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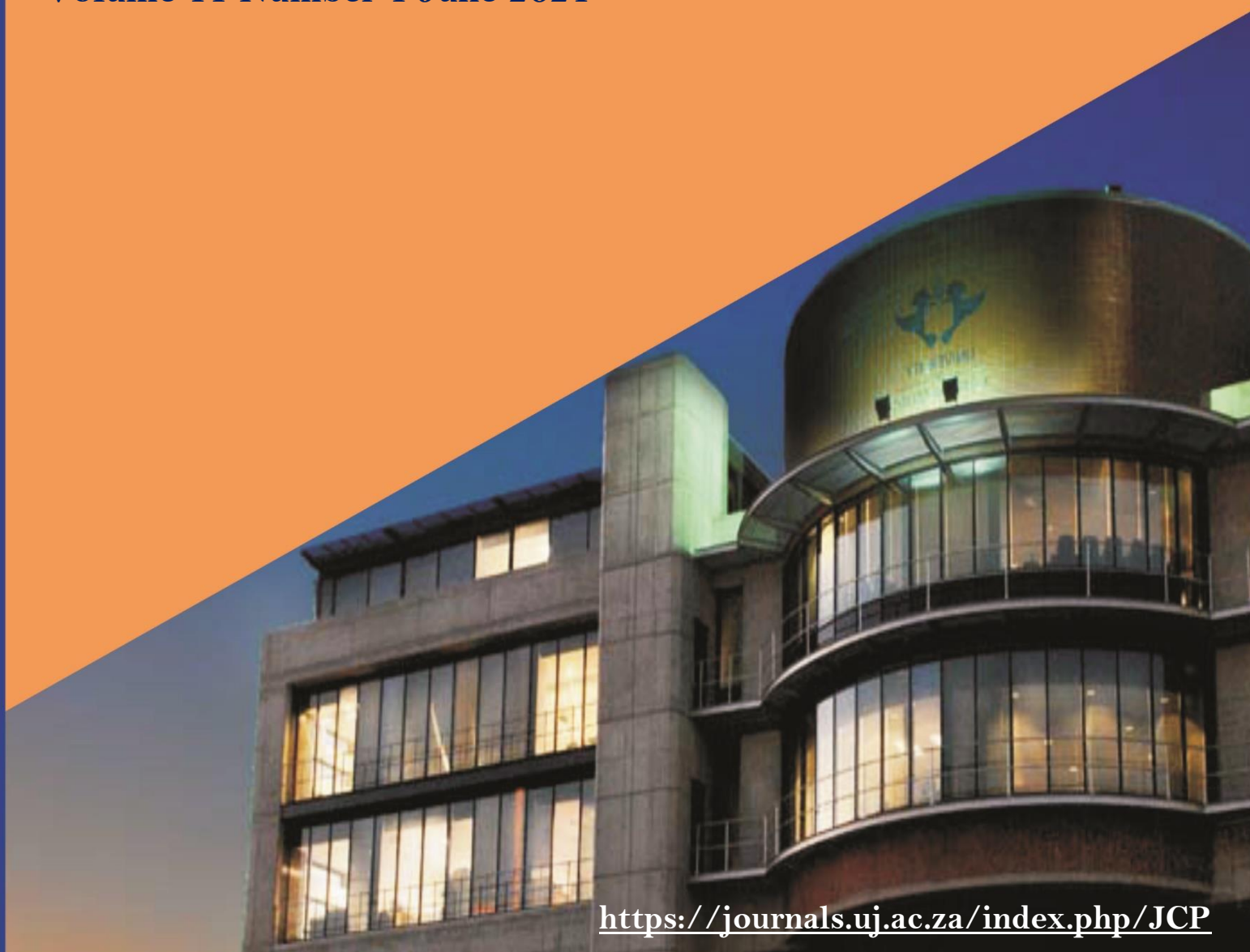

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**The Title** should be a brief phrase describing the contents of the paper. The Title Page should include the authors' full names and affiliations, the name of the corresponding author along with phone, fax and email information. Present addresses of authors should appear as a footnote.

The **Abstract** should be informative and completely self-explanatory, briefly presenting the topic, stating the scope of the experiments, indicating significant data, and pointing out major findings and conclusions. The Abstract should be 100 to 300 words in length. Complete sentences, active verbs, and the third person should be used, and the abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited. Following the abstract, about 3 to 10 key words that will provide indexing references should be listed.

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**The Acknowledgments** of people, grants, funds, etc. should be brief.

**Tables** should be kept to a minimum and be designed to be as simple as possible. Tables are to be typed in double-spacing throughout, including headings and footnotes. Each table should be on a separate page, numbered consecutively in Arabic numerals and supplied with a heading and a legend. Tables should be self-explanatory without reference to the text. The details of the methods used in the experiments should preferably be described in the legend instead of in the text. The same data should not be presented in both table and graph form or repeated in the text.

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Examples:

Aigbavboa (2012), Aigbavboa et al. (2012), (Thwala, 2000), (Aigbavboa and Thwala, 2012), (Aigbavboa, 2008; Lesito, 2007a, b; Aigbavboa, 2010, 2011), (Thwala et al., 2001)

**References** should be listed at the end of the paper in alphabetical order. Articles in preparation or articles submitted for publication, unpublished observations, and personal communications should not be included in the reference list but should only be mentioned in the article text (e.g., A. Kingori, University of Nairobi, Kenya, personal communication). Journal names are abbreviated according to Chemical Abstracts. Authors are fully responsible for the accuracy of the references.

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Aigbavboa CO (2010). Residential satisfaction in low-income housing: a South Africa perspective. Journal of Construction Project Management and Innovation. 1(2): 14 – 20.

Aigbavboa CO, Lesito K (2012). ICT benefit in South Africa Construction Journal of Construction Project Management and Innovation. 2(2): 75 – 81.

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## Disclaimer of Warranties

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### ARTICLES

# Preface to the JCPMI special issue on "Sustainable Infrastructure & Smart Innovations for Urban Development" (selected papers from the 5th International Conference on Transportation & 1st African-American International Conference on Sustainable Infrastructure & Smart Innovations held in Morgan State University, Baltimore, Maryland, USA)

Globalization and rapidly evolving technologies are driving profound changes in the role of transportation in our society. Through research studies, publications on various disciplines, we continue to provide authoritative and non-partisan policy advice to decision makers in government, academia, and the private sector. Although research in transportation is integral to our societies, there are persistent challenges to the vitality of this sector. Funding for scientific research is increasingly uncertain, and, in my view, this calls for trans-disciplinary and trans-sector research collaboration in order to ensure that fundamental advances are made in the areas of focus for the continuity and sustainability of transportation.

Despite the challenges facing the transport sector, there are many promising avenues to strengthen this sector. New models of cooperation among academia, industry and government can better enable transport experts to meet the formidable challenges ahead. The world is increasingly faced with complex problems that require the adoption of innovative researches and approaches that will bring about lasting and sustainable solutions. For instance, the challenges facing communities from climate change to providing adequate transport for the world's growing population are immense, urgent, and intimately connected. With proper coordination, transport experts are poised to help solve problems at this level of complexity and importance.

Redesigning dated organizational structures and cultural attitudes within and across the sectors could dramatically accelerate the development of new approaches. I believe we now have the critical mass in academia, government, and the private sector to achieve this. To attain global stature and tackle critical societal challenges in the transport sector will depend on how we nurture the research and publication ecosystem.

**Dr Adewole Simon Oladele** PhD, Pr. Eng
Guest Editor

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# ANALYZING THE IMPACT OF ROADSIDE FEATURES ON INJURY SEVERITY

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## ABSTRACT

The design and implementation of a multimodal transportation system must address the issue of mobility and sustainability with the objective of making transportation safer, better, faster, and more reliable. Roadway safety hardware which has been provided as a countermeasure to reduce the severity of highway crashes may have a contributing effect to injury severities on the highway. This emphasizes the need to evaluate the effects of roadside features on injury severity along rural and urban roadways. The study examines the effectiveness of roadside hardware in twenty-four (24) counties in the State of Maryland using the vehicular crash data for the years 2016 to 2018. The relationship between accident occurrence and the traffic and control characteristics of roadway was investigated to develop a Multinomial Logit Model to identify the factors determining the severity of vehicle crashes in relation to roadside features. Findings showed that roadside features such as trees may increase the propensity of a fatal and serious injury relative to a property damage.

**Keywords:** Roadside Safety Hardware, Countermeasure, Multinomial Logit Model, Pedestrian-Vehicle Crashes.

## 1. INTRODUCTION

The purpose of transportation engineering is to plan and implement multimodal transportation systems that can address the problem of mobility and sustainability. Transportation researchers are finding new ways to reduce crashes on the highway, with the objective of making our transportation system safer, better, faster and more reliable. Roadway safety hard wares have been used as countermeasures to reduce crash severity on the highway; however, these roadway safety hard wares may also be contributing factors to fatal, incapacitating, or non-incapacitating roadway crashes. Roadway safety hardwares are used to prevent dangerous collisions involving roadway features such as trees, utility poles, steep slopes or cliffs (Holdridge et al., 2005). These roadway features are also major contributors to roadway crashes. It is therefore imperative to address the issue of crashes resulting from roadway features and hardwares by analyzing the impact of these roadway features and hardwares on crash severities; it is also imperative to investigate new ways to solve this problem. This study therefore, seek to analyze and model roadside related crashes and injury severities along rural and urban roadways in Maryland with the objective of investigating and identifying factors (in relation to roadside features) that can increase or decrease injury severity level.

Studies have shown that the number of fixed roadside objects and their offset have greatly influence the occurrence of roadside crashes. Vehicle collisions cost the United States billions of dollars each year and resulted in an estimated 34,080 fatalities in 2012. Roadside features are increasingly accounting for injury severities ranging from fatal, incapacitating (serious injury), and non-incapacitating (minor injury) to Property Damage Only (PDO) (Watson et al., 2014). Every year, hundreds of people are killed in Maryland in car accidents, while thousands more are hurt. Although Tens of thousands of additional car crashes only lead to property damage, these crashes can cause serious problems for the people involved. According to report, in 2016 Maryland saw 120,120 car accidents. In total, these crashes injured 50,864 and killed 522 people (Bedigian, 2020). Based on crash data downloaded from Maryland open data portal, from 2016 to 2018 a total of 237, 080 vehicular crashes were recorded of which 920 were fatal crashes, 70,204 were injury Crashes and 165,956 were property damage crashes. In the United States, crashes involving fixed roadside objects account for approximately 30% of the total number of traffic fatalities and 60% of crashes on the highway.

## 2. LITERATURE REVIEW

Several literatures have analyzed crashes related to roadside features along state roads and corridors in the United States. Significant factors that affect crash severities involving roadside features through improved statistical efficiency along with disaggregate and multivariate analysis was done by Holdridge et al., 2005, their result shows that, roadside features such as the leading end of guard rails and bridge rails, trees and utility poles, increased the likelihood of a fatal injury. Their findings also state that the most frequently struck roadside features are trees and utility poles, while less frequently struck are guardrails, signs, mailboxes, and bridge ends. Roadside features with the highest percentage of fatal crashes were found to be culverts, trees, utility and light poles, bridges, rocks and earth embankments. Lee and Mannering (2002), analysed the impact of roadside features on run-off-road way accident frequency and injury severity using zero inflated count models and nested logistic models. Based on their analysis run-off-accident frequency will be reduced by reducing the distance between guardrails on the roadway and outside shoulder edge, reducing the number of isolated trees along the roadway, and increasing the distance between outside shoulder edge to light poles. Ewan et al., (2016), conducted a research on the impact of geometric and roadside features on crash occurrence and associated risks on low volume roads in Oregon. Their analysis show that roadways having lane width less than 12ft have a higher likelihood of crash occurrence compared to roads with the standard lane width of 12ft. Peng et al., 2012, investigated the impact of roadside features on road departure crashes. The evaluation was done on a 245-mile-long section of two-way lane roads in Texas. They used a negative binomial model for crash frequency and a multinomial logistic model for injury severity. Their analyses show that side slope condition, lateral clearance, shoulder width had significant effect on roadway departure crashes. According to Tung et al., (2008), roadside objects are the main contributing factors to motorcyclist fatalities. In 2005 there were over 25 000 fatalities as a result of a driver leaving their lane and either crashing with an oncoming vehicle, rolled over or hit an object located along the highway (FHWA, 2006).

Injury severity levels are usually ordered from the from the most critical (fatal injury) to the least critical (PDO under), as a result of this order, the ordered logistic models are best appropriate for modelling injury severity (Quddus et al. 2002, Kockelman and Kweon 2002, Khattak et al. 2002). However, for the independent variables to have a non-monotonic effect on the dependent variable, researchers have used multinomial logistic which is the opposite of ordered logistic (Wang and Abdel-Aty 2008, Tay et al. 2011). And according to Savolainen et al., (2011), multinomial logistic model is the most prominent model for modelling injury

severity. This paper has therefore employed a multinomial logistic model to develop an injury severity model in relation to roadside features.

## 3. METHODOLOGY

Three injury severity levels were considered in this study: Fatal, Property damage and injury crash. Multinomial logistic was employed using SPSS statistical software to develop an injury severity model. The crash data was first downloaded from Maryland Open Data Portal. The data was then screened to remove duplicates and crashes with incomplete information. The data was then analyzed using SPSS statistical software. See figure 1 for methodology adopted.

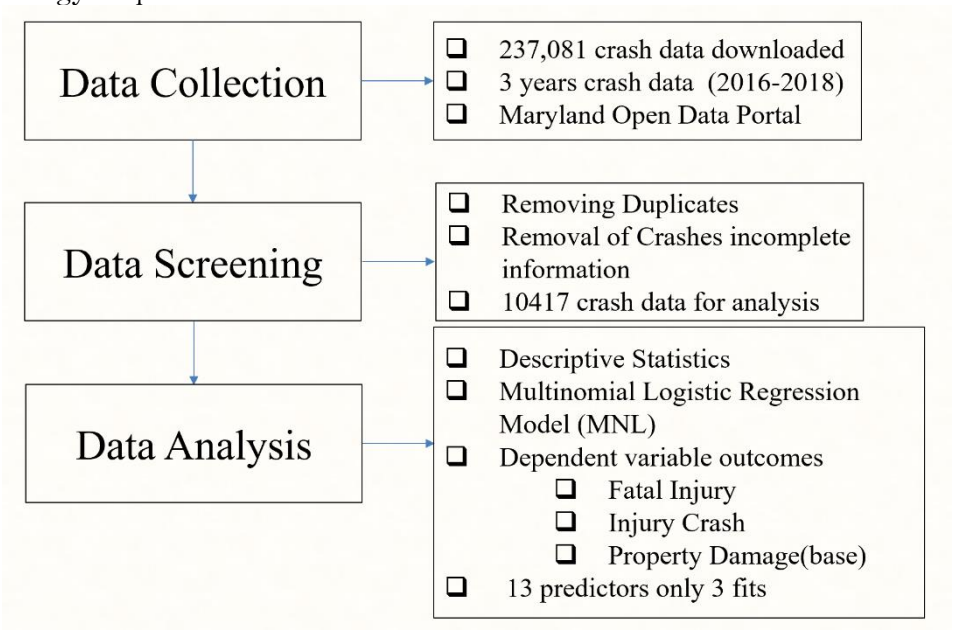


**Figure 1.** Research Methodology

### 3.1 Data

This paper utilized three years data from 2016-2018, extracted from Maryland Open Data Portal. A total of 237, 080 crashes were downloaded for 24 counties in the state of Maryland. Duplicate crashes were removed, and the data was screened for only roadside feature related crashes and other factors which are significant to affect injury severity. As a result of the screening only 10417 crash data were recovered. The crash data were downloaded with features such as number of lanes, type of terrain, date and time when the crash occurred, log mile, weather condition, manner of collision, light condition, manner of first collision, year of crash, and type of crash categorized as fatal, Property Damage, Injury crash.

### 3.2 Descriptive Statistics

After the downloaded data was screened a total of 10417 roadside related crashes were retained and used for analysis. Figure 2 shows the descriptive statistics for the variable lighting condition. From the result most of the crashes including fatal, injury and property damage crash occur in the dark with no lights. Descriptive statistics from Figure 3 show that majority of the fatal and injury crashes were caused by vehicle striking a tree along the cross section of the road. And majority of the injury crashes and property damage was caused by the vehicle striking a guardrail, Figure 4 shows that majority of the crashes occurred during clear weather that means during the daytime.

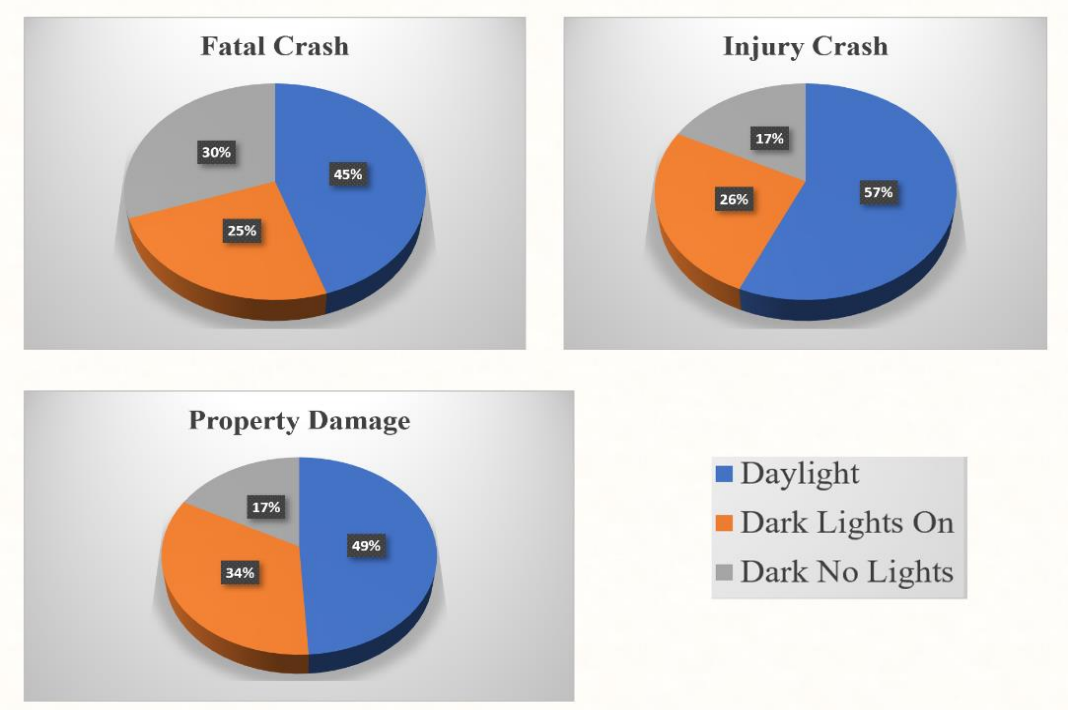


**Figure 2.** Descriptive Statistics for the Variable Lighting Condition

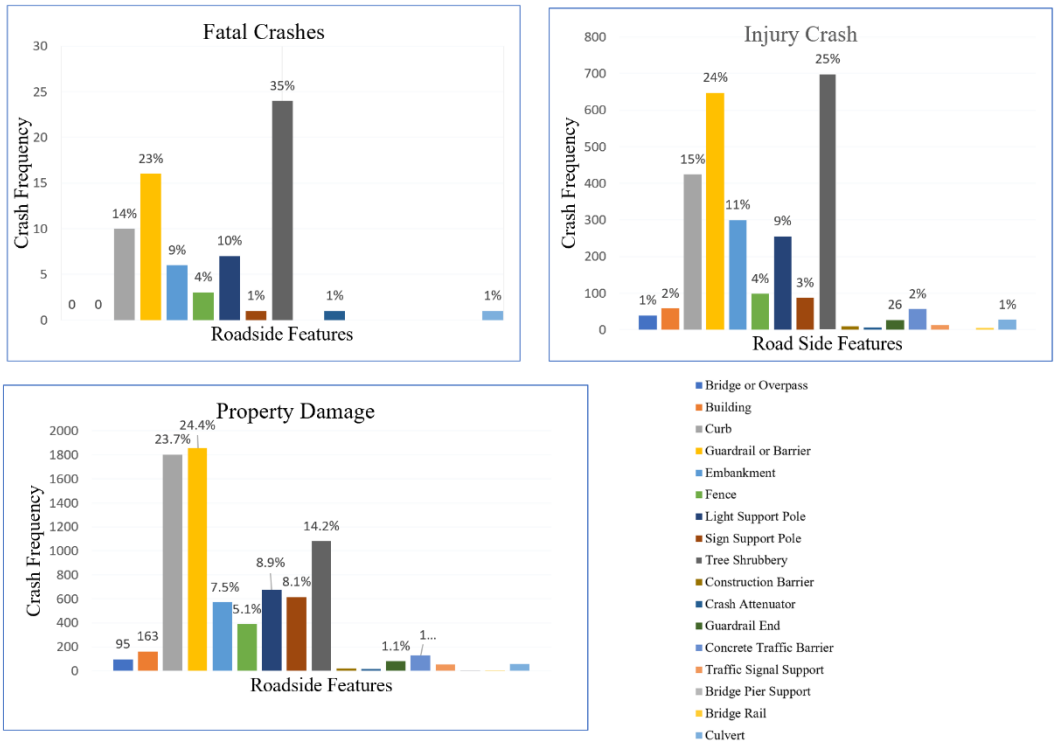


**Figure 3.** Descriptive Statistics for the Variable Roadside Features

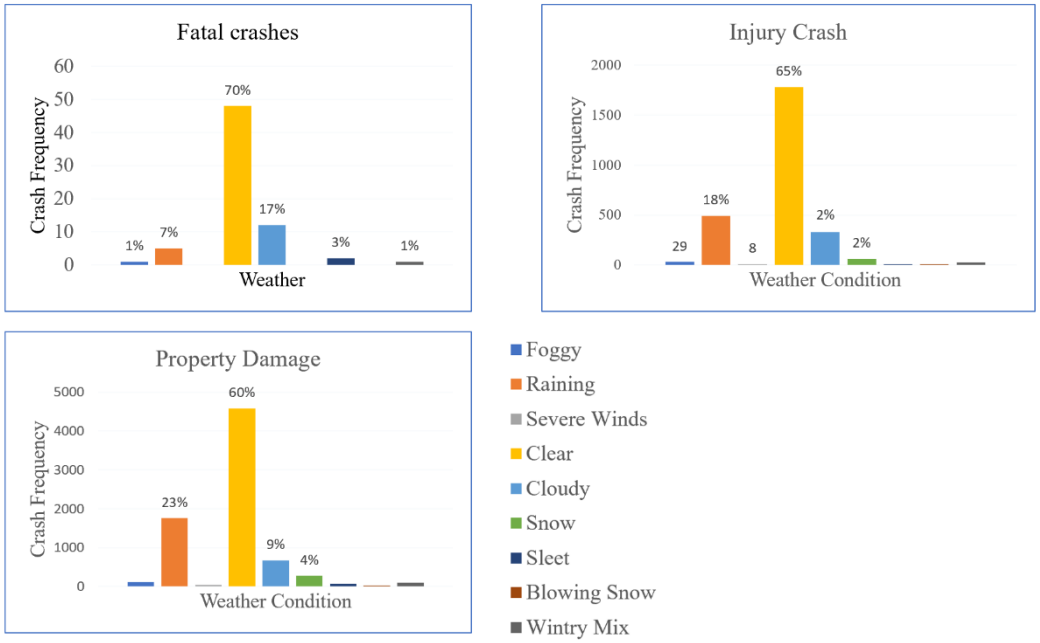


**Figure 4.** Descriptive Statistics for the Variable Weather Condition

## 4. INJURY SEVERITY MODEL RESULT DISCUSSION

The primary objective of this model is to estimate injury severity levels as a function of the explanatory variables such as roadside features and other significant factors that may affect injury severity level. The model developed is at a confidence interval of 95%. This means that variables with p-values greater than 0.05 (which is the standard reference P-value for a 95% confidence interval) are not significant variables affecting injury severity levels.

Variables with positive coefficient indicates that with the presence of the said variable there is a likelihood that the corresponding injury severity will increase in comparison to the base injury severity level (property damage). The reverse is the case for negative coefficient variables. According to the model developed, significant roadside features affecting injury severity levels are: Trees, sign support poles, traffic signal support and fence. Other factors found to significantly affect injury severity level are lighting and weather condition. When controlling for roadway features the model show that the variable standing tree have positive coefficients. This means that the presence of trees and embankments along the roadway increases the propensity of a fatal and serious injury relative to a property damage. This means that there is a high probability for a crash to be a fatal or serious injury when struck by a tree or an embankment along the road. The result also show that a cloudy weather may increase the propensity of a fatal or serious injury relative to a property damage. See table 1 for multinomial logistic result.

**Table 1:** Multinomial Logistic Result

| | | | | |
|---|---|---|---|---|
| Number of Observations | | | 10417 | |
| Log-Likelihood | | | 923.730 | |
| Chi-square | | | 525.398 | |
| P-Value | | | <.0001 | |
| Base Case: Property Damage | | | | |
| | Fatal Crash | | Injury Crash | |

| Variables | Coefficient | P-Value | Coefficient | P-Value |
|---|---|---|---|---|
| Intercept | -3.776 | .008 | -1.420 | <.0001 |
| Roadside Features | | | | |
| Bridge or Overpass | -14.239 | .990 | -.055 | .858 |
| Building | -14.228 | .986 | -.264 | .348 |
| Curb | -.877 | .410 | -.618 | .010 |
| Guardrail or Barrier | -.496 | .635 | -.222 | .354 |
| Embankment | -.375 | .731 | .167 | .499 |
| Fence | -.699 | .549 | -.584 | .025 |
| Light Support Pole | -.255 | .815 | -.146 | .556 |
| Sign Support Pole | -2.169 | .128 | -1.185 | <.0001 |
| Tree Shrubbery | .370 | .720 | .386 | .100 |
| Construction Barrier | -14.382 | .995 | -.061 | .896 |
| Crash Attenuator | 1.173 | .418 | -.384 | .468 |
| Guardrail End | -14.052 | .989 | -.290 | .376 |
| Concrete Traffic Barrier | -13.991 | .987 | .042 | .882 |
| Traffic Signal Support | -14.377 | .993 | -.690 | .084 |
| Bridge Pier Support | -15.078 | | -14.954 | .995 |
| Bridge Rail | -14.369 | .998 | 1.243 | .166 |
| Culvert | 0[c] | | 0[c] | |
| Weather | | | | |
| Foggy | -.256 | .857 | .145 | .645 |
| Raining | -1.202 | .276 | .210 | .382 |
| Severe Winds | -14.355 | .994 | -.180 | .698 |
| Clear | .099 | .922 | .582 | .010 |
| Cloudy | .643 | .541 | .755 | .002 |
| Snow | -13.971 | .983 | .000 | .999 |
| Sleet | 1.067 | .390 | -.258 | .524 |
| Blowing Snow | -13.894 | .995 | .736 | .100 |
| Wintry Mix | 0[c] | | 0[c] | |
| Lighting condition | | | | |
| Daylight | -.460 | .117 | .260 | <.0001 |
| Dark Lights On | -.664 | .050 | -.083 | .246 |
| Dark No Lights | 0[c] | | 0[c] | |

## 5. CONCLUSION

This study has successfully used SPSS statistical software to model injury severity, utilizing crash data downloaded from Maryland Open Data Portal. The objective was to analyze the impact of roadside features on injury severity levels and investigate the impact of other explanatory factors affecting crash severity level on rural and urban roads in the State of Maryland. To achieve the research objectives this study utilized the Multinomial logistic model in SPSS to model injury severity. Based on the data analysis from this study, most of the crashes including fatal, injury and property damage crash occur in the dark with no lights. And majority of the fatal and injury crashes were caused by vehicle striking a tree along the cross section of the road. And majority of the injury crashes and property damage was caused by the vehicle striking a guardrail. Most of these crashes occurred during clear weather that means during the daytime. From the Multinomial Logistic model, significant roadside features affecting injury severity levels where found to be trees, sign support poles, traffic signal support and fence. Other factors found to significantly affect injury severity level are lighting and weather condition. The presence of trees along the roadway have been found to

increase the propensity of a fatal and serious injury relative to a property damage. This means that there is a high probability for a crash to be a fatal or serious injury when struck by a tree along the roadway cross section. Cloudy weather may also increase the propensity of a fatal or serious injury relative to a property damage.

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# PORTERAGE OPERATION IN RURAL MARKETS - A PIVOTAL LINK AND TRANSFORMATION IN AGRICULTURAL COMMODITIES TRANSPORTATION SYSTEM: CASE OF SOUTH-WESTERN NIGERIA

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## ABSTRACT

Due to poor infrastructure, unmotorable and heavily congested many urban and rural market spaces in most African societies, Nigeria inclusive, and consequent use of head porters in transporting market goods and wares, this paper seeks to explore porterage operation in rural markets with a view to establishing the pivotal linkage between porterage, market and agricultural commodities transportation system in south-western Nigeria. Specifically, the porterage, market and transportation linkage were conceptualized; socio-economic statuses of the porterage workers were profiled; types of agriculturally based porterage activities and porterage workers' levels of involvement identified; reasons motivating and constraints limiting their involvement; and transformation in porterage operation in agricultural commodities transportation were discussed. Pre-tested and validated interview schedule was used to elicit information from 190 porterage workers randomly selected from across 10 agricultural commodity markets in the study area. Key informant interview was used to elicit qualitative information from their association leaders. Also, on-site photographs were captured to reinforced transformational innovation in rural porterage. Data collected were processed using statistical package for social sciences (SPSS) version 21. The paper established porterage as a sub-system in rural market transportation system. It also revealed that majority of porterage workers are young people (about 70%) under 40 years of age with a very low socio-economic status with no or little education. They earn an average income of ₦264,505.26 ($734.74) annually. They operate on an average of 6 days/week and about 21/2hrs/day without requiring any special skills and initial capital. They are mostly exposed to harsh weather condition and diverse physical risks. It noted the current transformational innovation the sub-system is undergoing with gradual migration from head carriage to wheelbarrow (34%), advancement into cart pushing (16%) and very few motorized tricycles. This is observed to be a strategic way of reducing stress and energy involve in the traditional porterage operation without losing the purpose of connecting the rural transportation system.

**Keywords:** Porterage, market, transportation, linkage, transformation, agriculture, Nigeria

## 1. INTRODUCTION

The informal economy has remained a major part of sub-Saharan African economic systems (Akanle and Chioma, 2013). Crucial to this are market place transactions where people meet to purchase and sell different items. As a result of the socio-cultural, geographic and economic infrastructures of many traditional African societies, goods to be sold and purchased are transported from one location to another for various purposes. Owing to high

level of under-development, majority of the urban and rural market spaces in most African societies are usually unmotorable and heavily congested, thus the head porters, popularly called alabaru among the Yoruba ethnic group prevalent in South-western Nigeria, are needed to transport market goods and wares. They are a major part of the transport systems and structures of developing countries with poor transport and market planning.

In south-western Nigeria, professional load porters whose ages may range from 10 to 70 years and above are commonly seen in the markets where they assist shoppers to carry their groceries of varying weights over varying distances for paltry economic reward (Babatunde, Regina and Adesola, 2014). Head porter is one that carries goods or burdens for someone else, charging for the service. In typical Nigerian markets, they provide a link among the wholesalers, retailers, transporters and the end users. In some cases, they also help the farmers to move some of their harvests from the farm to neighboring markets. These head porters help their patrons who are mostly shoppers and shop owners carry agricultural commodities purchased and, in some occasion, follow them from stall to stall, as they struggle to find their way in poorly laid out and often congested local markets.

As a result of globalization and rapid demographic changes, there has been an increasing demand for agri-food products. Many farmers and breeders in sub-Saharan Africa face significant difficulty when trying to bring their products to the market (Anne and Patrick, 2009). The agri-food supply chain is comprised of a set of sequential operations namely input supply, production, postharvest, storage, processing, marketing distribution, food services and consumption following a sequence of operations from 'farm-to-the-fork' (van der Vorst, 2006; Matopoulos et al., 2007; Jaffee, Siegel and Andrews, 2010). The development of smallholder agriculture in developing countries is extremely sensitive to transport strategies. Many isolated farmers have little opportunity to escape poverty, as their potential marketing activities are hampered by inadequate or poor transport facilities.

Past studies such as Yeboah and Yeboah (2009) investigated the cultural and socio-economic profiles of porters in Accra, Ghana; Akanle and Chioma (2013) carried out an anthropological study of head porterage in Ibadan; Kwankye et al. (2007) reveal head porterage as one of the coping strategies of independent child migrants from northern Ghana to southern Cities; Osotimehin et al. (2007) evaluated youths' participation in porterage services in Ogbomoso, Oyo State, Nigeria; while Babatunde et al. (2014) also studied spinal deformities among professional load porters in a Nigerian urban market. However, there is dearth of information on the socio-economic profiles and involvement of porterage workers in agricultural related activities in commodity markets vis-à-vis transformational innovation the porterage system is currently undergoing.

