentation, visualisation (design and construction), Material and

equipment quantities, cost estimates, construction sequencing and reporting (4-D), scheduling and fabrication data and tool paths. (adapted from Garber, 2014)

The construction industry in a developing country is often lacking in planning, skilled labour and support to innovate. The introduction of an innovative management tool such as BIM would allow for increased collaboration and efficiency.

## Benefits of BIM

The following Table 1 shows the benefits of BIM. It is important to note that the benefits of BIM are different for each stakeholder, this enables stakeholders to have multiple viewpoints about this systemic change.

Table 1: Benefits of BIM (Eastman, *et al.*, 2011)

| **Owner:** | **Maintenance and service:** |
|---|---|
| Concept, feasibility and design benefits | Improved commissioning and handover of facility information |
| Increased building performance and quality | Better management and operation of facilities |
| Improved collaboration using integrated project delivery | Integration with facility operation and management systems |
| **Designer (structural and architectural):** | **Contractors and Fabricators:** |
| Earlier and more accurate visualisations of a design | Use of design model for fabrication |
| Automatic low-level corrections when changes are made to the design | Quick reaction to design changes |
| Geometrically accurate and consistent 2D drawings at any stage of the design | Discovery of design errors and omissions before construction |
| Earlier collaboration of multiple design disciplines | Synchronization of design and construction planning |
| Easy verification of consistency to the design intent | Better implementation of lean construction technologies |
| Extraction of cost estimates during the design stage | Synchronization of procurement with design and construction |
| Improvement of energy efficiency and sustainability | |

The UK government’s BIM Task Group was created to guide its construction industry with BIM adoption, claims that some of the pilot projects already have achieved the targeted 20% savings in project costs.

## Systemic and Incremental Forms of Innovation

Tools used in the construction industry have evolved from hand drawings to 2D CAD to 3D CAD and recently BIM has become the latest form of technology. Taylor & Levitt (2004) defined incremental innovation as changes that reinforce the existing product or process and provide a measureable impact on productivity. Changes from hand drawings to 2D CAD were highly incremental as the changes improved how efficient individuals were. On the other hand, Taylor & Levitt (2004) defines systemic innovation as a form of innovation that reinforces the existing product but necessitates a change in the process that requires multiple firms to change their practice. Highly incremental changes like 2D CAD and 3D CAD could easily be implemented by some organisations in a project network independently. In an environment that is used to incremental changes in digital technology, one would question how the industry deals with systemic change envisaged by disruptive innovation like BIM. The barriers to BIM adoption from literature and specific to the Zambian construction industry (a market with no significant BIM adoption drivers as described in Sections 3.2 and 5.1) can shed some light to which theoretical frameworks need to be associated with the practical problems represented by the barriers.

### Aims and Objectives

The aim of this paper is to critically assess the barriers and drivers to the systemic change of using BIM in Zambia as an example, in order to further understand its slow adoption.

This aim is achieved by the following objectives:

- To establish the extent to which companies and professional bodies in the Zambian construction industry use digital technology;
- To see what the perception of upgrade in digital technology such as BIM is;
- To assess the drivers associated with the possible implementation of level 2 BIM;
- To carry out a qualitative survey with closed questions to find out what level of BIM is currently used;
- To carry out open question interviews with local professionals in the Zambian construction industry which will supplement results from the survey;
- To simplify BIM as a possible approach to management;
- To review techniques to drive implementation of forms of systemic innovation such as BIM in the construction industry;
- To relate possible theoretical frameworks to findings as a point of departure for further research.

## 2. METHODOLOGY

### Introduction

In order to find out what the status of BIM is in Southern Africa or to see what level of digital technology is being used, a qualitative survey designed with closed questions was used. The survey was electronically distributed amongst civil engineers, mechanical engineers, electrical engineers, project managers, architects, draftsman, quantity surveyors and site supervisors in the Zambian construction industry. The time frame used to design and circulate the survey was approximately 30 days. This section explains the objectives of the survey and interviews and clarifies the steps taken in the design stage. When considering the method, note that the results from both forms of primary research will be integrated to draw conclusions.

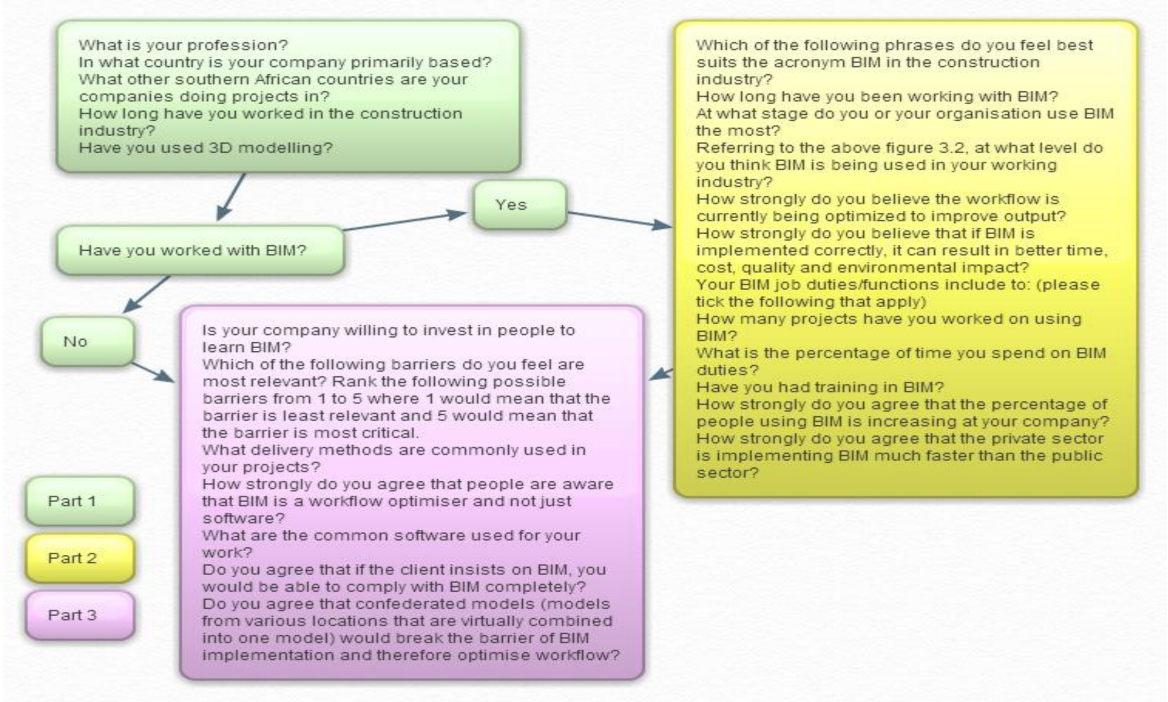
### Qualitative Survey

The survey was designed electronically using software called SelectSurvey with only closed questions. The use of a survey is appropriate in this circumstance as it can collect a large range of data in a short period of time. According to El Gohary, *et al.*, (2013) the philosophy of survey design is such that it has to be simple, clear and understandable.

A pilot study was conducted where 10 civil engineering students were used as possible respondents. One of the conditions for participation was that the student had to have previously taken part in the construction management module at the School of Engineering at the University of Liverpool. This was done to ensure that they would have been familiar with BIM related terminology and would therefore be similar to the sample. The need for a pilot study is to ensure the clarity and relevance of the survey to participants. (El Gohary, *et al.,* (2013)) The results and feedback from the pilot study were then utilised to improve the survey in order to ensure there was no ambiguity.

The options given to the respondent for each of the questions varied depending on the question. However a few questions asked the respondent how strongly they agree which allows for a five point Likert scale starting with strongly agree, agree, neutral, disagree and strongly disagree.

The sample of the survey was randomly chosen where any professional representing a business in the Zambian construction industry could take part. However only one survey per organisation was allowed, furthermore the professional who answers the survey must have valid experience in the construction environment. These two conditions were made clear in the introductory email. The aforementioned conditions were to avoid bias so that results would be valid collectively.



What is your profession?
In what country is your company primarily based?
What other southern African countries are your companies doing projects in?
How long have you worked in the construction industry?
Have you used 3D modelling?

Have you worked with BIM?

Which of the following phrases do you feel best suits the acronym BIM in the construction industry?
How long have you been working with BIM?
At what stage do you or your organisation use BIM the most?
Referring to the above figure 3.2, at what level do you think BIM is being used in your working industry?
How strongly do you believe the workflow is currently being optimized to improve output?
How strongly do you believe that if BIM is implemented correctly, it can result in better time, cost, quality and environmental impact?
Your BIM job duties/functions include to: (please tick the following that apply)
How many projects have you worked on using BIM?
What is the percentage of time you spend on BIM duties?
Have you had training in BIM?
How strongly do you agree that the percentage of people using BIM is increasing at your company?
How strongly do you agree that the private sector is implementing BIM much faster than the public sector?

Is your company willing to invest in people to learn BIM?
Which of the following barriers do you feel are most relevant? Rank the following possible barriers from 1 to 5 where 1 would mean that the barrier is least relevant and 5 would mean that the barrier is most critical.
What delivery methods are commonly used in your projects?
How strongly do you agree that people are aware that BIM is a workflow optimiser and not just software?
What are the common software used for your work?
Do you agree that if the client insists on BIM, you would be able to comply with BIM completely?
Do you agree that confederated models (models from various locations that are virtually combined into one model) would break the barrier of BIM implementation and therefore optimise workflow?

Figure 2: Chart showing path of questions used in survey

The survey consisted of 25 questions. Figure 3 shows the three parts of the survey which are represented by the three different colours in the chart. As shown in the chart, a respondent who had worked with BIM would answer all the questions; the second part of the survey aimed to find out the extent to which BIM is used. However if the respondent had not previously worked with BIM, the survey became shorter with only 13 questions. A page condition was used to allow for a conditional statement that let the respondent skip 12 questions associated with BIM. If a respondent had not previously worked with BIM then a link to a 4 minute video that introduced the BIM concept was presented. The purpose of the video was to enable the respondent to gather a basic understanding of the philosophy of BIM. The perception of the respondent coupled with experience from working in the market put them in the position to make valid judgement, assuming that the respondent would watch the short video.

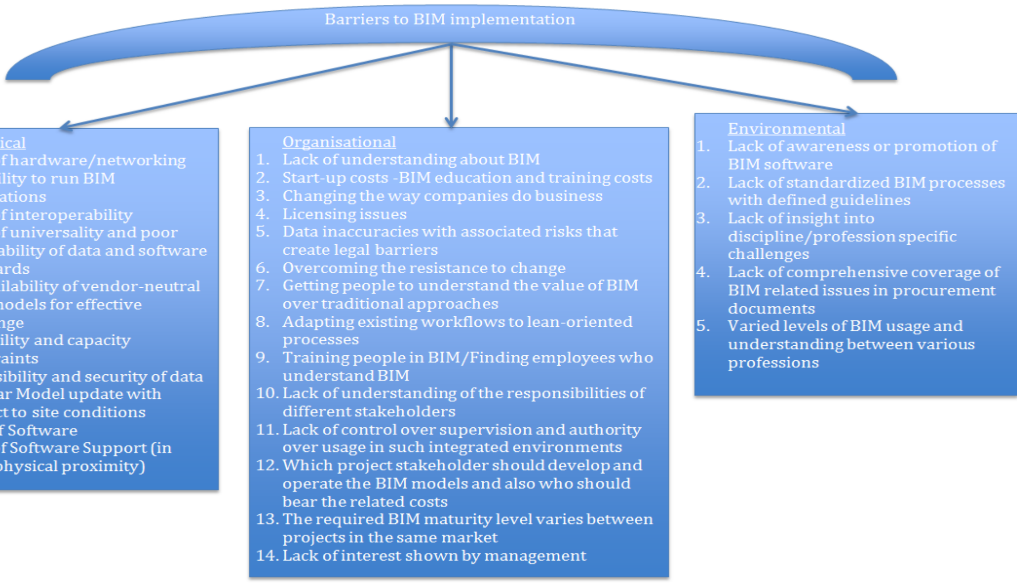
### Interviews

In order to gain insight into why BIM has not entered the Southern African market; interviews were held with professionals from quantity surveying companies, contractors, designers (architectural, electrical and structural) and members of professional bodies. Mechanical Engineering professionals were not considered in interviews as they tend to work in multiple industries and therefore could bring in a partially invalid viewpoint. The questions from the survey were presented to the interviewee in an open manner which allowed the interviewee to provide a detailed explanation of their viewpoint.

The project was run over a period of 3 months which only allowed for a few interviews. However, these interviews were not analysed independently but were supplementing responses from the survey and key findings in literature.

## 3. BARRIERS TO BIM IMPLEMENTATION

### Generalised Barriers to BIM implementation from Published Literature



Barriers to BIM implementation

Technical
1. Lack of hardware/networking capability to run BIM applications
2. Lack of interoperability
3. Lack of universality and poor adoptability of data and software standards
4. Unavailability of vendor-neutral data models for effective exchange
5. Scalability and capacity constraints
6. Accessibility and security of data
7. Regular Model update with respect to site conditions
8. Cost of Software
9. Lack of Software Support (in good physical proximity)

Organisational
1. Lack of understanding about BIM
2. Start-up costs -BIM education and training costs
3. Changing the way companies do business
4. Licensing issues
5. Data inaccuracies with associated risks that create legal barriers
6. Overcoming the resistance to change
7. Getting people to understand the value of BIM over traditional approaches
8. Adapting existing workflows to lean-oriented processes
9. Training people in BIM/Finding employees who understand BIM
10. Lack of understanding of the responsibilities of different stakeholders
11. Lack of control over supervision and authority over usage in such integrated environments
12. Which project stakeholder should develop and operate the BIM models and also who should bear the related costs
13. The required BIM maturity level varies between projects in the same market
14. Lack of interest shown by management

Environmental
1. Lack of awareness or promotion of BIM software
2. Lack of standardized BIM processes with defined guidelines
3. Lack of insight into discipline/profession specific challenges
4. Lack of comprehensive coverage of BIM related issues in procurement documents
5. Varied levels of BIM usage and understanding between various professions

Figure 3: Barriers to BIM implementation (Compiled from: Navendran, *et al.*, (2014), Tulenheimo (2015), Kang, *et al.*, (2012), McAdam, (2010), Davies and Harty, (2012), Azhar, *et al.*, (2011))

This section focuses on the barriers and drivers according to literature. These are considered when analysing results in section 4. Figure 3 shows the categories that barriers can be categorised into. These categories were defined by Navendran, *et al.*, (2014) as technical, organisational and environmental. Authors such as Tulenheimo (2015) categorised these barriers under different categories. The barriers shown in Figure 3 were combined from multiple papers and categorised under the aforementioned categories. From literature, there is a lack of understanding of the theoretical problems associated with barriers as authors fail to describe why these barriers are limiting BIM adoption. Therefore it is relevant to analyse these barriers to create a clear framework, from which further studies can depart. The following sub-sections cross-references the generalised barriers from Figure 3 with practical barriers presented by Booyens, *et al.*, (2013). For example, reference to the n^th organisational barrier would be 'O*n*' whereas technical barriers would be 'T*n*'.

***Examples of Organisational Barriers***

Booyens, *et al.*, (2013) presented findings suggesting that quantity surveyors who do not utilise BIM compliant software felt that their existing software was optimal and that advantages did not justify the expense required for use (O2). This suggests that quantity surveyors such as the interviewee lack understanding of BIM (O1). The respondent also added that Revit software was relatively unknown in South Africa and that architects have not completely mastered it. Since the interviewee names a piece of software, this pertains to the lack of understanding of BIM as this indicates that the interviewee is treating the change as incremental and not systemic (O1). Furthermore the respondent also states how if a mistake is made by the architect, the BOQ will also have a mistake. The perspective of the interviewee may be questioned here, as this could be perceived as follows; when mistakes made in the model are corrected, the BOQ is also automatically corrected. This reinstates the barrier associated with resistance to change. The quantity surveyor's role in the industry will be more refined as BIM is implemented therefore quantity surveyors may feel that they would lose business which can be related to the barrier pertaining to changes in the way companies do business (O3).

The authors found that only 19% of quantity surveyors interviewed use BIM compliant software and advises that BIM is not taking over the market yet. This can be linked to a respondent's comment; that companies could adopt BIM in time. (O7 & O8) Additionally, quantity surveyors that use BIM compliant software stressed that the BIM compliant software available to architects is not used in the intended manner (O1). The interviewee further stated that the technology was there but the knowledge and the skill required to operate a BIM model was lacking. (O9)

An interviewee who works with a large multinational construction firm stated that there is need for a central driving force that has to steer BIM implementation. This suggestion could solve three barriers; varied BIM maturity levels (O13) as a central body will unify the level of BIM maturity of various stakeholders, the stakeholders who are unsure about which stakeholder should take control of the supervision (O11) and operation of the BIM model (O12). Evidence of a central driving force working in the UK, the government in 2011 released the policy indicating level 2 BIM as a requirement for governmental construction projects starting in 2016; this was done by forming a national construction strategy which defined the goals, and the BIM Task Group to implement it into practice. Thus the public demand of BIM has become a central driving force.

A respondent from another construction company iterated the need to adapt existing workflows (O8). The respondent also added that the younger generation will have to make changes as they are more familiar with technology. This shows resistance to change (O6).

From the authors' interviews with architects, it is inevitable that hiring new personnel to utilise a BIM model costs a lot more (O2) than the traditional way of working. However, the cost to the client cannot be compromised as the business would lose its competitive edge. The amount of time used on familiarising the team with BIM may be significantly more than it should be. This makes team members less productive as the element of work refinement is lost. Therefore using BIM would then reduce profit margins for the architectural firm which would be a negative to the shareholders of the company. The interviewee's explanation envisage BIM as a form of disruptive innovation to some extent, however one could question whether the long term benefits such as improved quality and productivity are considered. The interviewee failed to see how the short term costs would be outweighed by the long term benefits which shows a lack of understanding (O1).

Another architect explained how engineers do not request 3D models and are satisfied with the 2D drawings. This claim can be related to two barriers; the lack of understanding of BIM (O1) as the benefits and use of a BIM model are not clear to the whole professional team; for example BIM compliant software can automatically produce 2D drawings. The second barrier that can be related to this finding is that of varying levels of BIM maturity (O13). A professional team is put together for each project and as the entire team would not be working together in other projects, this allows for varied levels of BIM experience within the industry.

One of the authors' findings were that sharing of information was not taking place appropriately between the professional parties; i.e. the architect would generate a model, however the engineering companies would have to make a new model from the beginning without any integration. This signifies a lack of control, supervision and authority over usage in an integrated environment (O11). Furthermore, an engineer that was interviewed justified the need for an integrated environment by explaining the importance of coordination between all parties for BIM to be effective.