It is against this background that this paper seeks to explore porterage operation in rural markets with a view to establishing the pivotal linkage between porterage, market and agricultural commodities transportation system in southwestern Nigeria. Specifically, the porterage, market and transportation linkage was conceptualized; socio-economic statuses of the porterage workers were profiled; types of agricultural based porterage activities and porterage workers' levels of involvement identified; reasons motivating and constraints limiting their involvement; and transformational innovation in porterage operation in agricultural commodities transportation were discussed.

## 2. PORTERAGE, MARKET AND TRANSPORTATION LINKAGE: CONCEPTUAL UNDERPINNINGS

A porter, also called a bearer, is a person who shifts objects for others. The word was derived from the Latin portare which means to carry, (The Concise Oxford Dictionary of English Etymology, 2003). Different kinds of porterage activities exist and critical to this are the head porters who operate in sub-Saharan African markets. According to Kwankye et al. (2007), the phenomenon of carrying loads on the head for commercial purposes was first

introduced in Ghana by male migrants from Mali in the 1960s. During the period, it was virtually a male dominated activity, but in the subsequent years, different people of both genders are now involved in the trade. Women, nowadays, also form a significant proportion of head porters in contemporary Africa's rural and urban markets. In the work of Akanle and Chioma (2013), it was reported that head porterage for commercial purposes was first introduced to Nigeria by male migrants from the northern part of the country and other parts of Africa and over the years, there has been an emergence of the physically demanding occupation of commercial load carrying. The occupation is engaged in by male and female of varying age groups as a way of surviving the downturns in the economy.

Agricultural marketing covers the services involved in moving an agricultural product from the farm to the consumers. To achieve this, there are numerous interconnected activities involved such as planning production, growing and harvesting, grading, packing, transport, storage, agro and food processing, distribution, advertising and sale. The role of transport and logistics is very crucial as production process is not complete until the commodity is in the hands of the final consumers. Availability of transport facilities is a critical investment factor that stimulates economic growth through increased accessibility of goods and services (Ajiboye, 1994). The peculiarity of most agricultural commodity markets in Nigeria in terms of congestion and poor layout necessitate porterage workers forming an integral part of the logistics and transportation link in these markets as they help farmers, market sellers and consumers move their agricultural produce from one point to another within or outside the market. In addition, high level of unemployment, especially of women, in Nigeria, has made head porterage to become and remain an important leeway.

Transport is regarded as an important factor involved in agricultural development all over the world. It is the only means by which farm produce at farm site is moved to different homes as well as markets (Tunde and Adeniyi, 2012). Transport creates market for agricultural produce, enhances interaction among geographical and economic regions and opens up new areas to economic focus. The special characteristics of agricultural products such as perishability, seasonality and bulkiness depend on a flexible transportation system. Aderamo and Mudashiru (2014) opined that efficient transport system is critically important to agricultural marketing. They assert that if transport services are infrequent, of poor quality or expensive, farmers will be at a disadvantage when they attempt to sell their crops. An expensive service will naturally lead to low farm gate prices (i.e., the net price the farmer receives from selling his produce).

According to Agarwal et al. (1997), transport responsibilities that were supposed to be performed by technology are often performed by humans in developing economies, since necessary technologies may not exist, or the socio-cultural or economic situation may not support them. Porterage activity is one of the means through which women pursue economic prosperity. Porters are faced with several challenges on their job which includes not being adequately paid for services rendered, health needs among many others. Some of the patrons of these porterage workers often exploit and harass them; they are also often subjected to ridicule and insults from family members and those who act as chaperons for them (Beauchemin, 1999; Opare, 2003).

The major risks the head porters are exposed to are health risks (body pain, head ache, back ache, etc.), the mistaken perception that they are worthless people, road accidents, on-the-job personal injuries and responsibility for product damage (Akanle and Chioma, 2013). They sometimes fall with the heavy load they carry as they try to meander their way through the heavy human and vehicular traffic. This sometimes results in fatalities or body injuries that take months to heal. Further evidences revealed that acute injury, such as metatarsal (foot) stress fractures, especially on rough terrain (Charteris, 2000), and acute injuries to the arm (e.g., Colles fractures of the wrist) and leg bones (e.g., ankle injuries) as a result of falls may impose an extra health burden on head porters. Kwamusi (2002) identifies fatigue and slippery paths in the wet season as common causes of falls among head porters, resulting in

widespread knee and toe injuries. Serious falls during head-loading can have both severe musculoskeletal and physiological repercussions (Porter et al., 2013). The porterage workers are sometimes knocked down by fast-moving vehicles as they try to cross the road at sometimes dangerous points. In most instances, the consequences of such risks are borne solely by the head porters even when sometimes it is not their fault. There are no systems to prevent them from such exposure or mechanisms to help them bear the consequences. However, they have evolved coping mechanisms over the years. Such coping mechanisms include resignation to faith, esprit de corps among the head porters and the optimism that things will get better over time (Akanle and Chioma, 2013).

## 3. METHODOLOGY

This study was carried out in the agricultural commodity markets in south-western Nigeria, a region where agriculture is the main occupation of the people, with an estimated population of about 32.5 million predominantly of the Yoruba ethnic group who made up approximately 21% of the national population. The population of the study comprised of porterage workers in agricultural commodity markets. Based on the availability of porterage workers, purposive sampling technique was used to select a total of 10 agricultural commodity markets, from each of which 19 porterage workers were selected making a total of 190 respondents. Primary data was collected from the respondents, using both quantitative and qualitative data collection methods. Structured interview schedule was used to obtain quantitative data from the porterage workers, while Key informant interview (KII) was used to elicit qualitative information from their association leaders. Information was collected on the personal and socio-economic characteristics such as age, sex, religion, annual income, marital status, occupation, household size and level of education; types of agricultural based porterage activities respondents are engaged in; and their level of and motives for involvement. The data collected were processed using statistical package for social sciences (SPSS) version 21. Both inferential and descriptive statistical analyses were carried out during this process. Descriptive statistical techniques used include frequency counts, percentages, means and standard deviations. Bar chart was used as appropriate.

## 4. RESULT AND DISCUSSION

### 4.1 Socio-Economic Statuses of the Porterage Workers

The mean age of the respondents was 36.89 years with ± standard deviation of 8.92019 years (See Table 1). This implies that the porterage workers were in their active age and still have the strength to carry out their porterage activities. This finding agrees with Babatunde et al. (2014) which indicated that the average age of people actively involved in porterage activities was 31.5 years but disagrees with Kwankye et al. (2009) which indicated that the age group of people that were actively involved in porterage activities was between the ages of 15-19 years.

**Table 1:** Respondents by their Age, Sex, Marital Status, Religion and Educational Level (N = 190)

| Variables | Frequency | Percentage (%) | Mean | S. D |
|---|---|---|---|---|
| Age (years) | | | | |
| ≤30.00 | 63 | 33.2 | | |
| 31.00 - 40.00 | 68 | 35.8 | 36.88 | 8.92 |
| 41.00 - 50.00 | 43 | 22.6 | | |
| ≥51.00 | 16 | 8.4 | | |
| Sex | | | | |
| Male | 129 | 67.9 | | |

| | | | | |
|---|---|---|---|---|
| Female | 61 | 32.1 | | |
| Marital status | | | | |
| Single | 51 | 26.8 | | |
| Married | 108 | 56.8 | | |
| Divorced | 4 | 2.1 | | |
| Separated | 12 | 6.3 | | |
| Widowed | 15 | 7.9 | | |
| Religion | | | | |
| Christianity | 107 | 56.3 | | |
| Islam | 81 | 42.6 | | |
| Traditional | 2 | 1.1 | | |
| Educational level | | | | |
| None | 55 | 28.9 | | |
| primary uncompleted | 11 | 5.8 | | |
| primary completed | 57 | 30 | | |
| secondary uncompleted | 21 | 11.1 | | |
| secondary completed | 46 | 24.2 | | |

Source: Field survey, 2018

The Table further shows that majority (67.9%) of the respondents were males, which implies that men dominated the population of the porterage workers in the agricultural commodity markets. This result is in line with the findings of Akanle and Chioma (2013) which asserted that women were compelled to join the porterage trade as the economy grew worse in Nigeria. This finding is also in consonance with Argawal et al. (1997) and Opare (2003) that women's engagement in porterage business is a recent phenomenon. However, this may be as a result of the fact that males are perceived to be the stronger gender and porterage work is a very tedious venture which requires a lot of physical strength. The following KII excerpt further supports this claim:

> *"This job is a very hard job, it is a job characterized by body pains, and there is no form of ease in it at all. This job is so tedious to the extent that we suffer from "awoka ara" (body pains). If you are not strong enough, you cannot do this our type of work." (A discussant at Odo-oba market, Ogbomosho)*

The results further show that more than half (56.8%) of the respondents were married and 26.8 percent were single. This implies that many of the respondents were married which indicates a sign of being responsible. This finding agrees with that of Yeboah and Yeboah (2009) who ascertained that majority of people that engage in porterage activities were married. This may however be as a result of the fact that married people have responsibilities that drive them to engage in any available income generating activities to meet their household need. More than 56 percent of the respondents practiced Christianity and 42.6 percent practiced Islam. This implies that modern religion has taken over the communities in the study area and this could be attributed to the massive influence of western culture on both rural and urban dwellers in Nigeria.

Only 30 percent of the respondents completed primary education, 28.9 percent had no formal education and 24.2 percent completed secondary education. This implies that a large number of the porterage workers had a low level of educational attainment which is why they could easily take up this porterage job in a bid to secure their survival amidst the current economic hardship in the country. This result agrees with the findings of Afriyie et al. (2015) which asserted that since porters have a low or no formal education or employable skills and coupled with lack of initial capital, these factors makes "head porterage" business a viable option.

The study further reveals that 65.8 percent of the respondents were non-natives of the communities where they were operating while 34.2 percent were natives. This implies that most of the respondents migrated from their communities in search of greener pastures. This is in consonance with Abass et al. (2013) that people often resort to migration when they cannot gain a secured livelihood in their homeland or cannot cope with adversities. About 47.4 percent of the respondents were attracted to the communities in order to secure opportunity for their livelihood, 35.3 percent got there through their parents, 11.6 percent through marriage while 5.3 and 0.5 percent were attracted to the communities due to the presence of markets and social amenities, respectively. This implies that most of the respondents who reside in these communities do so in a bid to secure their means of livelihood. The following KII excerpt further supports this assertion:

> *"…this is my fourth year on this job, I left my family and my small farmland back in the east to travel down here when things became very difficult for me. Since when I've started this job, I have been able to settle my immediate needs and my plan is to save enough money so that I can travel back home and also try to revive my farm…" (A discussant at Ajegunle market, Atiba LGA)*

The study further reveals that 45.3 and 20.5 percent of the respondents had lived below 10 years and between 21-30 years, respectively, in their community, 17.4 percent had lived for over 30 years while 16.8 percent had lived between 11-20 years in the community with a mean duration of residency of 18.2 ± 14.093 years of residency. This implies that most of the respondents have not lived for more than 18 years in the communities where they carry out their porterage activities and this may indicate a trend of migration among the porterage workers. This may be attributed to the fact that most of the porterage workers are non-indigenes of communities where they operate but are residing there to secure their means of livelihood and survival. About 34.2 percent of the respondents have a household size of between 3-4 people, 28.9 percent have a household size not more than 2 people, while 27.9 and 8.9 percent have a household size of between 5-6 people and over 7 people, respectively. The mean household size was 4 ± 2. This implies that most of the respondents have a small household size. This may however be as a result of the fact most of the population that are actively involved in porterage activities are still in their active childbearing ages, although their household sizes may tend to increase over time. This result agrees with the findings of Yeboah (2008) which indicated that majority of the porterage workers are between the ages of 16 and 35 years and that the active age of childbearing occurs within the same age group.

Data in Table 2 show that 45.8 percent of the respondents had less than 5years of experience in porterage activities and 30 percent had between 6-10 years of experience with a mean of 7.91 ± 5.779 years. It can be deduced that many of the people that engage in these porterage activities do not intend to make a career out of it, but they only do so as a temporary means of survival. They engage in it in order to raise capital for other profitable ventures.

**Table 2:** Respondents by their Age, Sex, Marital Status, Religion and Educational Level ( N = 190)

| Variables | Frequency | Percentage (%) | Mean | S. D |
|---|---|---|---|---|
| Years of experience | | | | |
| ≤5.00 | 87 | 45.8 | | |
| 6.00 - 10.00 | 57 | 30 | 7.91 | 5.77 |
| 11.00 - 15.00 | 29 | 15.3 | | |
| ≥16.00 | 17 | 8.9 | | |
| Major occupation | | | | |
| Porterage activities | 166 | 87.4 | | |

| | | | | |
|---|---|---|---|---|
| Trading | 10 | 5.3 | | |
| Artisan work | 8 | 4.2 | | |
| Farming | 4 | 2.1 | | |
| Driving | 3 | 1.6 | | |

Source: Field survey, 2018

This result agrees with the findings of Akanle and Chioma (2013) which postulated that many of the load porters entered the trade with the intention of getting money for more prestigious and less difficult jobs. Majority (87.4%) of the respondents identified porterage work as their major occupation implying that most of the respondents engaged in porterage activities as their major occupation. This is an indication that porterage activities serve as their major source of income and means of livelihood.

The study further reveals the mean annual income from porterage activities as ₦264,505.26[1] ($734.74) ± ₦145,095.47 ($403.04). Comparing the mean annual income from porterage activities with mean annual income from all sources, it shows that porterage activities contributed about 77% to respondents' income and livelihood. This is an indication that respondents' involvement in porterage activities is significant to their livelihood and survival. Concerning the type of health care services, the porterage workers patronized, it was discovered that 27.9 percent of them patronized traditional means of healthcare, 25.3 percent patronized government hospitals, 22.6 percent employed self-medication, 17.4 percent were not using any form of medication, 3.2 percent patronized both quack doctors/nurses and village dispensary while very few (0.5%) patronized recognized hospitals. This implies that majority of the respondents were not patronizing recognized hospitals. This may however be as a result of the fact that most of these recognized hospitals charge huge sums of money for their services which were not affordable to porterage workers because of their low-income level. This is in consonant with Yeboah and Yeboah (2009) which asserted that porters do not make enough money to seek medical attention from qualified personnel which has made self- medication to become a very common practice among them.

Majority (68.4%) of respondents lived in rented apartments, 19.5 percent were squatting, while a few (12.1%) lived in apartments owned by them. This may however be attributed to the fact that majority of the respondents were non-natives of the communities where they resided and worked. They were mostly migrants who have travelled in search of greener pasture and as such might prefer to acquire their own personal properties back in their towns and villages from where they migrated. Majority (76.3%) of the respondents did not own any automobile, while 23.7 percent owned at least one automobile. Furthermore, analysis show that from the percentage of respondents that own an automobile, 10.5 percent bought fairly used motorcycle, 7.5 percent bought new motorcycle, 4.7 percent bought fairly used car while a very few (0.5%) bought fairly used bicycle. This implies that majority of the respondents did not have the capability to purchase an automobile.

In overall, it was revealed that majority (77.4%) of the respondents had a low socio-economic status, 21.1 percent had a moderate socio-economic status while a very few (1.6%) had a high socio-economic status (See Figure 1). This implies that majority of the porterage workers in the study area were low income earners and could be classified as people of low social class. This result agrees with the findings of Yeboah and Yeboah (2009) which postulated that load porters have very little or no education and are from low socio-economic class.

[1] ₦360 = $1.00

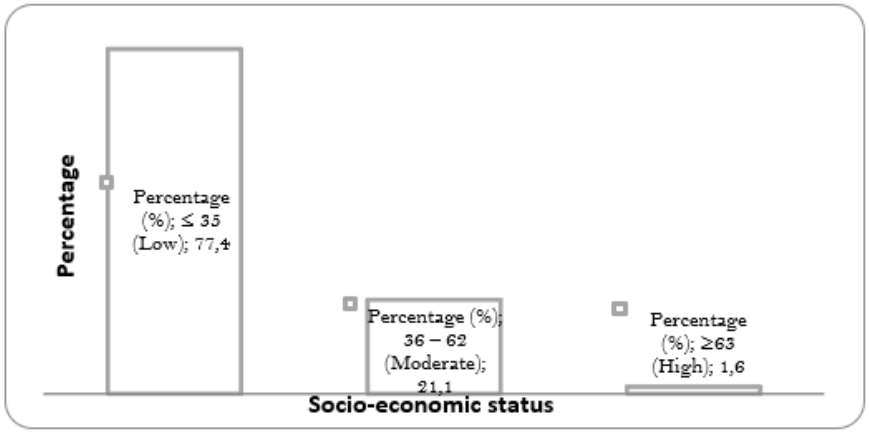


**Figure 1.** Overall socio-economic status of the respondents

### 4.2 Agriculturally Based Porterage Activities: Types and level of involvement

A list of agriculturally based porterage activities in the study area was documented. Results in Table 3 show that the most prominent porterage activities respondents were involved in was loading of goods back into the store for market sellers after closing hours (99.5%) followed by offloading of farm produce from trucks for the market sellers (67.4%); loading of agricultural commodities into trucks at the warehouse to be delivered to the market (61.1%); offloading of agricultural commodities from trucks into the warehouse for storage (61.1%); carrying of farm produce from the farm site to storage centre (61.1%); carrying of farm produce from the processing unit to storage centre (58.9%); offloading of farm produce at the processing unit (56.3%); head porterage for shoppers from the market to the car park (53.7%); head carriage of goods for the market sellers from their stores to their market stands (53.7); head carriage of farm inputs (51.6%); head porterage of harvested farm produce to the market (50%); head porterage for door to door delivery of agricultural produce (43.2%) and head carriage of meat and meat product at the slaughter house (40%). This implies that most of these porterage workers carried out their operations till closing hours of market days and are mostly involved in loading and offloading of farm products. The results also indicate that majority of their activities are carried out around the market areas.

Detailed analysis further shows the extent to which the respondents engaged in the different agricultural related porterage activities identified in the study area. Using the grand mean score of 1.65±0.478, the results indicated that activities such as: Loading of goods back into the store for market sellers after closing hours of market days (mean = 2.96); offloading of farm produce from trucks for the market sellers (mean = 2.01); loading of agricultural commodities into trucks at the warehouse (mean = 1.78); and offloading of agricultural commodities from the trucks into the warehouse for storage (mean = 1.77) were rated above the grand mean and were the activities the respondents were mainly involved in.

**Table 3:** Identification of Agriculturally Based Porterage Activities the Respondents are Involved in (N = 190)

| Types of agricultural related porterage activities | Frequency | Percentage (%) |
|---|---|---|
| Loading of goods back into the store for the market sellers after closing hours of market days | 189 | 99.5 |
| Offloading of farm produce from trucks for the market sellers | 128 | 67.4 |
| Loading of agric. commodities into trucks at the warehouse to be delivered to the market | 116 | 61.1 |

| | | |
|---|---|---|
| Offloading of agric. commodities from trucks into the warehouse for storage | 116 | 61.1 |
| Carrying of farm produce from the farm site to the storage centre | 116 | 61.1 |
| Carrying produce from the processing unit to the storage centre | 112 | 58.9 |
| Offloading of farm produce at the processing unit | 107 | 56.3 |
| Head carriage of goods for the market sellers from the stores to their market stands | 102 | 53.7 |
| Head porterage for shoppers from the market to the car park | 102 | 53.7 |
| Head carriage of farm inputs | 98 | 51.6 |
| Head porterage of harvested farm produce | 95 | 50 |
| Head porterage for door-to-door delivery of agricultural products | 82 | 43.2 |
| Head carriage of meat and meat product at the slaughterhouse | 76 | 40 |

Source: Field survey, 2018

However, activities such as carrying of farm produce from the farm site to the storage centre (mean = 1.60); head carriage of goods for the market sellers from the stores to their market stands (mean = 1.58); head porterage for shoppers from the market to the car park (mean = 1.57); offloading of farm produce at the processing unit (mean = 1.49); carrying of farm produce from the processing unit to the storage centre (mean = 1.48); head carriage of farm inputs (mean = 1.44); head porterage of harvested farm produce to the market (mean = 1,41); head porterage for door to door delivery of agricultural produce (mean = 1.17); and head carriage of meat and meat products at the slaughter house (mean = 1.12) were rated below the grand mean and were the activities the respondents were least involved in. This implies that many of the porterage workers operate mainly in the commodity markets and are usually around the market areas till the closing hours.

Level of respondents' involvement in porterage activities was measured by the number of days involved in the activities per week, number of hours of involvement per day, mode of involvement and extent of involvement in the agricultural related porterage activities.

The study reveals that 52.1 percent of the respondents engaged in porterage activities for 6 days in a week, 28.9 percent work for 7 days, 13.7 percent work for 5 days, 2.6 percent work for 3 days, while 2.6 and 0.5 percent work for 4 and 2 days, respectively. The mean number of days per week was 6.0105±0.9142. This implies that majority of the porterage workers engaged in different agricultural related porterage activities for between 6-7 days every week. This result agrees with the findings of Osotimehin et al. (2007) which indicated that a large proportion of porterage workers operate between 6 and 7 days in a week.

Concerning the number of hours per day, it was observed that 47.3 percent of respondents engaged in different agricultural related porterage activities for between 5-6 hours per day, 41.1 percent between 3-4 hours per day, 9.5 percent between 7-8 hours per day, while a very few (2.1%) worked for between 1-2 hours per day. The mean number of hours per day was 2.64 ± 0.68 hours. This shows that majority of the respondents engage in porterage activities for about three hours daily. This observation might be due to the fact that porterage activities are very tedious and people who engage in them may not be able to work for longer hours before they get tired. On the other hand, it could be that their working hours were limited because of the duration of active marketing activities during which their services are usually needed.

### 4.3 Reasons Motivating Respondents towards their Involvement in Porterage Activities

Results in Table 4 show the reasons that motivated respondents towards their involvement in porterage activities. When the grand mean score of 3.74±0.37 is compared with each of the individual mean score, reasons such as: no special skill is required (mean = 4.22) and no capital required to start (mean = 4.21) among others, were very important; while reasons

such as: the job is lucrative (mean = 3.32); there is nothing else to do (mean = 3.31); the job is seen as a hobby (mean = 1.85) were the least important reasons that motivated the respondents towards their involvement in porterage activities. This implies that major reasons that motivated the respondents in getting involved in porterage activities was the fact that the porterage work does not require any special skill and also does not require any capital to start. Some of these findings support that of Osotimehin et al. (2007) that ascertained some of the factors that motivated porterage workers as: it serves as a source of livelihood, there is nothing else to do and that the job is seen as a hobby. This is also in consonance with the findings of Akanle and Chioma, (2013) which asserted that many porterage workers get stranded in the trade as they get used to it because of the capacity of the trade to provide daily income and meet immediate needs.

**Table 4:** Reasons Motivating Respondents towards their involvement in Porterage Activities (N = 190)

| Motivational reasons | Mean | Standard Deviation | Rank |
|---|---|---|---|
| No special skill required | 4.22 | 0.535 | 1st |
| No capital required to start | 4.21 | 0.568 | 2nd |
| It serves as a source of daily income | 4.21 | 0.446 | 3rd |
| It serves as a source of livelihood | 4.18 | 0.471 | 4th |
| It helps to cater for household needs | 4.13 | 0.553 | 5th |
| lack of employment | 4.12 | 0.505 | 6th |
| It helps encourage savings investment in other profitable ventures | 3.91 | 0.784 | 7th |
| The job is lucrative | 3.32 | 1.220 | 8th |
| There is nothing else to do | 3.31 | 1.128 | 9th |
| The job is seen as a hobby | 1.85 | 1.098 | 10th |
| Grand mean: 3.74; Standard deviation: 0.371 | | | |

Source: Field survey, 2018

### 4.4 Constraints Limiting the Involvement of Respondents in Porterage Activities

This section was developed with a view to investigating the degree to which selected constraints identified from literature were affecting the involvement of the porterage workers in agricultural related porterage activities.

The results in Table 5 indicated that when the grand mean 0.82 was compared with each of the individual mean score, constraints such as harsh weather condition (mean = 1.66); exposure to physical risk (mean = 1.56); harassment from patrons (mean = 1.05); poor health condition (mean = 0.97); and stigma attached to the job by the society (mean = 0.95) were the most severe constraints, while underpayment for services rendered (mean = 0.79); insult from family members and friends (mean = 0.78); poor working conditions (mean = 0.43); lack of job security (mean = 0.38); lack of appropriate equipment (mean = 0.31); and lack of support from government (mean = 0.16) were the least severe constraints. This implies that harsh weather conditions which may range from heavy and torrential rainfall to extremely hot and scorching sun does hinder these porterage workers from carrying out their porterage activities promptly. Also, constraints such as exposure to physical risk which may be as a result of the environment in which they carry out their operations, harassment from people who patronise them, poor health condition and stigma attached to the job due to its nature hinders to a large extent, the porterage workers from active involvement in porterage activities. This result is in line with findings of Akanle and Chioma, (2013).

**Table 5:** Constraints Limiting Involvement in Porterage Activities (N = 190)

| Constraints | Mean | Standard Deviation | Rank |
|---|---|---|---|
| Harsh weather condition | 1.66 | 1.147 | 1st |
| Exposure to physical risk | 1.56 | 1.100 | 2nd |
| Harassment from patrons | 1.05 | 0.941 | 3rd |
| Poor health condition | 0.97 | 1.002 | 4th |
| Stigma attached to the job by the society | 0.95 | 0.913 | 5th |
| Underpayment for services rendered | 0.79 | 0.917 | 6th |
| Insult from family members and friends | 0.78 | 0.836 | 7th |
| Poor working conditions | 0.43 | 0.730 | 8th |
| Lack of job security | 0.38 | 0.716 | 9th |
| Lack of equipment | 0.31 | 0.546 | 10th |
| Lack of support from government | 0.16 | 0.504 | 11th |
| Grand mean: 0.82 | | | |

Source: Field survey, 2018

### 4.5 Transformation in Porterage Operation and Farm Products Transportation System

In recent time a lot of transformations are being observed in the way porterage workers are operating. Traditionally from inception, porterage operation was mainly done through the use of head carriage. For instance, this study reveals that half (50%) of the respondents use head carriage as a means of helping patrons move their items (see Figure 3). Head carriage is thus an economic activity in the sense that anyone that helps another to carry a load. They provide a link among the wholesalers, retailers, transporters and the end users. They carry item purchased by shoppers, sometimes following their hirers from stall to stall, struggling to find their way in congested, poorly laid-out and sometimes muddy urban markets.

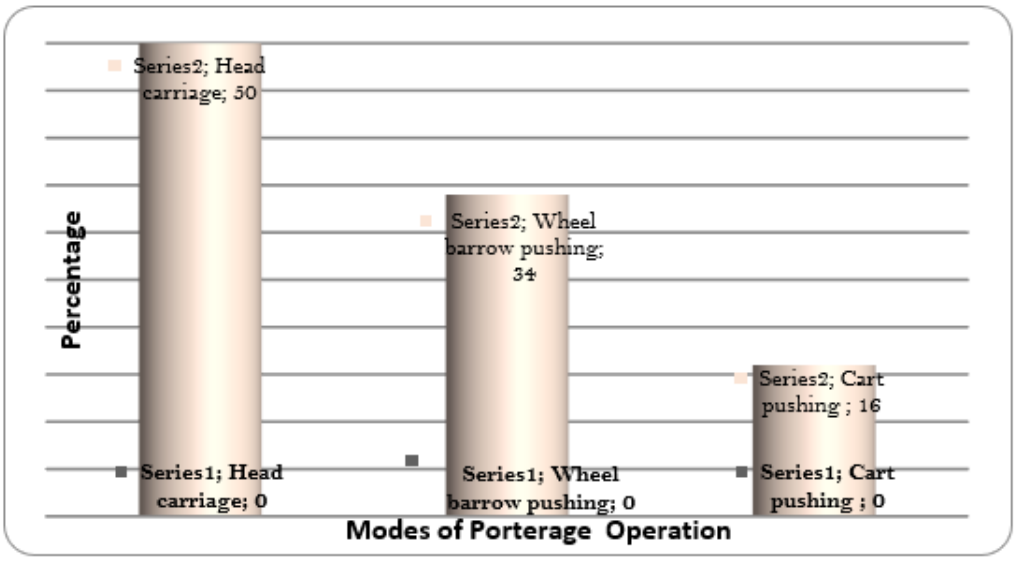


**Figure 2.** Distribution of respondents by modes of porterage operation
Source: Field survey, 2018

Today, transformation is taking place in the porterage operation, some of the porters, most especially men are gradually moving from head carriage to wheel barrow pushing (342%) as a means of porterage operation, which is easier than head carriage. Wheel barrow is less stressful and can carry a large amount of agricultural commodities. However, it is yet to be motorized as experienced in some countries like China. Also, cart pushing (15.8%) as part of transformation is gradually gaining prominence among the male porterage operators; it serves the same purpose as wheel barrow. This porterage operation also eases the movement of agricultural commodities. Photographs in Figure 3 show the various forms of rural transportation available in south-western rural markets. Labels A - D show gradual transformation from head porterage through wheel barrow, cart pushing to a motorized tricycle culminating into servicing rural buses.

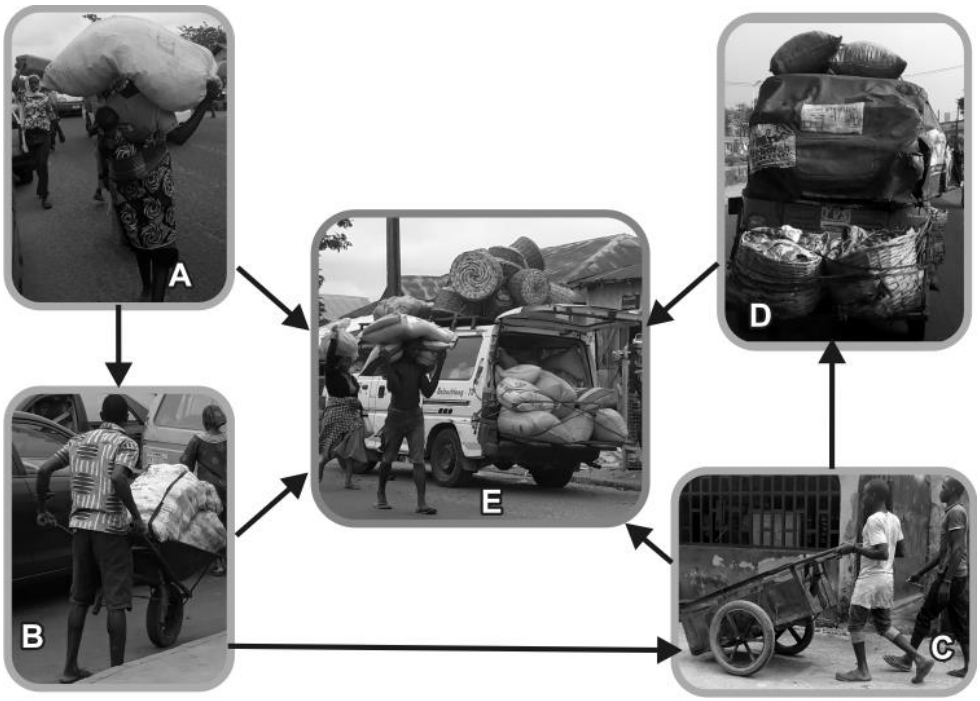


**Figure 3.** Photographs showing transformation from head carriage to a motorized tricycle. Keys: A - A female porter on head carriage; B – A male porter on wheelbarrow pushing; C- A male porter on cart pushing; D – A motorized tricycle carrying loads; E - A bus with loads of market products for transportation.

## 5. CONCLUSION

This paper established porterage as an important link for effective transportation system in rural markets of Nigeria being operated mostly by people of a very low socio-economic status with low income and education. Porterage has become a sub-system in rural market transportation system, which functions in transit connecting the markets sited in remote and unmotorable places with motor vehicles on the accessible roads. The porterage workers operate on an average of 6 days in a week and about 2hrs 30 minutes per day without requiring any special skills or any initial capital, but they are mostly confronted with harsh weather condition and exposure to diverse physical risks. However, there is a current transformation taking place in the mode of porterage operation with a gradual replacement of head carriage with wheel barrow, cart pushing and advancement into a motorized tricycle. This is a strategic way of reducing the stress and energy involve in the traditional porterage

operation without losing the purpose of connecting the bad inaccessible roads to better accessible roads in agricultural commodity transportation system.

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# INITIATING SMART PUBLIC TRANSPORTATION IN LAGOS: SETTING THE TONE FOR AFRICAN CITIES

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## ABSTRACT

After several initiatives in public transportation primarily anchored by both the private and public sector which were short-lived, the informal sector comprising two-wheeler motor cycles, the "danfoes" and "molues" being operated by the (National Union of Road Transport Workers and the Road Transport Employers' Association of Nigeria) became the dominate operator of urban bus operations in Nigerian urban cities including Lagos. With the growth in population and economic activities making Lagos a mega city, the breach in urban transport operations became ostensible. It therefore became imperative to introduce initiative particularly quick win interventions that would deliver smart mobility innovations for efficient movement of the commuting public. Smart public transportation is essential to meet the challenges of urbanization in Lagos and other African cities. A detailed analysis as encapsulated in the Bus Route Network study is required to determine travel pattern, route alignments, infrastructure gap, transit service type (Bus Rapid Transit, Rail or regulated bus system) and technology type that would be required to guide decision makers and politicians. For African cities, however, there is need to domesticate our public transportation requirements for implementation and gradually ramp up with the deployment of mobility application technology like Intelligent Transport Systems comprising mobile apps, electronic ticketing amongst others.

**Keywords:** Smart, Public, Transportation, Intelligent, Ticketing, Cities, Bus

## 1. INTRODUCTION

Lagos is the commercial and financial nerves of Nigeria and Africa. The city houses one of the largest and busiest ports on the African continent. It occupies 0.5% of Nigeria's total area, making it the state with the smallest landmass in the country (PwC, 2016). Lagos is the most populated city in the country, which is estimated at 21 million (12% of national population estimate) (LASG, 2017); it is also one of the most populated city in Africa and one of the fastest growing in the world. Its population surpasses over 25 individual African countries such as Zambia, Senegal, and Tunisia amongst others. Lagos urbanises at 6% annually and has an urban population density of about 20,000 people per km$^2$ (Fadairo and Taiwo, 2015); it is one of the densest cities in the world.

Lagos has always been an industrial city and currently enjoys the status of having one of the largest city economies in Africa, accounting for 90% of the nations' foreign trade flow (LASG, 2017). It had a GDP of about $136.6 billion in the year 2015, which is over 30% of the national GDP and about 65% of national non-oil GDP for the same year (LASG, 2017). Its GDP is higher than 42 individual countries GDPs in Africa and equivalent to a combination of 19 countries in Africa (PwC, 2016). Lagos GDP is ranked 4$^{th}$ amongst African cities; it is behind Cairo, Johannesburg and Cape Town consecutively (LASG, 2017).

Lagos is the home to many financial, telecommunications, manufacturing and oil companies, and accommodates some of the main and busiest ports (seaports and airport) in Africa (LAMATA, 2009). The city accounts for 65% of the nation's manufacturing activities and currently, "18 of the Fortune 100 companies operate in Lagos State" (PwC, 2016, p. 7). The city has the largest share of working population in Sub-Saharan Africa, and over 45% of Nigeria's skilled workforce reside in it (Orekoya, 2016; LASG 2017). It also has the highest standard of living in Nigeria with a per capita income of $2900 (Mhango, 2013; PwC, 2016). However, Lagos has the highest rate of unemployment and underemployment in the country (Banjo and Mobereola, 2012). The above-mentioned is because of the minimal job opportunities in other states, which has made the city more attractive to job seekers. The high rate of underemployment has created a large gap between the high income-earners and low-income earners. Though Lagos is the economic leader of Nigeria, the state's yearly operating budget is significantly lower than cities of similar sizes such as Delhi, Mumbai, and Jakarta (Stimson, 2009, cited in Msulwa and Gil, 2015).

## 2. THE HISTORY OF PUBLIC TRANSPORTATION IN LAGOS

The initial conscious attempt to develop public transportation in Lagos began in 1899. A public tramway system designed to connect Lagos Island to Lagos Mainland was implemented and fully operational in 1902. The first privately owned commercial bus service was established in 1915 by Charlotte Olajumoke Obasa. She was a leading indigenous entrepreneur who pioneered organised bus transport with her 'Anfani Bus Service' with a fleet size of two buses (MoT, 2019). This was followed with the establishment of J.N. Zarpas & Co in 1929. Zarpas, a company owned by expatriates provided bus services along Obalende, Apapa and Idi-Oro routes. They dominated the Lagos transport scene for several years until their assets were acquired by the Lagos Town Council to form the Lagos Municipal Transport Service (LMTS) in 1958 (MoT, 2019).

The Government Agency, LMTS, was saddled with the responsibility of regulating and controlling the transport system in the metropolis. LMTS was transformed to Lagos City Transport Service (LCTS) and Lagos State Transport Corporation (LSTC) when Lagos became a city and state in 1962 and 1967 respectively (MoT, 2019). LSTC played a leading role in delivering formal intra-city bus services alongside new private companies such as Benson Transport Company Limited, Oshinowo Transport Service Limited, Elias Bus Service Company and Union Nigeria Trading Company. There were minimal mobility issues encountered by commuters during this period with a population of about 1.5m in the state (LAMATA, 2013).

In the late 60s, about 750,000 passengers travelled in and out of Lagos daily, and the formal operators carried about 33% while the informal operators carried 67% (MoT, 2019). The informal operators use public transport vehicles known as 'Bolekaja', 'Jalekun e', and later, 'Molue' and 'Danfo'. The 'Molue' is a Mercedes 911 chasis remodelled locally into a High Occupancy Vehicle (HOV) with 44 passengers seating and 30 standing. The 'Danfo' is a Volkswagen Type 2 (T3) minibus with 14 passengers seating capacity. The 'Danfo' and 'Molue' operators were known for jagged driving behaviour and fatal accidents (MoT, 2019). Since 2008, there was gradual phasing out of the Molues with the introduction of regulated High Occupancy Buses.

In the early 70s, the oil boom prompted a rapid urbanisation and migration to Lagos, especially for the unemployed. Economic opulence coupled with increase in population escalated vehicle ownership geometrically. The unforeseen developments led to chaotic traffic jams because the road infrastructures could not cater for the increasing demand (LAMATA, 2019). This situation became a major challenge as successive administrations struggled to mitigate the traffic condition. Several infrastructure projects such as the Cater Bridge, Ikorodu Road, Eko Bridge, Apapa-Ikeja Expressway, Obafemi Awolowo Way, first

phases of Lekki-Epe Expressway etc (LAMATA, 2013). Traffic management in the city was then focused on moving vehicles rather than people. This approach led to further traffic gridlock due to the rapid growth of personal vehicles usage compared to the slow development of road infrastructures (MoT, 2019).

The Lateef Jankande administration attempted to develop a multimodal transportation strategy in the early 80s focused on rail mass transit, bus and ferry to reduce traffic congestion. Two ferries with about 400 passenger capacity commenced services between Mile 2 Jetty and Marina in 1980 (LAMATA, 2013). The use of motorcycles 'Okada' as PT originated due to the combined effect of rapid urbanization, unemployment and inadequate intra-city public transportation in early 80s The proposed metro line scheme was conceived as a 28.5km Light Rail Transit (LRT) system, with 19 stations from Race Course in Central Lagos to Agege (Via Iddo) at an estimated project cost of N6oom (LAMATA, 2013).

The Jubilee Scheme whereby PT was fully re-privatised was introduced in 1992 (MoT, 2019). The scheme discontinued previous transportation initiatives with government disengaging from direct operations of public transport. About 100 buses were released to private operators on a wet lease with 30% subsidy. The ferry service, which was almost moribund, was rejuvenated with acquisition of MF Odoragunshin in 1993, a 1000 passenger capacity vessel. Also, two trains were leased from the Nigerian Railway Corporation (NRC) to operate the first Intracity rail service in Lagos through a partnership between the Federal and State Governments (MoT, 2019).

Until the recent promulgated State Traffic Law came into effect, 'Okada' (the two wheelers) was a growing but highly worrisome phenomenon and a reflection of the states' poor transport system.

As economic activities prospered, the population proliferated, and the city expanded. Lagos population had tripled between 1980 and 2000 without a complementary urban transportation plan (Barredo and Demicheli, 2003). By the 21st century, Lagos seaports handled about 75% of the nations' import by weight, and its airport handled about 80% of passenger travel in and out of the country (LAMATA, 2009). Over eight million Lagos residents also required one form of motorised trip daily, and road transport accounted for over 95% of motorised travel (LAMATA, 2009; Osoba 2012). Lagos had minimal inter-city rail travel, and water transport was ignored despite its transit potentials. The unexpected population growth led to high demand on the city's struggling road transport system.

The city lacked an organised public transit system, and its citizens use the danfo (mini-buses), molue (large buses) and kabu-kabu (shared taxis) for long distance travel. Okada (commercial motorcycles) and Keke-Marwa (three-wheelers) were frequently used for short distance trips. Public transport in Lagos was described as "unregulated, chaotic, inefficient, expensive, low quality and unsafe" (Amiegbebhor et al., 2016, p. 2). Lagos gradually became an automobile-oriented city due to the unrestricted import of relatively cheap second-hand vehicles coupled with subsidized fuel prices. Over 2600Km of road existed in Lagos in 2005, and they were frequently congested with about a million vehicles daily. The city's vehicular density of 222vehicles/Km is larger than the country average of 11vehicles/Km (Taiwo, 2005, cited in Amiegbebhor et al., 2016). In 2007, Lagos was identified "as the only mega city (with a population of over 10 million) without any formal public transport system or functioning rail system" (World Bank, 2017).

Poor public transport coupled with road dependency and high travel demand (especially during peak periods) resulted in regular chronic congestion in the city which causes a typical half hour journey to take over two hours. ROM (2009) found that Lagosian lose between 0.6 to 3 billion hours annually due to congestion.

## 3. THE CONCEPT OF SMART CITY AND PUBLIC TRANSPORTATION

A Smart City is a growing concept that draws from the success of Dubai's innovative knowledge-based industry cluster " to empower business growth for companies and knowledge workers all over the world". It is an urban development vision to integrate multiple information and communication technology (ICT) solutions in a secure fashion to manage a city's assets – the city's assets include, but not limited to, local departments information systems, schools, libraries, transportation systems, hospitals, power plants, water supply networks, waste management, law enforcement, and other community services. The goal of building a smart city is to improve quality of life by using technology to improve the efficiency of services and meet residents' needs. ICT allows city officials to interact directly with the community and the city infrastructure and to monitor what is happening in the city, how the city is evolving, and how to enable a better quality of life.

Broadly, city can be defined as smart when investments in human and social capital, traditional transport and modern ICT communication infrastructure fuel sustainable economic development and high quality of life, with a wise management of natural resources (Taiwo, 2016).

Digitization drives the increasing importance of technology that would enable smarter public transportation. Information and Communication Technology players are continuously developing new solutions by using digital infrastructure and platform. Smart transportation is connected solutions for shared passenger transport services such as buses, trains and ferries. It includes applications for connected vehicles and related infrastructure such as passenger information, ticketing and payment systems, cloud and analytics services as well as traffic management and control (Arthur, 2017). There are benefits of smarter public transport both to the passengers, operators, society and the transport authority, respectively. For the passengers, users will experience higher safety, punctuality, clearer and more relevant information, increased comfort, simpler and more universal ways of trip payments which would decrease environmental impact of traveling and increase access to other modes (overall life quality). For the operators, profitability and efficiency can be increased through higher operational efficiency and new revenue. Information flows will improve leading to more efficient communication and environmental reporting (increased efficiency). For the society, cities will be able to increase the share of public transport as well as improving the environment and traffic safety. Improved public transport will help cities increase their competitiveness and attract more competence (improved society). For the public transport authority, data would be generated for planning and improving transit systems (Planning).

From the figure below, connected vehicles are equipped with internet services and on-board tracking devices, they can only provide smart transportation when they are intelligently communicating with infrastructure and third parties.

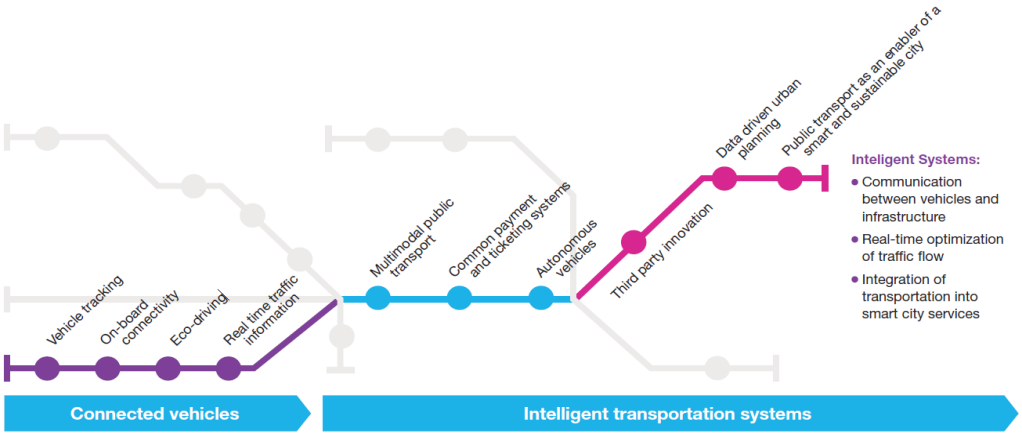


**Figure 1.** Connected Vehicle and Intelligent Transport Systems (Adapted, Arthur, 2017)

### 3.1 Lagos Bus Rapid Transit

LAMATA implemented the first BRT Lite system in Africa in 2008 as a quick intervention to alleviating the urban mobility challenges in Lagos. The scheme served as the first comprehensive and integrated approach to improving public transport in Nigeria.

The overall objective of the Lagos BRT system is to improve mobility and transport affordability in the city of Lagos through regulatory reform and by facilitation of person's movement on major corridors through a combination of traffic management and implementation of a high quality, high performance Bus Rapid Transit system. In 2015, the BRT Lite was upgraded to BRT classic with median and pass-up lanes. Each shelter is universally and safely accessible, equipped with Real-Time Passenger Information and using pedestrian bridges from sidewalks. They also provide weather protection and lighting, thus increasing comfort and security. They are physically integrated with other public and private transport modes; non-isolated and attractive (Wright and Hooker, 2007). The BRT-classics stations are quite basic but functional.

The Lagos BRT Classic buses are domesticated, but they do not meet the emission standard of high-quality BRT systems such as Silver Line in Boston, U.S.A or Guangzhou BRT, China (FTA, 2009; Hughes and Zhu, 2011; ITDP 2016).

#### *3.1.1 Lagos Bus Route Network (LBRN) Study*

To build the transport network that would meet the future needs of the commuting public, a Bus Route Network study was conducted to rationalize the bus routes in Lagos. Individual codes have been assigned to each bus route that forms part of the classified and rationalised network. According to the Lagos Bus Route Network study (ITP, 2015), the findings from the LBRN include:

- A future and rationalised network consisting of 485 individual bus routes, for context, the existing network contains 742 individual routes
- 38 new or extended bus routes have been proposed; thus, improving inter-connectivity and removing the need for forced passenger interchange
- The rationalised bus route network will cover 6,605km, with an average route length of 14km
- The shortest bus route is 3Km whilst the longest route measuring 77Km. These two services provide a demonstration of both a feeder bus service operating short distances and an inter-urban, commuter route serving the commercial hub
- During peak operating hours, it is estimated that the revised network will carry approximately 663,708 passengers
- All day, it is estimated that the revised network will carry approximately 7,000,000 passengers
- It is estimated that over approximately 12,000 buses will be required to service the demand across the network.

### 3.2 Smart Public Transportation Applications in Lagos

In Lagos, to align with the Smart City vision, the Lagos State government has deployed ICT to drive smart public transportation as follows:

#### *3.2.1 Electronic Payment System*

The culpabilities of the paper-ticketing systems necessitated the need for the introduction of electronic ticketing ie Lagos Connect Cards. The Lagos Connect Mifare Card is a public transport store-value contactless smartcard which allows you to "tap in and tap out" on the bus validators of the BRT-Class buses. The card can only be used to pay for public transport trips. Commuters are required to purchase value to top up the Mifare card.

The Mifare cards can be only be funded (topped –up) with the ticketing vendor's agents at the bus stops and terminals along the BRT corridor through a Point of Sale (POS) Machine. Complementing Mifare cards are the Fare-pay contactless cards linked to personal bank accounts which allows a commuter to "tap in and tap out" on the bus validators of the BRT-Classic buses. The innovation provides the ability to use a contactless bank card on ATMs, POS, web transactions and to pay for bus trips amongst others. Also, commuters pay for fares directly from their personal bank account, rather than purchasing value. The features of the Electronic ticketing system comprise the software, Smart Cards, Bus Validators, Driver Console, Ticket machines, Vendor Handheld Machines, Connectivity and Backend. The e-ticketing system provides greater utility for public transport users through the following:

- Reduce the inconvenience of interchange for passengers who have to make multi-leg journeys in a public transport network where interchange is predicted to dramatically increase.
- Minimize changes in fares for the bulk of passengers who don't interchange.
- Reduce queuing, complexity and inconvenience for passengers when moving around the network.
- Improve management information on travel patterns and improve operator responsiveness to changes in the market.
- Eliminate cash usage, reduce cash-handling costs and improve staff security without penalizing passengers.
- Permit a fair and efficient allocation of revenues earned between operators of different modes or different services within modes in the network.
- Reinforce the overall objective of achieving an integrated multimode transport system [including parking, park & ride, etc.].

The Fare-pay card can be funded (topped –up) through the Fare-pay agents, unstructured supplementary service data (USSD), Automated Teller Machines (ATM), Bank Deposit and Online inter-bank and intra-bank fund Transfer. The activities and transactions of the Fare-pay System is monitored and evaluated from the E-Ticketing Backend in real-time.

Both electronic ticketing systems coexist together to complement each other and provide the commuter with options. The Mifare Cards offer; Designated Transport Card with High Level of Flexibility, Integration and Interoperability, availability of ticketing card, through constant sales along the PT network, ease of purchase and usage without any personal information, support real-time reconciliation and settlement and high level of security. The EMV cards on the other hand, offer; use of personal banks cards to board PT systems, ease of topping up through various channels such as POS machines, USSD, ATM, Bank deposit and fund transfer, wide range of payment for both local and foreign transactions, flexibility of payment through Third party apps, barcodes, watches, wallets etc., higher level of security and support real-time reconciliation and settlement and auto-refund without physical presence.

### *3.2.2 Intelligent Transport System*

An Intelligent Transport System (ITS) was commissioned in 2017 on the BRT to improve operations, safety, efficiency and effectiveness of transport and traffic conditions. The ITS comprises several modules such as a scheduling system, real time Passenger Information System (PIS), Automatic Vehicle Location System (AVLS) and central intelligent system. A control centre was also implemented at the Authority's and Operator's depots each to monitor and evaluate the BRT classic operations in real-time.

The Lagos BRT App provides real-time BRT bus arrival times to passengers. The BRT buses are equipped with an on-board tracking device. This device sends the location of the

buses in real time to a central intelligence server, which converts the GPS details to arrival time predictions for onward forwarding to real time applications (e.g. bus stop displays, mobile app etc.).

The app has different components and functionalities such as with the ability to plan journeys, identify bus stops near user's location as well as other bus stops along the BRT corridor.

#### *3.2.3 Monitoring Mobile App*

The app would be used by regulator of the public transport to facilitate the monitoring and evaluation of the Bus Operations in the state. The monitoring mobile apps would complement data being generated from the ITS control centre. It is aimed at eradicating any manual data collection, there by resulting in faster and more accurate collection. The app shall have all major reporting requirements for monitoring and evaluation such as accidents, bus cleanliness, route adherence, etc. The app shall use GPS to pinpoint exact locations of incidents / accidents. In addition, an accompanying web portal shall be developed for the extraction of reports for further analysis.

### *3.3* Lagos Future Transport Initiatives

#### *3.3.1 Rail System*

Lagos has been identified as one of the few megacities without a functioning rail system. In the Strategic Transport Master Plan (STMP), seven rail lines have been identified for implementation. The rail systems will be developed using similar PPP models as adopted in comparable cities such as Kenya, South Africa and India.

#### *3.3.2 Multimodal Transport System*

The need to ensure transportation is integrated between all modes have been identified in the STMP. The integration will ensure seamless travel and high quality of service between each mode. The Lagos State Government aims to ensure all transport schemes such as the ferries, BRTs, LRT, buses and feeder systems are integrated physically, institutionally and operationally. Other soft components such as scheduling, passenger information system, ticketing and institutions will also be integrated. The concept of multimodality learnt from the Victoria Station (UK), King Cross Station (UK) and Grand Central Terminal (US) are currently being developed at the Mile 2 interchange and Marina interchange in Lagos. At these interchanges, all PT modes will be designed and operated together.

#### *3.3.3 Resilient Transport Development*

The Lagos State Government will ensure future transport infrastructures that will serve the need of commuters while considering the local environment. The infrastructures will be designed and built to withstand the local climate, flooding and users' attitude amongst others. This will ensure the sustainability, safety, reliability and economics of maintaining the infrastructures. The Lagos State Government will employ a proactive, life-cycle approach to resilient transportation infrastructure in-line with the World Bank Standards.

#### *3.3.4 Sustainable Transport*

Transportation contributes to about 35% of air pollution in cities, and the negative effects such as global warming, oil shortages, premature death, respiratory and kidney diseases cannot be overemphasised. Lagos State Government aims at reducing traffic pollution and its impacts. Initiatives such as Mass Transit Alternatives, electric buses, electric rails, alternative fuels, low emission vehicles, Non-Motorised Transport and green vehicle purchase cost incentives would be explored. The Lagos State Government will ensure PT schemes serve the needs of both the present and future needs whilst preserving the

environment. Collaboration with the energy sector to ensure power generation for vehicles are renewable will also be fostered.

*3.3.5 Land Use and Transport Integration*

The public transport authority aims to ensure the integration of land use development (urban physical planning) and urban transport planning. This will ensure the transportation system will be able to cater for the present and future need of communities and developments within the cities. Lagos State Government has introduced mandatory traffic impact assessment for major land use development projects while focusing future developments along the main transit corridors. NMTs will also be promoted especially inside communities through the development of Pedestrian and Bicycle Master Plans. The development of alternative activity centres within communities that will reduce need for long-distanced motorized trips will also be stimulated.

## 4. CONCLUSION

Smart public Transportation is a component of the overall smart city vision. It is imperative that to solve urban transportation challenges, there is need for urban cities in Africa to institutionalize public transportation through the creation of a public transport authority to champion the Strategic Transport Master Plan that would identify the bus routes, rail lines, water routes and the technology to deploy to facilitate the operations of their services to the commuting public.

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# A MACHINE LEARNING DISTRACTED DRIVING PREDICTION MODEL

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## ABSTRACT

Distracted driving is known to be one of the core contributors to crashes in the U.S., accounting for about 40% of all crashes. Drivers' situational awareness, decision-making, and driving performance are impaired due to temporarily diverting their attention from the primary task of driving to other tasks not related to driving. Detecting driver distraction would help in adapting the most effective countermeasures. To find the best strategies to overcome this problem, we developed a Bayesian Network (BN) distracted driving prediction model using a driving simulator. In this study, we use a Bayesian Network classifier as a robust machine learning algorithm on our trained data (80%) and tested (20%) with the data collected from a driving simulator, in which the 92 participants drove six scenarios of handheld calling, hands-free calling, texting, voice command, clothing, and eating/drinking on four different road classes (rural collector, freeway, urban arterial, and local road in a school zone). Various driving performances such as speed, acceleration, throttle, lane changing, brake, collision, and offset from the lane center were investigated. Here we investigated different optimization models to build the best BN in which a Genetic Search Algorithm obtained the best performance. As a result, we achieved a 67.8% prediction accuracy using our model to predict driver distraction. We also conducted a 62.6% true positive rate, which demonstrates the ability of our model to predict distractions correctly.

**Keywords:** Distracted Driving, Machine Learning, Bayesian Network, Driving Simulator, Data Mining

## 1. INTRODUCTION

Distracted driving is defined as diverting the attention of the driver from driving to other behaviors, tasks, or situations that lessen the drivers' ability to sustain awareness and be in full control of the vehicle (Masten et al., 2013). Distracted driving may have different causes such as eating, drinking, manipulating dashboard controls, visual deviations like looking at a smartphone screen, or cognitive activities like talking on the phone that take the attention of the driver away from driving. Some activities, such as texting, can include all different types of distractions. For example, texting while driving has physical, visual, and cognitive distractions. Distracted driving is a safety threat as it takes the drivers' eyes off the road, hands off the steering wheel, and thoughts elsewhere. Also, the probability of a crash happening is high among distracted drivers (Fitch et al., 2013; Klauer et al., 2014). Distracted driving has been known as one of the core contributors to crashes in the US; in 2017, distraction resulted in about 3,166 fatalities in the U.S. (NHTSA, 2015). Distracted driving is responsible for almost 40% of all crashes happening on roadways (Distracted Driving 2013).

The advent of in-vehicle technologies and smartphones, which result in distracted driving, prompted concern about driving safety (Ahangari et al., 2019; Mousavi et al., 2020) and inspired researchers to conduct more studies on distraction. Although in-vehicle systems such as adaptive cruise control systems and navigation are designed to advance security and convenience, working with in-vehicle systems occasionally diverts a driver's attention from the main driving tasks (Stanton and Young, 1998; Ahangari et al., 2020). For example, talking on the phone while driving is a distracting behavior, even with hands-free systems (Just et al., 2008; Patten et al., 2004). The subject of the conversation has a broader outcome of distracted driving than does the technique of phone conversation (Patten et al., 2004). Drivers' attention diverts from the driving task to the conversation, which depreciates driving performance. Over time, with improvements in technology, new forms of distraction, including voice command text (Mayhew et al., n.d.) and personalized phone-based digital assistance (Yager, 2013), cause distraction as well.

Several researchers have studied the influence of distracted driving on road safety (Horberry et al., 2006; Joo and Lee, 2014; Neyens and Boyle, 2007, 2008; Wilson and Stimpson, 2010). Different types of distracted driving contain a combination of manual, visual, auditory, and cognitive components, each of which can negatively impact the ability of drivers in keeping lane position, speed, and eyes on the road (Harbluk et al., 2007; Victor et al., 2005). Drivers whose eyes are away from the road because of distraction activity for prolonged periods cannot safely control their vehicles (Hosking et al., 2009; Owens et al., 2011). Driving is mainly a combination of visual, spatial, and manual tasks. Handheld phones diverted visual attention away from the roadway when dialing a number or picking up a call, and one hand was taken off the steering wheel to hold the phone to the ear. Texting not only diverted visual attention away from the roadway but also took both hands off the wheel. Studies show that distracted driving has a tremendous effect on traffic safety. Some studies concluded that distracted driving increases crash risk by increasing the reaction time and response time of drivers (Caird et al., 2008; Harbluk et al., 2007; Horrey et al., 2008). Distracted drivers tend toward unsafe driving behavior that increases the probability of a crash happening on roadways. The likelihood of using the phone while driving among younger and male drivers is higher when compared to older and female drivers based on the survey collected from 834 licensed drivers. The survey also presented that the longer the drive is, the more likely the driver is to use a cell phone. (Pöysti et al., 2005). The young driver may be more vulnerable to a distraction-related crash as they are among the most substantial users of cell phones (Lees and Lee, 2007).

Distracted driving may also reduce the proficiency of the traffic network by increasing the headway between vehicles unreasonably (Victor, Trent, and Emma Johansson). Studies about distracted driving showed that handheld cell phone talking while driving harms the drivers' capability to sustain their speed and location on the road (Narad, Megan, Annie A Garner, Anne A Brassell; Stavrinos et al., 2013); texting while driving increases reaction times to push the brake and increases the variability of lane changing with no change in speed (Hosking et al., 2009; Patten et al., 2004). Reading texts while driving is the most distracting activity for youthful drivers (Atchley et al., 2012).

Studies indicated that the use of cell phones among all drivers increases the risk of a crash by a factor of four (Hosking et al., 2009; McEvoy et al., 2005). Similarly, another study using a simulator involving adolescent drivers showed that texting while driving increases the frequency of deviations in a lane concerning the position from the centerline (Lee et al., 2008).

Talking and driving each requires different levels of an individual's attention, and the more attention-demanding the activity is, the less successful the performance of each task will be (Salmon et al., 2011). As a result of cell phone use, while driving, less visual information is processed by drivers in the driving scene (Strayer et al., 2006), drivers do not stop completely at stop signs (Strayer and Drews, 2007), braking response time increases

(Watson and Strayer, 2010), and more rear-end collisions occur (Strayer and Drews, 2007). Several studies used machine-learning techniques to recognize visual and cognitive distractions for in-vehicle distraction mitigation systems (Lee, J. D. (2009; Strayer, D. L., Drews, F. A., and Johnston, W. A. (2003); Liang et al., 2007; Liang and Lee, 2014; Reyes and Lee, 2008; Victor et al., 2005). Nevertheless, while there is not an absolute correlation between distractive driving and motor vehicle accidents, the probability of a crash happening is high, based on the driving patterns displayed by distracted drivers. Usually, the speed of distracted drivers using cell phones tends to be low (Strayer et al., 2006), their following distance is high (Cooper and Strayer, 2008; Shinar et al., 2005), and the frequency of lanes changing is less, all of which can result in disturbances in traffic flow and increased congestion.

As seen above, different aspects of distracted driving, including various sources of distraction, and their effect on driving performance and road safety have been studied by many researchers. However, to the best knowledge of the authors, there are very few studies related to prediction model development. Driving simulators have been a safe and inexpensive tool for studying distracted driving. Machine learning, which evolved from pattern recognition and computational learning theory in Artificial Intelligence (AI), has recently been applied in many fields. BNs have recently been used in studies that involved uncertainty and complexity.

In this study, we propose a new machine learning model to predict if the driver is distracted. To do this, we use a Bayesian Network (BN) to build our model and a Genetic Algorithm (GA) to optimize its network. We obtained driver performance (behavior) data from 92 participants in a driving simulator driving in various scenarios of distractions and road classifications. Using our model to predict the distraction based on the driver's behavior, we achieve over 70% prediction accuracy, which highlights that driving behavior is different between a distracted driver and a non-distracted driver.

## 2. METHODOLOGY

### 2.1 Data Collection

Driving data such as speed, acceleration, throttle, lane changing, brake, collision, and offset from the lane center were collected in a fixed high-fidelity driving simulator. The driving simulator directly logs all the related data. The driving simulator has three 40" screens, and the software (UCWinroad) has the capability of making realistic roads, signals, signs, models, and traffic (Figure 1).

**Figure 1.** Driving Simulator

A medium road network of Baltimore County, which consists of various road types (rural collector, freeway, urban arterial, and local road in a school zone), was considered as the study area (Figure 2).


**Figure 2.** Study Area
(Blue line is a rural collector, green line is a freeway, orange line is an urban arterial and purple line is a local road; the red icons show the location of the distraction)

### 2.2 Participants and designed scenarios

Using online advertisements, flyers, and email invitations, 92 participants were recruited from Morgan State University and the Baltimore metro area to drive eight different scenarios. Some 56.52% of participants were male, and 43.48% were female. The age group of participants was between 18 to 40 years old; 44.57% of which were in the age group of 21 to 25 years. Participants were required to have a valid U.S. driver's license and were compensated at $15 per hour for their participation in the study.

Participants drove from Hampton Lane (rural road) to I-695 (freeway) to Perring Parkway (urban arterial) to Radar Road (local, school zone) for six different distraction scenarios (hands-free calling, handheld calling, voice command, texting, clothing, and eating/drinking); each of which took about 15 minutes driving.

Each scenario consists of five distractions that each happens in the same location of each road, as shown in Figure 2 with a red icon. The driving experience started with the one-lane two-way rural collector that includes one distraction; then, two distractions happened in the three-lane two-way freeway; after that, one distraction happened in the two-lane two-way urban arterial, and finally, one distraction occurred in a one-lane two-way local road in a school zone.

The driving data consist of average speed, acceleration, throttle, lane changing, brake, collision, and offset from the lane center for each scenario before and during the distraction area; the length of the distraction area is different, based on the road types as the speed limit is different.

In the distraction mentioned above area on each road, the participants were asked a question that they needed to think about and answer in handheld, hands-free texting, and voice command scenarios. They were asked to do a task like eating/drinking or removing or adding clothing in the last two scenarios. For example, in the hands-free calling scenario, an observer called participants 5 times and asked them five different questions. The participants were required to use hands-free and answer the question. The questions—for example, how many of their friends' names start with M? — differed each time, but they had a similar cognitive effect.

Two areas, including before distraction area (no distraction) and during distraction area (hands-free calling, handheld calling, voice command, texting, clothing, and eating/drinking distraction), classified the binary states of distraction (i.e., distracted driving and not distracted driving) for the BN. In the driving experiment, participants drove six different driving with the distraction task, including hands-free calling, handheld calling, voice command, texting, clothing, and eating/drinking. To forecast the distraction based on the driver's behavior during and before the distraction, the area during the distraction task is considered as a distraction area while the area before the distraction task is not. There is a total of 3,877 simulator experiences done with 92 participants, of which half, or 1,952, contain distraction.

### 2.3 Bayesian Network

A Bayesian Network (BN) is a machine learning method aimed at utilizing Bayesian rules on subsequent simulation using directed graphical presentation of probability-based approach and relations among factors (Dechter and Pearl, 1988). A BN with the visual representation provides a better understanding of the interaction between variables. In its graphical presentation, nodes represent random variables, and links illustrate relationships and conditional dependencies between variables (Koski and Noble, 2011). The BN's learning procedure employs a training dataset, derived from actual events, to identify the possible connections between nodes to be used for future prediction of unseen data (Ben-Gal: Identification of Transcription Factor Binding... - Google Scholar, n.d.).

Building a Bayesian network consists of two steps. The first step is to make a network structure and find the arrangement of the nodes in the network. This process can be defined as an optimization task that can be done using different search or optimization techniques (e.g., Genetic Algorithm, Simulated Annealing, and Hill Climbing). The second step is to learn the probability tables given the network structure (Koski and Noble, 2011).

In this study, we use the BN implemented in a Weka 3.8 software package (Hall et al., 2009) to predict the distraction behavior using a driving simulator.