### *Examples of Technological Barriers*

Quantity surveyors explained how the cost of BIM compliant software is an issue. Their opinion was that the cost effectiveness of the software is inadequate for implementation (T8). Purchasing licenses for insufficiently used software would not be a good managerial decision. According to a quantity surveying software company, only 19% of quantity surveying companies utilise their software for a BIM model. A quantity surveyor that has purchased BIM software explained how the software was not used to its full potential as it was only used for quantity take-off and estimating. The reason for its restricted use is due to the inability to measure according to the standard system of measuring – ASAQS. This is an example of the lack of universality and adoptability of data and software standards (T3).

From the contractor's point of view, a respondent explained how the cost of BIM compliant software is a major constraint (T8). Furthermore, these programs need regular support in terms of updates and when users operate it; this will add to the cost and insufficient support (T9) can degrade productivity inevitably by affecting workflow and therefore losing efficiency. According to the authors' findings, there are two main software packages that architects use for BIM (Revit and ArchiCAD). The architect mentioned that the cost of the software (T8) was also a significant constraint. Another constraint is that of hardware capability (T1); current hardware used for traditional activities have to be upgraded which would be costly especially for small to medium sized enterprises.

### *Examples of Environmental Barriers*

One of the environmental barriers found was that architects, engineers, quantity surveyors and contractors have a varied understanding of BIM. This signifies that the manner that software companies are promoting the use of their respective software is inadequate (E1).

Furthermore, clients don't know about BIM and its advantages; the lack of comprehensive coverage of BIM in procurement documents as these documents directly link the client and their respective needs to the project (E3).

According to the interview results, BIM is not feasible for small to medium sized enterprises from a financial standpoint as there is a lack of understanding coupled with the lack of exposure. When the larger enterprises implement BIM compliant utilities, it will make them more competitive in the future; this will then increase the gap between large and smaller enterprises. Therefore this will change the environment or nature of the construction industry making it riskier for small to medium sized enterprises.

Training in BIM is required to existing professionals involved in the industry as well as to new professionals graduating from institutions in the area. This growing need of newly trained graduates with knowledge about BIM would exhibit pressure on institutions to revise their curriculums accordingly.

As shown by the advantages that apply differentially to various professions in section 1.2, we can see that different professions have different viewpoints about BIM as their motivations to its use vary. From a neutral standpoint the various professions use BIM to a varied effect (E5). This can be also due to the lack of understanding of BIM coupled by the resistance to change. The varied use of BIM can also be due to the lack of standardised BIM processes with defined guidelines. Defined standards would allow for a more refined role for each professional entity and ensure a certain level of BIM is used by the whole project team.

### Drivers to BIM adoption

The long term prospects of BIM implementation depend on drivers to change, these work against the obstacles that people and organisations in the construction industry are likely to face.

Eastman, *et al.,* (2011) claims that there are a number of economic, technological and societal factors that can drive the future development of BIM implementation; globalisation, specialisation, international drives for sustainability, the commoditisation of engineering and architectural practices, the move to lean construction methods, the increasing use of design-build and integrated project teams and the demand for facility management information.

Globalisation is a driver towards BIM adoption resulting from the elimination of barriers pertaining to international trade, e.g. the Southern African Development Community (SADC) is the organisation that makes trade agreements in the area this study is concerned with.

Eadie, *et al.,* (2013) analysed the drivers towards BIM adoption. The drivers that were analysed were government pressure, client/competitive pressure, desire for innovation to remain competitive, improving the capacity for the whole life value, streamlining design activities, designing health and safety, improving communication to operatives, cost savings and monitoring, time savings, accurate construction sequencing and clash detection, automation of schedule/register generation, facilitating increased pre-fabrication, facilitating facilities management and improving built output quality.

## 4. RESULTS AND DISCUSSION

This section presents results from the surveys and interviews independently. The interviews were initially designed to supplement the results of the survey for deeper understanding; these findings are generalised in Section 5.

### Surveys - Introduction

The total number of responses to the survey was 84; an overall response rate of approximately 35% as 238 introductory emails were send out. The UK's National BIM Survey's response rate of 23% further encourages the overall statistical validity of findings. (Dobson, 2014)

Respondents did not answer some of the questions. Therefore the number of responses per question is described when discussing the results of each question and can also be found on the bottom right corner of each figure. For example, if the number of responses is 78, then n=78 will be indicated. The results are presented in figures followed by a description and analysis.

Generally findings from the survey show that BIM is relatively new to the region as only 8% of respondents have previously worked with BIM. The results presented in this section are most relevant towards the findings of this study.

### *Survey Part 1*

The first section of the survey was to gain insight to the respondents' role in the construction industry. This is a significant section in order to avoid bias. The survey had 84 respondents which consist of various professions. The highest response was from civil engineers (19 responses), followed by mechanical engineers (14 responses), followed by electrical engineers (12 responses), project managers (5 responses), architects (5 responses), draftsman (3 responses), quantity surveyors (3 responses), site supervisors (2 responses) and 19 responses categorised under other. Other professions included interior designers, mining engineers, water engineers and geotechnical engineers. This question was designed to find out what the audience of the survey is in terms of profession. This is important in order to see the distribution of the audiences' professions when analysing the more technical questions.

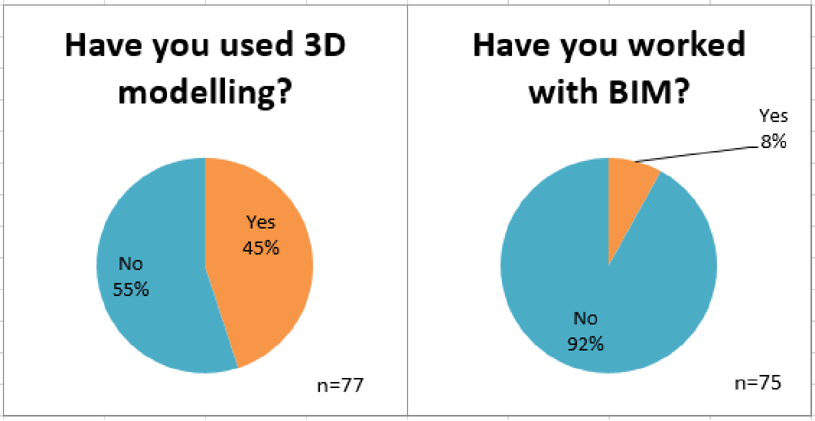


Figure 4: a) Left- Indication of level of digital technology used b) Right- Indication of status of BIM use

Figure 4a shows the number of respondents that have used 3D modelling. From the 77 respondents, 45 % of the respondents had used 3D modelling.

This question was relevant as it was required to find the level of digital technology used in the market. 3D modelling is very general and is a relatively old piece of technology as it was first used in 1982. (Garber, 2014)

Figure 4b represents the level of BIM use in Zambia. Only 8% of 75 respondents had working experience with BIM which signifies the lack of implementation in the market. This value can be compared to the figure presented by Booyens, *et al.*, (2013) where only 19% of all quantity surveying firms utilise BIM compliant software. This shows that the regional market has not taken BIM as a new method of management which indicates the lack of drivers towards its implementation.

***Survey Part 2***

This section of the survey was only answered by respondents who had previously worked with BIM. Since only 6 respondents answered this section, the sample size for this section makes the results statistically insignificant. We can see the following general findings from the results but have to be considerate of the statistical insignificance and therefore should be treated speculatively.

1. Most respondents (4 out of 6) felt that Building Image Modelling was better suiting to the acronym BIM which shows that there is a lack of understanding.
2. Most respondents (5 out of 6) use BIM at the design stage which can be linked to the previous question. This also shows improper use of BIM also verifies that the advantages of BIM aren't exploited as BIM is not utilised properly. This can be linked to the findings made by Booyens, *at al*., (2013) where the interviewees claimed improper use of BIM.
3. The claimed level of BIM use is predominantly level 1 with only one respondent claiming that it is level 2.
4. BIM is dominantly used to convert 2D drawings to 3D models and to create models of site logistics.

***Survey Part 3***

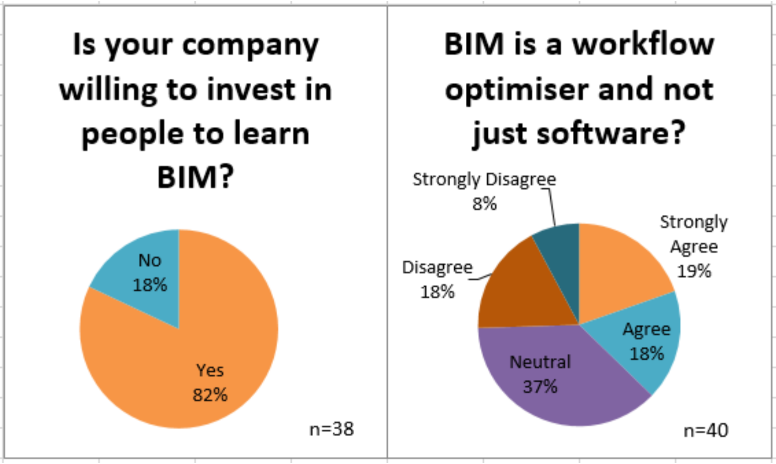


Figure 5: a) Left- Distribution of respondents view to prospect of investment to learn BIM b) Right- Distribution of the respondents' viewpoint on whether BIM is a workflow optimiser or just software

Figure 5a shows that 82% of the 38 respondents felt that their companies would invest in the workforce to learn BIM. This shows positivity towards the idea of BIM implementation which shows that the respondents have motivation towards the use of BIM and feel that it is the future way of working. The other 18% of the respondents that answered "no" may have a more traditional mind-set where they would like to keep their operations from advancing in order to keep operations refined and specific. The respondents that had previously worked with BIM all answered "yes" to this question which is an encouraging sign as they believe that it would be a step into the future.

Figure 5b shows the distribution of 40 responses to whether the respondent felt that BIM was just a piece of software or whether they thought of it as a workflow optimiser. Most of the respondents took a neutral standpoint (37%), whilst 37% agreed and 26% disagreed with this notion. This shows that the perception of BIM is questionable even after providing the respondents with a 4 minute video on OpenBIM as marketed in Finland. More respondents agreed as compared to the respondents that disagreed. It is important for the professionals of the construction industry to perceive BIM as not just software but as a workflow optimiser in order to motivate the industry to adopt.

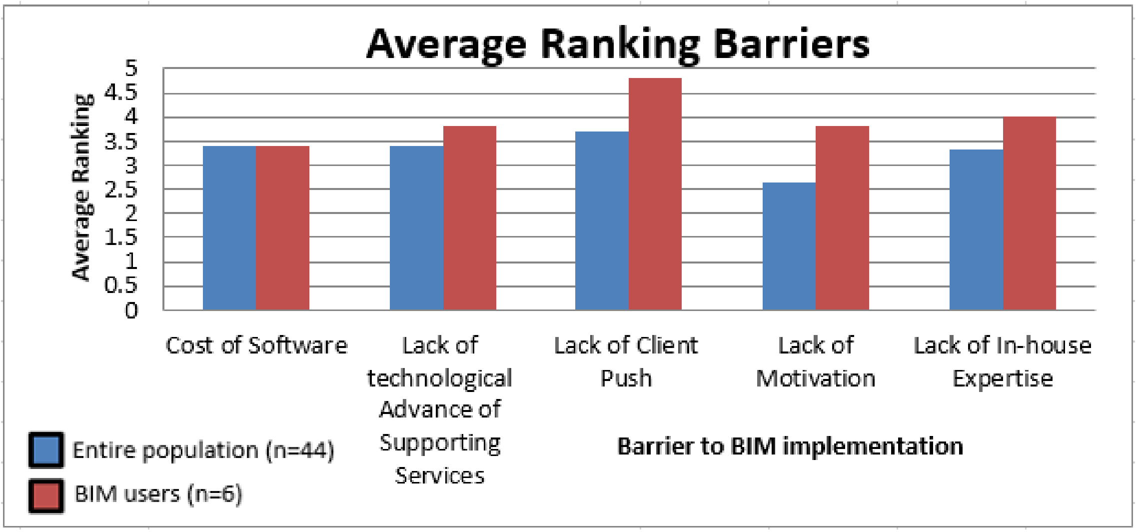


Figure 6: Respondent average ranking to common barriers of BIM implementation

Figure 6 is representative of the average ranking of barriers to BIM implementation according to the respondents' experience in the market. The ranking scale ranged from 1 to 5, where 1 would signify that the barrier was of low importance and where 5 would signify that the barrier was highly significant towards BIM implementation. The range between the lowest signified barrier (2.60) and the highest (3.70) for the entire population was 1.10 points and since the lowest ranking was of moderate level, it is safe to assume that the respondents agree that all the barriers are at least moderately significant. The 44 respondents to this question felt that the lack of client push was the most significant barrier to BIM implementation as the average ranking was 3.70. The following barrier was the lack of technological advance of supporting services in the area (3.40), followed by the cost of software (3.39), lack of in-house expertise (3.36) and finally, the lack of motivation (2.60) was ranked as the least significant barrier. Towards the long term goal of BIM implementation, the low ranking of the lack of motivation is a positive sign that the market is actually open to the idea of implementation.

From the respondents that have worked with BIM (n = 6), the following were the average rankings: Cost of software = 3.40; lack of technological advancement in area =3.80; the lack of client push = 4.80; lack of motivation = 3.80 and lack of in-house expertise =4.00. As compared to the entire sample of results we can see that lack of client push was found to be the most significant barrier. This subset of the entire sample is in agreement with the rest of the respondents. This shows that hands-on work done using BIM did not have a significant effect on most of the perceived barriers. However, the difference in the perception of lack of client push and lack of motivation is significant; from 3.70 to 4.80 and from 2.60 to 3.80.

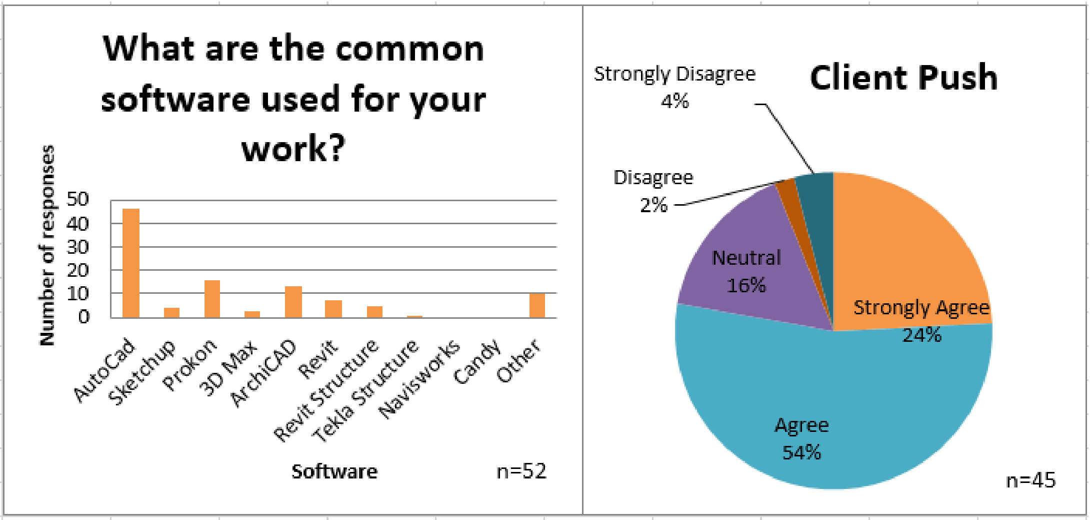


Figure 7: a) Left-Bar chart showing the distribution of responses to common software used in Zambia b) Right-Distribution of the respondents' viewpoint on client push

Figure 7a shows the number of responses with respect to the software used in the industry. 52 respondents answered this question, many with multiple entries. The most common piece of software was AutoCAD where 47 entries were made. The second most used software is Prokon (16 entries) which is a structural engineering tool used to design steel and concrete structures in 2D.

Figure 7b identifies that the majority of respondents (agree and strongly agree, 78% of 45 responses) approve of the client push scenario; this is in accordance with the driver towards BIM implementation described as the client's interest in Section 3.2 of the literature review. 16% of the other respondents took a neutral standpoint and only 6% disagreed. As compared to the respondents that had previously worked with BIM, all the respondents strongly agreed to this claim; client push is a relevant driver to change.

## Interviews - Introduction

The study was done over a short timescale of 90 days; the number of interviewees is minimal as 3 architects, 3 quantity surveyors, 2 structural engineers and 1 interior designer were interviewed. Therefore the independent analysis of results would inflict bias. Therefore the results from this section should supplement the results from the survey allowing for a better understanding of the barriers to adoption and current status of digital technology use.

### *Quantity Surveyors*

Three quantity surveyors from three different companies were interviewed. All the quantity surveyors interviewed had more than 15 years of working experience. All three interviewees had not heard of BIM. After a brief explanation of BIM; two of them gained interest.

However the third was more sceptical of the idea as he was involved in the higher levels of management.

When asked about the barriers, two of the interviewees felt that software acquisition was going to be the biggest problem as the cost of the software would not be affordable by each individual company at early stages of implementation. The third interviewee explained why convincing the professionals in the market would be the hardest; the resistance to change from methods that are already making the owners of these companies' high profits would not motivate them to do so unless it becomes legislation. However the interviewee raised the question of whether legislation would be enforced by the government's professional bodies. All three interviewees responded positively to the thought of bringing a standard into the market; however they were not sure who could regulate it.

The third interviewee felt threatened by the outlook of BIM as it seemed to the interviewee that this would change the role of the quantity surveyor. The refined nature of the traditional workflow coupled with high profits, made the interviewees perspective towards BIM much more negative than the others.

### *Architects and Interior Designers*

Three architects, (one with <15 years, >20 years and <10 years of experience) and one interior designer (<10 years of experience) were interviewed. Only one of the architects (<15 years) had previously worked with BIM but not in the southern African market. The other interviewees had a vague idea but they perceive it only as software which shows a lack of understanding. After presenting them with the brief explanation of what BIM is, a rise in interest was clear. It was obvious that they thought of it as a form of 3D modelling rather than a way of managing a building through its life cycle. Each architect had a different viewpoint on the most critical barrier; one architect stated that technology was a problem such as electricity outages, slow internet connections; the second interviewee stated that software acquisition was an issue; the architect who had worked with BIM already explained how convincing the professionals in the market would be the biggest barrier and unless the clients are educated about BIM it would be negatively perceived. The interview with the BIM experienced architect idealised that a BIM consultant may be used; the BIM consultant would be the direct contact to the client instead of the current ways of working e.g. the architect is the first connection to the client. When asked to elaborate on the idea, the architect explained that since there is no legislation to use BIM, why not market it to the clients through a neutral business enterprise such as a BIM consultant. The idea of having a neutral body within the private sector would break a significant amount of barriers as exemplified by the success of the BIM Task Group in the UK construction industry.

### *Engineers*

One senior electrical engineer (>30 years of experience) and two structural engineers (>15 years of experience) were interviewed. The electrical engineer and one of the structural engineers were also owners of the private limited companies that they worked for. All three of the interviewees felt that BIM was the future, however barriers such as the cost of software and convincing the professionals within the market were opinionated as most critical. The business owners pointed out that unless they get subsidised prices for software; the business would not be able to afford it as it would make them less competitive.

The electrical engineer who is a professional that has been involved in the construction industry for over 30 years explained that the change from ink drawings to 2D drawings was also not an overnight shift; it took up to 4 months to implement successfully in Zambia. On standardisation, the same aforementioned argument as the quantity surveyor arose; who can regulate it? The electrical engineer suggested using a form of a public-private partnership which would then involve some government bodies as well as a formed non-governmental organisation.

The structural engineer who was also the business owner explained how a standard for the whole SADC region would be difficult to establish. The business has operations in other countries, such as Zimbabwe and the Democratic Republic of Congo, which shows that the interviewee has significant experience working with industries in the region and would be in a good position to make a judgement. As an owner of a business, who is also a structural engineer, he has significant knowledge about regulation, procurement and contracts. Firstly all the countries in the SADC region are using different codes for design purposes; for example in South Africa they have SANS codes which are produced by their local professional body whereas in Zambia, a combination of British Standards, Eurocodes etc. which are pre-approved by the Zambia Bureau of Standards, are being used. Therefore, design integrated within the region has been significantly restrained. From experience of setting up operations, the structural engineer also explained how having operations in the regional countries can also result in problems due to legislation; the laws, procurement methods, contractual models, regulations and ways of working significantly vary in the region.

## 5. FINDINGS

### Significance of Results

The assumed level of digital technology used in the Zambian construction industry to design the survey was higher than what the findings reflect as only 8% of the respondents had previously worked with BIM and only 45% of respondents had previously used 3D modelling. In other words, the respondents' level of understanding of digital technology used in the construction industry was lacking with respect to that required to answer the survey. This is a finding in itself as there is a larger gap in the use of digital technology between construction industries in emerging economies such as Zambia as compared to more economically developed countries such as the United Kingdom. This increases the significance of this research as the gap is ever-growing due to the lack of innovation in the Southern African region. However, the level of digital technology does not necessarily have to develop the way it has in developed countries, a higher level of digital technology with the use of BIM can be implemented to suit the market. However, BIM inflicts a systemic change which involves changes in the way that organisations practice, which is not fully understood theoretically, making this study relevant towards further research.

The general barriers that are found from literature also apply to the construction industry in the region as shown by the high average response to the question on barriers in the survey. A positive sign was that the lack of motivation received the lowest ranking which shows that the respondents are interested in the idea of implementing BIM. If the lack of motivation is not a significant barrier, then one would have to question the drivers toward BIM implementation. From primary research done in this study, respondents that did not use BIM felt that government pressure, client pressure and competitive pressure were the most significant drivers. However, respondents using BIM felt that clash detection and cost-savings through reduced re-work are the most significant drivers towards BIM adoption.

Table 2 shows the drivers to change and the current situation in the region with respect to each driver. We can see that all the drivers to BIM implementation pertaining to the region do not exhibit any direct relation to the construction industry in Zambia. This could be because of the lack of awareness of BIM as the software companies do not actively market it in the industry.

Table 2: Drivers to change with respect to the findings of interviews and surveys

| **Driver to change** | **Current situation with respect to driver and digital technology use such as BIM** |
|---|---|
| Clients' interest | No client interest as BIM is unknown to most corporate clients in the area pertinent to the lack of marketing of BIM |
| Government support through legislation | There is no legislation defined to the level of use of digital technology in the construction industry |
| Cooperation and Commitment of Professional Bodies | Professional bodies do serve their purposes in the area however do not have any direct link to the way that digital technology is used. |
| Software availability | Software used in the industry is not marketed and no software companies operate locally in Zambia; Autodesk is the most common software provider and there is no local branch to provide software support which shows that the software is not locally available or maintainable |
| Collaborative procurement methods | Design-Bid-Build is the most common delivery method which is a traditional way of procurement; there is a lack of collaboration between professionals. |

The technical barriers presented are also significant but should be considered in terms of incremental improvements in technology coupled with the lack of knowledge about interoperability (an organisational barrier) e.g. allowing for interoperable data involves developing forms of data that can be converted to be used with various software packages, however, the user needs to know how to interoperate the models especially when data formats are constrained.

As organisational and environmental barriers are associated with people and behaviour; Xiang, *et al*., (2012) explained how the behaviour of people associated in a project can be a significant uncertainty. The organisational and environmental barriers are both qualitatively and quantitatively more significant than the technical barriers. This is supported by the numerous findings from Booyens, *et al.*, (2013) as well as the surveys and interviews done in this study. The most critical findings that support this viewpoint are found in the interview results where only a few technical barriers are raised except the cost of software. From the survey, organisational and environmental barriers were all ranked moderately highly supported by the number of barriers such as a lack of standardisation, lack of understanding of BIM, varied level of digital technology exemplified in interviews. This shows that the organisational and environmental barriers need more attention than the technical barriers. This also enables one to question the motivation of individuals in the industry when dealing with such systemic change.

Taylor & Levitt's (2004) definition of systemic innovation explains the need for change in how multiple firms practice. This further reiterates the importance of considering barriers associated with social behaviour. Taylor & Levitt (2004) generalised the construction industry as a project-based inter-organisational network. Keeping in mind that the barriers outlined in this study are respective of the difficulties of implementing systemic forms of innovation, it would be relevant to look at how other project-based industries have coped with systemic change and if they have had similar disruptions. Applying theories from sociology such as Structuration Theory by Anthony Giddens (1984) would therefore be relevant as this has been already used as a theoretical framework in the German TV industry which is also a project-based industry (Windeler, *et al.*, 2001).

## Conclusion

Research was done in order to find evidence to support the claim that BIM is fairly new to the southern African industry, using Zambia as a target market. Surveys with closed questions were distributed electronically and interviews with a range of open-ended questions were conducted in Zambia with professionals involved in the construction industry. Questions were designed under the assumption that BIM was known to the area, but used a lot less than the UK. The basis of this assumption was a study done by Booyens, *et al.,* (2013) where findings presented 20% use of BIM compliant software in the South African industry. A literature review was undertaken in accordance with the objectives of this study. One of the general barriers to BIM implementation found was that the research was not done from a profession specific basis. This has been considered when interviews were carried out where professionals, such as quantity surveyors, civil engineers, architects, electrical engineers, business owners as well as individuals who represent government professional bodies, were questioned in order to make sure that the findings of this study had substantial breadth.

From the survey, finding the level of BIM and digital technology used was involved. Only 45 % of respondents have used 3D modelling, coupled with only 8% having previously worked with BIM, which suggests that the assumed status of BIM in Zambia to design the survey was more advanced than the actual status is. Since BIM can be referred to as a subset of digital technology, we can see that the level of digital technology used in the area is a lot less advanced than previously envisaged. This further demonstrates the need for research in this area as the gap in literature and knowledge with respect to the global market is substantial and should be corrected before the ever-growing gap gets harder to fill. One of the objectives of this study was to simplify BIM as a possible approach to management. From the discussion section of the report we can see that the current drivers for change in the area are significantly lacking and have to be considered in further detail in order to implement BIM in Southern Africa. We can also see that approaching the organisational and environmental barriers from a socio-technical point of view would be valuable (as for any systemic change) there are changes in the way that organisations work together. The barriers presented to systemic change such as BIM in the construction industry can be compared to other project-based industries and could shed some light as to the theoretical problem at hand. Once the theoretical framework is established with respect to the current status as presented in this paper, possible solutions based on motivation or regulation can be developed.

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# SESSION 3C

# SOFTWARE APPLICATIONS

# MODELLING OF STORM WATER RUNOFF FOR KITWE CBD DRAINAGE SYSTEM USING SWMM SOFTWARE

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## ABSTRACT

*The modelled Kitwe Central Business District (CBD) Storm Water drainages using Storm Water Management Model (SWMM) software was bordered by Oxford, Chisokone, Obote and President Avenue, with length 561 metres and width 262 metres, total area of 0.146 square kilometres. In 1970s, when price of copper dropped on the international market, immediate consequence was the degeneration of infrastructure due to failure by Kitwe city Council to invest in infrastructure development. In 2004/2005 and 2006/2007 rain seasons, Zambia experienced urban floods in poorly drained shanty compounds like the Kanyama flood disaster and Chowa in Kabwe as well as the North Western, Western, Eastern and Northern Provinces respectively. Though Kitwe was not reported to be affected, ways to mitigate and prevent the likely occurrence of flood in the CBD by rational or modelling methods were needed. SWMM a widely used tool for planning, analysing, designing and sizing of drainage system components does conceptualise the drainage system in series of water and material flows through three (3) environmental compartments, namely: the atmosphere, where precipitation and pollutants falls to generate both runoff and pollutant loads, the land surface, where precipitation from the atmospheric compartment are received, and the transport, a network of conveyance elements of channels that transport water to outfalls. Modelled Kitwe CBD storm water drainage involved entering data into SWMM software from three (3) compartments, and simulation enabled to troubleshoot the modelled drainage system and to check performance in relation to rainfall pattern and condition of storm water drainage system.*

***Keywords**: Floods, Storm Water Management Model, Atmosphere compartment, Land surface compartment, transport compartment and modeling*

## INTRODUCTION

The modelled Kitwe Central Business District (CBD) Storm Water drainages was bordered by Oxford, Chisokone, Obote and President Avenue (see figure 1.0), with length 561 metres and width 262 metres respectively, total area of 0.146 square kilometres, located 350 kilometres North of Lusaka, 12°49’ South and 28°12’ East in the southern side of the equator, altitude of 1,295 metres above sea level and sandy to sandy clay loams soil characteristic.

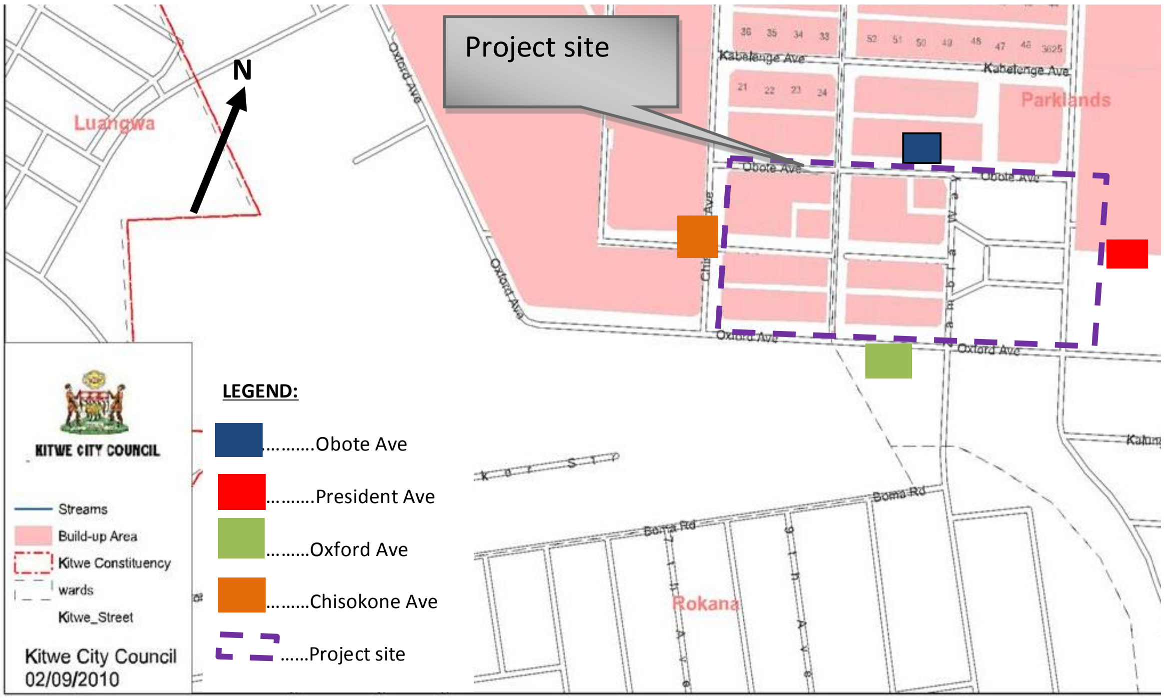


Figure1.0.Map of Kitwe Central Business District.

Kitwe District, a second largest city in Copperbelt Province, Zambia, with the most developed commercial and industrial area due to the mining activities was established in 1936 as an adjunct, elevated to Municipal and City status in 1954 and 1967 respectively, and afterwards developed tarred roads, efficient railway transport system and massive infrastructures in the central business district. In 1970s, when price of copper dropped on the international market, copper revenue reduced and immediate consequence was the degeneration of infrastructure due to failure by Kitwe City Council (KCC) to invest in infrastructure development (Banda, no date). In 2005, after Zambia experienced urban floods in poorly drained shanty compounds like the Kanyama flood disaster and Chowa in Kabwe, Zambia came up with a national disaster management policy framework, intended to help disaster management regime to assume and play a coordinating and implementation role before, during and after disaster outbreaks (Lupando, 2005). Despite that, the 2006/2007 intense rainfall caused an unusual level of destruction in several parts of Zambia, with some towns receiving a season amount of rain within a week, this resulted into floods which heavily affected the North Western, Western, Eastern and Northern Provinces (Sylwander, 2006).Though Copperbelt and Kitwe in particular was not reported be affected, it must be assumed that with rapid urbanisation, faulty storm water drainage network in CBD and change in rainfall pattern, these might cause urban flash floods in Kitwe CBD. Thus, the Kitwe local authority have to find ways to mitigate and prevent the likely occurrence of flash flood in the CBD by assessing the rainfall pattern, urbanisation/land cover and storm water drainages through either rational or modelling methods. The project aimed at modelling Kitwe-CBD storm water drainage system through Storm Water Management Model (SWMM) software and the objectives of the study assessed the rainfall pattern, changes in land use and the condition of storm water drainages within the study area.

## APPLICATION OF STORM WATER MANAGEMENT MODEL (SWMM)

To develop a sustainable urban water management strategy, though a complex challenge, encompass a broad range of technical, environmental and institutional parameters that operate over a variety of spatial and time scales. Worldwide regulatory practice have recognized the need for legislative and administrative frameworks, for example Zimbabwe flood management Practices (ZFMP), South Africa National Disaster Management Centre (NDMC) and the Zambia Disaster Management and Mitigation Unit (DMMU) to address the environmental problems caused by impermeable urban surface and to provide the need to work on prevention and mitigation of flood disasters (Andrea, 2011) and (Lupando, 2005) All aspects of disaster management are embraced in all national development plans through mitigation, prevention, preparedness, response relief, rehabilitation and construction by DMMU (Lupando, 2005). In 1999, Auckland Region Council in New Zealand, developed a model of storm water management for frequent and extreme events, and to simulate both natural and engineering system such as pipe network. A standard 24 hours temporal rainfall pattern with peak rainfall intensity, runoff depth, rainfall-runoff curves, time of concentration estimated using an empirical equation and separate analysis of pervious and impervious components of urban catchments were assessed (Carter, 1999). In United State of America, Washington Council modelled the Arthur Capper drainage systems using the SWMM model and simulated the dynamic rainfall-runoff for single or long-term events. The engineering department adopted SWMM to be used for analysing the hydrology of the environment (Department of Environmental Programs, 2003). In Zambia, no local authority have embraced the modeling of storm water drainage system for they planning, analysing and designing of related storm-water runoff drainages in urban areas.

## THEORETICAL ANALYSIS OF SWMM

Natural or man-made factors like atmospheric, hydrological and human influences might cause floods an environment. Their impacts on runoff could be evaluated by mitigation strategies on water resources through Storm Water Management Model (SWMM) a computer program developed in 1971. According to Rossman (2010) storm Water Management Model (SWMM) a widely used tool for planning, analysing, designing and sizing of drainage system components could also be used for flood controlling, natural system flood plain mapping, sizing of detention facilities and appurtenances for flood control and water quality protection in urban and non-urban areas. Rossman (2010) highlighted that SWMM does conceptualise the drainage system in series of water and material flows through three (3) environmental compartments, namely;

The atmosphere compartment, where precipitation and pollutants falls to generate both runoff and pollutant loads. Rain gauge objects are used to represent rainfall inputs into the system and to account for various hydrological processes such as time varying rainfall, evaporation of standing surface water, rainfall interception from depression storage, infiltration of rainfall into unsaturated soil layers, capturing and retention of rainfall/runoff with various types of low impact development (LID) practices that produce runoff from urban areas.

The land surface compartment, are represented through one or more Sub-catchment objects where precipitation from the atmospheric compartment are received, and does consider outflow in the form of infiltration as well as surface runoff and pollutant loadings. Large proportion of impervious materials such as buildings, paved streets, car parks, residential, commercial, industrial, rooftops, lawns, paved roads, undisturbed soils and undeveloped land are considered because of the direct impact on surface runoff.
The transport compartment, a network of conveyance elements of channels, pipes,

pumps and storage units that transport water to outfalls are represented inform of Node and Link objects.

## ANALYSIS OF COLLECTED DATA FOR KITWE-CDB STORM DRAINAGES

Accommodating urbanization in hydrological environment seemed complex but modification responses have been undertaken to replace empirical formulae in urban hydrology with the application of mathematical simulation models of the rainfall- runoff process. The simulation models require major parameters like rainfall data and drainage system to be assessed on subcatchments to enable the calculation of a time-series for storm water runoff flows and the node/inlets that receive runoff from the subcatchment.

On atmosphere compartment, average rainfall, return period and Intensity-Duration Frequency (IDF) of the study area were determined.

*Average rainfall;* Arithmetic Unweight Mean method (see equation 1.0 and figure 2.0) was used on collected rainfall data from Kafironda Zambia Agriculture Research Centre, Mwekera Fisheries College and Ndola National Airport.

$$P_{av}=\frac{P_1+P_2 .......+Pn}{N} \qquad (1.0)$$

Where; $P_{av}$ = Average rainfall in millimetres, P = Available annual rainfall in millimetres, and N = Total number sample.