## 3. RESULT AND DISCUSSION

A BN is originated based on the fundamental relationship among variables in a visual representation. As explained in Section 2.3, in the BN graph nodes represent the variables and links represent the relationship among them. Building the Bayesian Network and finding the best arrangements among the nodes can be defined as an optimization task.

There are different search algorithms in Weka that can be used for this task, such as Hill Climbing (Mitchell et al., 1994), Simulated Annealing (Aarts and Korst, 1988), Tabu Search (Glover and Laguna, 1998), and Genetic Algorithm (Whitley, 1994). Here we have investigated these algorithms for our task; the best results were obtained using a genetic algorithm. Genetic Algorithm (GA) is considered as a robust optimization algorithm based on the idea of natural selection. It uses mutation, cross over, and selection methods to shuffle the data to find the most optimal solution available (Deb et al., 2002). The structure of the final BN network is displayed in Figure 3.

After the recognition of an exemplary network structure, the conditional probability tables for each of the variables are estimated. A natural way to measure how well a Bayesian network performs on a given data set is to forecast its future performance by guessing expected functions, such as classification accuracy.

To be able to properly conduct our experimentation, avoiding bias, and investigating the generality of our model, we divide our data into training and independent testing sets. We separate 80% of our samples as training (1,563) and 20% as a testing (389). We report 10-fold cross-validation on the training set and the independent test set results to study the generality of our model.

The k-fold cross-validation is considered as an essential prediction estimator (Kohavi, 1995). In this model, the sample set is divided into mutually exclusive subsets. In each step, k - 1 of those subsets are used for training purposes, and the remaining one subset is used for testing. This process is repeated k times and until all the subsets are used for testing. In this way, we utilize our data to use it more efficiently and repeat our experimentation to investigate its generality. Using k = 10 has been shown as an efficient number and widely used in the literature. Note that we use 10-fold cross-validation just for our training set. We also train our model in a different task on the training set and use that for our independent test set. Achieving consistent results for 10-fold cross-validation and on the independent test set is a popular approach to study the generality of a proposed model.

To provide more insight on the performance of our model, we report the prediction accuracy (ACC), sensitivity (true positive rate), precision, Matthews Correlation Coefficient (MCC), and Area Under the ROC curve (AUC).

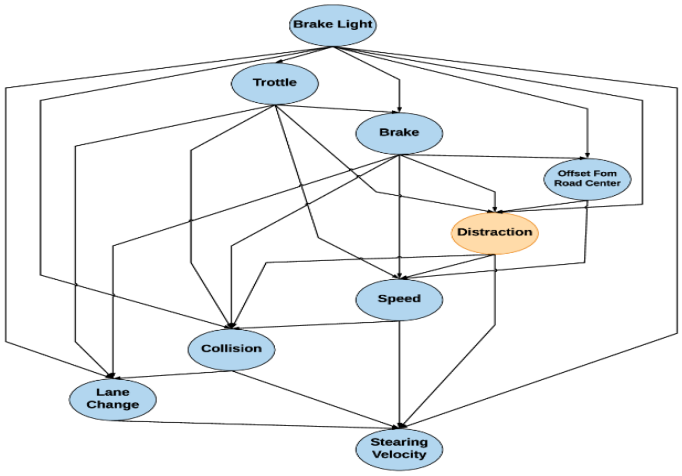


**Figure 3.** Bayesian Network Structure

As shown in Table 1, we achieve 67.8% prediction accuracy for our independent test set, which demonstrates the ability of the BN as a powerful technique for identifying distracted driving. As shown in this table, we also achieve 62.6% Sensitivity and 75.1% AUC, which highlights the ability of our proposed model to identify distractions correctly.

We also achieve 70.8% accuracy, which is consistent with our results on the independent test set, which demonstrates the generality of our model. Our results demonstrate the ability of the BN optimized using the GA to adequately capture the distraction pattern for our data and identify them for an independent test. Our results also demonstrate the promising performance of a machine-learning algorithm to predict drivers' distraction.

**Table 1.** Results achieved using Bayesian Network for 10-fold cross-validation and independent test

| Results for 10-fold cross-validation | | | | | |
|---|---|---|---|---|---|
| | Sensitivity | Precision | MCC | AUC | ACC |
| Before Distraction | 61.6% | 75.5% | 42.3% | 77.7% | 70.8% |
| During Distraction | 80.0% | 67.6% | 42.3% | 77.7% | 70.8% |
| Results on Independent Test | | | | | |
| | Sensitivity | Precision | MCC | AUC | ACC |
| Before Distraction | 73.0% | 66.0% | 35.8% | 75.1% | 67.8% |
| During Distraction | 62.6% | 69.9% | 35.8% | 75.1% | 67.8% |

## 4. CONCLUSION

This paper developed a methodology using a BN, a powerful machine learning method, to detect driver distraction from driving performance using a driving simulator. The connections between driving performance and driver distraction are explored in this paper, the results of which can be used to detect distracted driving and find the best strategies to overcome this problem. The results show that the BN model is able to detect driver distraction substantially with 67.8% prediction accuracy. This also demonstrates the promising performance of a machine learning model for the driver distraction prediction problem. More effective policies and technologies could be implemented when driver distraction can be predicted. For our future direction, we aim to investigate other powerful classification methods to tackle this problem.

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# EFFICIENCY UTILIZATION OF GREEN TIME AT COUNTDOWN SIGNALIZED INTERSECTION

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## ABSTRACT

The use of countdown traffic signals, although not common in North America, is increasing in Asia and European countries. Past studies conducted albeit outside the United States have addressed some operational benefits and issues associated with the use of countdown traffic signals, including but are not limited to effect on saturation flow rate, and red light running. Experience from the successful use of pedestrian countdown signals at urban traffic intersections has engendered some local interest in the use of countdown traffic intersections has engendered some local interest in the use of countdown traffic signal devices in the United States. The purpose of this research was to analyse using driver behaviour survey the efficiency of green-time utilization rate at countdown traffic signal devices in the United States. Specifically, this research performed a comparative analysis based on the postulation that countdown traffic signal is associated with underutilized effective green time when compared to the scenario at intersections controlled by traditional (non-countdown) traffic signals. Binary regression models were developed, using data obtained from the driver behaviour survey, to estimate decision probabilities for different combinations of vehicle position (i.e. distance to the stop line) and available green time (i.e. time left before the transition to yellow phase). A comparison between the estimated decision probabilities (determined from deductive reasoning) for traditional traffic supported a pattern of underutilization of green time for the countdown signal scenario. The underutilization of green time was associated with the likelihood of drivers slowing down prematurely to stop in reaction to the visual display of available green time before the change of signal phase. Underutilization of effective green time before the change of signal phase. Underutilization of effective green time translates into a lower saturation flow rate and hence reduced intersection capacity. The findings of this research could motivate additional studies pertaining to the determination of net operational benefits or plausibility of using countdown signal devices at urban traffic intersection in the United States.

**Keywords:** Countdown traffic signals, effective green time, binary regression models, decision probabilities

## 1. INTRODUCTION

A countdown traffic signal provides visual information and guidance to drivers regarding the amount of time remaining to safely cross an intersection. Specifically, a countdown traffic signal will provide the number of seconds left for each phase of green, yellow and red lights, enabling drivers to visualize the amount of time left to cross an intersection. A strategy currently being implemented at intersections is the countdown pedestrian traffic signal to improve safety of pedestrian crossing. Countdown traffic signals are sparingly used, mostly in Asian countries. There is little evidence in the use of countdown traffic signals in North America. However, it is conceivable that the recent widespread use of countdown pedestrian signals and their potential to aid drivers in making informed "stop or go" decisions at intersections could motivate the use of countdown traffic signals in the United States.

## 2. BACKGROUND

In 1967, countdown traffic signal was tested in the city of Clearwater, Florida. During the test period, accident decreased by 48% and property damage by 62%. After the removal of the countdown traffic signal, the intersection became one of the most hazardous, in both the number of accidents and property damaged. Although not many studies have been carried out in the United States, a few Asian and European countries have implemented the concept of using traffic signal heads that is equipped with timers. Many factors characterize intersection performance; however, safety and capacity issues are considered paramount. Some studies have revealed that countdown pedestrian signal tends to alter driver's behaviour and impact intersection safety. A similar effect is anticipated from the use of green countdown traffic signals made to inform drivers on the number of seconds remaining before changing to a red phase. Drivers ability to have real time information on the time remaining before a phase change reduces start-up lost time, red-light running and crashes at intersections.

## 3. RESEARCH OBJECTIVES

The overall objective of this research is to estimate the efficiency in the utilization of green time at countdown signal-controlled intersections. Analysis is done to determine how vehicle drivers utilize countdown green time information in making stop and go decisions at signalized intersections. Since countdown traffic signal is almost non-existent in the United States, this research relied on data from driver behaviour survey. The research objective was motivated by findings from the 1967 Clear Water, Florida study which showed that during the early stage of its countdown traffic signal deployment, 64.2% of vehicles sampled, stopped at yellow light and 26.4% stopped at green countdown. However, it should be stated that after one month of green countdown signal installation, premature stops decreased by 50%. The decrease was attributed to motorists getting use to countdown traffic signals. The notion of drivers stopping prematurely at an early stage of countdown traffic signal led to the following supplemental objectives:

- Determining the distance from which motorist will react to green countdown traffic signal, and Estimating the contribution of countdown signal to green time utilization at urban intersections

## 4. METHODOLOGY

The research methodology involved the following main components: Data Collection, Data Analysis, Model Development and Calibration, and Discussion of Findings.

### 4.1 Data Analysis

The data analysis involved forty-eight (48) scenarios, each representing paired distance and time, and the associated decisions. The decision variable was represented as binary codes 0 and 1 (stop = 0 and go = 1). Two separate models were developed for the two categories of speed limit (35 mph and 45 mph) considered in the survey. The data worksheet, analyzed in excel, comprises 6 columns and 11,040 rows of data, i.e., 48 rows of data per respondent. To better manage the large size of data associated with 115 records obtained from the survey, a random selection method was used to select sixty (60) respondents, resulting in a total of 2,880 (48x 60) rows of data for each of the two (35mph and 45mph) speed limit categories.

### 4.2 Model Development and Calibration

A binary Linear model was developed using variables to assess driver's reaction to countdown signal devices. Specifically, the model was intended to predict drivers' decision to either stop or proceed through the intersection for different for different scenarios of paired

distance (distance to intersection stop line) and time (green time remaining before transition to yellow phase). The model takes the following general:

$$Y=\beta 0+\beta 1X1+\beta 2\ X2+\beta 3\ X3+\beta 4\ X4+\beta 5\ X5+\beta 6t$$

where,

Y= Binary decision variable (go=1 and stop=0)

β0=Regression constant restricted to 0

β1, β2, β3, β4, β5, β6, =respective coefficients of independent variables

×1 = >50ft

×2 = 50 ft -100ft

×3 = 100ft-150ft

×4 = 150ft-200ft

x5=200ft/above

x6=>200

### 4.3 Regression Results

Results of the first and final stages of the stepwise process are summarized in Tables 1 through 12 for 35 and 45 mph speed limit.

**Table 1.** Regression Coefficients for 35 mph

| | |
|---|---|
| Multiple R | 0.9002 |
| R Square | 0.8104 |
| Adjusted R Square | 0.8092 |
| Standard Error | 0.3658 |
| Observations | 1801 |

**Table 2.** Regression Coefficients for 35 mph 7.5 sec and >50ft

| | Coefficients | Standard Error | Statistic | P-value | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|
| Intercept | 0.0000 | N/A | N/A | N/A | N/A | N/A |
| >50ft | 0.4990 | 0.0218 | 22.7883 | 0.000 | 0.4561 | 0.5420 |
| 50_100ft | 0.4796 | 0.0218 | 21.9005 | 0.000 | 0.4366 | 0.5225 |
| 100_150ft | 0.4046 | 0.0218 | 18.4758 | 0.000 | 0.3616 | 0.4475 |
| 150_200ft | 0.3101 | 0.0218 | 14.1632 | 0.000 | 0.2672 | 0.3531 |
| 200ft/abv | 0.2629 | 0.0218 | 12.0069 | 0.000 | 0.2199 | 0.3059 |
| secs | 0.1069 | 0.0035 | 30.0594 | 0.000 | 0.1000 | 0.1139 |

**Table 3.** Regression Coefficients for 45 mph less than 50ft and 7.5sec

| | |
|---|---|
| Multiple R | 0.9689 |
| R Square | 0.9389 |
| Adjusted R Square | 0.9382 |
| Standard Error | 0.2378 |
| Observations | 1799 |

**Table 4.** Regression Coefficients for 45 mph 7.5sec and less than 50ft

| | Coefficients | Standard Error | Statistic | P-value | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|
| Intercept | 0.0000 | N/A | N/A | N/A | N/A | N/A |
| >50ft | 0.9002 | 0.01423 | 63.2454 | 0.000 | 0.8723 | 0.928 |
| 50_100ft | 0.9002 | 0.01423 | 63.2454 | 0.000 | 0.8723 | 0.928 |
| 100_150ft | 0.8808 | 0.01423 | 61.8793 | 0.000 | 0.8528 | 0.909 |
| 150_200ft | 0.7669 | 0.01423 | 53.8783 | 0.000 | 0.7389 | 0.795 |
| 200ft/abv | 0.6656 | 0.01426 | 46.6632 | 0.000 | 0.6376 | 0.694 |
| secs | 0.0342 | 0.00231 | 14.7835 | 0.000 | 0.0296 | 0.039 |

The above tables summarizing results obtained from the regression analysis indicate significantly high adjusted-R2 values, and all coefficients of the models have p-values of approximately 0.00 (considered highly significant at the 95 percent level of confidence). The results also indicate that approximately

76.69% of the survey participants would proceed through the intersection under the scenarios of 35 mph posted speed limit, available green time threshold of 0 sec to 10 sec, and distance within 200 feet to the intersection stop line. Under the 45-mph posted speed limit, approximately 94.89% of the survey participants would proceed through the intersection for similar scenarios of available green time and distance to the stop line thresholds.

Notwithstanding that the binary linear model developed from the driver behavior survey is characterized by highly significant adjusted 2 and p-values, the model's output is not restricted to (0,1) interval as it should. The dependent variable value exceeds 1 (one) albeit very slightly in some extreme scenarios. For example, if the distance to the stop line is less than 50ft and available green time is 5 seconds, the corresponding decision variable (Y) values are 1.034 and 1.071 for posted speed of 30 mph and 45 mph, respectively. Two options were considered to address the (0, 1) domain issue. The first option considered was conversion of linear models to equivalent logit model as follows:

### 4.4 Efficiency Reduction Analysis

Participants drove through scenarios with level of service A, B, C, D, E and F. Data; acceleration, brake, steering control, deviation from lane center and others were collected, and the acceleration, braking, throttle-handling and lane-change behaviour were analysed.

The use of countdown traffic signal has been associated with drivers' tendency to stop premature even during the green indication. In this research, a comparative analysis was undertaken (based on survey data and deductive reasoning) on the utilization of green time at countdown versus non-countdown (traditional) signalized intersections. The following heuristic rules were applied in the efficiency analysis:

- Drivers usually will not stop in the green phase at traditional (non-countdown) signalized intersections
- Drivers usually will stop in the yellow phase if they perceive that they will not be able to safely cross the intersection before the signal changes to red, and their distance to the intersection stop line is adequate to stop their vehicles
- Drivers will decelerate at a maximum rate of 0.4g or 12.8ft/sec$^2$ to stop [see Gates et al, (2007)]
- In the dilemma zone (distance perceived to be too long to safely cross or inadequate to safely stop), 50% of the drivers will proceed through intersection and 50% will attempt stopping
- If their distance to the stop line is perceived to be adequate to either safely proceed through the intersection or stop, 50% of the drivers will stop and 50% will proceed.

Figure 1 is an illustrative example of a vehicle approaching an intersection at a speed of 35 mph. In one second, the vehicle's displacement from its initial position of 100 ft to the intersection stop line is approximately 51.45ft, which translates into approximately 48.55ft upstream of the stop line. In this example, the vehicle will have adequate time (3 seconds of yellow time) to safely proceed through the intersection; and requires a stopping distance greater than 48.55ft.

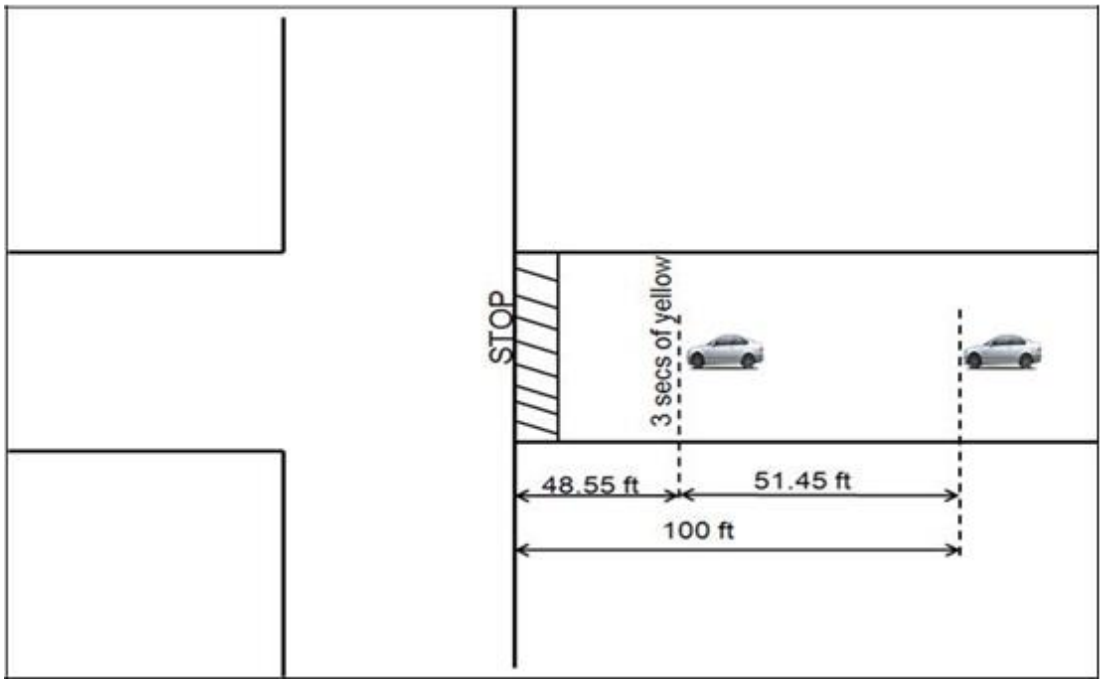


**Figure 1.** Minimum clearing distance to the Intersection

- Logit of Binary Linear Model

$$Logit\,(Y) = \beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t$$

.....(Eq 1)

$$Y = \frac{exp(\beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t)}{(1 + exp(\beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t)}$$

- Logit of Y

$$Logit\,(Y) = Log\frac{Y}{1-Y}$$

.....(Eq 2)

**Table 5.** Minimum Stopping Distance

| Minimum Stopping Distance | | |
|---|---|---|
| Distance | 45 mph | 35 mph |
| 50 ft | 237.08 | 154.85 |
| 100 ft | 237.08 | 154.85 |
| 150 ft | 237.08 | 154.85 |
| 200 ft | 237.08 | 154.85 |
| 250 ft | 237.08 | 154.85 |

**Table 6.** Efficiency Table

| | 45 mph | 35 mph |
|---|---|---|
| Mean for traditional signal Probability | 0.8857 | 0.9571 |
| Mean for GSCD 45mph | 0.7034 | 0.85 |
| Difference in the Mean | 0.1823 | 0.1071 |
| Reduction of Efficiency | 20.50% | 11.19% |

## Minimum Distance Analysis

**Table 7.** Minimum Drive-on Distance

| | 35 mph -Available green + yellow time distance (Drive-on distance) | | | | | | |
|---|---|---|---|---|---|---|---|
| secs | 0 | 1 | 2 | 3 | 4 | 5 | 7.5 |
| 50 ft | 154.35 | 205.8 | 257.25 | 308.7 | 360.15 | 411.6 | 540.225 |
| 100 ft | 154.35 | 205.8 | 257.25 | 308.7 | 360.15 | 411.6 | 540.225 |
| 150 ft | 154.35 | 205.8 | 257.25 | 308.7 | 360.15 | 411.6 | 540.225 |
| 200 ft | 154.35 | 205.8 | 257.25 | 308.7 | 360.15 | 411.6 | 540.225 |
| 250 ft | 154.35 | 205.8 | 257.25 | 308.7 | 360.15 | 411.6 | 466.875 |

**Table 8.** Minimum Drive-on Distance

| | 45 mph - Available green + yellow time Distance (Drive-on distance) | | | | | | |
|---|---|---|---|---|---|---|---|
| secs | 0 | 1 | 2 | 3 | 4 | 5 | 7.5 |
| 50 ft | 198.45 | 264.6 | 330.75 | 396.9 | 463.05 | 529.2 | 694.6 |
| 100 ft | 198.45 | 264.6 | 330.75 | 396.9 | 463.05 | 529.2 | 694.6 |
| 150 ft | 198.45 | 264.6 | 330.75 | 396.9 | 463.05 | 529.2 | 694.6 |
| 200 ft | 198.45 | 264.6 | 330.75 | 396.9 | 463.05 | 529.2 | 694.6 |
| 250 ft | 198.45 | 264.6 | 330.75 | 396.9 | 463.05 | 529.2 | 694.6 |

Using the heuristic rules described earlier with information in Tables 4-22 and 4-24, decision probabilities for 35 mph and 45 mph speed-limit groups were developed for non-countdown (traditional) signalized traffic intersection.

**Table 9.** Non-Countdown Decision Probability for 35mph

| secs | 0 | 1 | 2 | 3 | 4 | 7.5 |
|---|---|---|---|---|---|---|
| 50 ft | 1 | 1 | 1 | 1 | 1 | 1 |
| 100 ft | 0 | 1 | 1 | 1 | 1 | 1 |
| 150 ft | 0 | 0.5 | 1 | 1 | 1 | 1 |
| 200 ft | 0 | 0 | 0.5 | 1 | 1 | 1 |

**Table 10.** Non-Countdown Decision Probability for 45mph

| secs | 0 | 1 | 2 | 3 | 4 | 7.5 |
|---|---|---|---|---|---|---|
| 50 ft | 1 | 1 | 1 | 1 | 1 | 1 |
| 100 ft | 1 | 1 | 1 | 1 | 1 | 1 |
| 150 ft | 0 | 1 | 1 | 1 | 1 | 1 |
| 200 ft | 0 | 0.5 | 1 | 1 | 1 | 1 |

Table 9 and 10 show the decision probabilities for 35 mph and 45mph speed limits, respectively. Probability of 1 was assigned red, 0.5 was assigned purple, and 0 was assigned red. The mean decision probabilities were determined from Table 9 and 10 as 0.70 (21/30) and 0.85 (25.5/30) for 35 mph and 45 mph, respectively.

The mean decision probabilities for the survey data were determined as 0.89 and 0.96 for 35 mph and 45 mph speed limit, respectively. Tables 11 and 12 summarize the difference in green time utilization at countdown and non-countdown (traditional) signalized intersections, respectively. For 35 mph speed limit, the estimated reduction in green time utilization associated with GSCD was approximately 20.50%; and for 45 mph speed limit, the estimated reduction was approximately 11.19%.

**Table 10.** Efficiency Reduction in green time Utilization for 35mph

| Efficiency Table for 35 mph | |
|---|---|
| Mean for traditional Signal Prob | 0.8857 |
| Mean for GSCD for 35mph | 0.7034 |
| Difference in mean | 0.1823 |
| Reduction of Efficiency | 20.50% |

**Table 11.** Efficiency Reduction in green time Utilization for 45mph

| Efficiency Table for 45mph | |
|---|---|
| Mean for traditional signal Prob | 0.9571 |
| Mean for GSCD 45mph | 0.85 |
| Difference in the Mean | 0.1071 |
| Reduction of Efficiency | 11.19% |

## 5. CONCLUSION

Results indicated that drivers' ability to see the real-time display of seconds remaining before the transition to yellow light negatively affects their green time utilization. When analytically compared to operating situation of traditional (non-countdown) signalized intersections, the efficiency of green time utilization dropped by approximately 20% and 11% for 35 mph and 45 mph speed limit scenarios, respectively. It was also concluded from the analysis of survey data that the presence of red-light camera further reduces the efficiency of green time utilization. Approximately 66% of drivers in the survey indicated that the presence of red-light camera would more likely contribute to premature stopping during the transition from green to yellow or yellow to red light. Since countdown signals are not used in the United States, findings from this research can serve as a guide for assessing the plausibility of using the technology.

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# P-TECH SCHOOL IN TRANSPORTATION AND SUPPLY CHAIN MANAGEMENT PROGRAM: A CASE OF BALTIMORE CITY COMMUNITY COLLEGE

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## ABSTRACT

Four years high school students took the opportunity of early college access and dual enrolment program by taking college courses while they are at a high school. In recent years several states including Maryland supported the development of a new model of early college access program for high school students called Pathways in Technology Early College High Schools (P-TECH) 9-14 schools. With the P-TECH 9-14 school model in six years or less students graduate with a high school diploma and a no cost two-year associate degree in STEM fields. This paper discusses the recently developed new P-TECH transportation program at Baltimore City Community College. The program focuses on supply chain management career pathway to meet the present and future needs of the region. P-TECH schools works with industry partners and a local community college to ensure an up-to-date curriculum that is academically rigorous and economically relevant. P-TECH programs also include mentoring, workplace visits and instruction on the skills needed for the industry and paid internships and job consideration with the partnering companies.

**Keywords:** P-TECH**,** Early college access, Transportation, Supply chain management

## 1. INTRODUCTION

Pathways in Technology Early College High Schools (P-TECH) 9-14 school model is a global education reform initiative started by IBM. P-TECH programs prepare high school students with technical and professional skills where in six years or less students graduate with a high school diploma and a no cost two-year associate degree in STEM fields. Currently in the United States alone P-TECH 9-14 school model has 94 school partners, 63 college partners, 229 industry partners in 12 career pathways (1).

The 2017-2021 Maryland Higher Education Commission Maryland State Plan for Postsecondary Education, states that "Most recently, Governor Hogan has supported the development and implementation of several Pathways in Technology Early College High Schools, or P-TECH schools, throughout Maryland (2)." There are currently eight P-TECH programs in Maryland operating at seven high schools that partner with five community colleges. P-TECH schools works with industry partners and a local community college to ensure an up-to-date curriculum that is academically rigorous and economically relevant. P-TECH programs also include mentoring, workplace visits and instruction on the skills needed for the industry and paid internships and job consideration with the partnering companies.

P-TECH graduates can earn both a high school diploma and an associate degree in six years. Students participate in college classes when ready and develop workplace skills through mentoring, internships and more. Students enter a P-TECH 9-14 schools in grade

nine and begin college courses as early as the tenth grade, and as through the process, they attain an industry-recognized associate degree (3). The first P-TECH school was launched in Brooklyn, New York in September 2011. There are more than 100 P-TECH programs throughout the country with a capacity to serve more than 200,000 students (4).

Recently Baltimore City Community College (BCCC) is selected to develop a new supply chain management career pathway P-TECH program in partnership with the New Era Academy high school in Baltimore city. Industry level partners for this new P-TECH program include the Port of Baltimore and United States Coast Guard. Baltimore City Public Schools, BCCC and Baltimore Port Alliance signed a Memorandum of Understanding (MOU) for the development and support of a P-TECH grades 9-14 school program in Transportation and Supply Chain Management (TSCM) at BCCC (5).

The BCCC program is designed to meet the framework of the MOU with the City Schools and the Port Alliance. The program will be also open to other potential students within BCCC service area. The program provides students and city resident's access to a growing industry and delivers an innovative solution to the workforce needs in the modern occupation category of Transportation, Distribution and Logistics. The TSCM Associate of Applied Science (AAS) degree program at BCCC provides a pathway for students to fill a workforce gap in STEM fields. Students will have the options to obtain academic, experience and industry credentials for their careers in the pivotal Maritime, Transportation, distribution, and Supply Chain industries.

Including the new P-TECH in transportation program at New Era Academy with the port of Baltimore and United States coast guard as industry partners BCCC has three P-TECH programs. In the other two P-TECH 9-14 programs Carver high school partner with IBM preparing students for cybersecurity and information technology careers. Dunbar high school partners with Johns Hopkins University, Johns Hopkins Hospital, Kaiser Permanente, and the University of Maryland, Baltimore for careers in nursing and allied health careers. The TSCM program is an essential first step to accelerating entry into the job market which impacts the local and national economy and our global competitiveness.

## 2. PROGRAM DESCRIPTION

The TSCM program at BCCC prepares students for jobs in the transportation and supply chain management industries. Emphasis is placed on supply chain logistics, commercial, freight, and maritime transportation systems. The program offers a 60-credit course work that provides students' opportunity to master conceptual and technical skills in transportation, distribution, maritime, and supply chain management. Students will fill positions in port operations and port-based logistics, vessel operations, and emerging maritime technologies. Whether they come in at the entry level or changing careers, student can use the skills and knowledge gained to obtain certifications and to advance or qualify for higher paying jobs for a more rewarding position.

As the P-TECH Community College in Baltimore City BCCC is committed to making the attainment of employment-oriented credentials a priority. This program supports the signed MOU between the College, Baltimore City Public Schools, and Baltimore Port Alliance to provide students with an education that "culminates in attainment of an Associate of Applied Science in Transportation, Distribution, and Maritime Logistics degree or related degrees, thus preparing students to succeed in college and career (6)." The TSCM program is an essential first step to accelerating entry into the job market which impacts the local and national economy and our global competitiveness. The program is developed in partnership with Baltimore City Public Schools and The Baltimore Port Alliance as part of the expansion of P-TECH program offerings.

The first cohort of 21 New Era Academy high school students started their P-TECH 9-14 transportation program. The second cohort just started their 9$^{th}$ grade education in

September 2019. Based on the MOU New Era Academy will accept up to 50 students a year until it reaches it maximum.

## 3. PROGRAM OUTLOOK

Baltimore's citizens face significant barriers to employment within the middle-skills jobs market that often pay higher wages. There is a strong level of alignment between the State Plan's occupational composition, BCCC's TSCM program and the expanding choices for disadvantaged students. This program goes beyond the notion of a traditional student. Many of the students will be non-traditional students that represent the reality of most postsecondary students. The TSCM program provides students with a focused pathway that fosters an efficient plan to a successful career. State jobs are changing, favoring higher skilled occupations. Employers are demanding a more highly skilled and educated workforce. Baltimore City has a diversified economy, with workforce demands across many sectors and skill levels.

The widening of the Port of Baltimore will be beneficial to this new program's advancement and the state of Maryland, through more jobs and a larger economic impact. Jobs that require high levels of knowledge represent a growing component the local and state labor market. With 68 % of the current jobs in the Port of Baltimore not requiring a college degree the new program can be a bridge for many non-traditional students/employees who come to college with unique backgrounds. Middle-skill jobs represent a significant opportunity for unemployed and underemployed residents who seek to earn a family supporting wage. The average wages for middle-skills workers was $58, 504 in 2015. Maryland Port Administration Vision2025 identified that the Port continues be an economic engine and is the 12th largest employer in the state of Maryland (7). The Port remains as Maryland's economic jewel far into the future. The Port generates more than 33,000 jobs statewide. 13,650 jobs are related to day-to-day operation.

### 3.1 P-Tech Schools in Maryland

According to the 2017-2021 Maryland state plan for postsecondary education, Maryland had five P-TECH schools in 2017: Two programs at Baltimore City/ Baltimore City Community College, One program at Allegany County/ Allegany College, two programs at Prince George's County/Prince George's Community College. Since 2017 it added three more P-TECH programs: One program at Baltimore City/ Baltimore City Community College, One program at Baltimore County/Community College of Baltimore County, and one program at Montgomery County/Montgomery College. BCCC currently has three P-TECH 4-16 programs with three high schools and industry partners as shown in Table 1.

**Table 1.** BCCC P-TECH Schools

| Community College | School | Industry Level | Career Pathway |
|---|---|---|---|
| Baltimore City Community College | New ERA Academy | Port of Baltimore and United States Coast Guard | Supply Chain Management |
| Baltimore City Community College | Carver Vocational Technical High School | IBM | Cybersecurity Assurance and Computer Information Systems |

| | | | |
|---|---|---|---|
| Baltimore City Community College | Paul Laurence Dunbar High School | John Hopkins Hospital, Kaiser Permanente, and University of Maryland, Baltimore | Nursing, Respiratory Care, Physical Therapy Assistant, Health Information Technology |

Source: 2017-2021 State Plan for Postsecondary Education, p. 23

### *3.2* BCCC Transportation Program Curriculum

The Transportation and Supply Chain Management AAS degree program as shown in Table 2 offers a 60-credit course work that provides students' opportunity to master conceptual and technical skills in transportation, distribution, maritime, and supply chain management (8).