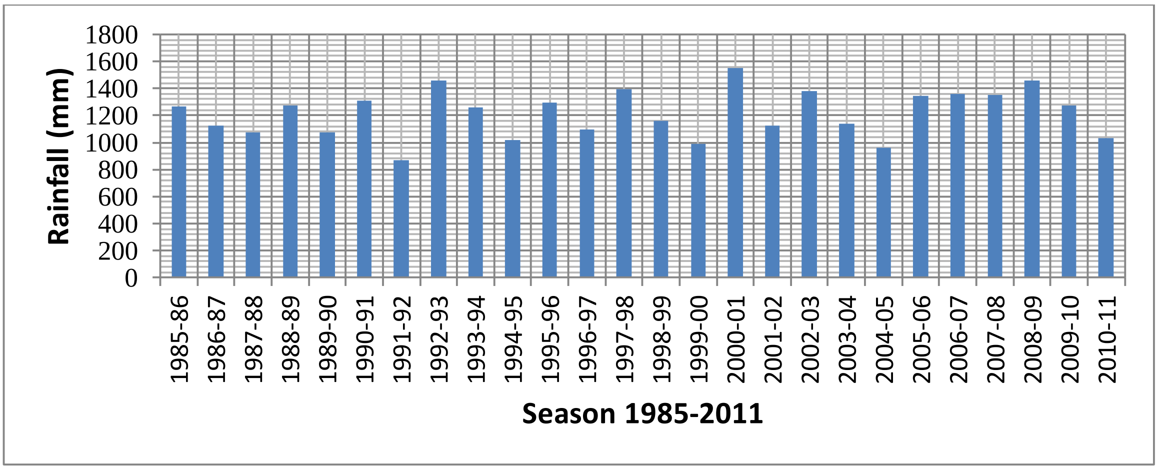


Figure 2.0.Histogram of estimated average rainfall for the project site

*Return Period;* Correlation of rainfall records approach was used and storms of different intensities were extracted and ranking of various durations to form a relationship between intensities and duration. Weibull formula (see equation 2.0) was used to determine the recurrence interval (Return period) of the storm magnitude in table 1.0 (Raghunath, 2006).

$$T=\frac{n+1}{N} \qquad (2.0)$$

where; T=return period in year, n=Number of rainfall events, and N=Rank of the event

Regression techniques was used to linearise the distribution, flood rainfall do not obey the normal distribution curve but required distribution must be skewed where data was symmetrical about the mean. To obtain Gumbel linear regression (see equation 4.0), reduced variate (equation 3.0) was used (Raghunath, 2006). See computation in table 3.0 and probability of event occurrence (1/T) was determined as an inverse of return period (see table 1.0 and figure 3.0).

$$X_T = -\log_e \log_e[T/ (T-1)] \qquad (3.0)$$

where; $X_T$= Reduced variate, T= Return period (years)

$$Y= aX_T + b \qquad (4.0)$$

where; Y = average rainfall (mm), $X_T$ = reduced variate, a = rate of change of rainfall depth with respect to $X_T$ and b = minimum value of rainfall depth.

Table 1.0 Rainfall data analysis

| **Rank** | **Season** | **Average Annual Rainfall (mm)** | **Return Period (T)** | **Reduced Variate ($X_T$)** | **Probability of Event Occurring (1/T)** | **Rank** | **Season** | **Average Annual Rainfall (mm)** | **Return Period (T)** | **Reduced Variate ($X_T$)** | **Probability of Event Occurring (1/T)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1977-78 | 1746.00 | 46.00 | 3.82 | 0.02 | 24 | 1974-75 | 1250.20 | 1.92 | 0.31 | 0.52 |
| 2 | 1968-69 | 1730.00 | 23.00 | 3.11 | 0.04 | 25 | 1973-74 | 1231.00 | 1.84 | 0.24 | 0.54 |
| 3 | 1984-85 | 1564.20 | 15.33 | 2.70 | 0.07 | 26 | 1980-81 | 1229.80 | 1.77 | 0.18 | 0.57 |
| 4 | 2000-01 | 1550.95 | 11.50 | 2.40 | 0.09 | 27 | 1971-72 | 1228.10 | 1.70 | 0.12 | 0.59 |
| 5 | 1970-71 | 1462.00 | 9.20 | 2.16 | 0.11 | 28 | 1976-77 | 1216.30 | 1.64 | 0.06 | 0.61 |
| 6 | 1992-93 | 1461.55 | 7.67 | 1.97 | 0.13 | 29 | 1966-67 | 1206.00 | 1.59 | 0.01 | 0.63 |
| 7 | 2008-09 | 1455.40 | 6.57 | 1.80 | 0.15 | 30 | 1998-99 | 1162.05 | 1.53 | -0.06 | 0.65 |
| 8 | 1979-80 | 1452.20 | 5.75 | 1.66 | 0.17 | 31 | 2003-04 | 1137.15 | 1.48 | -0.12 | 0.67 |
| 9 | 1982-83 | 1412.30 | 5.11 | 1.52 | 0.20 | 32 | 1986-87 | 1123.55 | 1.44 | -0.17 | 0.70 |
| 10 | 1997-98 | 1392.15 | 4.60 | 1.41 | 0.22 | 33 | 2001-02 | 1122.05 | 1.39 | -0.24 | 0.72 |
| 11 | 2002-03 | 1382.00 | 4.18 | 1.30 | 0.24 | 34 | 1969-70 | 1119.10 | 1.35 | -0.30 | 0.74 |
| 12 | 2006-07 | 1355.75 | 3.83 | 1.20 | 0.26 | 35 | 1983-84 | 1101.40 | 1.31 | -0.37 | 0.76 |
| 13 | 2007-08 | 1355.20 | 3.54 | 1.10 | 0.28 | 36 | 1996-97 | 1097.55 | 1.28 | -0.42 | 0.78 |
| 14 | 1978-79 | 1355.00 | 3.29 | 1.02 | 0.30 | 37 | 1989-90 | 1075.25 | 1.24 | -0.50 | 0.80 |
| 15 | 1975-76 | 1353.40 | 3.07 | 0.93 | 0.33 | 38 | 1987-88 | 1071.45 | 1.21 | -0.56 | 0.83 |
| 16 | 2005-06 | 1346.20 | 2.88 | 0.85 | 0.35 | 39 | 2010-11 | 1030.27 | 1.18 | -0.63 | 0.85 |
| 17 | 1967-68 | 1335.30 | 2.71 | 0.78 | 0.37 | 40 | 1994-95 | 1019.60 | 1.15 | -0.71 | 0.87 |
| 18 | 1990-91 | 1310.35 | 2.56 | 0.70 | 0.39 | 41 | 1972-73 | 1006.90 | 1.12 | -0.80 | 0.89 |
| 19 | 1995-96 | 1292.25 | 2.42 | 0.63 | 0.41 | 42 | 1999-00 | 989.11 | 1.10 | -0.87 | 0.91 |
| 20 | 1988-89 | 1272.70 | 2.30 | 0.56 | 0.43 | 43 | 2004-05 | 959.15 | 1.07 | -1.00 | 0.93 |
| 21 | 2009-10 | 1271.40 | 2.19 | 0.49 | 0.46 | 44 | 1981-82 | 949.40 | 1.05 | -1.11 | 0.96 |
| 22 | 1985-86 | 1263.75 | 2.09 | 0.43 | 0.48 | 45 | 1991-92 | 870.80 | 1.02 | -1.37 | 0.98 |
| 23 | 1993-94 | 1257.10 | 2.00 | 0.37 | 0.50 |  |  |  |  |  |  |

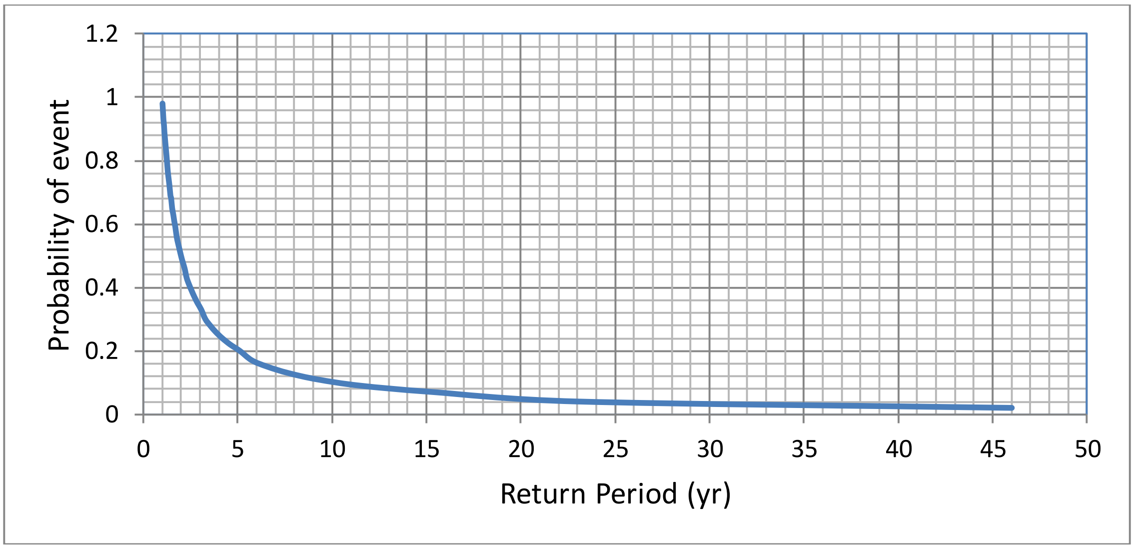


Figure 3.0. Probability of event verses return period

The lowest return periods in figure 3, had the highest probability of event occurrence, 1 in 2 and 1 in 5 years are recommended design return periods for urban drainage systems, hence 1 in 5 years was used as return period and gave event occurrence of 20 percent (Raghunath, 2006). To understand the rainfall pattern and obtain regression techniques (equation 5.0), the relationship between Reduced variate and rainfall depth data was plotted on scatter graph (see figure 4.0).

$$Y = 166.5X_T + 1166 \quad (5.0)$$

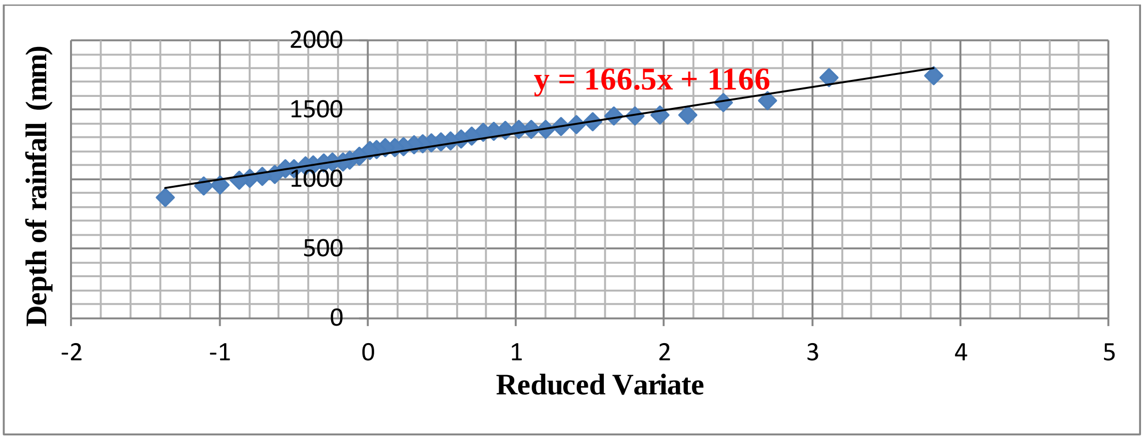


Figure 4.0. Relationship of Depth of Rainfall to Reduced Variate

**Using equation 5 and** the relationship between the reduced variate and 5 year return period in figure 5.0, the value of average rainfall in Kitwe CBD was obtained and as 1415.75mm. Equally the depth of annual rainfall for 2, 10 and 25 years return period was also determined (see table 2.0).

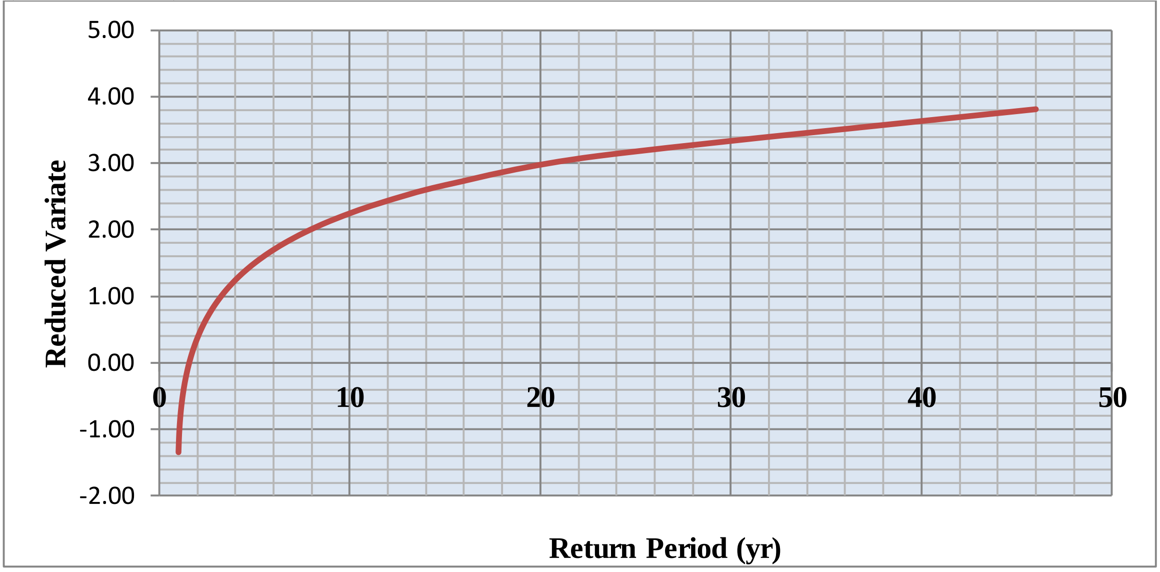


Figure 5.0. Relationship between reduced variate and return period

Table 2.0 Depth Of Annual Rainfall For Various Return Period

| RETURN PERIOD | **2-year** | **5-years** | **10-years** | **25-years** |
|---|---|---|---|---|
| Max. Annual rainfall (Y) mm-6 months | 1227.6 | 1415.75 | 1565.6 | 1683.82 |
| Max. Annual rainfall (Y) mm-30 days | 204.6 | 235.96 | 260.93 | 280.64 |
| Max. Annual rainfall (Y) mm-per day | 6.82 | 7.87 | 8.70 | 9.35 |

*Intensity-Duration Frequency (IDF);* Rainfall that falls over a catchment varies with time, but intensity-duration frequency (IDF) curves are used to determine the distribution of rainfall in time (Raghunath, 2006).The variation over an area was estimated using an area-reduction factor, length of time, 24 hour rainfall data and estimated 4 hours effective duration ($t_{eff}$) storm in the area were used, since 60 percent of the day's rainfall are expected occurs in a particular area and assumed the value of coefficient $b$ of 0.4. The value of $n$ = 0.748 and $a^T$ = 3.58 were obtained using equation 6.0 and 7.0. IDF values (see table 3.0) were obtained using equation 8.0 and the relationship of IDF against 5 year return period was plotted in scatter line graph (see figure. 6.0).

$$n = \frac{\ln\frac{14.4}{\text{teff}}}{ln\frac{b+24}{0.4+teff}} \qquad (6.0)$$

$$a^T = i_{24}^T \text{ x } (b + 24)^n = i_{24}^T * (b + 24)^n = 7.87/24 * (0.4 + 24)^{0.748} = 3.58 \qquad (7.0)$$

$$I = \frac{a^T}{(b+T)^n} \qquad (8.0)$$

where; I= Rainfall intensity (mm/hr), T=Duration in hour, and $a^T$, and b and n are fitting coefficients.

Table 3.0 Values of IDF Obtained

| RETURN PERIOD | 2-year | 5-years | 10-years | 25-years |
|---|---|---|---|---|
| Assumed *b* | 0.4 | | | |
| Assumed *teff* (*hr*) | 4 | | | |
| Resultant *n* | 0.748 | | | |
| 24 hr Intensity (mm/hr) | 0.28 | 0.33 | 0.36 | 0.39 |
| Estimated $a^T$ | 3.10 | 3.57 | 3.95 | 4.25 |
| Duration (min) | Intensity (mm/hr) | | | |
| 0 | 6.15 | 7.09 | 7.84 | 8.43 |
| 5 | 5.34 | 6.15 | 6.80 | 7.32 |
| 10 | 4.74 | 5.46 | 6.04 | 6.50 |
| 15 | 4.28 | 4.93 | 5.45 | 5.86 |
| 20 | 3.91 | 4.50 | 4.98 | 5.36 |
| 30 | 3.35 | 3.87 | 4.27 | 4.60 |
| 45 | 2.79 | 3.22 | 3.56 | 3.83 |
| 60 | 2.41 | 2.78 | 3.95 | 3.30 |
| 75 | 2.13 | 2.46 | 2.72 | 2.92 |
| 90 | 1.92 | 2.21 | 2.44 | 2.63 |
| 120 | 1.61 | 1.86 | 2.05 | 2.21 |

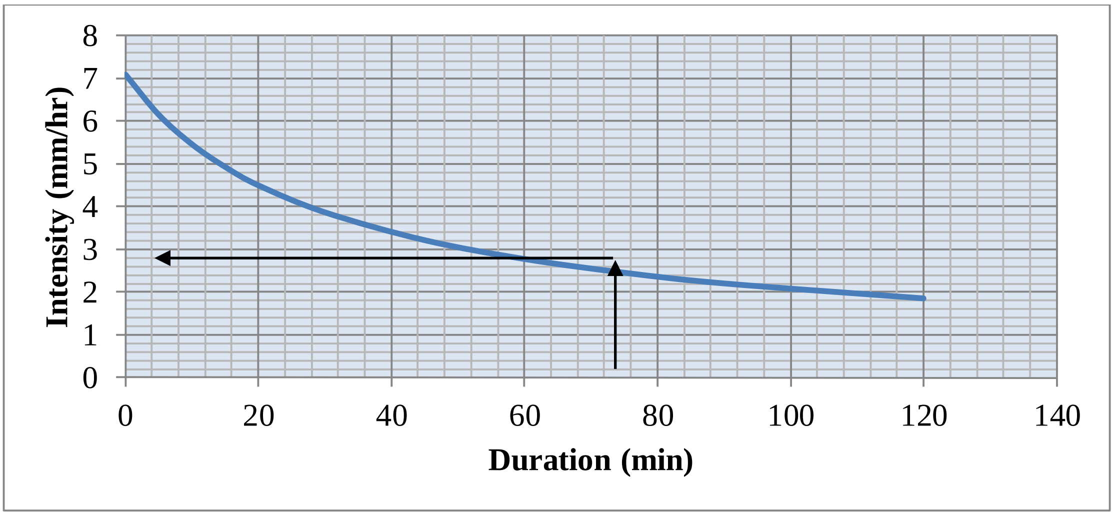


Figure 6.0. Estimate of a 5 year IDF curve

***Checking atmosphere compartment***

Coefficient *b* = 0.4 was checked to ascertain its suitability for the catchment under study and a reasonably accurate representation of IDF curves was redone (see equations 9.0 and 10.0) and solved using simultaneous method.

$$i = a^T/(D + b) \quad \text{for } D \leq 2\text{hrs} \qquad (9.0)$$

$$y = f + gD \qquad (10.0)$$

where i = calculated rainfall intensity (mm/hr), D = duration (hours),
Using two (2) arbitrary points on table 3.0, figure 6.0 and equation 9.0 the calculated intensity values were compared with IDF curve values to check the validity of the IDF curve developed earlier (see table 4.0).