**Table 2.** TSCM Program Course Listing Organized by Content Area

| Course ID | Credits | Course Name | Category** Requirement Fills: |
|---|---|---|---|
| PRE100 | 1 | Preparation for Academic Achievement | College Requirement |
| HLF | 2 | Health and Life Fitness | College Requirement |
| Total Credit by Category | | | 3 |
| SP 101 | 3 | Fundamentals of Speech Communication | GE Cat I |
| ECO 201 | 3 | The American Economy I: Macroeconomics | GE Cat II |
| ES 110 | 3 | Biological and Physical Science Elective | GE Cat III |
| MAT 125 | 3 | Finite Mathematics | GE Cat IV |
| ENG 101 | 3 | English Writing | GE Cat V |
| BUAD 112 | 3 | Computers for Business Management | GE Cat VI |
| Total Credit by Category | | | 18 |
| BUAD100 | 3 | Introduction to Business | Program Requirement |
| ACCT221 | 3 | Financial Accounting | Program Requirement |
| MGMT222 | 3 | Principles of Management | Program Requirement |
| TSCM 101 | 3 | Introduction to Transportation Systems | Program Requirement |
| TSCM 120 | 3 | Commercial Transportation Systems | Program Requirement |
| TSCM 140 | 3 | Supply Chain Management | Program Requirement |
| TSCM 160 | 3 | Maritime Transportation | Program Requirement |
| TSCM 200 | 3 | Freight Transportation | Program Requirement |
| TSCM 210 | 3 | Supply Chain Logistics | Program Requirement |
| CADD 101 | 3 | Introduction to CADD | Program Requirement |

| | | | |
|---|---|---|---|
| CADD 200 | 3 | Geographic Information Systems Applications | Program Requirement |
| PHI 105 | 3 | Introduction to Professional Ethics | Program Requirement |
| Total Credit by Category | | | 36 |
| Electives: | | | |
| COP 200 | 3 | Cooperative Education/Internship | Program Elective |
| MGMT127 | 3 | Customer Relationship Management | Program Elective |
| Program Total: | | | 60 |

### *3.3* Transfer Articulation Agreements

Based on the model in six years or less, P-TECH students graduate with a high school diploma and a no-cost AAS degree in Transportation and Supply Chain Management from BCCC. For TSCM graduates who wish to further their education at four-year institution a transfer articulation agreement is in progress for students to transfer credits from the AAS degree in TSCM towards a bachelor degree in transportation systems, transportation systems engineering, and civil engineering programs at Morgan State University.

## 4. CONCLUSION

The TSCM program is an essential first step to accelerating entry into the job market which impacts the local and national economy and our global competitiveness. The program is developed in partnership with Baltimore City Public Schools and The Baltimore Port Alliance as part of the P-TECH 9-14 program offerings. Whether they come in at the entry level or changing careers, student can use the skills and knowledge gained to obtain certifications and to advance or qualify for higher paying jobs for a more rewarding position.

## 5. ACKNOWLEDGEMENT

A team of BCCC faculty from the business and technology department worked on the development and approval of the new P-TECH 9-14 transportation program. The team include Dr. Yohannes Weldegiorgis, Dr. Shawn Lane, Dr. Solomon Fakinlede, Prof. Linda Benjamin, and Associate Dean Quintin Davis. Acknowledgement goes to all team members who worked on the new TSCM program development and approval at the college level and by the Maryland Higher Education Commission.

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# OVERVIEW OF THE IMPACT OF SUBSTANCE USE DISORDER ON TRAFFIC CRASHES: A CASE OF BOTSWANA

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## ABSTRACT

Addictions to drug and alcohol, which stem from substance abuse (SA), are universal public health problems and cause a significant burden to individuals and societies resulting in a multitude of physical, social, economic and legal problems including transport crashes. In spite of epidemic levels of substance abuse in society, many individuals do not receive treatment at all let alone adequate treatment. This continues to make substance use disorder a major cause of transport crashes (with the attendant menace) in developing countries. Research suggests that counsellors (and other helping professionals) are disinterested in SA counselling, and have SA training, attitude, and skill deficits. There is a dearth of empirical research particularly in developing countries that addresses counsellors' (or trainee counsellors') knowledge and attitudes in relation to substance use and substance users. This paper therefore reviewed the effect of substance abuse, the overall burden of which could have been reduced, had there been adequate and appropriate exposure to treatment, on highway traffic crashes.

**Keywords:** Substance abuse, knowledge, attitude, training, counsellors, traffic crashes

## 1. INTRODUCTION

Substances refer to alcohol and other drugs (whether illicit or not) that are capable of being misused or abused by their users. Substance Use Disorders (SUD), according to the Diagnostic and Statistical Manual, Fifth Edition (DSM-5) is a cluster of cognitive, behavioral, and physiological symptoms indicating that individual continues using a substance despite significant substance related problems. Alcohol use disorder (AUD) is a problematic pattern of alcohol use leading to clinically significant impairment or distress as manifested by at least two of the diagnostic features indicated in figure 1, occurring within a 12-month period. To be concise, SUD is the recurrent use of alcohol and/or drugs causing clinically significant impairment, including health problems and disability. In addition, Substance Abuse (SA) which is a sine qua non of SUD is the harmful or hazardous use of psychoactive substances, including alcohol and illicit drugs. Substance Use Disorder is said to be one of the most prevalent mental health disorders in the Diagnostic and Statistical Manual of Mental Disorders-5 (DSM-V, 2013).

Drugged driving (driving after recent use of intoxicating drugs) and driving after ingesting alcohol both expose road users to untold risks. According to the National Institute on Drug Abuse (NIDA), "research studies have shown negative effects of marijuana on drivers, including an increase in lane weaving, poor reaction time, and altered attention to the road. Use of alcohol with marijuana makes drivers more impaired, causing even more lane weaving. Some studies report that opioids can cause drowsiness and impair thinking and judgment. Other studies have found that being under the influence opioids while driving can

double your risk of having a crash." According to NIDA (2020), major effects of commonly misused drugs on driving are as follows:

Marijuana: affects psychomotor skills and cognitive functions critical to driving including vigilance, drowsiness, time and distance perception, reaction time, divided attention, lane tracking, coordination, and balance.

Opioids: can cause drowsiness and can impair cognitive function.

Alcohol**:** can reduce coordination, concentration, ability to track moving objects and reduce response to emergency driving situations as well as difficulty steering and maintaining lane position. It can also cause drowsiness.

| | DSM–IV | | DSM–5 | |
|---|---|---|---|---|
| Any 1 = ALCOHOL ABUSE | Recurrent alcohol use resulting in a failure to fulfill major role obligations at work, school, or home (e.g., repeated absences or poor work performance related to alcohol use; alcohol-related absences, suspensions, or expulsions from school; neglect of children or household. | 1 | Alcohol is often taken in larger amounts or over a longer period than was intended. (See DSM–IV, criterion 7.) | The presence of at least 2 of these symptoms indicates an **Alcohol Use Disorder (AUD).**<br>The severity of the AUD is defined as:<br>**Mild:** The presence of 2 to 3 symptoms<br>**Moderate:** The presence of 4 to 5 symptoms<br>**Severe:** The presence of 6 or more symptoms |
| | Recurrent alcohol use in situations in which it is physically hazardous (e.g., driving an automobile or operating a machine when impaired by alcohol abuse). | 2 | There is a persistent desire or unsuccessful efforts to cut down or control alcohol use. (See DSM–IV, criterion 8.) | |
| | Recurrent alcohol-related legal problems (e.g., arrests for alcohol-related disorderly conduct).<br>****This is not included in DSM–5**** | 3 | A great deal of time is spent in activities necessary to obtain alcohol, use alcohol, or recover from its effects. (See DSM–IV, criterion 9.) | |
| | Continued alcohol use despite having persistent or recurrent social or interpersonal problems caused or exacerbated by the effects of the alcohol (e.g., arguments with spouse about the consequences of intoxication, physical fights). | 4 | Craving, or a strong desire or urge to use alcohol.<br>****This is new to DSM–5**** | |
| Any 3 = ALCOHOL DEPENDENCE | Tolerance, as defined by either of the following:<br>a) A need for markedly increased amounts of alcohol to achieve intoxication or desired effect<br>b) Markedly diminished effect with continued use of the same amount of alcohol | 5 | Recurrent alcohol use resulting in a failure to fulfill major role obligations at work, school, or home. (See DSM–IV, criterion 1.) | |
| | Withdrawal, as manifested by either of the following:<br>a) The characteristic withdrawal syndrome for alcohol<br>b) Alcohol is taken to relieve or avoid withdrawal symptoms | 6 | Continued alcohol use despite having persistent or recurrent social or interpersonal problems caused or exacerbated by the effects of alcohol. (See DSM–IV, criterion 4.) | |
| | Alcohol is often taken in larger amounts or over a longer period than was intended. | 7 | Important social, occupational, or recreational activities are given up or reduced because of alcohol use. (See DSM–IV, criterion 10.) | |
| | There is a persistent desire or unsuccessful efforts to cut down or control alcohol use. | 8 | Recurrent alcohol use in situations in which it is physically hazardous. (See DSM–IV, criterion 2.) | |
| | A great deal of time is spent in activities necessary to obtain alcohol (e.g., driving long distances), use alcohol, or recover from its effects. | 9 | Alcohol use is continued despite knowledge of having a persistent or recurrent physical or psychological problem that is likely to have been caused or exacerbated by alcohol. (See DSM–IV, criterion 11.) | |
| | Important social, occupational, or recreational activities are given up or reduced because of alcohol use. | 10 | Tolerance, as defined by either of the following:<br>a) A need for markedly increased amounts of alcohol to achieve intoxication or desired effect<br>b) A markedly diminished effect with continued use of the same amount of alcohol (See DSM–IV, criterion 5.) | |
| | Alcohol use is continued despite knowledge of having a persistent or recurrent physical or psychological problem that is likely to have been caused or exacerbated by the substance (e.g., continued drinking despite recognition that an ulcer was made worse by alcohol consumption). | 11 | Withdrawal, as manifested by either of the following:<br>a) The characteristic withdrawal syndrome for alcohol (refer to criteria A and B of the criteria set for alcohol withdrawal)<br>b) Alcohol (or a closely related substance, such as a benzodiazepine) is taken to relieve or avoid withdrawal symptoms. (See DSM–IV, criterion 6.) | |

**Figure 1.** DSM-V Definition. Adapted from NIH Publication No.13-7999, 2013

### 1.1 Magnitude of SUD

Substance (drug) abuse is an enormous and escalating problem in the world, especially among teenagers and young adult. According to the report of the World Health Organization, there were 200 million of drug addicts throughout the world in 2005 (Geramian et al, 2012). Addiction to tobacco, alcohol and illicit drug are universal public health problems and cause significant burden to individuals and societies resulting in a multitude of physical, social, economic and legal problems including HIV/AIDS (Rasool et al, 2006). As a result, it has become a serious problem in social and psychological health issues. In the same vein, substance misuse has been linked with a variety of health problems, including respiratory

problems, cardiovascular disease, thyroid functioning, cancer, and metabolic syndrome. (Caspers et al., 2009). Tobacco, alcohol and illicit drug use has been shown to account directly and indirectly for about a quarter of annual death rate (McGinnis, and Foege, 1993 in Cape et al., 2006) and is responsible for approximately 9% of the global burden of disease (WHO, 2002). In its 2018 Global Status Report on Alcohol and Health, WHO also stated that 3 million deaths every year result from harmful use of alcohol. This notwithstanding, high levels of alcohol are still being consumed by people across the globe.

In the United States, lifestyle related illnesses account for half the annual mortality rate and alcohol and drugs account for half of it i.e. 25% of annual deaths (McGinnis and Foege, as cited in Au, 2006). In 2019 in the United States, estimates show that almost 44 percent of drivers in fatal car crashes tested positive for drugs (NIDA. 2020). In Europe, 11.8% of all deaths in the age group 15–64 years are attributed to alcohol related causes (World Health Organization, 2012, cited in Van Boekela et al., 2013).

Hughes (2009) also posits that "Many of the accidents and deaths that occur on European roads are caused by drivers whose performance is impaired by a psychoactive substance. Alcohol alone is estimated to account for up to 10 000 road deaths a year in the European Union, one quarter of all road deaths." In Nigeria, studies have consistently shown that there is considerable prevalence of drugs and substance use; with varying prevalence rates found both for overall and specific drug abuse (Abdulkarim et al., 2005). Additionally, it is reported that approximately 50% of accidents, and its attendant consequences, on Nigerian roads are related to alcohol use (Welcome and Pereverzev, 2010, cited in Makanjuola et al. 2014). It is noteworthy that similar pattern exists across the continent of Africa (Figure 2).

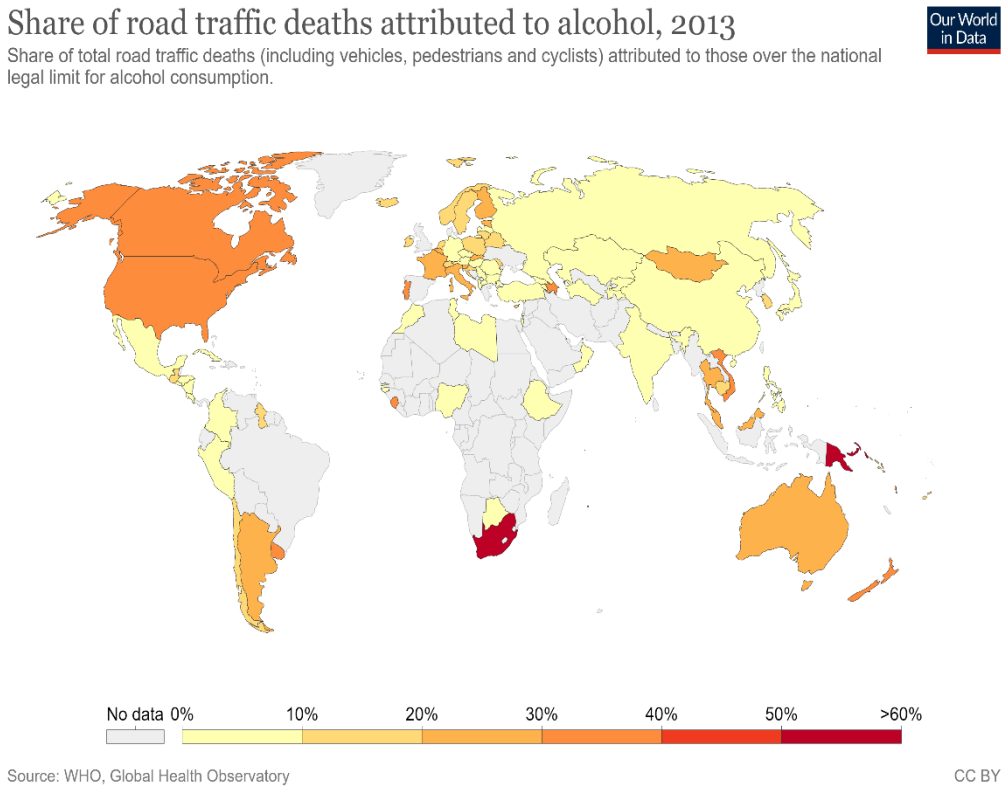


**Figure 2.** Share of Road Traffic Deaths Attributed to Alcohol

## 2. A CASE OF BOTSWANA

Alcohol and other substance use prevalence in Botswana have risen in the last decade. It has become increasingly commonplace in terms of the social demography of users, age, location, drugs of choice, and availability of a wide range of drugs. In Botswana, alcohol abuse appears to be at a pandemic stage and everyone in the community seems to be affected one way or the other. The impact of this on the road traffic accidents, annual death toll, community violence and HIV/AIDS spread is overwhelming! According to a data collected for the Botswana Epidemiology Network on Drug Use (BENDU) in 2003 from four treatment centres, alcohol remains the most common primary substance of abuse reported by patients, accounting for 84% of patients (www.who.int/substance_abuse/publications/en/botswana.pdf COUNTRY PROFILES AFRICAN REGION Global Status Report on Alcohol 2004 3 © World Health Organization 2004). Furthermore, the 2007 population-based survey indicated that approximately 49% of adults in Botswana drink alcohol regularly with 30% being males and the remainder females. Among the 49% of alcohol consumers, 50% reported binge drinking, which is defined as more than six drinks per day for men and more than four beers on daily basis for women (The Midweek Sun, 2012). This statistics is absolutely alarming.

Similarly, the Botswana Alcohol Aids Project (BAAP, 2004) posits that alcohol is the most heavily used substance in Botswana. Dagga (Pot) is second but the ratio of use is about 95% Alcohol and 4% Pot with other drugs like Ecstacy and Glue at about 1%. Alcohol use in Botswana is clearly linked, by its negative impact on behaviour, to the continued spread of HIV/AIDS. In 2004, the Botswana Aids and Alcohol Project (BAAP) stated that the death rate in Botswana had already exceeded the birth rate, and that without significant nationwide behavioural change (as regards alcohol use), the Country of Botswana was on a long march to extinction (BAAP, 2004). Although the life expectancy in Botswana has since increased from 47.16 in 2004 to 54.06 as at August 2014, because of lesser deaths from HIV-AIDS owing mainly to ARV treatment, Kutil (2014) posits that the Botswana populace is still heavily influenced by health factors resulting from alcohol abuse. According to him, statistics from the Botswana Police Service, collected by the Ministry of Health, show that 50% of reported rape happened when alcohol was involved. Further, when male and females are identified as heavy drinkers, the risk of HIV, due to multiple partners, unprotected sex, and transactional sex (paying or selling sex) increased three-fold. In the same vein, in violent crime acts, the purely anecdotal evidence suggests that alcohol is a prominent factor (von Rudloff, cited by Kutil 2014).

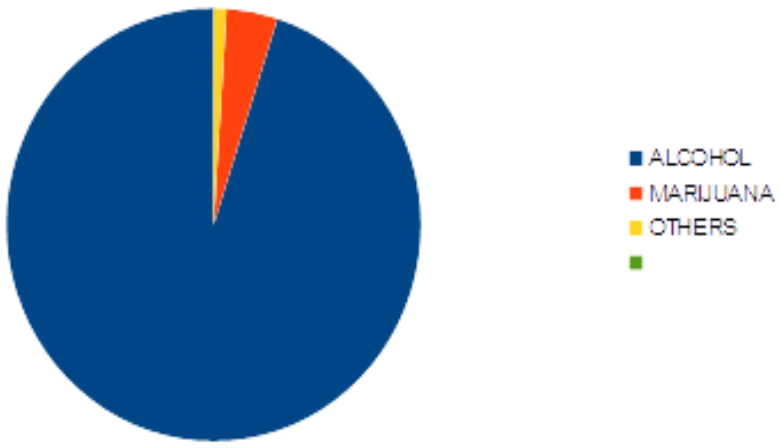


**Figure 3.** Substances of Abuse in Botswana

Botswana has one of the highest rates of increase in road traffic accidents and fatalities in the world. The World Health Organization (WHO) Global Status report on Road Safety revealed that Botswana has a recorded death rate of 20.1 per 100 000 population against the global death rate of 17.4 per 100 000 population (Thatayamodimo, 2019). However, the overall crash rate declined significantly in June 2009 and June 2010, such that the overall crash rate from June 2010 to December 2011 was 22% lower than the overall crash rate from January 2004 to May 2009 (Sebego et al. 2014). This significant decrease occurred while policies were being aggressively implemented to reduce alcohol consumption. Another great eyeopener to the great impact of alcohol and other substance use disorders on traffic crashes.

Regrettably, despite the epidemic levels of substance abuse in society, many individuals do not receive treatment at all let alone adequate treatment. This continues to make substance use disorder a major cause of transport crashes (with the attendant menace) in developing countries, Botswana inclusive. Various factors are responsible for this. Among them are reluctance to seek help by the populace, inadequate facilities and insufficient and/or under-trained care givers. The Global Health Observatory (2018) showed only very few people with alcohol use disorders got any form of treatment at all. See Figure 3.

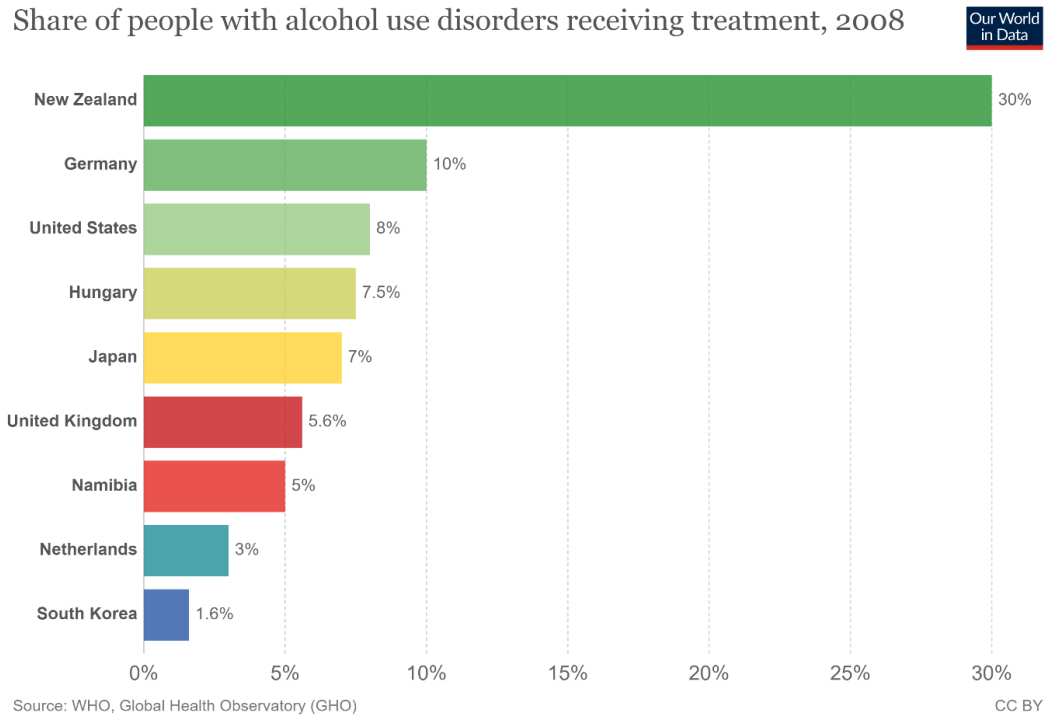


**Figure 4.** People with AUD receiving treatment

The medical and other helping professions practitioners both globally and locally are the human resources for managing and treating victims of substance misuse as well as educate them on preventive measures regarding this menace. However, a growing body of literature globally documents the deficient/inadequate education of medical, paramedical, and other helping professions (counselling, social work, psychology) about addiction. (See for example, as reflected by Senreich and Straussner, 2012; Galvani and Hughes, 2008; Cape et al, 2006; Rasool et al, 2006; Abed and Neira-Munoz, 1990 in Landy et al., 2005). Senreich and Straussner (2012), for instance, posits that the National Association of Social Workers

(NASW) Standards for Social Work Practice with Clients with Substance Use Disorders (SUDs; NASW, 2005), indicate: "Social workers shall screen clients for SUDs and, when appropriate, complete a comprehensive assessment toward the development of a service plan for recommended placement into an appropriate treatment program". Yet very few schools of social work require that students take a course on assessment and treatment of substance abusing clients.

In like manner, Rasool et al (2006) concurred that "an extensive review of drug and alcohol content within nursing curricula at both undergraduate and postgraduate levels in the United Kingdom (Rassool and Oyefeso 1993; Rassool 2000), United States of America (Murphy 1991; Hagemaster et al. 1993), Australia (Pols et al. 1993; Crespigny 1999) and Brazil (Villar-Luis 2001; Pillon et al. 2004; Rassool and Villar-Luis 2004) reveal that content related to substance use and misuse education in nursing curricula is inadequate".

Apart from paucity of educational exposure and possible inadequate knowledge, another important area of concern is the negative attitudes towards victims of substance abuse (Pabian, 2013; Gerace et al. 1995 in Rasool, 2006). According to Au (2006), substance abuse and substance abusers stir up complex responses in society. Stigma, rejection and punitive responses to "addicts' and "alcoholics" are common. Service providers are likely to be exposed to biased and uninformed beliefs and attitudes regarding substance abuse. Professionals may be unaware of the biases and attitudes they have assimilated from the larger society. In fact, many graduating students in mental health fields simply do not want to work with substance abusers. (For example, one study found that 70% of graduates did not find addiction work satisfying). Once in practice, they are slow to respond to the addiction field's demand for their services. It is possible to be a licensed psychologist (and of course, a practicing counsellor) having only very limited knowledge of substance use disorders. Critics have concluded that the lack of adequate addiction training can only be described as institutional denial or minimization of the significance of addictive disorders (Pabian, 2013).

However, given the escalating evidence about the social harms and great negative impact on traffic crashes of alcohol in particular, and other substances abuse in general, as well as the anecdotal evidence from mental health workers who are struggling to come to terms with these issues, as well as the limited counselling and human services literature on the knowledge and attitudes of trainee counsellors towards substance abuse in Botswana cum, concerted efforts must be made from all quarters to fight the monster of SUD.

## 3. CONCLUSION

The overview shows substance use disorder as a great hazard not only to the drivers, but all highway users both globally and locally in African countries. In all its ramifications, it causes a significant burden, resulting in not only in high incidence of traffic crashes, but also other imbroglio like health, social, economic, and legal problems,

Evidently much higher risks of traffic crashes are faced by drivers as well as pedestrians who have been on psychoactive substances including alcohol and illicit drugs than others who have not. Some of the effects of ingesting/misusing substances include, but not limited to drowsiness, poor concentration and reaction time, impaired cognitive function, lane tracking, altered psychomotor skills and reduced coordination.

Interestingly, implementation of aggressive policies to reduce alcohol (and by extension, other substances) consumption was shown to have a direct relationship to traffic crashes reduction in some countries especially when accompanied by promotion and/or enforcement of road safety rules. However, on a sad note, treatment for substance abuse appears to be far from adequate. While people with substance use disorder need more motivations to seek help, many health care (and other helping) professionals, especially in Africa need more trainings and re-orientation of their mindset to be able to adequately treat substance users. Curricular review might also be needed in institutions of training to that effect.

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# MONITORING PERFORMANCE OF LATERITE BASE TRIAL SECTION: A CASE OF ADDIS ABABA, ETHIOPIA

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## ABSTRACT

This paper is aimed to present an overview of the provision of a demonstration/research trials with particular reference to pavement performance of a laterite base under a double bituminous surface treatment (DBST) as part of a long-term pavement performance (LTPP) monitoring in Ethiopia. The research components were aimed at increasing the use of locally available materials and solving specific problems related to the performance of some roads constructed with thin asphalt seals. In Ethiopia, most roads are built using crushed rock for road base. The project aim was to demonstrate that whether laterite can be used for base course, assess and evaluate the effect of sealed and unsealed shoulder in cut and fill sections. Out of the various field data measurements carried out in each monitoring period (wet and dry season) the paper reviews the in-situ dynamic cone penetrometer (DCP) test results and visual condition assessment observations. It is demonstrated that for such low volume roads laterite base trial sections are performing well, however DCP test results in these sections reveals that the crushed base control sections perform slightly better than the laterite base trial sections and the sections in cut are stronger than in fill while the shoulder sealing doesn't provide consistent effect on the layer strengths.

**Keywords:** laterite, pavement performance, field monitoring, trial section

## 1. INTRODUCTION

Four research projects have been initiated in Ethiopia under ReCAP/AFCAP program in collaboration with the Ethiopian Roads Authority – Road Research Center. Each of the four projects involved the construction of trial sections aimed at demonstrating alternative technology for road provision developed elsewhere. The research components were aimed at increasing the use of locally available materials and solving specific problems related to the performance of some roads constructed with asphalt seals. The overall goal of the research is to reduce costs and help increase cost-effective, safe and sustainable road provision in Ethiopia, which are the core objectives of ReCAP/AFCAP.

Research carried out by TRL in southern Africa on behalf of the UK Department for International Development (DFID), (Gourley & Greening, 1999), clearly indicated that existing standards and specifications for sealed roads carrying relatively low levels of traffic (approximately 200vpd) were generally too conservative and impeding rural road provision and development. Included in this research were roads that had been constructed with lateritic material as base course. [Whilst the use of lateritic material for sub-base is fairly common, it often fails to meet the required specifications for base course and, when it used, it is usually modified with cement, or more commonly with lime]. The roads with laterite base course included in the research had performed exceptionally well although not meeting a number of the 'standard' specifications for road base such. as plasticity, strength or grading.

Some roads had also been subjected to overloading and some had received no maintenance in the form of a reseal since construction and had still performed well (Greening, 2014).

In Ethiopia, most roads are built using crushed rock for road base. On road bases that have been constructed with natural gravel, they are usually surfaced with asphalt rather than a thin bituminous seal. Both these options (crushed rock for base course and asphalt surfacing) are more expensive than using natural lateritic gravel for base course plus a surface treatment which is the normal design for the relatively lightly trafficked rural roads in most developing countries.

The project has the following main objectives: demonstrate that laterite can be used for base course, evaluate the relative effects of sealed shoulders (in fill and cut) on pavement moisture, assess the benefit of designing road bases on the strength of materials at their in-situ moisture content. The trial section was constructed in the middle of the standard road construction, Assosa – Kumruk road project in Ethiopia, so that the performance can be easily compared. The project road was constructed using DBST, 200mm Crushed Stone Base and 150mm Selected Laterite Sub-Base. The base was replaced with laterite of 200mm thickness on a laterite sub-base of 150mm for the trial sections. As part of the long-term pavement performance (LTPP) monitoring, four monitoring cycles has been carried out so far in two years 2017 and 2018 representing wet and dry season in each year in addition to the baseline monitoring carried out in 2012 (Otto and Greening, 2012).

## 2. MATERIAL AND METHOD

### 2.1 Laterite Material

Laterite, first defined by Buchanan (1807) as "a massive, vesicular or concretionary ironstone formation" is mainly found in wet tropical and subtropical areas. It is a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminium. This concentration may be by residual accumulation or by solution, movement and chemical precipitation. In all cases it is the result of secondary physico-chemical processes and not of the normal primary process of sedimentation, metamorphism, volcanism or photoism (Molenaar, 2005). The accumulated hydrated oxides are sufficiently concentrated to affect the character of the deposit in which they occur (Araya, 2011).

Laterite formation requires particular conditions which concentrate the iron- and aluminium rich weathering products sufficiently to allow concretionary development, often progressing to a cemented horizon within the weathering profile (Netterberg, 2014). According to Charman (1988), before the concretionary development of true laterite can take place, an additional process is required – the concentration of the weathering products within the residual soil/completely weathered zones. The hardening or concretionary development after the iron enrichment seems to proceed by a number of mechanisms including chemical precipitation, loss of water of crystallization (dehydration) and the development of a continuous fabric of cementing materials (Alexander and Cady, 1962).

Laterite soils are formed in situ from the intense weathering of parent material, whether primary or sedimentary, in the tropical and subtropical climate environment (Aginam et al, 2015). This weathering process primarily involves the progressive chemical alteration of primary minerals, the release of iron and aluminium sesquioxides, increasing loss of silica and the increasing dominance of new clay materials (such as smectites, allophones, halloysite, and as weathering progresses, kaolinite) formed from dissolved materials (Northmore et al, 1992). Tuncer et al, (1977), described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal sesquioxides, and precipitation of the oxides with increasing crystallinity and dehydration as the soil is weathered.

The laterite soils used in the project are generally coarse non plastic materials, their gradation compared to the Ethiopian Road Authority gradation specifications for base and subbase material is shown in Figure 1. Compared to the gradation specification for base

material, the laterite falls out of specification before and after compaction. The laterite however falls within gradation specifications for subbase both before and after compaction (Otto and Greening, 2012).

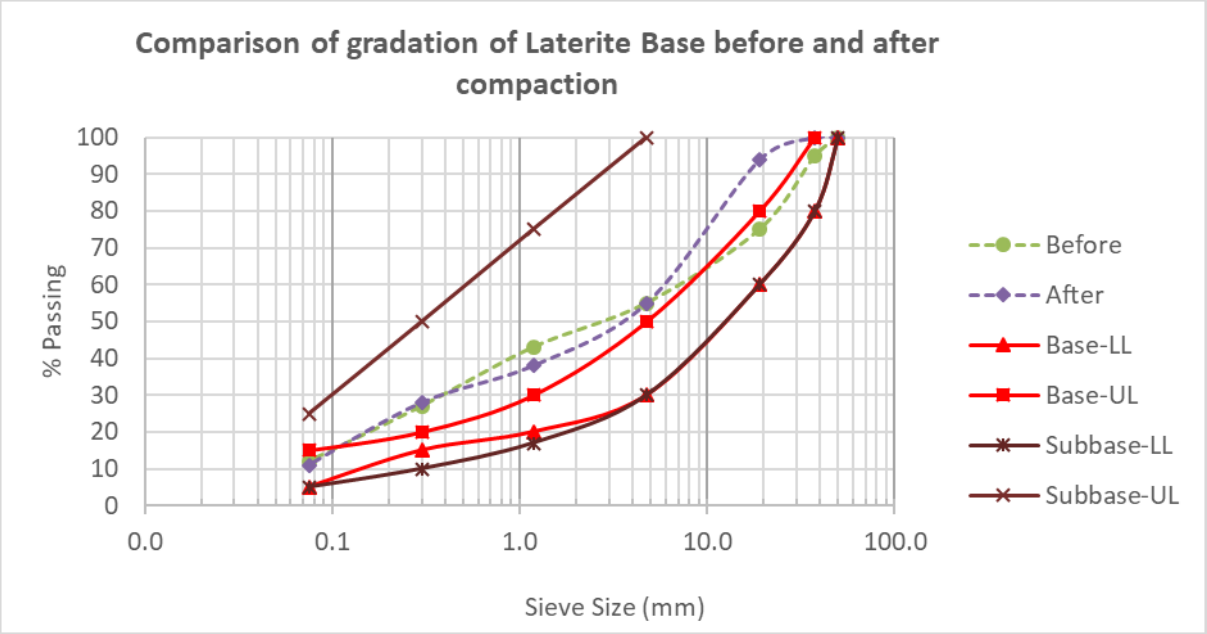


**Figure 1.** Gradation of laterite base as compared to the design specifications

## 3. MONITORING TRIAL AND CONTROL SECTIONS

To maximise the benefits of any experimental, trial, demonstration, or LTPP sections, it is essential that the design is such that the trial produces the results that are desired. Trial sections can be developed for several purposes, the main ones of interest in this monitoring being to prove the technical viability of an innovation compared with conventional alternatives.

Generally, the following are typical types of experimental sections requiring long-term monitoring (Paige-Green, 2016):

- Replacement materials for traditional ones in structural layers, e.g. an alternative material such as slag or industrial waste
- Innovative treatment of sub-standard materials in structural layers to improve their quality, including the use of mechanical, traditional or non-traditional stabilisation.
- Innovative treatment of subgrades to reduce common subgrade problems, e.g. collapsible, expansive or saline materials
- Different pavement structures such as thinner layers or even omission of specific layers, e.g. For low volume roads
- Alternative surfacing such as Otta and sand seals, polymer slurry seals, hand-laid cold-mix asphalt, etc.
- Different construction methods, e.g. conventional versus in-place recycling

The monitoring sections on Assosa-Kurmuk Road the conventional crushed aggregate base under double bituminous surface treatment (DBST) is replaced with natural laterite base. Seven trial sections with laterite base and two control sections with crushed base are developed as shown in Table 1. The sections are developed in such a way that effect of shoulder sealing condition and section location in the performance of the laterite base can be demonstrated. The fill embankments are up to 10m high whereas the cuts up to 6m deep.

**Table 1.** Monitoring Sections on Assosa-Kurmuk Road

| Chainage | Section ID | Length (m) | Pavement Surfacing | Shoulder condition | Location (Cut/Fill) | Remark |
|---|---|---|---|---|---|---|
| Section 1: 49+140 – 49+225 | UC1 | 85 | DBST, Laterite Base | Unsealed | Cut | |
| Section 2: 49+225 – 49+292 | UF1 | 67 | DBST, Laterite Base | Unsealed | Fill | |
| Section 3: 49+292 – 49+445 | SF1 | 163 | DBST, Laterite Base | Sealed | Fill | |
| Section 4: 49+445 – 49+558 | SC1 | 103 | DBST, Laterite Base | Sealed | Cut | |
| Section 5: 49+558 – 49+668 | UC2 | 110 | DBST, Laterite Base | Unsealed | Cut | |
| Section 6: 49+668 – 49+768 | SF2 | 100 | DBST, Laterite Base | Sealed | Fill | |
| Section 7: 49+768 – 50+026 | UF2 | 258 | DBST, Laterite Base | Unsealed | Fill | |
| Section 8: 60+000 – 60+200 | CS1-UC | 200 | DBST, Crushed Base | Unsealed | Cut | Control section |
| Section 9: 60+200 – 60+400 | CS2-UF | 200 | DBST, Crushed Base | Unsealed | Fill | Control section |

### *3.1* Field Measurements

The objective of the monitoring program is to provide performance-based evidence which will contribute to the establishment of appropriate standards for Low Volume Sealed Roads in Ethiopia.

Field measurements and characterisation of the performance of paved roads usually requires an evaluation of the road roughness, rut depths, deflection, pavement strength (usually using a DCP), moisture contents and regular visual assessments following a standard technique. The monitoring requirements, however, vary depending on the type of pavement and surfacing as well as whether the factor of interest is functional (mostly surfacing type) or structural, related to pavement strengths and layer thicknesses.

The assessment of the performance of bituminous surfaced roads depends on the nature of the experimental section. For the monitoring section various field data measurements has been carried out in each monitoring period (wet and dry season); such as rutting, surface deflection, in-situ DCP test, trial pit for field moisture and density, visual condition assessment in addition to the traffic count, axle load measurement, sampling for laboratory tests. This paper will, mainly, focus on the analysis of the in-situ DCP test measurement and visual condition assessment.

The original development of the DCP dates back to the mid-1950s in Australia based on an older Swiss original, and was used initially as a non-destructive testing device to evaluate the shear strength of a material in a pavement. The use of the DCP for pavement design purposes was further enhanced in the mid-1960s and 1970s in South Africa where results from back analysis of some 57 roads in different traffic and climatic environments, together with some accelerated pavement testing with the Heavy Vehicle Simulator (HVS) were used to verify the concepts used in the design method and to establish expected life versus DCP penetration curves (Kleyn and van Zyl, 1988, TRL, 1993, MTPW, 2013).

### *3.2* DCP Tests

On all of the monitoring trial and control sections DCP tests are performed using 60-degree cone DCP test equipment. For each Long term pavement performance (LTPP) panels, the

nine sections in Table 1, five DCP test points are marked and tests were carried out across the road as follows: Outer wheel path left (OWL), Inner wheel path left (IWL), centreline (CL), Inner wheel path right (IWR) and Outer wheel path right (OWR).

The results of the DCP tests carried out on the monitoring sections for one representative the fourth monitoring period is summarised in Table 2. In the next result and discussion section summary of average of each panel are presented for the various section conditions. It is customary to predict the CBR strength from the DCP rate of penetration into gravel and soil layers (i.e. the DN value in mm/blow) using various equations developed elsewhere (Kleyn, 1982, TRL, 1993) that relates CBR and DN values. However, it is used directly and compare the DN values of the base and subbase for the respective pavement layers, and the DSN values (#blow) of DSN450 and DSN800 which are the cumulative number of blows required to penetrate the pavement to a depth of 450mm and 800mm from the top of the base layer.

*DCP number (DN)*: The DCP measures the penetration per blow into a pavement through each of the different pavement layers. This rate of penetration in mm/blow (the DN value) is a function of the in-situ shear strength of the material at the in-situ moisture content and density of the pavement layers at the time of DCP testing.

*DCP structure number (DSN):* The DCP structure number is the number of DCP blows required to penetrate a pavement structure or layer. For example, the DSN800, a parameter which allows the bearing capacity of different pavements to be compared, is the number of blows required to penetrate the pavement to a depth of 800 mm.

From a knowledge of the DN values of various pavement layers, those of relatively high and relatively low strength can be distinguished from each other and the balance of the pavement at any depth can be evaluated. This has led to the development of a pavement classification system in which shallow, deep and inverted pavements can be distinguished from each other and further differentiated in terms of whether they are well-balanced, averagely balanced or poorly balanced.

**Table 2**. DCP tests on the Assosa – Kurmuk 4th round monitoring [11-2018 wet season]

| Section ID | Location | DN-Base | DN-Subbase | DSN450 | DSN800 |
|---|---|---|---|---|---|
| UC1 | OWL | 4.5 | 5.5 | 83 | 111 |
| | IWL | 4 | 6.5 | 93 | 141 |
| | CL | 5 | 6.5 | 88 | 136 |
| | IWR | 5 | 8 | 82 | 116 |
| | OWR | 6.5 | 6 | 71 | 95 |
| | Average | 5 | 7 | 83 | 120 |
| UF1 | OWL | 6 | 8.5 | 58 | 88 |
| | IWL | 6 | 12 | 55 | 81 |
| | CL | 4.5 | 18 | 68 | 93 |
| | IWR | 7 | 10.5 | 55 | 79 |
| | OWR | 7.5 | 10.5 | 47 | 68 |
| | Average | 6 | 12 | 57 | 82 |
| SF1 | OWL | 6 | 14 | 63 | 81 |
| | IWL | 5.5 | 13 | 62 | 81 |
| | CL | 7 | 11.5 | 53 | 77 |
| | IWR | 8 | 14 | 55 | 78 |
| | OWR | 8 | 13 | 55 | 83 |
| | Average | 7 | 13 | 58 | 80 |
| SC1 | OWL | 8 | 10.5 | 54 | 120 |
| | IWL | 7.5 | 10.5 | 55 | 140 |
| | CL | 6 | 10.5 | 61 | 145 |
| | IWR | 8 | 11.5 | 49 | 115 |
| | OWR | 9 | 10 | 48 | 106 |

| | | | | | |
|---|---|---|---|---|---|
| | Average | 8 | 11 | 53 | 125 |
| UC2 | OWL | 7 | 7 | 83 | 173 |
| | IWL | 4 | 5 | 89 | 178 |
| | CL | 6 | 8 | 72 | 104 |
| | IWR | 6 | 8.5 | 66 | 125 |
| | OWR | 7 | 9 | 54 | 84 |
| | Average | 6 | 8 | 73 | 133 |
| SF2 | OWL | 9.5 | 12.5 | 51 | 82 |
| | IWL | 4 | 5.3 | 105 | 210 |
| | CL | 5 | 6.5 | 83 | 143 |
| | IWR | 6 | 6.5 | 78 | 155 |
| | OWR | 8.5 | 7 | 56 | 87 |
| | Average | 7 | 8 | 75 | 135 |
| UF2 | OWL | 10.5 | 13 | 40 | 70 |
| | IWL | 10.5 | 9.5 | 45 | 84 |
| | CL | 6.5 | 10.5 | 53 | 91 |
| | IWR | 6 | 10.5 | 48 | 77 |
| | OWR | 12 | 21 | 50 | 61 |
| | Average | 9 | 13 | 47 | 77 |
| CS1-UC1 | OWL | 2 | 4 | 160 | 230 |
| | IWL | 2.5 | 4 | 135 | 185 |
| | CL | 3 | 5 | 125 | 190 |
| | IWR | 3 | 8 | 96 | 122 |
| | OWR | 3 | 5.5 | 130 | 195 |
| | Average | 3 | 5 | 129 | 184 |
| CS1-UC2 | OWL | 2.5 | 6 | 145 | 220 |
| | IWL | 2.5 | 6.5 | 104 | 131 |
| | CL | 2.5 | 6 | 141 | 170 |
| | IWR | 3 | 5 | 125 | 190 |
| | OWR | 3 | 6 | 115 | 177 |
| | Average | 3 | 6 | 126 | 178 |
| CS2-UF1 | OWL | 2.5 | 4 | 140 | 170 |
| | IWL | 3 | 5 | 130 | 173 |
| | CL | 3 | 5.5 | 140 | 176 |
| | IWR | 2.5 | 4 | 144 | 170 |
| | OWR | 2.5 | 6 | 116 | 155 |
| | Average | 3 | 5 | 134 | 169 |
| CS2-UF2 | OWL | 6 | 8.5 | 62 | 95 |
| | IWL | 6 | 9 | 81 | 104 |
| | CL | 4 | 6 | 100 | 146 |
| | IWR | 10 | 15 | 36 | 61 |
| | OWR | 12 | 15.5 | 33 | 56 |
| | Average | 8 | 11 | 62 | 92 |

## 4. RESULTS AND DISCUSSION

The DCP test result, DN and DSN values, are compared for the different conditions of the demonstration section. The following comparisons are tabulated and discussed i.e.: average DN values for laterite base trial sections vs crushed stone base control sections, sections in cut vs sections in fill and sections with sealed shoulders vs unsealed shoulders.

These measured results have been demonstrated for the average of all values and the average of the outer wheel track values only.

### 4.1 Average DN values of all wheel tracks and centreline

Table 3 demonstrates DN value comparison for the various sections based on the average of all values for the four monitoring cycles or rounds i.e. 1st round 2017 dry, 2nd round 2017 wet, 3rd round 2018 dry and 4th round 2018 wet season.

**Table 3.** DCP tests on the Assosa – Kurmuk [04-2017 / dry season]

| Monitoring round | Section | DN-Base (mm/blow) | DN-Subbase (mm/blow) | $DSN_{450}$ (#blow) | $DSN_{800}$ (#blow)Monitoring round/ Season |
|---|---|---|---|---|---|
| *Laterite Base Trial Sections vs Crushed Stone Control Sections* | | | | | |
| 1st round | Average Laterite Base Trial Sections | 6 | 10 | 60 | 93 |
| | Average Crushed base Control Sections | 4 | 9 | 84 | 120 |
| 2nd round | Average Laterite Base Trial Sections | 7 | 10 | 65 | 96 |
| | Average Crushed base Control Sections | 6 | 9 | 65 | 129 |
| 3rd round | Average Laterite Base Trial sections | 6 | 10 | 71 | 110 |
| | Average Crushed base Control Sections | 3 | 7 | 117 | 146 |
| 4th round | Average Laterite Base Trial Sections | 6 | 10 | 66 | 113 |
| | Average Crushed base Control Sections | 4 | 7 | 113 | 156 |
| All rounds | Average Laterite Base Trial Sections | 6 | 10 | 65 | 103 |
| | Average Crushed base Control Sections | 4 | 8 | 95 | 138 |
| *Sections in Cut vs Sections in Fill* | | | | | |
| 1st round | Average Sections in Cut | 5 | 9 | 73 | 107 |
| | Average Sections in Fill | 6 | 10 | 65 | 98 |
| 2nd round | Average Sections in Cut | 6 | 9 | 70 | 113 |
| | Average Sections in Fill | 6 | 9 | 66 | 104 |
| 3rd round | Average Sections in Cut | 5 | 9 | 81 | 120 |
| | Average Sections in Fill | 5 | 9 | 91 | 120 |
| 4th round | Average Sections in Cut | 5 | 7 | 93 | 148 |
| | Average Sections in Fill | 7 | 10 | 72 | 106 |
| All rounds | Average Sections in Cut | 5 | 10 | 65 | 103 |
| | Average Sections in Fill | 4 | 8 | 95 | 138 |
| *Sections with Sealed Shoulder vs Sections with Unsealed Shoulder* | | | | | |
| 1st round | Average Sections with Sealed Shoulder | 7 | 12 | 49 | 76 |

| | | | | | |
|---|---|---|---|---|---|
| | Average Sections with Unsealed Shoulder | 5 | 9 | 68 | 104 |
| 2nd round | Average Sections with Sealed Shoulder | 8 | 12 | 55 | 79 |
| | Average Sections with Unsealed Shoulder | 5 | 7 | 81 | 117 |
| 3rd round | Average Sections with Sealed Shoulder | 6 | 11 | 65 | 96 |
| | Average Sections with Unsealed Shoulder | 6 | 10 | 72 | 112 |
| 4th round | Average Sections with Sealed Shoulder | 7 | 10 | 62 | 114 |
| | Average Sections with Unsealed Shoulder | 7 | 10 | 65 | 103 |
| All rounds | Average Sections with Sealed Shoulder | 7 | 11 | 58 | 91 |
| | Average Sections with Unsealed Shoulder | 6 | 9 | 71 | 109 |

### 4.2 Average DN values of the outer wheel track only

Table 4 demonstrates DN and DSN value comparison for the various sections based on the average of the outer wheel track values only for the four monitoring cycles or rounds.

**Table 4.** DN and DSN for sections based on average of the outer wheel track values only

| Monitoring round | Section | DN-Base (mm/blow) | DN-Subbase (mm/blow) | $DSN_{450}$ (#blow) | $DSN_{800}$ (#blow) |
|---|---|---|---|---|---|
| *Laterite Base Trial Sections vs Crushed Stone Control Sections* | | | | | |
| 1st round | Average Laterite Base Trial Sections | 6 | 10 | 60 | 93 |
| | Average Crushed base Control Sections | 4 | 9 | 84 | 120 |
| 2nd round | Average Laterite Base Trial Sections | 7 | 10 | 65 | 96 |
| | Average Crushed base Control Sections | 6 | 9 | 65 | 129 |
| 3rd round | Average Laterite Base Trial sections | 6 | 10 | 71 | 110 |
| | Average Crushed base Control Sections | 3 | 7 | 117 | 146 |
| 4th round | Average Laterite Base Trial Sections | 6 | 10 | 66 | 113 |
| | Average Crushed base Control Sections | 4 | 7 | 113 | 156 |
| All rounds | Average Laterite Base Trial Sections | 6 | 10 | 65 | 103 |
| | Average Crushed base Control Sections | 4 | 8 | 95 | 138 |
| *Sections in Cut vs Sections in Fill* | | | | | |
| 1st round | Average Sections in Cut | 5 | 9 | 73 | 107 |
| | Average Sections in Fill | 6 | 10 | 65 | 98 |

| | | | | | |
|---|---|---|---|---|---|
| 2nd round | Average Sections in Cut | 6 | 9 | 70 | 113 |
| | Average Sections in Fill | 6 | 9 | 66 | 104 |
| 3rd round | Average Sections in Cut | 5 | 9 | 81 | 120 |
| | Average Sections in Fill | 5 | 9 | 91 | 120 |
| 4th round | Average Sections in Cut | 5 | 7 | 93 | 148 |
| | Average Sections in Fill | 7 | 10 | 72 | 106 |
| All rounds | Average Sections in Cut | 5 | 10 | 65 | 103 |
| | Average Sections in Fill | 4 | 8 | 95 | 138 |
| *Sections with Sealed Shoulder vs Sections with Unsealed Shoulder* | | | | | |
| 1st round | Average Sections with Sealed Shoulder | 7 | 12 | 49 | 76 |
| | Average Sections with Unsealed Shoulder | 5 | 9 | 68 | 104 |
| 2nd round | Average Sections with Sealed Shoulder | 8 | 12 | 55 | 79 |
| | Average Sections with Unsealed Shoulder | 5 | 7 | 81 | 117 |
| 3rd round | Average Sections with Sealed Shoulder | 6 | 11 | 65 | 96 |
| | Average Sections with Unsealed Shoulder | 6 | 10 | 72 | 112 |
| 4th round | Average Sections with Sealed Shoulder | 7 | 10 | 62 | 114 |
| | Average Sections with Unsealed Shoulder | 7 | 10 | 65 | 103 |
| All rounds | Average Sections with Sealed Shoulder | 7 | 11 | 58 | 91 |
| | Average Sections with Unsealed Shoulder | 6 | 9 | 71 | 109 |

#### *4.2.1 Comparison of DN values for the different sections*

As stated above the structural strength of the pavements (DN and DSN values) comparisons have been demonstrated for the average of all values and the average of the outer wheel track values only.

In the comparison of laterite base trial sections and crushed stone base control sections all section in cut and fill as well as with sealed shoulder and unsealed are averaged as shown in Figure 2. It is clearly demonstrated that the DN and DSN value of the control sections with crushed stone base are stronger than the trial sections with laterite base. Even the DN value of the laterite subbase shows significant difference that the laterite subbase under the control section is stronger than under the lateritic base. Moreover, it is noted that the difference between the control section and the trial section DN and DSN values it is slightly higher in the outer wheel track than all average.

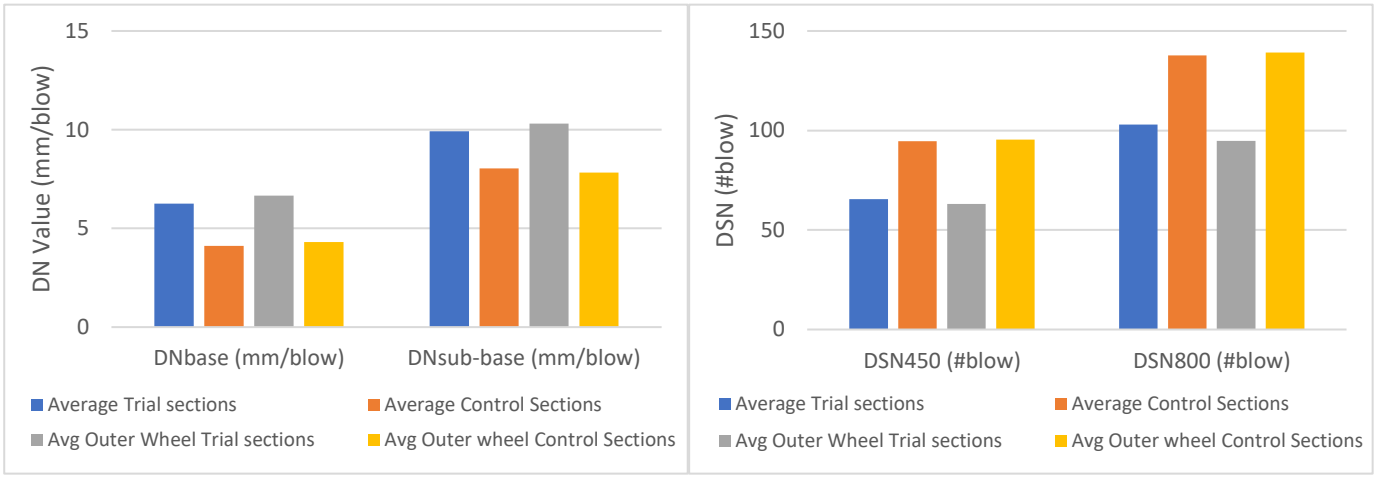


**Figure 2.** Laterite Base Trial Sections vs Crushed Base Control Sections

In the case of sections in cut and sections in fill comparison both trial and control sections as well as sealed and unsealed sections are taken into account and averaged. It is clearly demonstrated that for both the base and subbase the DN and DSN value of the sections in cut are stronger than the sections in fill as shown in Figure 3. Slight difference in DN and DSN average values is shown between all average and the outer wheel track only for the fill sections, while it is no significant difference for the cut section.

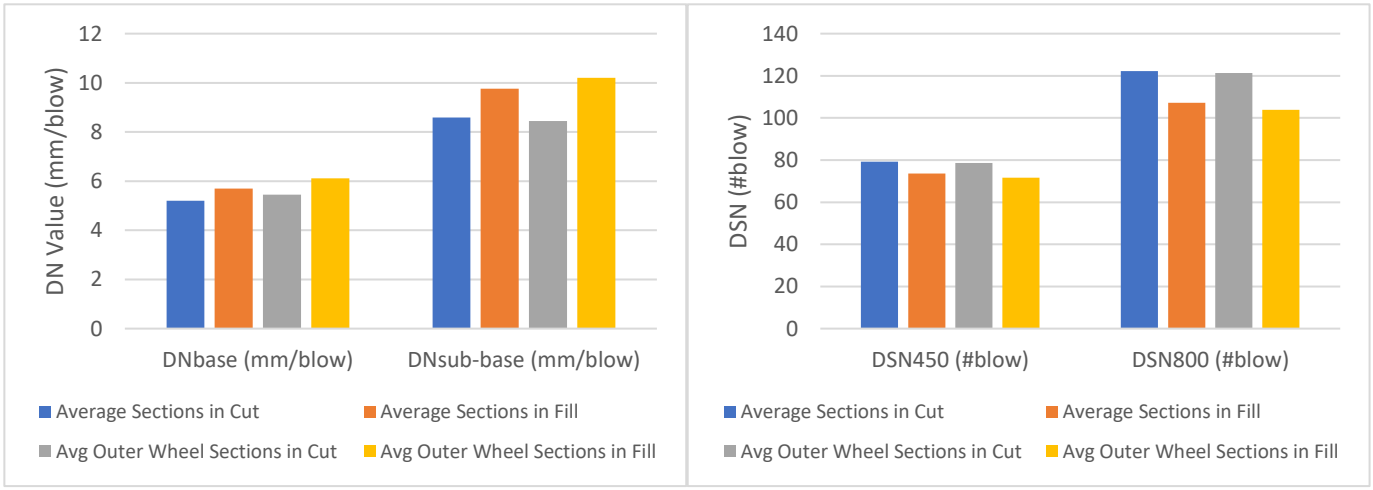


**Figure 3**. Sections in Cut vs Sections in Fill

In the case of sections with sealed and unsealed shoulders comparison, sections in cut and fill in the laterite base trial sections is taken into account excluding the crushed base control sections to avoid any bias as both the control sections are only with unsealed shoulder. The result seems opposite to what is expected for both the base and subbase layers, the DN and DSN value of the sections with unsealed shoulder shows more stronger than the sections with sealed shoulder, see Figure 4. Looking in details especially for the 3rd and 4th round monitoring for both all average and the outer wheel track only no difference in DN values is observed specially for the base layer. This is not the case however for the 1st and 2nd round

monitoring, which can be attributed to some errors in proper location of the sections in the earlier rounds.

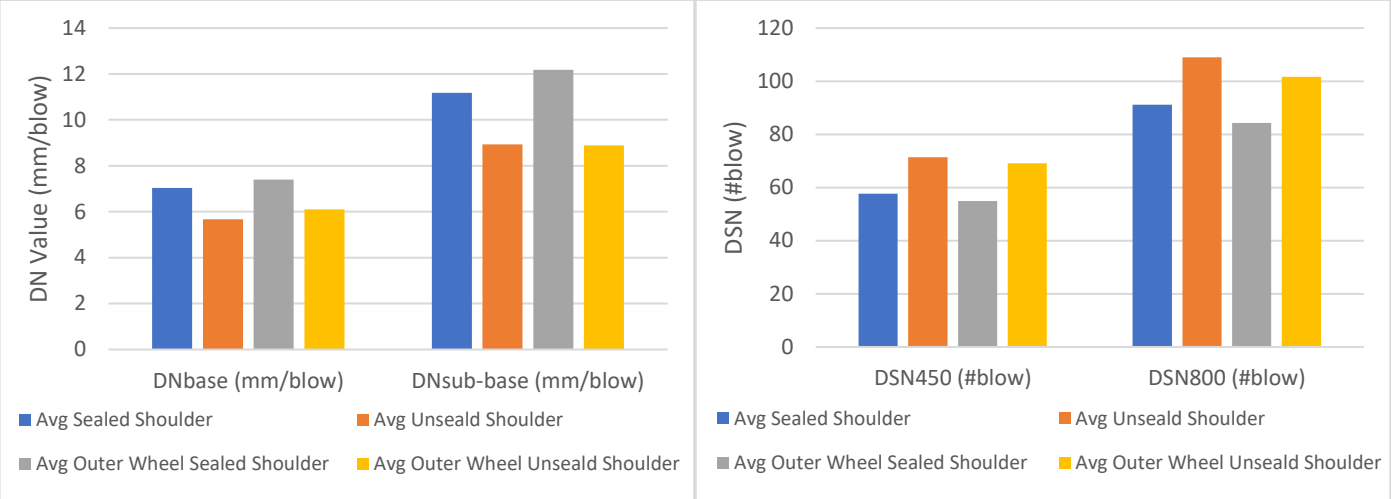


**Figure 4**. Laterite Base Sections with Sealed Shoulder vs Sections with Unsealed Shoulder

### 4.3 Visual Condition Assessment

Visual condition assessment has also been carried out on the trial and control sections. Generally, most sections of the monitoring are in a good condition, without significant or visible defects. In terms of performance between cut and fill sections as well as with sealed and unsealed shoulder section no significant difference is observed. However, with slight difference a better surface performance is visually observed in the crushed base control sections comparing to the laterite base trial sections.

Typical photographs of defects on the monitoring section during 4th round is shown in Figure 5 for each section. From the visual condition assessment commonly observed defect types are rough surface texture, ravelling and to some extent beginning of minor surface crack. However, there was no significant structural related defects such a rutting or crocodile cracking even for the laterite base unsealed section in both cut and fill sections.

| | |
|---|---|
|  |  |
| Roughness surface texture | Ravelling |
| ***Unsealed Shoulder Cut Section 1 – UC1*** | |
|  |  |
| Ravelling/ rough texture | No defect |
| ***Unsealed Shoulder Cut Section 1 – UF1*** | |
|  |  |
| Start of minor/surface crack | No defect |
| ***Sealed Shoulder Fill Section 1 – SF1*** | |

Start of ravelling

No defect

***Sealed Shoulder Cut Section 1 – SC1***

No defect

Rough surface texture

***Unsealed Shoulder Cut Section 2 – UC2***

No defect

Potential wheel path ravelling

***Sealed Shoulder Fill Section 2 – SF2***

Start of stone loss

No defect

***Unsealed Shoulder Fill Section 2 – UF2***

Rough surface texture

No defect

***Control Section 1 - Unsealed Shoulder Cut Section – CS1-UC***

No defect

Potential wheel path ravelling

***Control Section 2 - Unsealed Shoulder Fill Section – CS2-UF***

**Figure 5.** Illustrative typical defects

## 5. CONCLUSION

Generally, it can be stated that to reach on a sound comparative performance and comprehensive analysis of results on the long-term pavement performance an extended monitoring period of several years is needed. However, the following brief comparative performance is provided from the measurements and observations made so far.

Although the traffic volume in this trial section road is low, including all classes of trucks; both in terms of DCP structural test and visual assessment, except some minor surface texture defects, all of the laterite base trial sections are performing well. To a certain extent the crushed base control sections are performing better.

DCP test results in these sections reveals that the crushed base control sections perform better than the laterite base trial sections and the sections in cut are stronger than in fill while the shoulder sealing doesn't provide consistent effect on the layer strengths.

From this monitoring section, it can be demonstrated that for such low volume roads especially in areas where hard rock for crushed aggregate is scarce, a good performing pavement can be designed and constructed with such available natural gravel as base material in addition to its use as a subbase.

## 6. ACKNOWLEDGEMENT

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# PLANNING AND DESIGNING STANDARD OF RURAL ROAD CONSTRUCTION - AN EXPLORATORY STUDY: A CASE OF LUSAKA PROVINCE IN ZAMBIA

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## ABSTRACT

The state of rural roads in Zambia is very poor and in a deplorable condition. Drainages are missing, or where they exist, they are narrow, inadequate and not constructed correctly. Bridges are missing, old, inadequate or wrongly constructed and usually very poorly maintained. In most roads, the shoulders are not stable. From reviewed literature, several gaps in the planning, design, specifications, funding and general roads management in Zambia were identified as being the root causes of poor-quality rural roads. An in-depth literature review was carried out as secondary sources using journals, rural road construction handbook, peer reviewed articles, dissertations and the internet. In-depth interviews were further carried out with the staff at Ministry of Finance, Road Development Agency (RDA), National Road Fund Agency (NRFA), National Council for Construction (NCC), Rural Road Unit and also the Royal Highnesses and their subjects in Chongwe and Lusaka North areas. The results show that the planning is adequate but the problem lies with the planning personnel who are not adequately trained to undertake the tasks. Designs and specifications needed to consider the alignment requirements, technical performance, pavement solutions, material requirements and structures that are specific to an area. Results indicate that planners use a one-size fits all approach kind of designing resulting in the quality deficiency in some areas. The research assist government in developing and disseminating improved policies that assists in better planning, constructing and maintenance of rural roads. It introduces mitigatory actions and recommendations which the government can utilize in coming up with sustainable and reliable quality rural roads.

**Keywords:** Rural, Roads, quality, compaction, Transmitter road design.

## 1. INTRODUCTION

It has been acknowledged that rural roads should be treated as the last link of the transport network. Despite this, they often form the most important link in terms of providing access for the rural population. Their permanent or seasonal absence acts as a crucial factor in terms of the access of rural communities to basic services such as education, primary health care, water supply, local markets and economic opportunities (Donnges, 2003). In a study in Ethiopia (Dercon et al., 2008) on 15 villages that were surveyed between 1994 and 2004, they concluded that access to all – weather rural roads reduced poverty by 6.9 per cent and increased consumption growth by 16.3 per cent. Dercon and Hoddinott (2005) found that, in Ethiopia, an increase of 10 km in the distance from the rural village to the closest market town had a dramatic effect on the likelihood that the household purchased inputs. Mu and Van de Walle (2007) showed that markets in Vietnam were more likely to develop as a result of rural road improvements where communities had access to extended networks of transport infrastructure.

It was shown in Uganda that benefits from improving access to basic education depended on complementary investments in infrastructure (Deininger and Okidi, 2003). Road improvements in Bangladeshi led to lower input and lower transportation costs, higher production, higher wages and higher output prices (Khandker et al., 2011). Access to rural roads in Nepal improved the productive capacity of poor households (Jacoby, 2000). Rural road rehabilitation in Georgia increased the opportunities for off – farm and female wage employment (Lokshin and Yemtsov, 2005). Rehabilitation and maintenance of rural roads in Peru improved access and attendance to schools and child health centres (Escobal and Ponce, 2003). According to The Rural Accessibility Index of 2010 and also Torero and Chowdhury, 2004, majority of rural communities in Africa have inadequate and unreliable infrastructure services with only 34% of rural Africans living within 2 kilometres of an all - weather road compared to 59% in Latin America, 65% in East Asia and over 90% in other developed regions. Africa Infrastructure Country Diagnostic of 2010 indicated that even where feeder roads exist; the rural environment presents particular institutional challenges for road maintenance. Only half of the existing rural road network is in good or fair condition, which is much lower than the 80% found for the inter – urban network.