Table 4.0 Comparing the validity of the value of *b*

| Duration (min) | Computed Intensity (mm/hr) | IDF intensity (mm/hr) | Error (mm/hr) | Duration (min) | Computed Intensity (mm/hr) | IDF intensity (mm/hr) | Error (mm/hr) |
|---|---|---|---|---|---|---|---|
| 0 | 6.62 | 7.09 | -0.47 | 45 | 3.25 | 3.22 | 0.03 |
| 5 | 5.94 | 6.15 | -0.22 | 60 | 2.78 | 2.78 | 0.00 |
| 10 | 5.38 | 5.46 | -0.08 | 75 | 2.43 | 2.46 | -0.03 |
| 15 | 4.92 | 4.93 | -0.01 | 90 | 2.15 | 2.21 | -0.06 |
| 20 | 4.53 | 4.50 | 0.03 | 120 | 1.76 | 1.86 | -0.10 |
| 30 | 3.91 | 3.87 | 0.05 | | | | |

Errors calculated in Table 4.0 showed that the data fairly fits the curve developed with an exception of the data that had duration less than 15 and greater than 75 minutes. The computed intensity was plotted against the existing IDF curve (see figure 7.0) to check the suitability of the assumed value of the constant *b*.

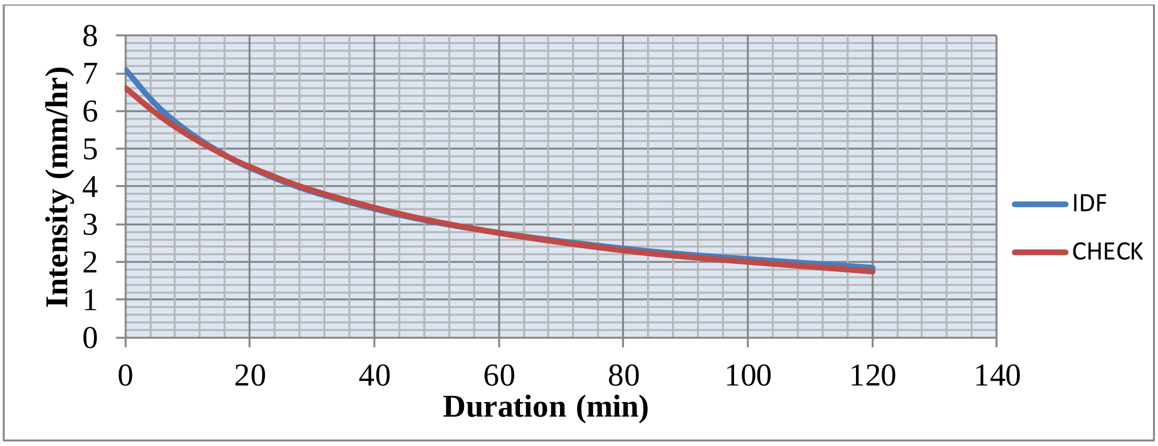


Figure 7.0.Checking intensity against existing IDF

On land surface compartment, catchment dimensions, drainage parameters, topography of catchment area and land usage were considered and assessed physically.

*Catchment dimensions;* Area was divided into sub-catchment, measurement conducted and coverage area calculated using simple mathematical and Simpson's rules (see table 5.0).

Table 5.0. Areas of each Sub Catchment

| Catchment | SHAPE | DIMENSIONS(meters) | | | | | | Areas ($m^2$) | Areas (Ha) | Width of Overland |
|---|---|---|---|---|---|---|---|---|---|---|
| | | L | W | a | b | c | d | | | |
| 1 | Trapezoidal | 181 | 102 | 126 | 65 | 78 | | 17742 | 1.77 | 181 |
| 2 | Hexagonal | 97 | 60 | 129 | 65 | 129 | 65 | 15170 | 1.51 | 181 |
| 3 | Trapezoidal | 181 | 100 | 129 | 65 | 87 | | 17742.5 | 1.77 | 181 |
| 4 | Rectangular | 169 | 131 | | | | | 22139 | 2.21 | 169 |
| 5 | Rectangular | 169 | 131 | | | | | 22139 | 2.21 | 169 |
| 6 | Rectangular | 211 | 131 | | | | | 27641 | 2.76 | 211 |
| 7 | Rectangular | 211 | 131 | | | | | 27641 | 2.76 | 211 |
| ***NOTE: L, W, a, b, c and d represents dimension on each sub catchment.*** | | | | | | | | | | |

*Topography of catchment area;* using table 6.0 study are was considered flat with a slope of 1.0 percent.

Table 6.0. Average catchment slope (source: Rossman, 2010)

| Slope class (s) | Average catchment slope (%) | Description |
|---|---|---|
| 1 | 0.0-1.0 | Flat |
| 2 | 1.0-4.0 | Undulating |
| 3 | 4.0-10.0 | Rolling |

*Land usage;* Impervious and pervious sections were determined by subtracting total area of pervious (vegetation and bare land) from impervious (building roof cover and pavement) sections (see table 5.0 and 7.0). Manning coefficients of 0.011 and 0.13 for impervious and pervious section respectively were obtained from Table 8.0.

Table 7.0. Percentage of impervious and pervious area

| Catchment | Impervious | | Pervious | |
|---|---|---|---|---|
| | Area (m²) | Percentage (%) | Area (m²) | Percentage (%) |
| 1 | 15791.46 | **89.01** | 1950.54 | **10.99** |
| 2 | 7555 | **49.80** | 7611.50 | **50.20** |
| 3 | 15600.90 | **87.93** | 2141.60 | **12.07** |
| 4 | 16521 | **74.62** | 5487 | **24.78** |
| 5 | 21308 | **96.24** | 700 | **3.16** |
| 6 | 25353 | **91.72** | 2296 | **8.3** |
| 7 | 26941 | **97.47** | 700 | **2.53** |

Table 8.0 Manning's overland flow coefficient (Source: Rossman, 2010)

| **SURFACE** | **n** | **SURFACE** | **n** |
|---|---|---|---|
| Smooth asphalt | 0.011 | Range (natural) | 0.13 |
| Smooth concrete | 0.012 | **Grass** | |
| Ordinary concrete lining | 0.013 | Short prarie | 0.15 |

Table 9.0 was used to determine the average depression storage, hence for impervious 1.27 to 2.54 mm and 2.54 to 5.08 mm for pervious sections were considered.

Table 9.0. Depression storage (source: Rossman, 2010)

| **Land cover** | **Storage (mm)** |
|---|---|
| Impervious surfaces | 1.27 – 2.54 |
| Lawns | 2.54 – 5.08 |
| Pasture | 5.08 |
| Forest litter | 7.62 |

Soil infiltration data was obtained using double cylinder infiltrometer with the assistance of Kafironda National Agriculture Research Centre personal (see table 10.0). Horton's (equation 12.0) was used and infiltration rate determined at varying dry time (t) ranging from 2 to 14 days (see table 10.0) and other parameters like the decay constant (k) 2.14 hrs$^{-1}$ and dry time for a fully saturated soil were considered. Decay constant specific to the soil obtained using equation 13.0. Using figure 8.0, maximum infiltration rate ($f_o$) *of 0.13cm/hr* and minimum infiltration rate ($f_c$) of *0.04cm/hr* were determined.

$$f_t = f_c + (f_o - f_c)e^{-kt} \qquad (12.0)$$

where; $f_t$= infiltration rate at time t, $f_o$ = initial infiltration rate or maximum infiltration rate, $f_c$ = constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate and, k = decay constant specific to the soil.

$$K=(f_o-f_c)/Fc \qquad 13.0$$

where; $F_c$= Shaded area

Table 10.0. Analysis of infiltration test

| **Time (min)** | **Readings (mm)** | | | **Infiltration (cm)** | | | **Infiltration rate (cm/hr)** | | | **Average infil. rate (cm/hr)** | **Parameters** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***i*** | ***ii*** | ***iii*** | ***i*** | ***ii*** | ***iii*** | ***i*** | ***ii*** | ***iii*** | | **$f_t$ cm/hr** |
| 0 | 22 | 26 | 20 | 0 | 0 | 0 | 0.122 | 0.144 | 0.111 | 0.13 | 0.53 |
| 10 | 10 | 24 | 9.8 | 1.2 | 0.2 | 1.02 | 0.12 | 0.02 | 0.102 | 0.08 | |
| 20 | 15 | 24.8 | 10 | 0.7 | 0.12 | 1.00 | 0.07 | 0.012 | 0.100 | 0.06 | |
| 30 | 16 | 24.9 | 10 | 0.6 | 0.11 | 1.00 | 0.06 | 0.011 | 0.100 | 0.06 | |
| 40 | 16 | 24.9 | 10.1 | 0.6 | 0.11 | 0.99 | 0.06 | 0.011 | 0.099 | 0.06 | |
| 50 | 16 | 24.9 | 10.1 | 0.6 | 0.11 | 0.99 | 0.06 | 0.011 | 0.099 | 0.06 | |
| 60 | 16 | 24.9 | 10.1 | 0.6 | 0.11 | 0.99 | 0.06 | 0.011 | 0.099 | 0.06 | |
| 75 | 17 | 24.7 | 9.9 | 0.5 | 0.13 | 1.01 | 0.033 | 0.009 | 0.101 | 0.05 | |
| 90 | 16.5 | 25 | 10.2 | 0.55 | 0.10 | 0.98 | 0.037 | 0.007 | 0.098 | 0.05 | |
| 105 | 16.5 | 25.1 | 10.2 | 0.54 | 0.09 | 0.98 | 0.036 | 0.006 | 0.098 | 0.05 | |
| 120 | 16.6 | 25.1 | 10.3 | 0.53 | 0.09 | 0.97 | 0.035 | 0.006 | 0.097 | 0.05 | |
| 140 | 16.5 | 24.8 | 10.1 | 0.53 | 0.12 | 0.99 | 0.027 | 0.006 | 0.099 | 0.04 | |
| 160 | 16.7 | 25 | 10.2 | 0.53 | 0.10 | 0.98 | 0.027 | 0.005 | 0.098 | 0.04 | |
| 180 | 16.7 | 25 | 10.2 | 0.53 | 0.10 | 0.98 | 0.027 | 0.005 | 0.098 | 0.04 | |

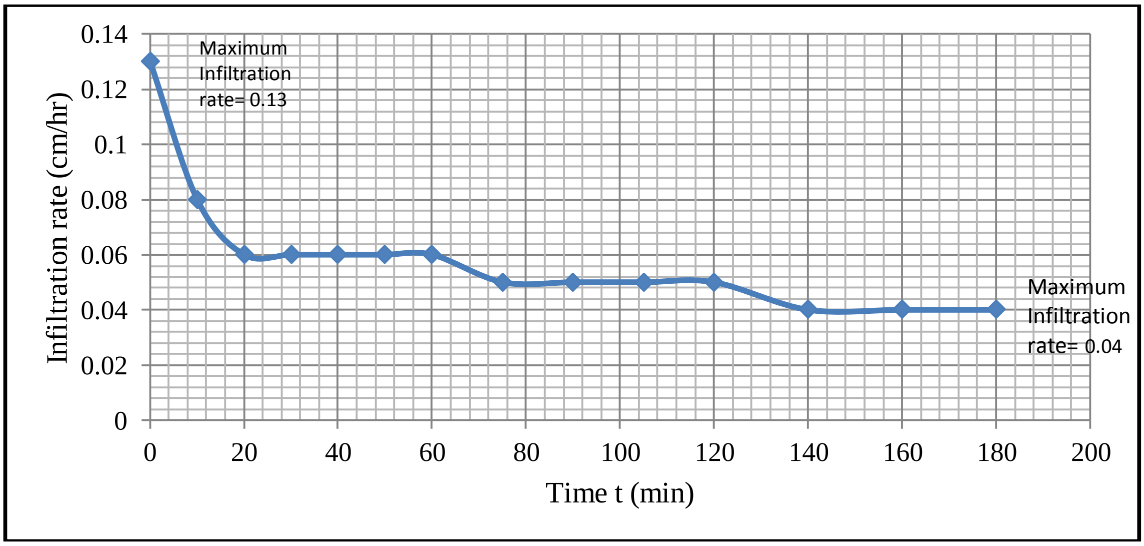


Figure 8.0. Average infiltration rates against Time

On transport compartment, infrastructure audit, engineering survey and structure measurements were conducted (see table 11.0).

To estimate the surface runoff, Rational/Lloyd-Davies method, Department of Transport's Advice Note HA37/88 method, and Transport and Road Research Laboratory (TRRL) hydrograph method are considered (O'Flaherty, 2008). Rational method was used, it illustrated the factors to consider in surface runoff calculation and relatively confined to 80 hectares for drainage areas. Manning's coefficients on open, closed and overland was used since manning's equation shows the relationship between flow rates, cross sectional area, hydraulic radius and slope in all conduits (see table 12.0). On open channels the range 0.012-0.018 was used for brick type, on closed channels 0.011-0.015 for Asbestos-cement pipe and on overland flow 0.011 for smooth asphalt.

Table 11.0 Conduit characteristics

| **Streets** | **Dimensions (mm)** | **Shape** | **Material** |
|---|---|---|---|
| President | Diameter 300 and 600 | Circular | Asbestos cement pipe |
| Zambia | | | |
| Library | Diameter 300 mm | | |
| City Square | Diameters 300 and 450 | | |
| Obote | Diameters 300, 600 and 900 | | |
| Matuka | Diameter600 mm | | |
| Zambia | WIDTH-450, DEPTH-600 | Closed Rectangular | Built Bricks |
| Obote | WIDTH-450 and 500mm<br>DEPTH-600 and 900mm | | |
| Independence | WIDTH-600, DEPTH-500 | | |
| Chisokone | WIDTH-600, DEPTH-500 | Open rectangular | Built Bricks |

**CURRENT INLET/PIPE CONDITION**

| **CONDITION** | **DESCRIPTION** | | | |
|---|---|---|---|---|
| | KERBS/GULLEYS | MANHOLE | CIRCULAR | RECTANGULAR |
| Ok | 90 | 9 | 7 | 2 |
| Partially Blocked | 3 | 0 | 0 | 0 |
| Blocked | 12 | 1 | 0 | 1 |
| **TOTAL** | **105** | **10** | **7** | **3** |

Table 12.0. Manning's channels coefficient (source: Rossman, 2010)

| **Channel type** | n | **Channel type** | n |
|---|---|---|---|
| **OPEN** | | **OVERLAND** | |
| Asphalt | 0.013-0.017 | **Smooth asphalt** | **0.011** |
| **Brick** | **0.012-0.018** | Smooth concrete | 0.012 |
| Concrete | 0.011-0.020 | **CULTIVATED SOILS** | |
| **CLOSED** | | Residue cover <20% | 0.06 |
| **Asbestos-cement** | **0.011-0.015** | Residue cover >20% | 0.17 |
| Brick | 0.013-0.017 | **Range(natural)** | **0.13** |
| Concrete pipe | 0.011-0.015 | **GRASS** | |
| | | Short,prarie | 0.15 |
| | | Dense | 0.24 |

## MODELLING AND SIMULATION

Modelling of Kitwe CBD involved entering data on atmosphere, land surface and transport compartment into SWMM software (see table 13.0).

Table 13.0 Checklist of SWMM input data

| **Compartment** | **Main property** | **Model input** | **Input data** |
|---|---|---|---|
| Hydrological | Rain gauge | Intensity | Table 4.0 |
| Land Cover | Sub-catchment | Area | Table 5.0 |
| | | Width of overland flow path | Table 5.0 |
| | | Average surface slope | Table 6.0 |
| | | Per cent of impervious area | Table 7.0 |
| | | Manning "n" of impervious and pervious area | 0.11 and 0.13 |
| | | Depth of depression storage on impervious area and pervious area | 1.27-2.54<br>2.54-5.08 |
| | | Percent of impervious area without depression storage. | N/A |
| | Infiltration | Method | HORTON |

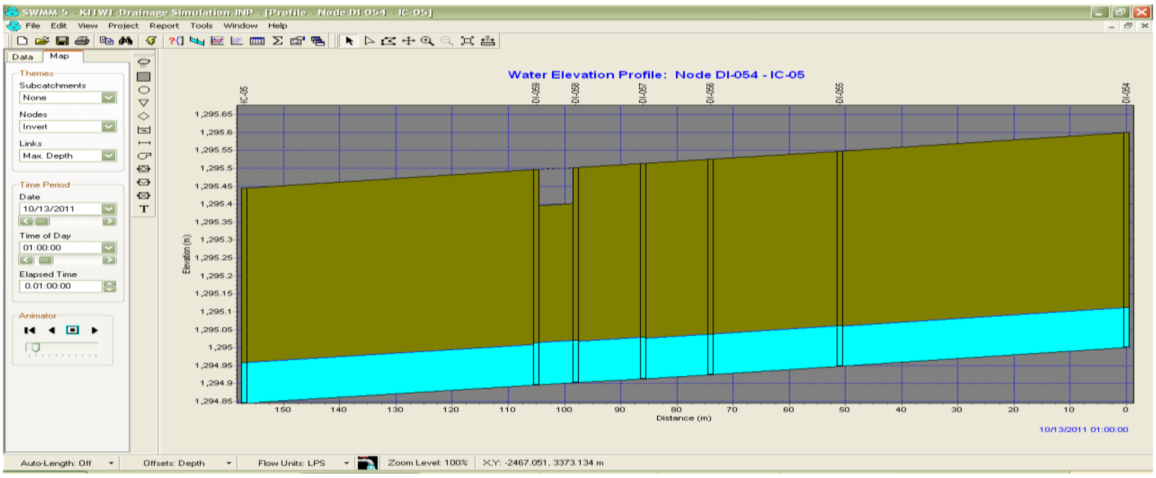
|  |  |  |  |
|---|---|---|---|
|  |  | Maximum | 0.13 |
|  |  | minimum rate | 0.04 |
|  |  | Dry soils | N/A |
|  |  | Dry time | 2-14 |
|  |  | Decay constant | 2.14 |
| Hydraulic | Conduit | Shape | TABLE 11.0 |
|  |  | Maximum depth (diameter) | TABLE 5.0 and 11.0 |
|  |  | Length | TABLE 5.0 |
|  |  | Manning's Roughness coefficient | TABLE 12.0 |
|  | Inlet | Elevation of inlet invert | Reduced levels |

After entering the information in table 13.0, the SWMM was ran to simulate Kitwe CBD SWMM model so to enable for drainage system analysis. The simulation enabled to troubleshoot the modelled drainage system and to check performance in relation to rainfall and condition of storm water drainage system (see figure 9.0).