Pinstrup - Anderson and Shimokawa (2010) and Fan (2011) indicated that the provision of rural infrastructure contributed to the delivery of goods and services that promoted prosperity and growth, contributed to quality of life, including social well - being, health and safety, and the quality of the environment. It will help reduce the cost of inputs and transport to markets, also increase farmer's access to enlarged markets, facilitate trade flow and spur value addition and crowd – in investment. Foster and Briceno – Garmendia in 2010 stated that the variation in road quality throughout the various Sub Saharan African countries reflected several interacting factors. Firstly, the relation to affordability where the GDP per capita is most strongly correlated with the percentage of the main road network in good condition, signifying that richer countries tended to spend more on maintenance. No such clear relationship exists for rural roads. The second factor relates to topographic and climatic influences where mountainous and wet countries normally have poorer road conditions in both main and rural networks (Johannessen, 2008). Thirdly, they observed that countries with road funds and road agencies have considerably better road conditions than those that have neither.

Addo – Abedi, in 2007 noted that a number of African countries had embarked on reforms in the last few decades supported by four "building blocks" namely Ownership, Financing, Responsibility and Management. The main aim of the reforms was to manage roads as a business and bring them into the market place by charging for road use on a fee – for – service basis. The mean distance to services and community assets diminished significantly due to rehabilitation of rural roads in Zambia's eastern province (Kingombe, 2011). The purpose of this study therefore is:

1. To review whether the planning of rural road construction in Lusaka province is adequate.
2. To determine whether the design standards and the technology used in Lusaka province are appropriate.

## 2. RESEARCH METHODOLOGY

Primary data was collected through three check lists that were filled with data collected through observations and field measurements. To help the researcher understand how to collect this data, the researcher had to undergo Rural Road Construction and Maintenance training with The National Council for Construction for a period of four months. This programme consisted of two parts: The theory part comprising Mathematics, Road Rehabilitation and Maintenance, Construction Materials, Construction Management,

Pricing and Bidding, Communication Skills and Entrepreneurship and the Practical part comprising Road Rehabilitation and Maintenance only.

The research also relied on supplementary secondary data that was readily available from;

- National Road Fund Agency
- Road Development Agency
- National Council for Construction
- Ministry of Transport, Communication, Works and Supply
- Ministry of Local Government and Housing
- Ministry of Finance

Three areas were picked because of proximity, less transport cost, security reasons, assuredly supervised roads, ease of contacting the contractors and also the ease of sourcing the contract documents from the ministries involved. Two rural roads per area were also picked at random. Road dimension tests, road profile tests and physical check of the road features were conducted on the full length of these rural roads. The first test was the road dimension test using tapes to check the accuracy of the carriageway and the side drains. The second test was the road profile test using the line level were the camber of the carriageway and the longitudinal profile of the carriageway were checked and the final test was the visual test that was checking for the presence of culverts, culvert rings, wing walls, headwalls, ramps, outfalls, mitre drains, scour checks, laybys, ditch and the shoulder and these were presented in the form of check lists. The following were the check lists used:

### 2.1 Road Dimension Tests

The standard cross section of rural roads in Zambia is one having a carriageway of 5.5m, with a gravel coarse of 5m span, side slope of 1.2m, a ditch of 1m and a back slope of minimum 3:1 and a maximum of 1:1. Type of Tests carried out were simple checks on the dimensional accuracy of the construction works using measuring Tapes.

To Test for the camber of the carriageway and Checking on the longitudinal profile of the carriageway, the research used the line level. For the simple checks on the dimensional accuracy of the construction works, measuring Tapes were used.

### 2.2 Road Profile Tests

Two types of Tests were carried out.

1. Check on the camber of the carriageway
2. Check on the longitudinal profile of the carriageway

For both of them the line level was used.

### 2.3 Gravel Layer Test

To test the gravel for thickness of compaction and Degree of compaction, measuring Tapes and special laboratory tests were carried out.

#### *2.3.1 Compaction*

The compaction method is usually specified. The following are factors that can influence compaction.

- Moisture content
- Amount of compaction
- Thickness of layer

### 2.4 The Study Population and Sample

Leedy and Ormrod (2010) mention a two-stage descriptive survey as one of the means of data collection. In this study, the second stage data collection of descriptive survey was used. This approach works through collection of quantitative data coming from a designed checklist. This specific checklist was used for recording measurements from field survey. The target area being the sampled population was divided into three:

a. Two rural roads in Chongwe
b. Two rural roads in Lusaka West
c. Two rural roads in Lusaka North

### 2.5 Interviews and Checklist

Under qualitative analysis, structured interviews with headmen and their subjects, staff at National Council for Construction, Ministry of Finance staff, National Road Fund Agency staff, Ministry of Works and Supply and Ministry of Local Government and Housing staff were conducted. The data collected was used to come up with an informed opinion that was correlated to measurements collected. The results helped to identify the gaps in specifications and implementation. A desktop study using published literature on rural roads was also carried out.

Interviews and in-depth discussions were carried out with engineers under the Rural Road Unit and The National Council for Construction. This was done in order to understand the challenges that they went through and the successes as well. The interviews were aimed at obtaining preliminary data that would enhance the measurements. The interviews were limited to participants within Lusaka, the capital city, due to the short time that was required to get preliminary data and also due to the cost implications. Security reasons were also taken into account as the field visits required walking the whole length of the sampled rural road. A check list was adopted as the main research instrument which was based on the advantages that a representative sample would be realised with little time or costs. It was explained to the participants who assisted in the measurements. It was accompanied with a cover letter. The tool that was used in the research was a semi structured checklist. Interviews were another means of data collection and field measurements.

### 2.6 The Study Area

The study area was Lusaka Province. Lusaka province is one of the 10 provinces in Zambia. It is located in the southern part of the country. Lusaka province was taken because of its proximity to the ministries hence reducing on transport costs and lodging fees. Also, it was much easier to access data from the concerned institutions. Even interviews were easier to conduct with the officials as well. Efforts to prevent variability in sample size and analysis were made. The sample size was confined to Lusaka province because according to statistics, most of the rural roads are concentrated around the province.

## 3. FINDINGS AND DISCUSSION

The following data was collected on six rural roads from Lusaka West, Chongwe and Lusaka North areas. The results were compared to theory with the view of finding out whether our rural roads are built to specifications, or if not, why?

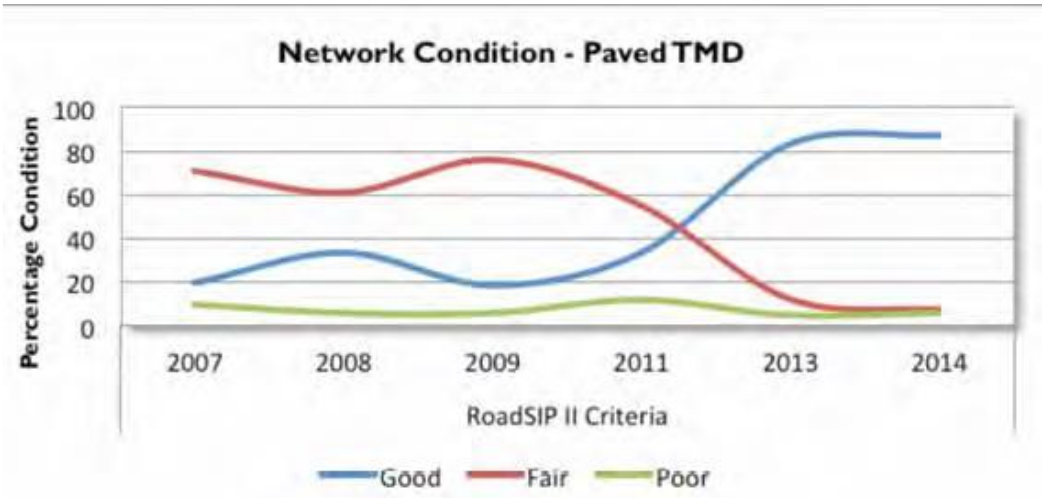


**Figure 1.** Network Condition – Paved TMD (Source: Road Sector Annual Work Plan for 2014)

In Zambia, the Road Development Agency undertakes annual surveys to determine the road condition indices for unpaved roads within the Core Road Network. The variations are considerable, as can be seen in figures 4-1 and 4-2 which give the status of the condition on the Core Road Network. For example, during the period 2014/2015 over 70% of unpaved Trunk, Main and District roads and 82% of the unpaved Primary Feeder Roads were in poor condition. The condition of PFR substantially remained unchanged.

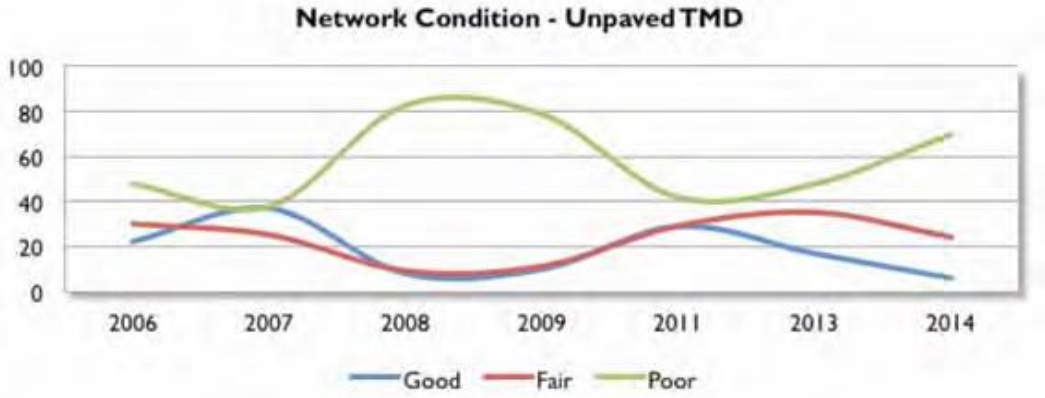


**Figure 2.** Network Condition – Unpaved TMD (Source: Road Sector Annual Work Plan for 2014)

It is clear from the findings that the planning process is followed adequately. It starts from the National Development Plans to The Transport Sector Plans. These are then incorporated into the Annual programs and Budgets. Local plans are then drawn from them. That is when Project plans are done and then the Detailed plans and finally the Maintenance plans are done. All these plans are governed by a Legal and Regulatory framework.

The Roads in Zambia are properly classified and those providing access to and from local communities are often under the jurisdiction of the local authorities. The government develops a set of design guidelines. These design guidelines include general directions on the geometric features of the roads, such as appropriate dimensions of the road cross – section and curvature, surfacing options, drainage solutions and road reserves.All public expenditure is governed by a comprehensive set of procedures and directives detailing how funds are to

be used and accounted for. These procedures include budgeting and accounting procedures as well as detailed regulations on the contracting arrangements.

The planning process forms the basis for all budgeting and resource scheduling required in civil works projects. Roads to be constructed, improved or maintained under a particular programme are not selected in an arbitrary manner. These are done in distinct stages. The initial identification is the first step in the preparation of a list of proposed roads to be improved and maintained. This initial list is in most cases prepared with the involvement of the local communities and it must meet the pre – determined criteria by the central government. This is done in order to qualify or disqualify those roads that meet or don't meet certain criteria, are or aren't technically or economically feasible or are likely or not likely to have the expected impact. Local participation in the ranking of projects for screening is through elected representatives.

A more detailed assessment for supporting investment Cost needs is estimated and socioeconomic data assembled. After the screening and the appraisal stage, roads are selected against the limited resources. The roads are then ranked based on social impact, economic impact, and environmental impact. The road with the best score is then selected. As in all infrastructure works, the three main criteria for finally selecting a rural road are Technical Feasibility, Economic Justification and Social Considerations.

On the spot check on six rural roads that were picked in Lusaka North, Lusaka West and Chongwe, the following data was collected.

**Transmitter Road in Lusaka West of Lusaka District**

Total Length of Road: 2.5km; Carriageway: 5.5m.

**Table 1**. Transmitter Road Dimension Test (Rural road dimension test using the tape)

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriageway | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.5m, and 0.2m | Field | 10m | +/ - 20mm |

**Table 2.** Transmitter Road Profile Test (Rural road dimension test using the line level)

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | 0.1m | Field | 20m | +/ - 10mm |
| Longitudinal profile | - | Field | 20m | +/ - 50mm |

**Table 3.** Transmitter Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |
| Surface Material | Laterite | Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | <6% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | 1m |
| Side Slope | 1:4 | 0.2m |
| Side Drain Left | 1m | 0.5m |
| Side Drain Right | 1m | 0.5m |
| Tree and Stump Removal | 6m clearance from centre | Not adhered to |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | No presence of boulders observed |
| Clear Side Drain | Must be cleared | Overgrown with grass |
| Clear Mitre Drains | Must be cleared | Overgrown with grass |
| Scour Checks | 12% gradient must be 6m apart | No Scour Checks observed |

| | | |
|---|---|---|
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Present but less than 5m from the Side Drain |
| Gravel Surface Thickness | 125mm after compaction | Less than 50mm thickness |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | No Culvert for the entire stretch of the road |
| Culvert Pipe Size | 600mm | No Culverts Pipes present |
| Wing Walls | 45°<Centreline<75° | No Wing Walls present |
| Head Walls | 200mm | No Head Walls present |
| Ramp | 20m approach distance | No Ramp present |
| Layby | 5m | No Layby found |

**China – Zambia Road in Lusaka West of Lusaka District**

Total Length: 1.9 km; Carriageway: 5.5m

**Table 4.** China – Zambia Road Dimension Test

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriage | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.8m and 0.2m | Field | 10m | +/ - 20mm |

**Table 5.** China – Zambia Road Profile Test

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | <0.1m | Field | 20m | +/ - 10mm |
| Longitudinal profile | - | Field | 20m | +/ - 50mm |

**Table 6.** China – Zambia Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |
| Surface Material | Laterite | Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | <6% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | 1m |
| Side Slope | 1:4 | 0.2m |
| Side Drain Left | 1m | 0.8m |
| Side Drain Right | 1m | 0.8m |
| Tree and Stump Removal | 6m clearance from centre | Not adhered to |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | Presence of boulders observed along the road |
| Clear Side Drain | Must be cleared | Overgrown with grass |
| Clear Mitre Drains | Must be cleared | Overgrown with grass |
| Scour Checks | 12% gradient must be 6m apart | No Scour Checks observed |
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Present but less than 5m from the Side Drain |
| Gravel Surface Thickness | 125mm after compaction | 125mm thickness |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | No Culvert for the entire stretch of the road |
| Culvert Pipe Size | 600mm | No Culverts Pipes present |
| Wing Walls | 45°<Centreline<75° | No Wing Walls present |

| | | |
|---|---|---|
| Head Walls | 200mm | No Head Walls present |
| Ramp | 20m approach distance | No Ramp present |
| Layby | 5m | No Layby found |

**Kapepe School to Nyendwa Bar Road in Chongwe District**
Total Length: 10.8 km; Carriageway: 5.5m

**Table 7.** Kapepe – Nyendwa Road Dimension Test

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriage | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.5m and 0.2 | Field | 10m | +/ - 20mm |

**Table 8.** Kapepe – Nyendwa Road Profile Test

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | <0.1m | Field | 20m | +/ - 10mm |
| Longitudinal profile | - | Field | 20m | +/ - 50mm |

**Table 9.** Kapepe – Nyendwa Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |
| Surface Material | Laterite | Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | <6% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | 1m |
| Side Slope | 1:4 | 0.2m |
| Side Drain Left | 1m | 0.5m |
| Side Drain Right | 1m | 0.5m |
| Tree and Stump Removal | 6m clearance from centre | Adhered to specifications |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | No presence of boulders observed |
| Clear Side Drain | Must be cleared | Overgrown with grass |
| Clear Mitre Drains | Must be cleared | Overgrown with grass |
| Scour Checks | 12% gradient must be 6m apart | No Scour Checks observed |
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Present at 5m from the Side Drain |
| Gravel Surface Thickness | 125mm after compaction | Less than 50mm thickness |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | Two Culverts per km observed |
| Culvert Pipe Size | 600mm | 300mm Culverts Pipes |
| Wing Walls | 45°<Centreline<75° | Not to specifications |
| Head Walls | 200mm | Not to specifications |
| Ramp | 20m approach distance | < 20m approach distance |
| Layby | 5m | No Layby found |

**Evergreen to Nyendwa Road in Chongwe District**
Total Length: 9km; Carriageway: 5.5m

**Table 10.** Evergreen – Nyendwa Road Dimension Test

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriage | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.6m and 0.1m | Field | 10m | +/ - 20mm |

**Table 11.** Evergreen – Nyendwa Road Dimension Test

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | 0.2m | Field | 20m | +/ - 10mm |
| Longitudinal profile | | Field | 20m | +/ - 50mm |

**Table 12.** Evergreen – Nyendwa Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |
| Surface Material | Laterite | Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | <6% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | 1m |
| Side Slope | 1:4 | 0.1m |
| Side Drain Left | 1m | 0.6m |
| Side Drain Right | 1m | 0.6m |
| Tree and Stump Removal | 6m clearance from centre | Adhered to |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | No presence of boulders observed |
| Clear Side Drain | Must be cleared | Cleared |
| Clear Mitre Drains | Must be cleared | Cleared |
| Scour Checks | 12% gradient must be 6m apart | Scour Checks observed |
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Present and at 5m |
| Gravel Surface Thickness | 125mm after compaction | Spot gravelling 125mm thickness |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | 6 Culverts |
| Culvert Pipe Size | 600mm | 300mm Culverts Pipes |
| Wing Walls | 45°<Centreline<75° | Present |
| Head Walls | 200mm | Present |
| Ramp | 20m approach distance | Ramp present |
| Layby | 5m | No Layby found |

**Headman Mpandika's Palace Road in Lusaka North**
Total Length: 4.2km; Carriageway: 5.5m

**Table 13.** Mpandika Palace Road Dimension Test

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriage | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.6m & 0.2m | Field | 10m | +/ - 20mm |

**Table 14.** Mpandika Palace Road ProfileTest

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | 0.1m | Field | 20m | +/ - 10mm |
| Longitudinal profile | | Field | 20m | +/ - 50mm |

**Table 15.** Mpandika Palace Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |
| Surface Material | Laterite | Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | 12% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | 1m |
| Side Slope | 1:4 | 0.2m |
| Side Drain Left | 1m | 0.6m |
| Side Drain Right | 1m | 0.6m |
| Tree and Stump Removal | 6m clearance from centre | Adhered to |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | No presence of boulders observed |
| Clear Side Drain | Must be cleared | Overgrown with grass |
| Clear Mitre Drains | Must be cleared | Overgrown with grass |
| Scour Checks | 12% gradient must be 6m apart | No Scour Checks observed |
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Not Present |
| Gravel Surface Thickness | 125mm after compaction | Earth road |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | 3 Culverts |
| Culvert Pipe Size | 600mm | 600mm Culverts Pipes |
| Wing Walls | 45°<Centreline<75° | No Wing Walls present |
| Head Walls | 200mm | Head Walls present |
| Ramp | 20m approach distance | No Ramp present |
| Layby | 5m | No Layby found |

**Spin-Along Road in Lusaka North**

Total Length: 3.2km; Carriageway: 5.5m

**Table 16.** Spin - Along Road Dimension Test

| Test | Average | Location | Every | Tolerance |
|---|---|---|---|---|
| Width of carriage | 5.5m | Field | 300m | +/ - 50mm |
| Width and depth of side drains | 0.5m and 0.3m | Field | 10m | +/ - 20mm |

**Table 17.** Spin - Along Road Profile Test

| Test | Average | Location | Test Interval | Tolerance |
|---|---|---|---|---|
| Camber | 0.1m | Field | 20m | +/ - 10mm |
| Longitudinal Profile | Ok | Field | 20m | +/ - 50mm |

**Table 18.** Spin - Along Road Condition Inventory Check List

| Road Condition Inventory | Specifications | Comments |
|---|---|---|
| Soil Type | Laterite | Laterite soil present |

| | | |
|---|---|---|
| Surface Material | Laterite | In situ Laterite |
| Road Surface Width | 5.5m | 5.5m |
| Maximum Gradient | 12% | <6% |
| Camber | 5% after compaction | 5% |
| Shoulder | 1.2m | No Shoulder observed |
| Side Slope | 1:4 | 0.3m |
| Side Drain Left | 1m | 0.5m |
| Side Drain Right | 1m | 0.5m |
| Tree and Stump Removal | 6m clearance from centre | Adhered to |
| Sand Removal | Must be removed | Done |
| Boulder Removal | <0.5m boulders buried along the road | No presence of boulders observed |
| Clear Side Drain | Must be cleared | Overgrown with grass |
| Clear Mitre Drains | Must be cleared | Overgrown with grass |
| Scour Checks | 12% gradient must be 6m apart | No Scour Checks observed |
| Grass Planting | Must be done | Done |
| Catch Water Drains | 5m away from the Ditch | Not Present |
| Gravel Surface Thickness | 125mm after compaction | No gravel |
| Culverts per km | For Maximum Gradients of 12%, 2 to 4 per km | No Culvert for the entire stretch of the road |
| Culvert Pipe Size | 600mm | No Culverts Pipes present |
| Wing Walls | 45°<Centreline<75° | No Wing Walls present |
| Head Walls | 200mm | No Head Walls present |
| Ramp | 20m approach distance | No Ramp present |
| Layby | 5m | No Layby found |

## 4. LIMITATIONS

This research was only conducted in Lusaka West, Chongwe and Lusaka North areas because most of the ministries and agencies responsible for rural road design, approval, procurement, construction and supervision are located in Lusaka. Coupled to this were also issues of limited resources and time constraints. Security concerns to the researcher were also considered. Only two rural roads per area were selected arbitrarily and assessed to help understand the level of the problem.

Another limiting factor was the scarce availability of data on causes of poor quality of rural roads. That which exists is often not readily available or tailored to local conditions. Engineering guidelines are either very old or have not been refined in recent years to exploit possible potential cost savings. There are inadequacies in knowledge also and the issues of climate change adaptation and mitigation pose difficult questions about how to design, plan and build resilient rural roads and transport services without incurring even greater costs, either on the environment or on strained government budgets.

## 5. RECOMMENDATION

The potential contribution of rural roads to the socio – economic development of Zambia cannot be overemphasised. The impact of quality rural road infrastructure could be far – reaching, going beyond poverty reduction – a goal which many leaders now view as unambitious – to sustain economic growth and structural transformation. Zambia's large and sparsely populated landmass underscores the relevance and important role of rural roads in the successful implementation of most, if not all, development policies. In essence, poor quality rural road systems negatively affect other sectors of the economy.

1. The Public Service Management Division must recruit qualified personnel to fill up the vacant positions. The local councils must be encouraged to employ competent people who will help, especially during the planning process, to come with detailed plans, project plans and local plans. These when forwarded to Central government will help with the formulation of Annual Programmes and Budgets, Transport Sector Plans and finally National Plans. This will assist in limiting Central Government's role to coordination, guidance and oversight, policy, formulating guidelines and providing technical support in planning and contract management thereby reducing bureaucracy particularly in making payments to contractors.
2. Design standards should be based on reliability and durability not just concentrating on accessibility. We need rural roads that are adequate, cost effective and sustainable. Standards such as economic road access should place importance on essential access, spot surface improvement in critical seasons, on surface drainage and essential structures rather than on geometric characteristics determined by design speed. Attention must also be paid to topography.

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# TRIP GENERATION OF ADULT WORKERS: A CASE OF GHANA

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## ABSTRACT

Understanding the travel behaviour of road users is important in the development of transportation plans. In Ghana, most studies focus on mode choice modelling with truly little studies on trip generation. This paper examines the influence of household and individual characteristics together with other explanatory variables on trip generation using data from the 2012 Ghana Transport Indicator Database Survey which was conducted by the Ghana Statistical Service. Linear regression models were used to model the number of trips by car, bicycle, motorcycle, foot, taxi and bus for all working adults. The results from the study show that gender, age, education level and residential location all show a significant impact on the number of trips generated for the different trip modes. From the results, the cultural background of a worker also significantly affect bicycle trips a worker make. Also, adult household is that reside in the city center make fewer trips by car than similar adults that live outside the city center. The number of trips generated by an adult worker can also be used to explain the perception variables estimate. The model results can also be used to make trip generation prediction in developing transportation plans for Ghana.

## 1. INTRODUCTION

Travel demand forecasting plays a significant role in the development of transportation plans and evaluation of transportation infrastructure. The travel needs/demands keep on changing as such it is imperative to make plans that accounts for the possible future changes. In developing countries, especially Ghana, there is a growing need for a transportation system which captures the growing needs of its population. In Ghana, the vehicle population grows higher than the transportation network as such increasing pressure on the transportation infrastructure (The Report: Ghana 2018). Also, land use planning conflicts with transportation planning. For example, residential areas being used for commercial purposes. There is a critical need to understand the travel pattern of users to be able to make better prediction in meeting the transport needs of the country. Therefore, this study contributes towards developing a trip generation model which relates individual and household characteristics, residential location and other perception explanatory variables to the number of trips by mode.

Trip generation models is the first of the traditional four-step travel demand model which predicts the number of trips by purpose. The model determines the number of trips undertaken by a household or individual usual based on the characteristics at the person level and household level. Trip generation models employ the traditional linear regression model to determine its model estimates.

## 2. LITERATURE REVIEW

The trends of trip generation are common and well developed. In the United States, it is done by purpose as trip generation captures the reason behind a trip being made. An example of how trip generation by purpose is done in the US is reflected in the studies by Lim and Srinivasan (2011). Their study focused on comparing four different econometric structures (linear regression, log linear model, negative-binominal model, and ordered-probit model) for trip generation modelling for three trip purposes – home-based-work (HBW), home-based-other (HBO) and non-home-based (NHB). The data source for their study was from the 2001 and 2009 U.S. National Household Travel Surveys. The 2001 data was used to estimate the trip generation models and the 2009 data was used to validate the estimated model. Their findings recommend the use of ordered-probit models against the traditional regression models.

In Ghana and most developing countries, there appear to be few studies on trip generation, however there is a bunch of studies which have looked at mode choice. For example, Abane (2011) study the attitudes and travel behaviour of Ghanaians from four metropolitan areas – Accra, Tamale, Kumasi, Sekondi-Takoradi. Their study shows that mode choice is significantly impacted by the affordability and availability of those modes. This study is supported by the paper by Agyemang (2017) which identifies perceptions of convenience (that can be related to affordability and availability) as a strong predictor for choosing a 'trotro' (minibus) over a car. Additionally, older persons and persons with higher levels of education were less likely to travel by trotro than car and this result is consistent with the finding by Ye and Titheridge (2017). In comparing the mode choice of employees in the formal sector in the two largest cities in Ghana, that is Accra and Kumasi, Abane (1993) and Amoh-Gyimah and Nimako Aidoo (2013) found that high income workers are less likely to use public transport, Furthermore, findings from Amoh-Gyimah and Nimako Aidoo (2013) show that workers with households of family sizes greater than two are less likely to choose non-motorized transport. From their study, the distance from home significantly affects mode choice as workers are less likely to travel to work by public transport for distances greater than 5km.

In terms of trip generation by purpose, Takyi (1990) employed the cross-classification method to determine household characteristics and its influence in trip making. Results from the study significantly show that an increase in the household size will increase the trotro and walking trip rate for work, shopping and school trips. Also, Afolabi et al. (2017) shows a relationship between commuter's frequency of travel by their level of income.

Overall, there has been appreciable study on mode choice in developing countries but very few on trip generation. Therefore, this paper aims to study the trip generation by mode of working adults in Ghana.

### 2.1 Data

This study was performed using data from the 2012 Ghana Transport Indicator Database Survey which was conducted by the Ghana Statistical Service. This data which represents the second phase of the first ever nationwide household-based transport survey was conducted over a 3-month period between September 2012 and December 2012. The survey was administered to 6000 households which represent all the households in Ghana from all the ten regions. However, this analysis focuses only on all adult workers. The data includes some basic socio-economic characteristics of the individuals of a household (such as age, gender, ethnic group) in addition to variables that show the detailed characteristics of the individual's educational background (such as highest educational level, current grade, means of transport to and from school). Also, the data provides some socio-economic characteristics of the household characteristics such as size and income, and some location variables such region and district where household lives.

The survey also collected data on the various transport activities of individuals in the household with respect to health, economic activities, market activities and other household activities. The detail characteristics of the individual and households' characteristics makes the data viable in understanding the travel behaviors of households in respect to mode choice by purpose (work, school, health facility, market) and help generate a travel behavior model for the nation.

The data contains individual and household variables for 23238 individuals from 6000 households' selection from a total of 400 Enumeration Areas (EA). However, the data does not explicitly provide any variable that identifies each household member belonging to the same household. Therefore, with supplemental information on the enumeration areas listing that was used for the survey, which was provided by the Ghana Statistical services, a unique Household ID code was generated to match the household members with their respective households. The data provides a variable as household number (HHID) however, a frequency distribution of this variable showed that there were 20 household number with 15 of them each having more than 1450 households. From a further probe into this variable, we were able to identify that the household numbers referred to the number (staring from 1) assigned to each household that was randomly selected in each enumeration area for the interview. Therefore, a unique code combining each HHID in their respective EA was generated. For example, a code of 2312 refers to an EA of 231 and a HHID of 2). With this code generated, household members were linked to their respective households and we were able to generate some household characteristics such as household size, and total number of adults, children, workers and students in a household.

Out of the national sample of 23,238, 58.4% of them representing 12734 were adults (that is 18 years or older) from which 9836 are engaged in some sort of employment activity. Further basic statistics of this study is based on the sample size from adult workers.

In preparing the data for analysis, the data was subject to thorough cleaning and some data variables were reclassified and adjusted for clarity. There were some inconsistencies in the data sample, therefore some cases were filtered out to help clean the data. Some data cases showed a value of zero for the average travel time to/from school, work, health facility, and market, therefore careful check was done before filtering out the zero values in this variable. For school-related purpose, the average travel time of zero was filtered off for every transport means except boarding school. It is assumed that there is no major travel activity from residence or any origin to a school if it is a boarding school. For health and market, the average travel time of zero for every transport mode was filtered off. In terms of work, 1863 of the cases had an average travel time of zero. However, a crosstabs of average travel time to/from work with the variable: "does work require travel from residence", revealed that the time of zero was stemming from households that required travel from residence to work. A cross tabulation of the average travel time with the variable: "means of travel to work" shows that the average travel time of zero is predominantly by traveling by foot thus making it difficult to explain. Therefore, the 1863 cases were kept for this analysis purpose.

The different modes of transport for each purpose were also reclassified. All trips done by a shared public taxi or individual taxi was reclassified as taxi based on purpose. All means of transport by bus or 'trotro', a public minibus, were classified as bus, and the 'other' variable represented all other means of transport including boat/canoe/ferry and train. Therefore, the main means of transport identified in this data are taxi, bus, private cars, motorcycles, bicycles, foot and others.

Due to the constant evolution of the education system in Ghana, the highest-grade variable of the individuals in the household were reclassified into a standard educational system for easy comprehension.

*Data Descriptive*

Thorough cleaning and consistency checks generated a clean sample of 9833 cases with Table 1 showing a brief description of the key variables considered in this analysis describing the travel behavior of the various household workers. Table 1 presents descriptive for all workers, workers in households that own car, own bicycle or motorcycle. The full sample shows a gender distribution of 53% female and 47% male with an average age of 38.16. On average, there are about 4.86 persons per household, 2.15 children and 2.72 adults per household. In terms of culture, 46.8% of the households are from the Akan ethic group, 19.7% are Mole Dagbanis, 13.1% are Ewes, 6.7% are Ga/Dangmes with the remaining 12.8% belonging to the other ethnic groups. The highest education level of all persons in the household were also considered with only 1.4% of the workers having a bachelor's degree. Table 1 also presents the monthly income each household. Residential location of household, marital status of household person, religion and some perception variables. Descriptive of the households' vehicle ownership – 28.4% of the households' own bicycles, 8.75% own motorcycles, 4.8% own cars and 0.4% each own busses and trucks.

Figure 1 shows the frequency distribution of the total number of trips by car, bus, taxi, motorcycle and bicycle made by workers in the last seven days from the day the respondent completed the survey. For trips on foot, the number of trips the worker makes on a normal day was recorded as such Figure 2 shows the frequency distribution for that. In both figures, the number of trips after the 40th trip (which represents 0.1% of the sample) was aggregated with the 40th trip.