Figure 9.0. Modelled part of Kitwe CBD.

The model was ran to simulate and test the operation of the storm water drainage systems based on two (2) parameters rainfall condition and the design size of storm drainage.

Assuming a better maintained storm water drainage system and the calculated intensity of rainfall, Kitwe CBD modelled storm water drainage system showed that the 5 year return period of rainfall intensity (table 4.0) could not cause flash flood if it was to repeat (see figure 10.0). When the assessed unmaintained storm water drainage system and the calculated intensity of rainfall were used, Kitwe CBD modelled storm water drainage system showed that failure to maintain storm water drainage could contribute to flash flood in CBD (see figure 11.0). For a completely blocked storm water drainage, a channel depth of 50mm was used instead of zero because the SWMM software limitation. After a successful simulation of the modelled Kitwe CBD, a status report was produced to help check the storm water drainage point that required maintenance or upgrade and part of the report was reproduced (see figure 12.0).

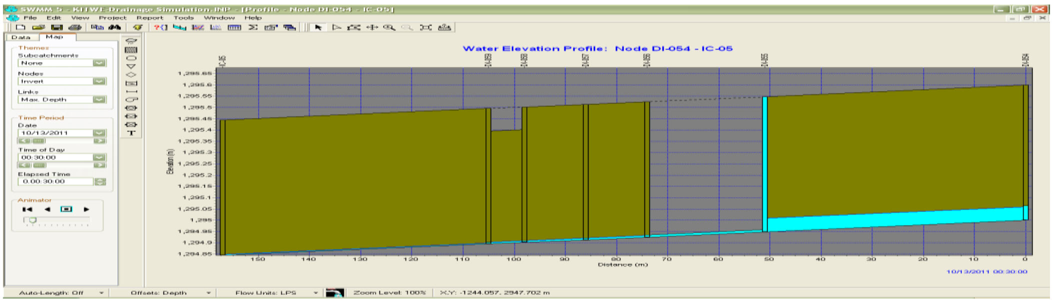


Themes
Subcatchments: None
Nodes: Invert
Links: Max. Depth

Time Period
Date: 10/13/2011
Time of Day: 01:00:00
Elapsed Time: 0.01:00:00

Auto-Length: Off | Offsets: Depth | Flow Units: LPS | Zoom Level: 100% | X,Y: -2467.051, 3373.134 m

Figure 10.0. Effect of calculated intensity on a maintained storm water drainage.

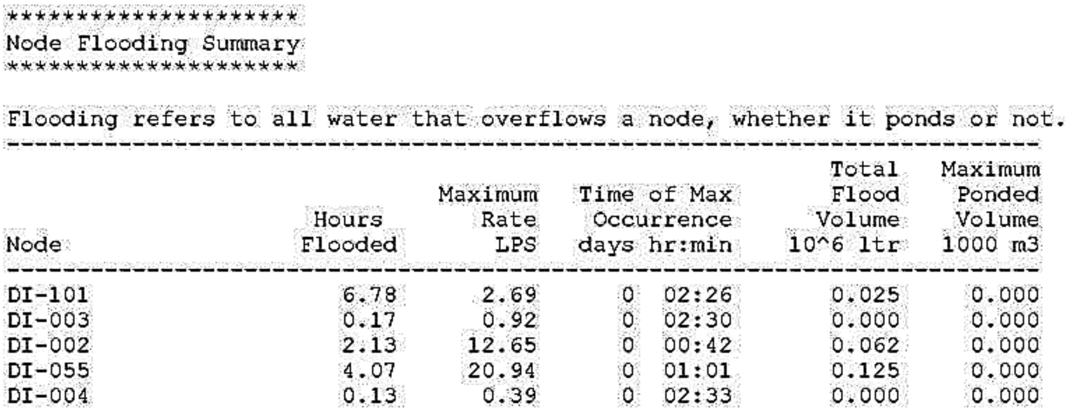


Themes
Subcatchments: None
Nodes: Invert
Links: Max. Depth

Time Period
Date: 10/13/2011
Time of Day: 00:30:00
Elapsed Time: 0.00:30:00

Auto-Length: Off | Offsets: Depth | Flow Units: LPS | Zoom Level: 100% | X,Y: -1244.057, 2947.702 m

Figure 11.0. Effect of calculated intensity on unmaintained storm water drainage.



```
**********************
Node Flooding Summary
**********************

Flooding refers to all water that overflows a node, whether it ponds or not.
--------------------------------------------------------------------------
                                                            Total   Maximum
                                 Maximum   Time of Max      Flood    Ponded
                         Hours      Rate    Occurrence     Volume    Volume
Node                   Flooded       LPS   days hr:min   10^6 ltr  1000 m3
--------------------------------------------------------------------------
DI-101                    6.78      2.69     0  02:26      0.025     0.000
DI-003                    0.17      0.92     0  02:30      0.000     0.000
DI-002                    2.13     12.65     0  00:42      0.062     0.000
DI-055                    4.07     20.94     0  01:01      0.125     0.000
DI-004                    0.13      0.39     0  02:33      0.000     0.000
```

Figure 12.0. Part of Kitwe CBD simulation summary report.

## CONCLUSION

After modelling Kitwe CBD storm water drainage system, the software was used as an office/field checking instrument to check the impact of change in rainfall or unmaintained storm water drainage in the Central Business District. From the model, it was discovered that infrastructure development and lack of routine maintenance on CBD storm water drainages have an impact on urban floods.

## RECOMMENDATION

Thus Storm Water Management Model SWMM was discovered to be a user friendly tool which Zambian local authority in particular engineering department must attempt to use and link it to Geographical Information System (GIS) for easy mapping and identifying of objects such as location of surcharging inlets/manholes. Additionally, it was discovered that SWMM has the ability to analyse the effect of water quality caused by the suspended solid waste carried in storm water drainage channel. A project on storm water quality should be conducted to identify the effect of pollutants due to build up and wash off parameters.

## ACKNOWLEDGEMENT

To God for the gift of daily healthy life, knowledge and wisdom. To Mr. Phiri. S. for the direction, support, comments and tireless effort spent. To all personals at Kafironda Zambia Agriculture Research Institute for their knowledge and field support. To my wife (Karen), daughter (Chiphazuwa) and son (Chikondano) for standing on my side and disturbing me whenever busy schedule comes forth. To parents and all family members for your inspiration.

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# Coverage Prediction of Digital Terrestrial Television in Zambia

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## ABSTRACT

*Digital Terrestrial Television (DTT) arises from the Regional Radio Communication Conference of 2006 (RRC06) and the subsequent Geneva 2006 agreement (GE06) of International Telecommunication Union (ITU) recommendations which resolved that member states signatory to the agreement must migrate from analogue to digital television broadcasting services.*

*The focus of this research was to study the detailed DTT implementation plan, analyse the optimal application of Single Frequency Network (SFN) and Multiple Frequency Network (MFN) in order to attain full DTT coverage in Zambia. In addition, the footprint of DTT coverage and field signal strength test of the selected points of the DTT coverage areas were determined. This study also highlights various factors that were critical in the full DTT implementation and recommended some remedial measures to accomplish full territorial coverage of digital television.*

*Software simulation analysis was used to predict the coverage of Phase 1 DTT implementation in Zambia. The results demonstrated that signal field strength to be strong between 81.0dBuV/M and 69.0DBuV/M, indoor receiving antennas can be used to capture DTT signal. Also outdoor YAGI receiving antennas can be recommended for signal field strength of 40.0dBuV/M and above.*

*From the results, also it can be deduced that MFN provided large signal coverage areas in relatively large flat lands and SFN in complex geographical terrains like Kafue and Chingola. Gapfiller transmitters (low power transmitters) were recommended to be installed in areas where MFN and SFN networks did not provide threshold field signal strength for set top boxes (STBs) to lock to DTT signal. The portable TV test receiver was used to determine field signal strength in various places along the line of rail. Vulnerable areas where terrestrial transmission would be a challenge to provide minimum signal strength for STBs to lock, the alternative recommended solution would be to obtain direct-to-home (DTH) satellite feed.*

***Keywords****: Coverage prediction, Terrestrial, Field signal strength, Single Frequency Network, Multiple Frequency Network.*

## INTRODUCTION

Digital Terrestrial Television (DTT) is a modern technology, which employs digital modulation techniques for the broadcasting of television services. Programme content flexibility and specific inherent technical advantages put DTT in a significant position to supersede current analogue television systems. The purpose of digital terrestrial television is characterised by reduced utilisation of spectrum and more programme capacity, a better-quality picture, and lower operating costs for transmission after the initial upgrade cost.

International standards are in place for DTT, and these are undergoing refinement as the base of understanding and experience as the technology continue to develop (Fischer, 2010).

The worldwide migration from analogue to digital broadcasting followed a resolution of the International Telecommunications Union (ITU) and subsequent Regional Radio communication conference (RRC-06) held in 2006 in Geneva, Switzerland. The RRC-06 established the Geneva Agreement of 2006 (GE06) whereby member countries were required to replace the existing analogue television with digital television broadcasting transmission equipment (Geneva. ITU report, 2012).

However, many countries have failed to meet the ITU resolution to migrate before the deadline due to some of the following constraints;

a) Set top box (STB) technical specifications, availability and cost;
b) Infrastructure development and sharing;
c) Human capital (management, technical and operational);
d) Public awareness and campaigns;
e) Production and availability of content;
f) Finance, general funding and economic beneficiation (Kekana, 2014).

## Implementation of digital terrestrial transmission in Zambia

Zambia, like other countries across the world, is moving towards terrestrial television broadcasting platform from analogue to digital transmission. The migration from analogue to digital broadcast systems is a most significant drift in Zambian terrestrial television broadcast as the technology rapidly develops. DTT is a modern and advanced technology, which employs digital techniques for the broadcasting of television services. Programme content flexibility and specific inherent technical advantages put DTT in a significant position to supersede analogue systems.

The Zambian Government's objective is countrywide coverage with at least eighty-four (84) DTT transmission sites to cover the entire Zambia as Figure 1 indicates. High power transmitters have to be installed along the line of rail, medium power transmitters in provincial centres and low power transmitters in districts across the Zambia (Zambia. Ministry of Broadcasting and Information Services, 2014).

The DTT implementation is segmented into two phases, namely phase 1 includes installation of DTT along the line of rail that is from Chililabombwe to Livingstone as indicated in Table 1. Phase 2 implementation of DTT will include all provincial centres and selected districts not along the line of rail.

## DTT Content distribution network in Zambia

Fibber network will be used for backbone signal distribution between the headend and various transmission sites across the country. At the same time, a C-band satellite signal distribution system will be provided as a backup for the public channels and as redundancy in case of fibre challenges. On the other hand, satellite signal distribution will be used to provide direct-to-home (DTH) service via Ku-band to some areas where terrestrial transmission will be difficult to access. Both national and private television station programs will be uplinked to the satellite transponder and downlinked to remote transmission sites for terrestrial retransmission across the country.

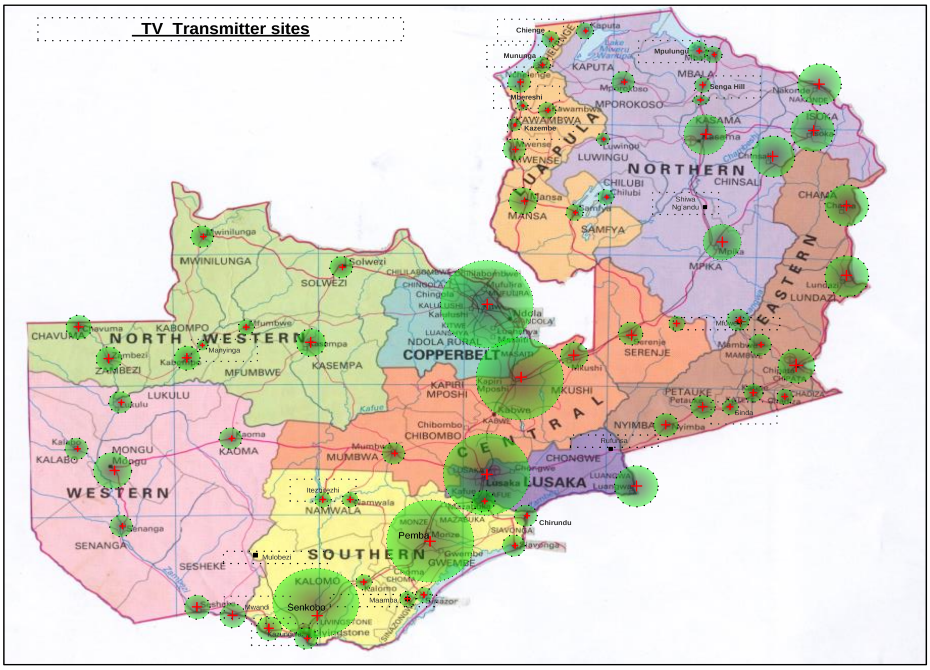


Figure 1: Proposed DTT sites in Zambia [18]

Table 1: Phase 1 DTT station

| No. | Station | Location | Transmitter power |
|---|---|---|---|
| 1 | Lusaka | 15.40639S; 28.3224E | 5kW |
| 2 | Kitwe | 12.788683S; 28.227014E | 5kW |
| 3 | Kapiri Mposhi | 14.0147868S; 28.6814E | 5kW |
| 4 | Pemba | 16.523832S; 27.324352E | 5kW |
| 5 | Senkobo | 17.602139S; 25.324352E | 5kW |
| 6 | Ndola | 13.04954S; 28.67263E | 0.5kW |
| 7 | Chingola | 12.52615S; 27.89176E | 0.5kW |
| 8 | Kalomo | 17.02914S; 26.49148E | 0.5kW |
| 9 | Kafue | 15.75454S; 28.20424E | 0.5kW |
| 10 | Chilanga | 15.58089S; 28.27597E | 0.5kW |

## DTT Central Headend

The DTT central headend will undertake the following; digital TV signal reception for monitoring, input signal encoding, multiplexing, compression, conditional access and network management system. The monitoring transmission status of the system will include the following; input and output video and audio signals, transport streams (TS), power supply system for each station, security of the whole system and remote maintenance of equipment.

Signal contents have to be channelled to the central headend to be encoded, multiplexed and fed into T2 gateway unit for compression, into 2Mbps transport stream called MPEG-2 stream. The T2 Gateway encapsulates the incoming MPEG-2 transport stream into baseband frames, inserting synchronization information for SFN broadcasting, modulator configurations and scheduling of multiple physical layer pipes (M-PLP) broadcasting. The second generation digital video broadcasting (DVB-T2) gateway output is fed to DVB-T2 modulators. The DVB-T2 Gateway perform channel encoding by adding the forward error correction information, build DVB-T2 frames, and modulate into DVB-T2 stream (Farcy, 2015).

The DVB-T2 standard defines a new protocol interface the DVB-T2 modulator interface (T2-MI) to interface between the DVB-T2 gateway and modulators. The T2-MI packets carry the data encapsulated into black and burst Frames and provide synchronization information when broadcasting over SFN and include all the signalling information for the transmission (Ronald, 2010). The signal distribution network is as illustrated in Figure 2.

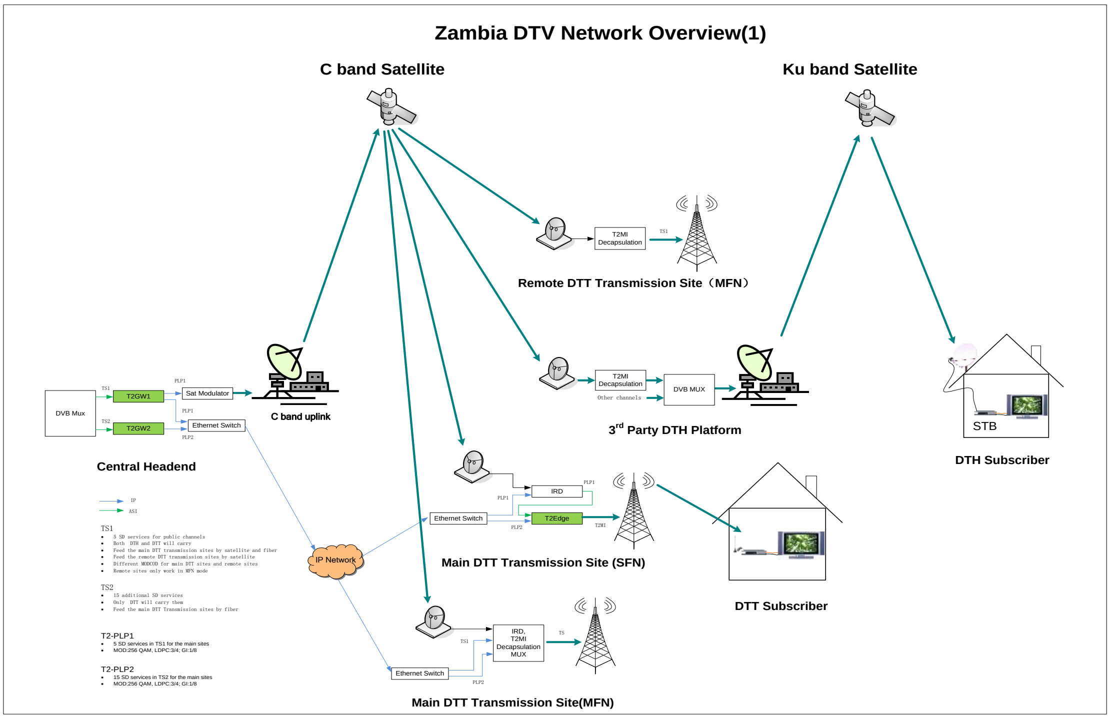


Figure 2: Content distribution network (Ministry of information and services, 2014)

## Transmission network

The DTT transmitters can be operated as Multi Frequency Network (MFN) or as Single Frequency Network (SFN) transmission systems in order to service respective digital television coverage areas. DTT implementation project in Zambia intends to apply both SFN and MFN systems throughout the country due to complicated geographical terrain.

### *Single frequency network*

Single Frequency Network (SFN) is a broadcast transmitter network consisting of synchronised transmitters with overlapping coverage areas that transmit same programmes in the same frequency channel at the same time as illustrated in Figure 3.

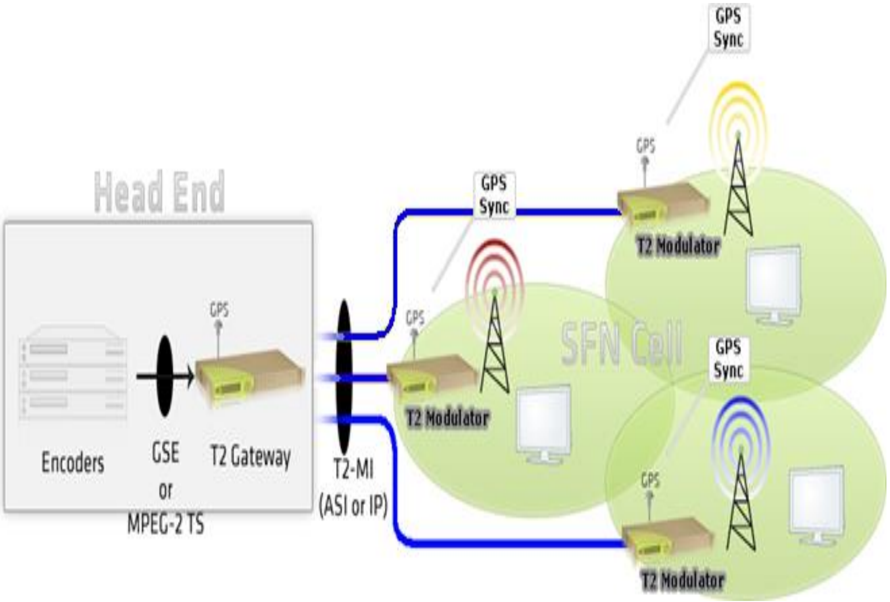
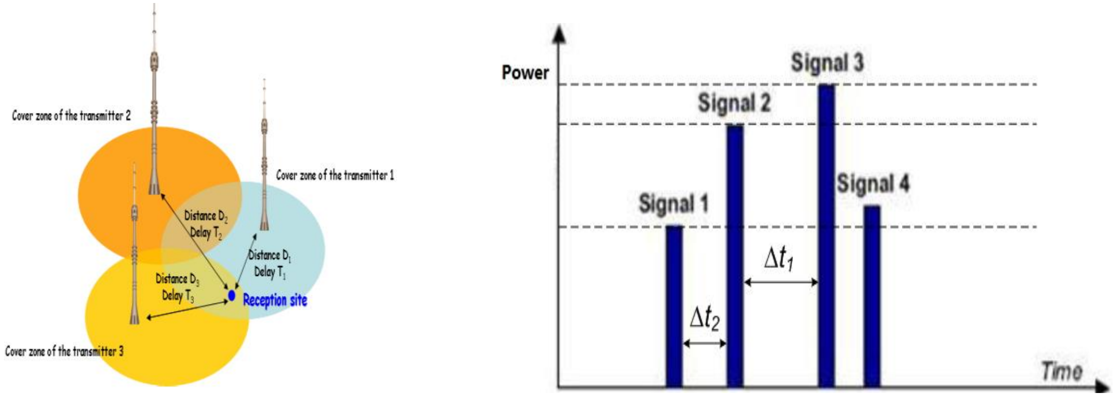


Figure 3: Single frequency Network Topology (ETSI EN 302 755 V1.3.1, 2010)

In SFN system, individual transmitters are synchronised with one another. However, it is necessary to note that in each DVB-T2 modulator in SFN network the same transport stream packets are processed into coded orthogonal frequency Division multiplexing (COFDM) symbols. Each transmitter modulator in SFN operates in synchronism with other transmitter modulators across network. The packets, bits and bytes are processed at the same time. Every DVB-T2 transmitter site broadcast, absolutely, identical COFDM symbols at exactly the same time. SFN transmitters are synchronised through the globe position system (GPS) with one pulse per second (1PPS) so that transmitters broadcast at the same time in order to avoid echoes interferences. Also, GPS provides 10MHz frequency as a reference for transmitters to modulate at same COFDM subcarriers as shown in Figure 3. Identical signal from different SFN transmitters arrive at a receiver antenna each with its own delay time due to the distance between receiver and transmitter. The multipath from atmospheric ducting, ionospheric reflection and refraction, reflection from water bodies and terrestrial objects such as mountains and buildings contribute to delay of the signals to reach the receiver. Signals are delayed according to different distances between the transmitter (TX) and signal receiver (RX) as illustrated in figure 3b. In the receiver, signals are added and appear to be the result of a transmission over a single time-dispersive channel. Figure 4 demonstrates transmitted signals of the same content reaching the receiving antenna at different times (ENENSYS, 2014)



(a) (b)

Figure 4: Multipath delay at the reception site (DVB BlueBook A136, 2010)

As shown in Figure 4, Signals arriving from distant transmitters are considered as echoes from the signal arriving from the nearest transmitter. In conventional analogue transmission schemes multipath reception results in ghost images as seen on analogue television sets. Since OFDM systems with guard intervals are inherently capable of handling multipath, SFN becomes practical in digital television broadcasting and improve efficiency of spectrum usage.

*Guard interval in single frequency network*

In order to overcome the inter-symbol interference problem resulting from multipath propagation, part of the symbol is extended from the beginning of the symbol to the end, increasing its duration by a certain amount of time called the guard interval (Farcy 2015). This cyclic prolongation of the original symbol is shown in Figure 5. The guard interval is denoted by delta (Δ). The new increased symbol duration is denoted by Ts and the original symbol duration is often called useful symbol duration, $T_u$. The duration of the Fast Fourier Transform (FFT) window during which the symbol is evaluated is kept at the original value, $T_u$. The orthogonal relationship is kept with the original symbol duration, $T_u$ not the extended, $T_s$. Signals arriving within guard interval are considered as constructive (received signals 1, 2, 3, 4) and signals arriving after the guard interval are destructive interferers (received signal 5). The exact choice of frame length will depend on the selections made for several of the other parameters, including; FFT size, guard interval, use of extended-carrier mode and combinations of different types of PLPs.

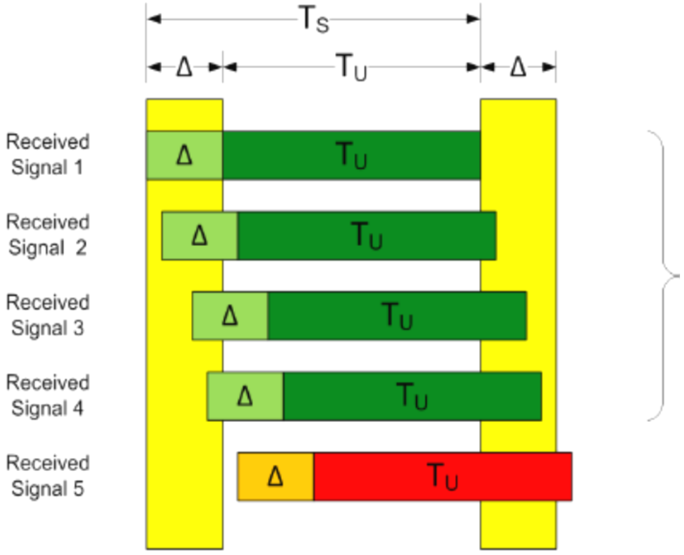


Figure 5: Guard interval (ETSI EN 302 755 V1.3.1, 2010)

### *Multiple frequency network*

A multiple frequency network (MFN) is a network in which multiple radio frequencies are allocated to many transmitters to cover different geographical areas, independently. In order to transmit DVB-T2 signal to large areas, each transmitter is assigned with its own frequency channel as illustrated in Figure 6. These different channels can be feed with the same or different DVB-T2 signals. As it can be observed in Figure 6, three different broadcast frequencies (channels) are allocated to three transmitters each having a spectral bandwidth of 8 MHz. Therefore, the MFN results in a total spectrum consumption of 24 MHz in this situation.

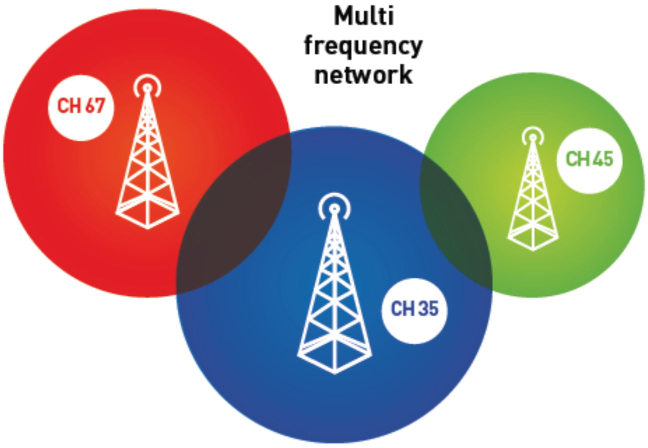


Figure 6: Multiple Frequency Network topology (ETSI EN 302 755 V1.3.1, 2010)

## METHODS AND MATERIALS

### Method 1: Simulation method for coverage map predictions

Simulation results are important to glean the maximum amount of information from each set of simulation outcomes so that accurate conclusions can be drawn and employed to make critical design decisions of systems. Simulation technology was used to determine the coverage map predictions for Single and Multiple Frequency Networks for DTT transmission networks carried out in Phase 1 for DTT implementation in Zambia. WRAP version 4.8.2 simulation software, from StarTimes technologies of China, was used to simulate coverage map predictions and exported onto Google Earth software to encompass actual geographical terrains.

Simulation parameters and configurations to generate coverage map prediction scenarios were chosen and used with respect to DVB-T2 model parameters as indicated in Table 2. The coverage map predictions were based on a terrain-sensitive propagation model for DVB-T2 system.

### Scenario 1: Antenna radiating patterns simulation

Table 2 shows the input parameters for the simulation of antenna radiation pattern.

Table 2: Antenna input parameters

| | |
|---|---|
| Name of antenna panels | Kathrine PHP-8*4 |
| Frequency range | 470-862 MHz |
| Operating frequency | 682MHz |
| Polarization | Horizontal/vertical |
| Cross polarisation | 20dB |
| Maximum gain | 16.05dB |
| Inclination angle | 0 degree |
| Attenuation in dB | 0 dB |
| Input power | 5kW |
| EIRP | 17.5kW |
| Antenna | 8 bay x 4 |

### Scenario 2: Multiple Frequency Network simulation parameters

Table 3 shows key input parameters for Lusaka DTT transmitter used to generate coverage map prediction simulation operating as a Multiple Frequency Network transmitting station.

Table 3: Parameter details of coverage prediction of Lusaka DTT transmitter

| **Location** | **Lusaka** |
|---|---|
| Coordinate | 15°24’23.89“S, 28°19’20.86"E |
| Transmitter Power (TX) | 7.7kW |
| ERP | 17.24kW |
| Mode | 256QAM, 32K, CR3/5, GI 1/16, PP4 |
| Transmission antenna Height | 91m |
| Antenna System Gain | 13.5dB |
| Receive antenna Gain | 0dB |
| Receive antenna Height | 10m (above the roof top) |
| Frequency | 682MHz |
| Antenna (8 panels) | 8,8,8,8 (4 bay) |
| Propagation Model | ITU-R -525 |

### Scenario 3: Single Frequency Network simulation parameters

Table 4 shows the technical parameters used to generate coverage map prediction for Lusaka-Chilanga-Kafue single frequency network.

Table 4: Lusaka-Chilanga-Kafue SFN parameters

| **Location** | **Lusaka** | **Chilanga** | **Kafue** |
|---|---|---|---|
| Coordinate | 15°24’23.89“S,<br>28°19’20.86"E | 15.58089S<br>28.27597E | 15.75454S<br>28.20424E |
| Transmitter Power | 7.7kW | 100w | 600w |
| ERP | 17.24kW | 125w | 750w |
| Mode | 256QAM, 32K, CR3/5, GI 1/16, PP4 | 256QAM, 32K, CR3/5, GI 1/16, PP4 | 256QAM,32K, CR3/5, GI 1/16, PP4 |
| Antenna Height | 91m | 80m | 50m |
| Antenna System Gain | 13.5dB | 13.5dB | 13.5dB |
| Receive antenna Gain | 0dB | 0dB | 0dB |
| Rx antenna Height | 10m | 10m | 10m |
| Frequency | **682MHz** | **682MHz** | **682MHz** |
| Antenna (8 panels) | 8,8,8,8 (4 bay) | Super turnstile Antenna | Super turnstile Antenna |
| Propagation Model | ITU-R -525 | Isotopic | Isotopic |

### Method 2: Field signal strength measurement

The actual field signal strength (FSS) results were taken from different places within Lusaka and surrounding areas. FSS varied from point to point based on a variety of factors, including, but not limited to, building obstructions, mountains and trees, specific reception hardware and receiving antenna orientation. Field signal strength were significantly lower in extremely hilly areas where the geographical terrain was uneven. Figure 7 shows some of the equipment used to measure field signal strength in different locations namely: portable TV test receiver, standard and outdoor and indoor antennas.

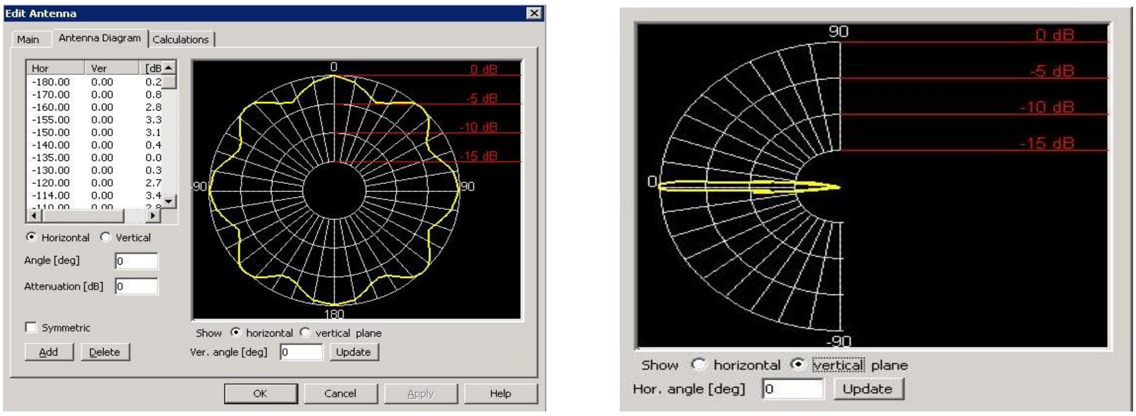
(a) (b) (c)

Figure 7: (a) Portable TV test reciever (b) Standard and outdoor antennas (c) Indoor antenna

## RESULTS AND DISCUSSION

### Scenario 1: Antenna radiating patterns simulation

The antenna system provided 360 degrees isotopic radiation about the transmitter as shown by simulated results in Figure 8a for horizontal polarization plane and Figure 8b for vertical plane, respectively. The simulated horizontal pattern showed that antenna would radiate evenly with equal effective isotopic radiated power (EIRP) in all directions.



| Hor | Ver | [dB |
|---|---|---|
| -180.00 | 0.00 | 0.2 |
| -170.00 | 0.00 | 0.8 |
| -160.00 | 0.00 | 2.8 |
| -155.00 | 0.00 | 3.3 |
| -150.00 | 0.00 | 3.1 |
| -140.00 | 0.00 | 0.4 |
| -135.00 | 0.00 | 0.0 |
| -130.00 | 0.00 | 0.3 |
| -120.00 | 0.00 | 2.7 |
| -114.00 | 0.00 | 3.4 |

● Horizontal ○ Vertical

Angle [deg] 0

Attenuation [dB] 0

☐ Symmetric

Show ● horizontal ○ vertical plane

Ver. angle [deg] 0

Show ○ horizontal ● vertical plane

Hor. angle [deg] 0

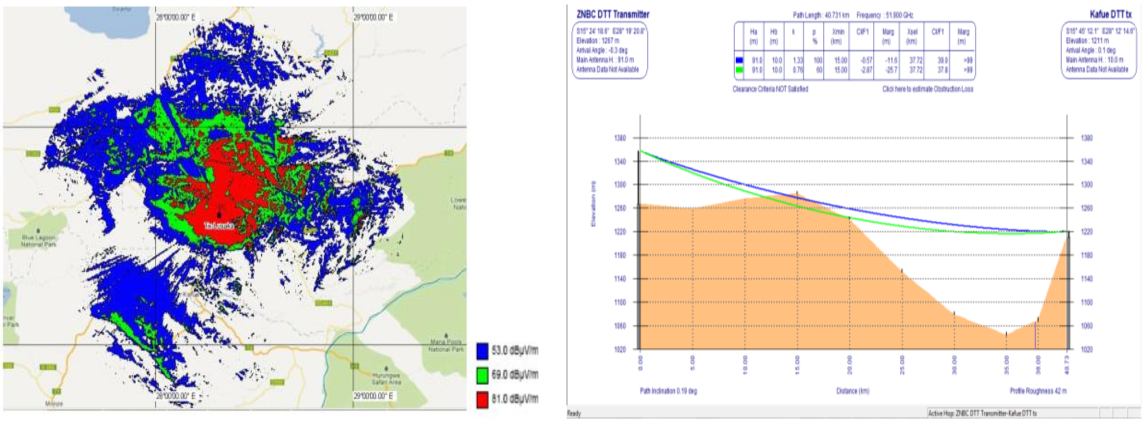
(a) (b)

Figure 8: (a) Horizontal radiating pattern (b) Vertical radiating pattern

Horizontal and vertical patterns of the transmitting sites under investigation are identical because similar *Katherin* antenna types would be used for high power transmitters at Kitwe, Senkobo, Pemba, Lusaka and Kapiri Mposhi and for low power while Super turnstile *Katherin* Antennas would be used for low power transmitters namely Kalomo, Ndola and Chingola.

### Scenario 2: Multiple Frequency Network simulation results

Figure 9 shows simulation results for Lusaka DTT transmitter. Red and green indications on the coverage map prediction demonstrate field signal strength level to be very strong at 81.0 dBµV/M and 69.0 dBµV/M, respectively. Mostly, indoor receiving antennas can be recommended to receive DTT signal. The blue indication shows a weaker signal at 53.0 dBµV/M and end users must employ outdoor YAGI antennas in order to capture a stronger signal.



(a) Lusaka MFN coverage map prediction (b) Lusaka-Kafue path profile

Figure 9: Coverage map prediction and path profile

However, there are some isolated cases noted where the single Lusaka DTT transmitter will not provide field signal coverage due to geographical terrain e.g. some areas in Kafue and Chilanga. As it can be observed from Figure 9 (b), Lusaka DTT transmitter is at 1267m above sea level with an added transmitter antenna height of 91m. The receiving antenna at Kafue DTT transmitting site at 1004m above sea level with an outdoor YAGI receiving antenna at 10m above the ground, cannot receive the terrestrial transmitted signal because it can be obstructed by mountainous area in direct signal path profile. Similar situation can occur because Chilanga is on the reward side of the mountain at the level of 1160m above the sea level.

### Scenario 3: Lusaka-Chilanga-Kafue SFN simulation results

Figure 10 shows the coverage map prediction for a Lusaka-Chilanga-Kafue Single Frequency Network. Low power transmitters (gapfillers) installation at Kafue and Chilanga will resolve field signal strength challenges that are faced by these two areas as described in scenario 2 analysis. The DTT signal coverage will be enhanced by the three transmitters operating in SFN at 682MHz with different effective isotopic radiated power (EIRP). Chilanga and Kafue areas will be adequately covered by respective DTT gapfiller transmitters. Most of the surrounding areas that would not be serviced as described in Scenario 2 would be covered by Lusaka-Chilanga-Kafue SFN field signal strength coverage as illustrated in Figure 10 .

### Scenario 4: Possible challenges – Mazabuka

It can be observed from Figure 11, Mazabuka will not receive field signal strength despite being 40.8km line of site from Lusaka and about 22.4km from Kafue digital transmitter (1064m above sea level), because of uneven path profile due to Mazabuka topography. Places on mountain tops rather than areas in the low and flat lands may receive digital signal from Lusaka and Kafue. It shows that mountain elevation at 1029m above sea level along the Kafue - Mazabuka path profile (around Nega area) will block the signal path for Lubombo and Mazabuka (1000m above sea level) as illustrated in Figure 10 (b). It will be recommended that a gapfiller transmitter must be installed at Mazabuka.

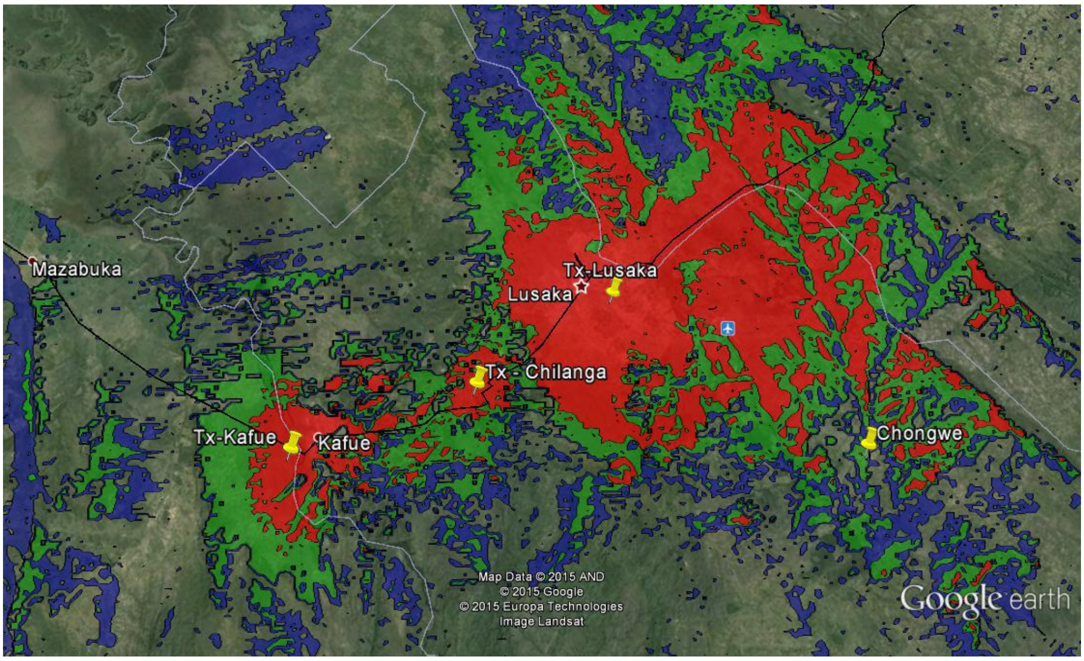


Figure 10: Lusaka-Chilanga-Kafue SFN coverage

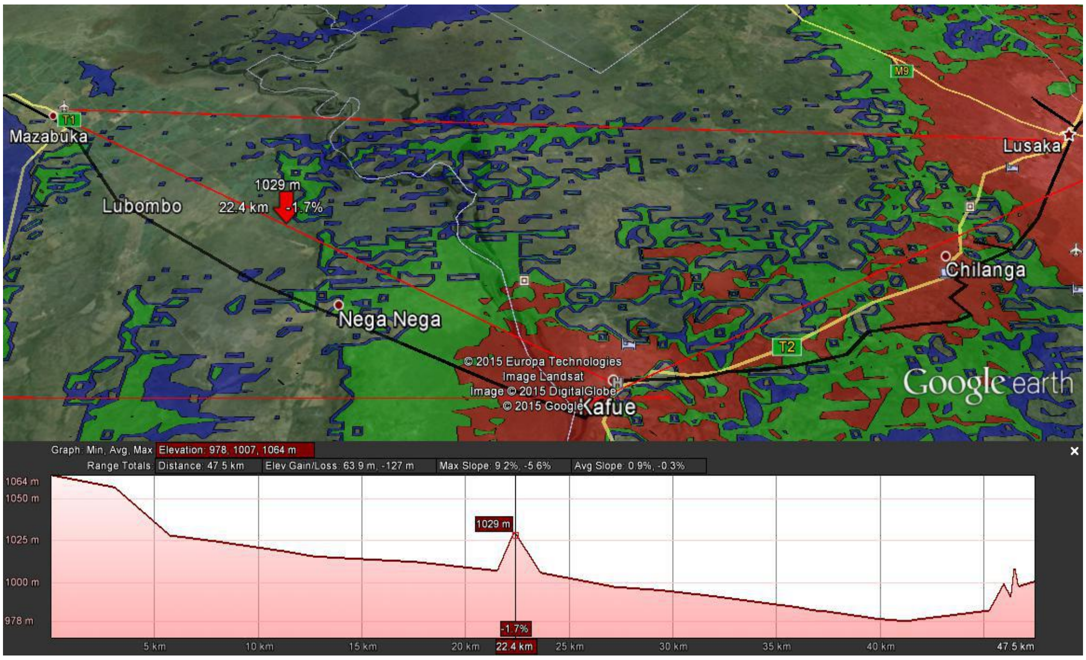


Figure 12: Mazabuka DTT technical challenge

### Scenario 5: Overall DTT coverage for Phase 1 implementation in Zambia

The overall coverage map prediction simulation for phase 1 DTT implementation project from Chililabombwe through to Livingstone is shown in Figure 13. It can be observed that there are some areas between Kabwe and Lusaka; and also between Kafue and Pemba that will not be covered by digital terrestrial transmission from transmitting stations, for example, Chibombo and Mazabuka. Therefore, recommendations should be made to install fill-in SFN transmitters which can operate on the same frequency as the main station or gapfiller operating on MFN with a different frequency allocation.

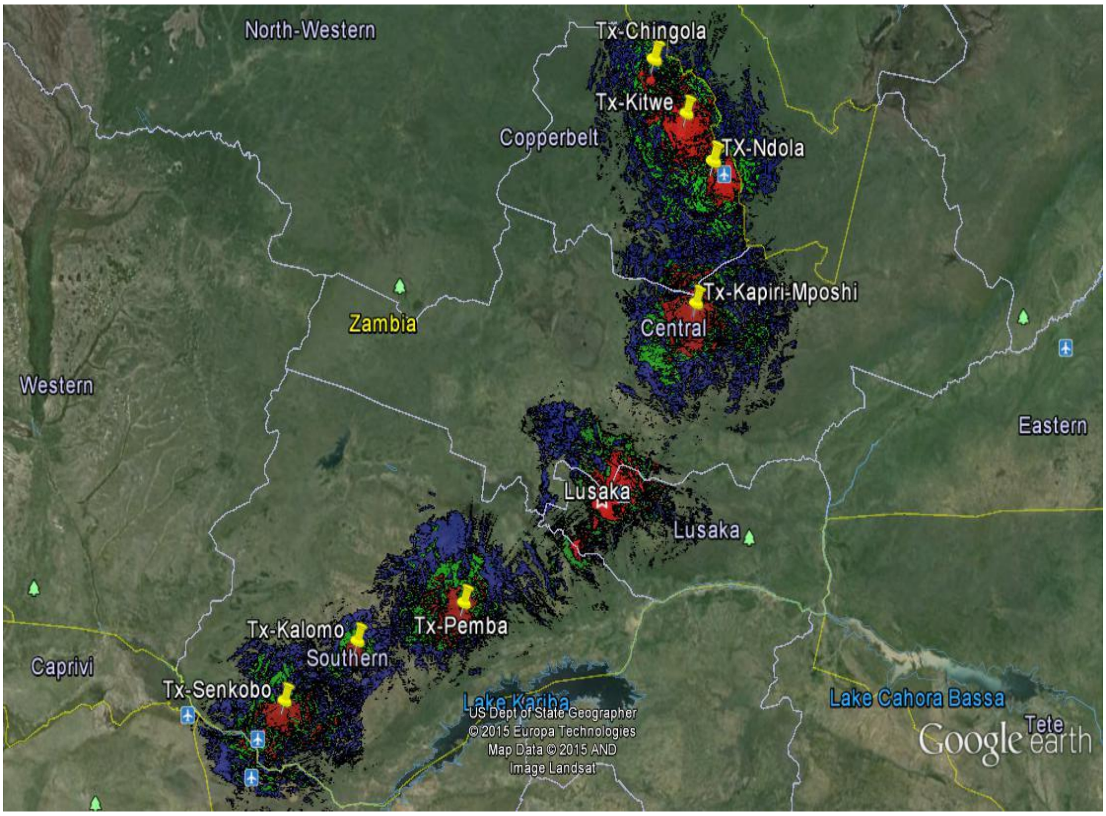
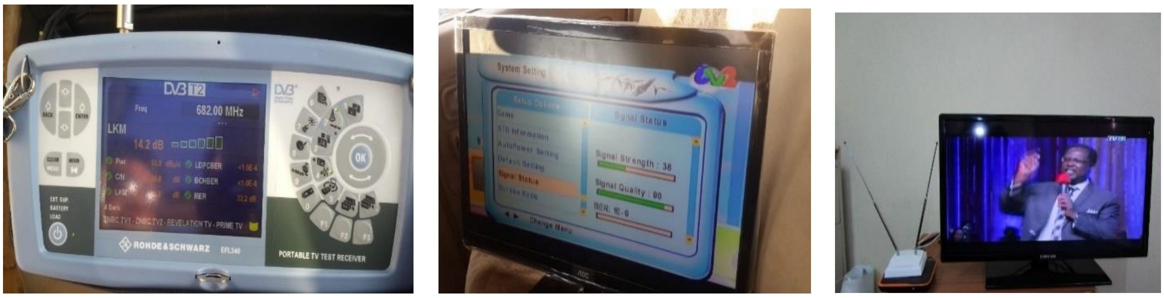


Figure 13: Overall Phase 1 DTT implementation in Zambia

**Scenario 5: Field signal strength measurement**

In order to ascertain field signal strength from coverage map prediction simulation results in the Lusaka-Chilanga-Kafue SFN, field signal strength measurements were carried out in several places using a portable TV receiver. Three types of receiving antennas namely standard, outdoor and indoor antennas were used to determine STB receiver field signal strength, bit error rate (BER) and modulation error rate (MER). The standard and outdoor receiving antennas were connected and oriented together on the same antenna supporting pole and at the same height; and the indoor antenna was pressed at, not more than above or beside the TV set or portable TV test receiver inside the buildings. The maximum readings obtained at any test points were record in Table 5.
Figure 13 (a) and (b) shows the portable TV receiver, STB signal strength and TV set receptions taken from different places.



(a) (b) (c)

Figure 13: (a) Portable TV test receiver (b) STB signal reception (c) TV reception

Table 5 shows the actual coordinates, elevation and distance from Lusaka DTT transmitter.

Test points 1 and 2 in the table shows that the field signal strength is strong and indoor antennas can be used to receive DTT signal while points 3 and 4 indicate that only outdoor antennas can be used. Test points 5 and 6 illustrate that indoor or outdoor antennas can be used and depends on the orientation of the antenna towards the transmitter. Test point 7 in the table shows the lack of DTT signal presence in those areas, e.g. Mazabuka and Chibombo because none of the three antennas captured the signal. Hence, those areas can only be covered by DTH or the installation of gapfiller transmitter.

Table 5: Field signal strength measurement

| **SFN Frequency: 682MHz**<br>**Power: Lusaka(5kW); Chilanga (500W); Kafue (100W)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test equipment/equipment | RS EFL340,Standard Antenna（900E), Outdoor Antenna Indoor Antenna, Portable TV Receiver | | | | | | | |
| Test Points on the Google Map | GPS Readings | | | | Antenna Type | Transmitter Freq（682MHZ） | | |
| | Latitude | Longitude | Elevation (meters) | Distance from the Lusaka DTT Antenna (km) | | Field Signal Strength (dBμV) | BCH BER | MER (dB) |
| 1 | 15°4437 | 28°9'10" | 999 | 5.64 | Standard Antenna | 70.1 | <1.0E-8 | 35 |
| | | | | | Outdoor Antenna | 71.8 | <1.0E-8 | 35 |
| | | | | | Indoor Antenna | 46.8 | <1.0E-8 | <16 |
| 2 | 15°45'46" | 28°10'42" | 997 | 2.29 | Standard Antenna | 73.2 | <1.0E-8 | >35 |
| | | | | | Outdoor Antenna | 75.5 | <1.0E-8 | >35 |
| | | | | | Indoor Antenna | 50.9 | <1.0E-8 | 20 |
| 3 | 15°36'24" | 28°15'41" | 1160 | 17.47 | Standard Antenna | 44.2 | <1.0E-8 | 21.4 |
| | | | | | Outdoor Antenna | 43.7 | <1.0E-8 | 21.5 |
| | | | | | Indoor Antenna | | | |
| 4 | 15°10'2" | 28°14'24" | 1124 | 27.94 | Standard Antenna | 58 | <1.0E-8 | 30.2 |
| | | | | | Outdoor Antenna | 58.4 | <1.0E-8 | 27.8 |
| | | | | | Indoor Antenna | | | |
| 5 | 15°4'47" | 28°12'22" | 1133 | 38.27 | Standard Antenna | 54.5 | <1.0E-8 | 28.5 |
| | | | | | Outdoor Antenna | 55.7 | <1.0E-8 | 28 |
| | | | | | Indoor Antenna | 40.6 | <1.0E-8 | 16.8 |
| 6 | 14°55'39" | 28°5'7" | 1182 | 58.82 | Standard Antenna | 66.4 | <1.0E-8 | 31.8 |
| | | | | | Outdoor Antenna | 66.6 | <1.0E-8 | 31.8 |
| | | | | | Indoor Antenna | 50.4 | <1.0E-8 | 27.3 |
| 7 | 14°47'31" | 28°3'18" | 1182 | 73.86 | Standard Antenna | Nil | | |
| | | | | | Outdoor Antenna | Nil | | |
| | | | | | Indoor Antenna | Nil | | |

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

It can be concluded that coverage map predictions are important for determination of the outcome of the entire project. As it was observed during the field strength signal survey, digital television coverage is characterized by a very rapid transition from near perfect reception to no reception at all. Zambian topography is not even as such it is not possible to only apply SFN or MFN across the country because some areas are challenged with severe geographical terrain. As shown from the overall simulation results for Phase 1 DTT implementation show that Mazabuka and Chibombo will not be serviced.

From the simulation results, it can be concluded that the MFN will provide large coverage areas i.e. Senkobo, Kalomo, Pemba and Kapiri Mposhi because the geographical terrain is fairly flat. However, it is at the expense of bandwidth serving, that is, 32MHz bandwidth

(8MHz per transmitter) will be occupied and capital expenditure on the high power transmitters. SFN will provide adequate signal coverage in complex areas like Chilanga and Kafue. Also SFN provides spectrum band optimization and bandwidth serving over MFN. Consider two SFN systems namely, Lusaka-Chilanga-Kafue and Ndola-Kitwe-Chingola, will occupy 8 MHz, respectively. The total bandwidth to be occupied will only be 16 MHz for six transmitting stations as compared with 32 MHz for four transmitters in the MFN system. It can be, generally, concluded that for DTT planning and coverage optimization requires adequate planning software tools together with detailed geographical terrain, clutter information and an up-to-date transmitter station data base. The more accurate field strength predictions and data base, the more reliable are the results. This can be attest by the results obtained through coverage map prediction simulations and the actual field signal strength measurement that were taken and recorded in Table 5.

In conclusion, it is important to perform actual measurements of FSS at different geographic locations after coverage map predictions and installation in order to guarantee good reception. With the help of these coverage map predictions and field signal strength measurements, operators can adjust the transmission parameters of the transmitters in the system in order to achieve optimal signal coverage.

## Recommendations

It can be recommended that gapfillers (fill-in lower power) transmitters should be installed in Mazabuka and Chibombo in order to optimize signal coverage for Phase 1 DTT implementation. Gapfiller transmitters are a cost effective way to improve coverage in small, complex and vulnerable areas, provided that a sufficiently strong input signal can be received from the standalone transmitter, via satellite fed, fibre network, microwave or cable link. Though the Direct-To-Home satellite transmission can be used to feed vulnerable areas, prices for satellite equipment may be a challenge to ordinary Zambians.

## Future Work

Future works should include, but not be limited to the following:

(a) Simulation of entire country in order to recommend for gapfillers to optimize DTT coverage in Zambia because only Phase 1 of DTT implementation was considered.

(b) Development of regulatory framework which is to facilitate the use of TV white spaces, help improve spectrum efficiency and provide universal broadband access resulting from DTT, e.g. improving rural broadband connectivity

(c) Future hybrid works which should incorporate distribution fundamentals via broadcasting and broadband technology together with smart receiver solutions, e.g. DVB-T2 Lite in order to use mobile cell phones to receive DTT services.

(d) Guaranteed access to digital dividend is needed to provide certainty to broadcasters and mobile industry alike and encourage further standardization work and investments in enhanced technologies for service delivery.

(e) Considering that digital dividend will be available in DTT, policies should be formulated to incorporate implementation of more services such as digital audio broadcasting (DAB) and DVB-T2 lite for radio and portable mobile devices reception, respectively.

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