**Table 1:** Connected components and average clustering coefficient

| Variable | Proportion of households by trip mode | | | |
|---|---|---|---|---|
| | All modes | Car | Bicycle | Motorcycle |
| **Gender** | | | | |
| Male | 47.00 | 51.40 | 51.10 | 53.50 |
| Female | 53.00 | 48.60 | 48.90 | 46.50 |
| **Age Categories** | | | | |
| 18-24 | 14.00 | 14.40 | 14.60 | 13.60 |
| 25-44 | 56.20 | 60.50 | 56.00 | 62.70 |
| 45-64 | 24.80 | 23.70 | 24.50 | 20.80 |
| >=65 | 5.00 | 1.50 | 4.90 | 2.90 |
| **Highest Education Level** | | | | |
| Less than middle school | 19.10 | 8.20 | 15.40 | 13.60 |
| Middle school graduate/ BECE | 25.90 | 23.00 | 15.70 | 19.00 |
| Some High School | 2.00 | 2.70 | 1.40 | 2.00 |
| Vocational Training | 2.00 | 3.60 | 1.20 | 1.60 |
| SSCE certificate/ A level certificate | 8.50 | 14.60 | 6.50 | 10.20 |
| Training College/Polytechnic | 2.70 | 7.80 | 1.70 | 4.20 |
| Bachelors | 2.40 | 18.40 | 1.30 | 4.10 |
| Other | 0.70 | 2.70 | 0.50 | 1.00 |
| HH member currently in school | 5.70 | 14.40 | 6.20 | 6.60 |
| Total number of students in household | | | | |
| **Household monthly Income** | | | | |
| Monthly income less than 200.01 ghc | 38.10 | 5.30 | 43.40 | 32.30 |
| Monthly income between 200.01 ghc and 600 ghc | 34.40 | 26.60 | 34.00 | 36.50 |
| Monthly income between 600.01 ghc and 1000 ghc | 12.30 | 19.70 | 10.20 | 15.20 |
| Monthly income between 1000.01 ghc and 1200 ghc | 3.50 | 10.60 | 3.30 | 6.20 |
| Monthly income greater than 1200 ghc | 6.00 | 32.30 | 6.40 | 7.20 |
| **Marital Status** | | | | |
| Married | 68.30 | 67.40 | 76.60 | 80.70 |
| Divorced/Separated | 5.90 | 3.20 | 2.70 | 2.00 |

| | | | | |
|---|---|---|---|---|
| Widowed | 5.20 | 2.30 | 3.40 | 1.60 |
| Never married | 20.60 | 27.10 | 17.20 | 15.70 |
| **Ethnicity** | | | | |
| Akan | 46.80 | 67.20 | 23.00 | 25.90 |
| Ga/Dangme | 6.70 | 0.40 | 2.60 | 2.20 |
| Ewe | 13.10 | 12.50 | 9.00 | 8.00 |
| Mole Dagbani | 19.70 | 8.70 | 39.00 | 36.60 |
| Other ethnicity | 12.80 | 3.00 | 25.70 | 26.10 |
| **Religion** | | | | |
| Christian | 72.20 | 88.60 | 52.00 | 53.40 |
| Islam | 17.60 | 8.00 | 32.90 | 37.40 |
| Traditional | 5.10 | 0.20 | 11.00 | 5.80 |
| Other religion | 5.10 | 3.20 | 4.00 | 3.40 |
| **Residential location** | | | | |
| Houselhold member in urban area | 41.30 | 77.00 | 30.20 | 47.90 |
| Houselhold member in rural area | 58.70 | 23.00 | 69.80 | 52.10 |
| Household lives in city center | 4.70 | 8.20 | 2.30 | 1.90 |
| Household lives in town | 35.80 | 27.90 | 27.60 | 35.70 |
| Household lives in a suburban area | 32.40 | 53.70 | 26.30 | 28.20 |
| Household lives along a major road | 8.50 | 6.30 | 13.20 | 10.90 |
| Household lives on the farm | 8.50 | 1.30 | 15.10 | 9.80 |
| Household lives near transport terminal | 0.20 | 0.00 | 0.00 | 0.00 |
| Other household location | 8.70 | 1.90 | 14.80 | 12.90 |
| **Regional census** | | | | |
| Western | 9.80 | 4.20 | 3.70 | 3.70 |
| Central | 6.30 | 4.20 | 1.20 | 1.40 |
| Greater Accra | 12.90 | 32.60 | 6.20 | 6.00 |
| Volta | 8.00 | 2.10 | 8.40 | 8.90 |
| Eastern | 11.60 | 13.70 | 4.30 | 3.40 |
| Ashanti | 19.80 | 28.80 | 9.60 | 10.80 |
| Brong Ahafo | 10.80 | 7.20 | 16.30 | 13.10 |
| Northern | 11.20 | 5.20 | 27.20 | 31.40 |
| Upper east | 6.50 | 0.60 | 15.70 | 12.00 |
| Upper west | 3.10 | 0.80 | 7.40 | 9.30 |
| Sekondi Takoradi | 1.40 | 1.10 | 0.10 | 0.20 |
| Gomoa East (Central) | 0.60 | 1.30 | 0.00 | 0.00 |
| Accra Metropolitan Area | 4.80 | 13.70 | 1.60 | 2.40 |
| Ho Municipal | 0.20 | 0.00 | 0.20 | 0.20 |
| Kwaku North (Eastern Region) | 0.70 | 0.40 | 1.30 | 1.50 |
| Kumasi Metropolitan Area (Ashanti Region) | 6.90 | 20.70 | 1.50 | 5.00 |
| Techiman (Brong Ahafo Region) | 0.90 | 0.80 | 1.20 | 1.40 |
| Tamale Metro | 1.70 | 4.40 | 3.90 | 9.50 |
| Bolgatanga Municipal (Upper East Region) | 0.90 | 0.20 | 1.80 | 1.70 |
| Wa Municipal (Upper West Region) | 0.30 | 0.80 | 0.50 | 1.40 |
| **Vehicle Ownership** | | | | |
| Bicycle | 28.40 | 17.12 | 100.00 | 57.30 |
| Motorcycle | 8.75 | 10.57 | 17.70 | 100.00 |
| Car | 4.80 | 100.00 | 2.90 | 5.81 |
| Bus | 0.40 | 3.00 | 0.20 | 0.80 |
| Truck | 0.40 | 1.90 | 0.54 | 1.50 |
| **Perception Variables** | | | | |
| Bus route convenient | | | | |
| Yes | 47.10 | 46.10 | 44.60 | 48.10 |

| | | | | |
|---|---|---|---|---|
| No | 39.40 | 43.30 | 42.90 | 42.60 |
| Satisfied with bus condition | | | | |
| Yes | 70.30 | 75.30 | 63.60 | 66.60 |
| No | 16.10 | 14.20 | 23.90 | 24.30 |
| Satisfied with bus frequencies schedule | | | | |
| Yes | 52.60 | 67.00 | 46.40 | 56.00 |
| No | 32.70 | 22.20 | 39.90 | 33.10 |
| First important transport problems | | | | |
| Transport fares too high | 19.40 | 11.00 | 26.40 | 22.50 |
| Long delays at transport station | 22.00 | 14.40 | 20.10 | 18.60 |
| Bad roads | 39.00 | 34.90 | 39.10 | 39.10 |
| Traffic jam | 11.00 | 30.00 | 5.10 | 7.90 |
| Other transport problems | 3.00 | 4.90 | 4.20 | 5.70 |

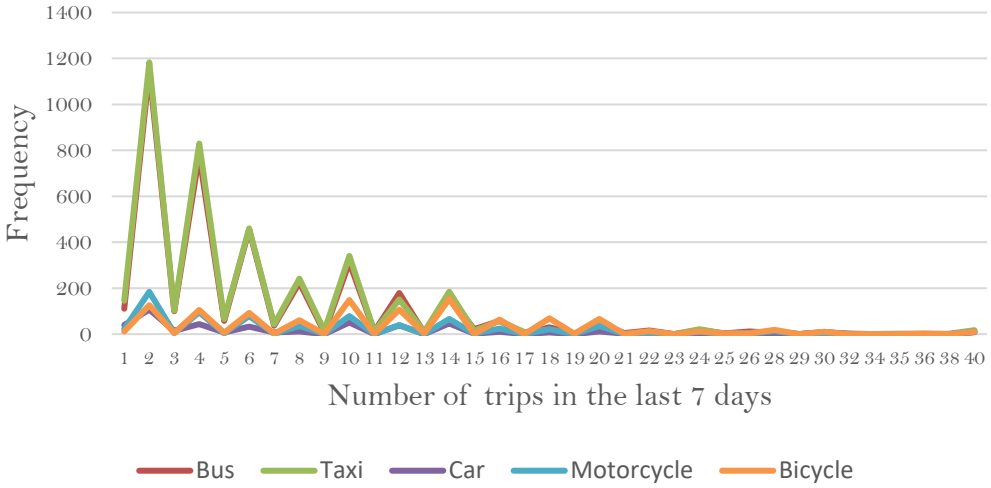


**Figure 1.** Frequency Distribution of the Total Number of Trips Per Mode

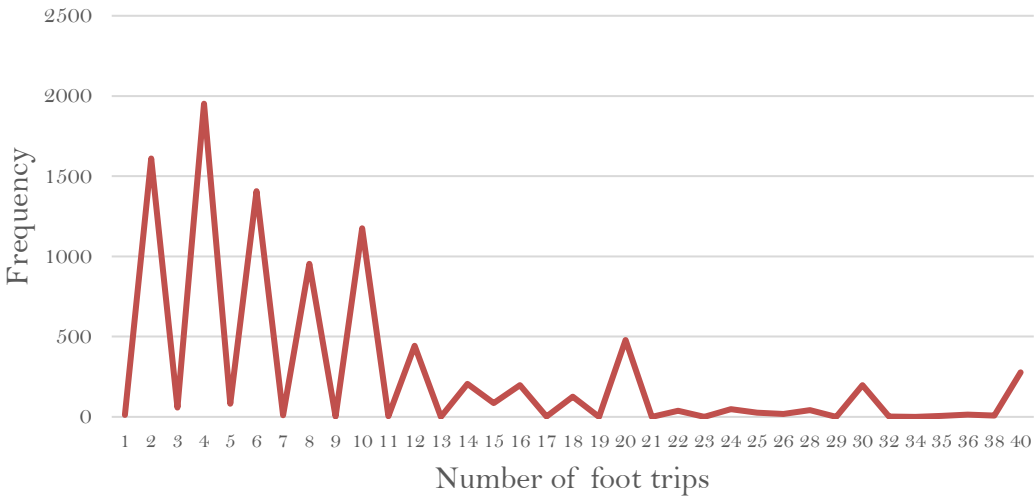


**Figure 2.** Frequency Distribution of the Total Number of Foot Trips on a Normal Day

## 3. METHODOLOGY AND ANALYSIS

This section of the paper discusses the modeling methodology used for analysis. In understanding how household characteristics, person characteristics, residential location, and vehicle ownership impact the frequency of trips made by a working adult, the conventional linear regression model (give reference) was employed. The Linear regression model is used extensively for trip generation models. The model developed examines the relationship between the number of trips a working adult makes for all trip purposes based on a set of explanatory variables. The general form of this model is given by:

$$Y_i=\beta_0+\beta_1 X_1+\beta_2 X_{(2)}+\cdots+\beta_i X_i+\xi_i$$

where

i= index for households

$Y_i$= number of trips made by household i for a given purpose

$\beta_0$= constant term which captures the mean effect of excluded factors

$X_i$= explanatory variable

$\beta_i$= coefficient of explanatory variable to be estimated

$\xi_i$= random error term which captures the impact of unobserved characteristics

## 4. FINDINGS

In this section, we present the results of the linear regression model with the coefficients of the estimate and their t-statistics as shown in Table 2. All the explanatory variables explain their impact on the number of trips made except for the perception variables which may not explain the number of trips; as their perception is controlled by all the other explanatory available such as education level, income, and residential location. The number of trips rather explain these perception variables.

The negative coefficients of the household size on trips made by car and bus show that the number of trips decreases with increasing household size for car and bus trips. From the results, workers in households with more adults make fewer trips by bicycle. The gender composition of a household also plays a significant role in the trip generation by car, bicycle and motorcycle. Male adult workers make fewer trips by these modes than female adult workers. The large negative coefficient with high t-stats values on the gender variable for bicycle and motorcycle show its strong determinant in the trip generation by bicycle or motorcycle. The age of an adult worker has a significant impact on trip generation by car and foot - older workers make more trips by car and fewer trips by foot. This is consistent with the findings from Agyemang (2017) on older person traveling more by car.

Education level plays a significant role in trip generation and mode choice in general. Workers with a bachelor's degree make most trips by car than workers with lower educational levels. Findings by Amoh-Gyimah and Nimako Aidoo (2013) also identified that households with a diploma, degree or higher to make car trips compared to households of lower educational status. Furthermore, trip generation decreases with workers who have a middle school certificate, training college degree or bachelors. However, the workers with a bachelor's degree make fewer trips than those with a middle school certificate or training college degree. Interestingly, the results suggest that all workers with a middle school certificate or higher make more trips by taxi although adults with bachelor's degree would make more taxi trips.

Similarly, workers with a household income greater than 200ghc ($104 per 2012 cedi to dollar conversion rate) make more taxi trips. According to the data, about 85% of the taxi trips are shared and the remaining 15% are individual trips. This could be a possible explanation of why trip generation increases irrespective of worker's educational level or household income. Household income, which also shows a positive association with level of education significantly impacts trips generation. The highly positive significant variable of

an adult with a household income greater than 1200ghc ($624) indicate that trip generation by car increases with high income. Workers with a household income between 1000.01 ghc and 1200ghc make fewer foot trips than workers with a household income less than 200ghc.

**Table 2.** Model for Trip Generation

| | Car | | Bicycle | | Motorcycle | | Foot | | Taxi | | Bus | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | *Coeff.* | *T-stat* | *Coeff.* | *T-stat* | *Coeff.* | *T-stat* | *Coeff.* | *T-stat* | *Coeff.* | *T-stat* | *Coeff.* | *T-stat* |
| Constant | -0.74 | -0.32 | 12.39 | 10.98 | 13.36 | 11.37 | 4.88 | 1.01 | 2.01 | 9.71 | 4.19 | 12.72 |
| **Socio-Economic Variables** | | | | | | | | | | | | |
| Household (HH) size | -0.72 | -4.16 | - | - | - | - | - | - | - | - | -0.06 | -2.63 |
| Total number of adults in household | - | - | -0.70 | -8.71 | - | - | - | - | - | - | - | - |
| Total number of employees/workers in household | | | | | -0.98 | -5.00 | - | - | -0.21 | -4.25 | - | - |
| Male | -2.63 | -3.43 | -5.43 | -22.14 | -6.08 | -11.08 | - | - | - | - | - | - |
| Age in years | 0.18 | 5.40 | - | - | - | - | -0.04 | -5.44 | - | - | - | - |
| **Highest Education Level** | | | | | | | | | | | | |
| Less than middle school graduate | - | - | - | - | 1.83 | 2.26 | - | - | - | - | - | - |
| Middle school graduate/BECE | - | - | -1.20 | -3.31 | - | - | - | - | 0.73 | 4.72 | 0.60 | 4.41 |
| Vocational Training | - | - | - | - | - | - | - | - | 2.39 | 5.31 | | |
| SSCE certificate/A level certificate | - | - | - | - | 2.21 | 2.41 | - | - | 0.85 | 3.54 | 1.28 | 6.09 |
| Training College/Polytechnic | - | - | -2.60 | -2.69 | 6.51 | 4.69 | - | - | 1.35 | 3.31 | 1.14 | 3.19 |
| Bachelors Degree | 2.70 | 2.52 | -3.27 | -2.92 | - | - | - | - | 3.54 | 8.22 | - | - |
| Household member currently attending school | - | - | 1.81 | 3.49 | - | - | 1.05 | 2.21 | - | - | - | - |
| Total number of students in household | - | - | - | - | - | - | -0.23 | -3.93 | - | - | - | - |
| **Household Monthly Income** | | | | | | | | | | | | |
| HH with monthly income less than 200.01 ghc | - | - | - | - | 1.71 | 2.47 | 0.97 | 4.41 | - | - | -0.41 | -3.11 |
| HH with monthly income between 200.01 ghc and 600 ghc | - | - | - | - | 1.80 | 2.69 | - | - | 0.44 | 3.02 | | |
| HH with monthly income between 600.01 ghc and 1000 ghc | - | - | - | - | - | - | - | - | 0.80 | 3.80 | | |
| HH with monthly income between 1000.01 ghc and 1200 ghc | - | - | - | - | - | - | -1.27 | -2.29 | 1.77 | 5.06 | -0.78 | -2.61 |
| HH with monthly income greater than 1200 ghc | 3.49 | 4.19 | 1.09 | 2.14 | - | - | - | - | 1.07 | 3.65 | -0.61 | -2.60 |
| **Marital status** | | | | | | | | | | | | |
| Never married | - | - | - | - | - | - | - | - | -0.39 | -2.44 | - | - |
| **Ethnicity** | | | | | | | | | | | | |
| Akan | - | - | -2.01 | -5.45 | - | - | - | - | 1.06 | 7.58 | - | - |
| Ga/Dangme | - | - | -2.33 | -2.85 | - | - | - | - | - | - | - | - |
| Ewe | - | - | -2.66 | -5.51 | - | - | - | - | - | - | - | - |
| Mole Dagbani | - | - | 1.22 | 3.96 | - | - | - | - | - | - | - | - |
| **Residential Location** | - | - | - | - | - | - | - | - | - | - | - | - |
| Household lives in city center | - | - | -1.74 | -2.12 | | - | 6.50 | 11.37 | | | | |
| Household lives in town | 4.83 | 3.36 | - | - | 1.32 | 2.19 | 0.75 | 2.28 | | | | |
| Household lives in a suburban area | 5.60 | 4.25 | - | - | | | 3.27 | 9.71 | 0.83 | 5.69 | 0.75 | 5.49 |
| Household lives along a major road | 6.41 | 3.38 | - | - | 2.14 | 2.35 | 2.01 | 4.65 | | | | |
| **Regional Census** | | | | | | | | | | | | |
| Sekondi-Takoradi (Western Region) | - | - | - | - | - | - | - | - | - | - | 1.18 | 2.52 |
| Accra Metropolitan Area (Greater Accra Region) | 6.51 | 5.22 | - | - | 3.81 | 2.15 | 4.08 | 7.40 | - | - | 3.08 | 10.13 |
| Kwahu North (Eastern Region) | - | - | - | - | - | - | -4.51 | -3.90 | - | - | - | - |
| Gomoa East (Central Region) | - | - | - | - | - | - | - | - | 1.77 | 2.01 | - | - |
| Kumasi Metropolitan Area (Ashanti Region) | - | - | - | - | - | - | - | - | 0.77 | 2.84 | 2.69 | 11.62 |
| Techiman (Brong Ahafo Region) | - | - | - | - | - | - | - | - | - | - | -1.22 | -2.10 |
| Tamale Metro (Northern Region) | - | - | - | - | 3.64 | 3.81 | - | - | 2.91 | 6.05 | -1.30 | -3.18 |
| Wa Municipal (Upper West Region) | - | - | -5.32 | -2.98 | 6.50 | 2.82 | -4.54 | -2.26 | | | 7.91 | 3.61 |
| **Vehicle Ownership** | | | | | | | | | | | | |
| Car owned by household | - | - | - | - | - | - | - | - | -0.43 | -2.37 | - | - |
| Motorcycles owned by household | - | - | - | - | - | - | 0..513 | 2.27 | - | - | -0.27 | -2.22 |
| Bicycles Owned by household | 1.12 | 2.19 | - | - | - | - | | | - | - | | |
| Bus owned by household | - | - | - | - | - | - | -2.17 | -2.71 | - | - | -1.29 | -3.06 |
| **Perception Variables** | | | | | | | | | | | | |
| Bus route convenient | -2.70 | -3.37 | - | - | - | - | - | - | - | - | -0.54 | -4.16 |
| Satisfied with bus frequency | - | - | - | - | - | - | - | - | - | - | -0.32 | -2.38 |
| Fares too high | - | - | - | - | - | - | 2.64 | 7.76 | - | - | - | - |
| Long delays at transport stations | - | - | - | - | - | - | 2.53 | 7.74 | - | - | 0.37 | 2.44 |
| Traffic Jam | 2.98 | 3.45 | -1.80 | -3.12 | - | - | | | 1.89 | 8.79 | 0.60 | 3.07 |
| Bad Roads | - | - | -0.94 | -3.65 | - | - | 1.27 | 4.26 | | | | |
| **Other Explanatory Variables** | | | | | | | | | | | | |
| Time to walk to the nearest taxi rank (min) | - | - | - | - | - | - | 0.16 | 3.67 | -0.20 | -7.86 | -0.06 | -2.44 |
| Time to walk to the nearest bus stop (min) | - | - | - | - | - | - | - | - | - | - | -0.14 | -5.14 |
| Time to walk to the nearest train station (min) | - | - | - | - | - | - | - | - | - | - | -0.11 | -3.43 |
| Distance from residence to station /boarding point (km) | - | - | - | - | - | - | 0.05 | 2.17 | - | - | - | - |
| Time to walk to the nearest station/boarding point (min) | - | - | -0.03 | -3.01 | - | - | - | - | - | - | - | - |
| Number of observations | 473 | | 2791 | | 861 | | 9983 | | 9983 | | 9983 | |
| R Square | 0.336 | | 0.232 | | 0.239 | | 0.060 | | 0.089 | | 0.109 | |
| Adjusted R Square | 0.316 | | 0.227 | | 0.228 | | 0.058 | | 0.087 | | 0.106 | |

Adults with more children in the household tend to make fewer trips by foot. A possible explanation to this is that such adults who are more likely to be the parents of the children may find it difficult walking together with many children whiles ensuring their safety and not losing sight of any of them. Across all trip modes except taxi trips, the marital status of a worker shows no significant impact on trip generation. It was interesting to find out that single working adults generate fewer trips that married workers.

The cultural background of a worker also significantly affect bicycle trips a worker make. The coefficients of the ethnicity variables for bicycle trips establishes a significant relationship with trip generation. The Mole Dagbani adult workers generate more bicycle trips than workers of other ethnicities. As seen in the descriptive statistics, the Mole-Dagbanis' (located largely in the northern part of the country) major mode of travel is by bicycle and motorcycles with a higher mode share by bicycles. Therefore, a plausible explanation for the significance in generating more trips.

In terms of residential location, adult household is that reside in the city center make fewer trips by car than similar adults that live outside the city center. Similarly, such adults create fewer trips by bicycle. In contrast, such adults living in the city center generate more foot trips although the number of foot trips generally increases across all the residential location variables. A conceivable reason for this is that the travel activity of such workers can be located within the city center. This result can also be linked with the finding by Haybatollahi, et al., (2015) that people in highly dense areas of the city center often walk or bike. Working adults in the Accra Metropolitan Area (AMA) create more trips than workers in all the other major metropolitan areas in the country. Also, the number of motorcycle and taxi trips increases whereas the number of bus trips decreases for adults in the Tamale Metro area. This result is also consistent with the findings from Abane (2011) which did not identify any trip by "trotro"- the most popular form of bus trips, in his study.

The number of trips generated by an adult worker can be used to explain the perception variables estimate. Workers who make foot trips complain about high fare price, long delays at transport terminals and the bad conditions of the road. Also, adults who make car trips, taxi trips and bus trips would generally complain traffic jam on the roads. Some of the explanatory variables also show some significance in the trip generation for all modes except car and motorcycle.

## 5. CONCLUSION AND SUMMARY

Although understanding the travel behavior of road users is key in travel demand forecasting, there has been little contribution in the modeling of trip generation by purpose. This study, however, presents a trip generation model by mode for adult workers using the 2012 Ghana Transport Indicator Database Survey. Apart from the Ghana Statistical Services which developed a report based on this survey, the data has not been used for any research relating to transportation or trip generation as such. Therefore, results from this data serve as a useful contribution to the Ghana Statistical Services and other governmental transportation agencies in developing national policies. Of the national sample of 23,238, 58.4% of them represent 9833 were adults (that is 18 years or older) who are engaged in some sort of employment activity. A linear regression model was used to model the trip generation by car, bicycle, motorcycle, foot, taxi and bus for these working adults. The results from the study show that gender, age, education level and residential location all show a significant impact on the number of trips generated for the different trip modes. Also, workers with a household income greater than 200ghc ($104) make more taxi trips. Meanwhile, from the data, about 85% of the taxi trips are shared and the remaining 15% are individual trips. Therefore, a better understanding of this finding will be to separate induvial taxi trips from shared taxi trips and develop trip generation models based on these modes. In terms of location, AMA, Tamale Metro and Wa Municipal show a strong positive relation

with motorcycle trip generation. The main mode for travel in the northern part of the country which is captured by the Tamale Metro area and Wa Municipal is the motorcycle. However, over the past few years, there has been an increase in motorcycle trips in the AMA because of the vehicle population growing higher than the transportation network and the heavy vehicular traffic.

The linear regression model gives a baseline explanatory model across all modes therefore the need to employ other econometrics modelling structures like poisson regression to generate the trip generation trips. There may not be much difference between the linear regression and poisson regression if we only want to other stand the relation between trip generation and the explanatory variables. However, there may be some differences in replicating the trip generation patterns in making prediction.

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# ROAD TRANSPORT CRASHES AND SOCIO-ECONOMIC INDICATORS: A CASE OF NIGERIA

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## ABSTRACT

The aim of this study is to provide basis for the understanding of transport crashes as affected by socio-economic indicators with a view to providing basis for road safety policies for transport management and control in Nigeria. The objectives were to (i) examine the trend of road transport crashes in Nigeria from 1960 to 2010, (ii) identify the socio-economic development indicators and incidences that are related to road transport crashes in Nigeria, (iii) examine the road transport safety measures aimed at reducing road transport crashes and (iv) assess the contributions and challenges of road safety related agencies in the reduction of road transport crashes. Except for annual life expectancy, other socio-economic development indicators had relationship with road transport crashes in Nigeria ($R2 = 0{,}956$, $p = 0.000$, $P<0.05$). The model of this study was defined as follows: RTC= 8047.7 + 0.041(GDP) - 0.000000812 (FDI) + 0.0006 (population) - 0.0005 (vehicle) + 0.199 (telecom) – 0.388 (road length) + 0.016 (wages) – 0.001 (goods by road). The road transport safety counter measures have reduced transport crashes by these percentages: use of seat belt (35 percent), standard speed limit signs (18 percent), speed limiters/governors (14.4 percent), use of child restraints (12.9 percent), issuance of standard licence (12 percent) and reflective pavement marking (7.7 percent). Insufficient funding (34 percent), political challenges/interferences (26 percent), lack of modern equipment and logistics (16 percent), poor training and retraining of road safety personnel (10 percent), and security challenges (8 percent) constituted the challenges of road transport crash related agencies in the reduction of road transport crashes. The study concluded that national socio-economic development indicators (Gross Domestic Product, Foreign Direct Investment, Population, Vehicle, Telecommunication, Wages, Road Length and Tonnage of Goods) have a significant relationship with road transport crashes except the annual life expectancy.

**Keywords:** Transport, Crashes, Socio-Economic and Indicators.

## 1. INTRODUCTION

Road transportation safety is a very strong instrument and an inalienable part of social and economic development. It is also an essential part of human activities and in many ways form the basis of all socio-economic interactions. Indeed, no two locations will interact effectively without a viable means of movement. However, the development of road system as an engine of growth is always associated with the menace of road traffic crashes. There are at least two major schools of thought on road transport crashes which are the direct and indirect viewpoints. The former perhaps championed by the World Health Organisation (WHO) stress common causes of road transport crashes to be drunk driving, wrong over taking and loss of control whereas the latter viewpoint propagated by Khair (1990), Kopits and Copper (2005), Koornstra (2007), Grimm and Treibich (2010) and Tay (2011), lay more emphasis on increasing road networks and the effect of socio-economic factors. On road transport crashes, the second scenarios are those scholars that lead emphasis on the effects of variety of socio-economic indicators on road transport crashes. Tay, (2011) noted that road transport crashes

are leading cause of deaths and injuries in many developed and developing countries with strong influence on economic activities and business environment.

The menace of road transport crashes is increasing at a fast rate in developing countries due to rapid motorization, increase population and other factors such as length of the road, tonnage of goods by road. The World Health Organization (WHO, 2004) revealed that road transport crashes will increase by 65 percent between the year 2000 and 2020 in developed countries and 80 percent in low- and middle-income countries. This, therefore, requires concerted efforts for effective and sustainable prevention. Furthermore, it was estimated that the number of people killed in Road Transport Crashes each year worldwide is almost 1.2 million and the number injured could be as high as 50 million, (WHO, 2004). This is the combined population of five of the world's largest city.

The African Union's (2008) found that road transport crashes are the leading causes of morbidity and mortality accounting for over one million deaths per year in Africa. It was also revealed that 59,000 people lost their lives in road crashes in 1990 and this will increase to 144,000 people indicating 144 percent increase in 2020, Kopits and Cropper (2005). This tragic loss of lives is more than the total losses resulting from all the wars and terror attacks combined, Tay (2011). For this reason, the state of road networks is very important, and it contributes largely to the socio-economic development, safe movement of people, goods and services. Therefore, the reduction in the risk of travelling population is expected to be of importance to government and other stakeholders.

There is need to focus on providing solutions to the problems associated with road transport crashes and increasing urban population. The developed and developing economies of the world have suffered from varying degrees of road crashes. Nigeria is among the developing countries having one of the highest rates as denoted by the high number of deaths per 10,000 vehicles, Sheriff (2009). Nigeria has one of the highest rates of crashes among 181 countries being ranked 176th with estimated death rate of 33.7 per 100,000 population (WHO, 2010). Recently, in Nigeria 10,350 road transport crashes were recorded in the year 2014, killing 5,996 people (FRSC Annual Report, 2014). However, hardly a day goes by without the occurrence of a road transport crash which is leading to increasing incidence of deaths as well as socio-economic consequence that are involved. This trend of increasing carnage on roads in Nigeria has become a scene with trauma, groaning and tears. One may be made to believe that if this rate continues, road transport crashes and deaths becomes "tears we cannot stop" since the invariable road system which is the nature of motorization generated by economic growth is responsible for the high rate of road transport crashes in Nigeria.

### 1.1 Goal and Objectives

The goal of this research is to provide basis for the understanding of traffic crashes as affected by socio-economic indicators with a view to providing basis for road safety policies for traffic management and control in Nigeria. The objectives of this research are to:

i. examine the trend in the rate of road transport crashes in Nigeria from 1960 to 2010;
ii. identify the socio-economic indicators and incidences that are related to road transport crashes in Nigeria;
iii. examine the road transport safety measures (standard driver's license, provision of road shoulders, reflective pavement markings, speed limit and signs and enforcement of use of seatbelt) aimed at reducing road transport crashes;
iv. assess the contributions and challenges of road safety related agencies (Nigeria Army, Nigeria Police, Nigerian Security and Civil Defence Corps, Vehicle Inspection Office, National Emergency Management Agency and Federal Road Maintenance Agency) in the reduction of Road Transport Crashes; and
v. make recommendations on policy planning options.

## 1.2 Theoretical Framework

The challenges and consequences of road transport crashes on national economies are very significant yet scientific studies into the causes and probable socio-economic factors leading to road carnages are few. For the purpose of this research, Economic and Traffic Safety Concept have been examined.

### *1.2.1 Economic Activities and Traffic Safety Concepts*

Tay (2004), states that there is a relationship between the level of economic activities and traffic safety. However, as a country becomes developed, the rate of motorisation is likely to slow down. In addition, the demand for safety increases and becomes increasingly important. This shift will often lead to more investment in road safety, thereby resulting in fewer traffic crashes and deaths. (Tay, 2011). This is as shown in Figure 1.

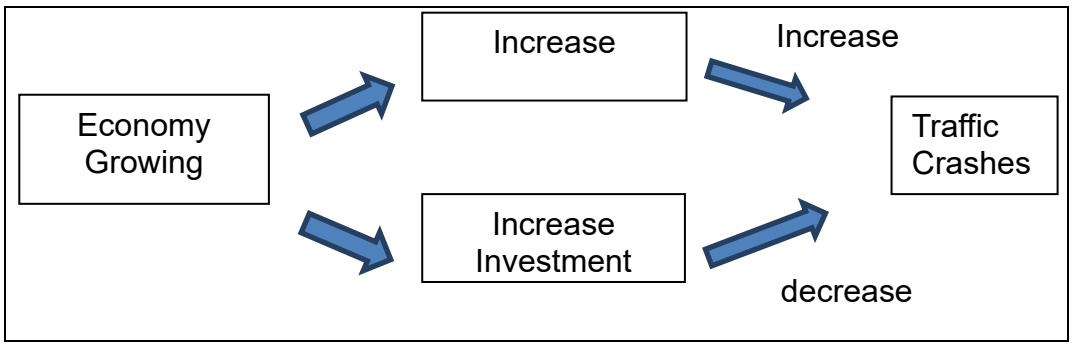


**Figure 1:** Growing economy and traffic crashes
Source: Richard Tay (2011)

Many developing countries are going through these cycles of development and transport crashes. According to Tay (2011), as motorisation in developing countries increases, there is an increase in the likelihood of collisions between motor vehicles and vulnerable road users like cyclists, pedestrians and other motorised road users who are not well protected. Moreover, unlike developed countries, much of the initial increase in motorisation often results an increase in motorised two wheelers that are also not well protected.

Another key aspect of economic activities and transport fatalities in developing countries that is not often seen in developed countries is the overloading of heavy vehicles. Overloaded converted pick-up trucks and minibuses are often the only affordable means of motorised transport for many of the poorer members of the society Tay (2011). The researcher further indicated in a study; trends in leading index and serious crashes in Australia that a variety of economic indicators have been used in the literature, this includes employment, retail index, new car sales and unemployment rate. Overall, there appears to be an inverse relationship between economic activities and road safety in developed countries. The impact of transport crashes on economic activities depends on factors such as the effect of a disruption in labour supply that is unemployment and the substitutability of labour (for example, death and injury to the skilled operator of expensive and highly specialised equipment versus an unskilled labour).

The effect of a disruption in transport as a result of crash will also depend on how critical delays in transportation service are to the particular sector of the economy (for example, just-in-time production, perishable items and fragile goods). It is very difficult to disentangle the various causes and effects between economic growth and transport crashes. This is as shown in Figure 2.

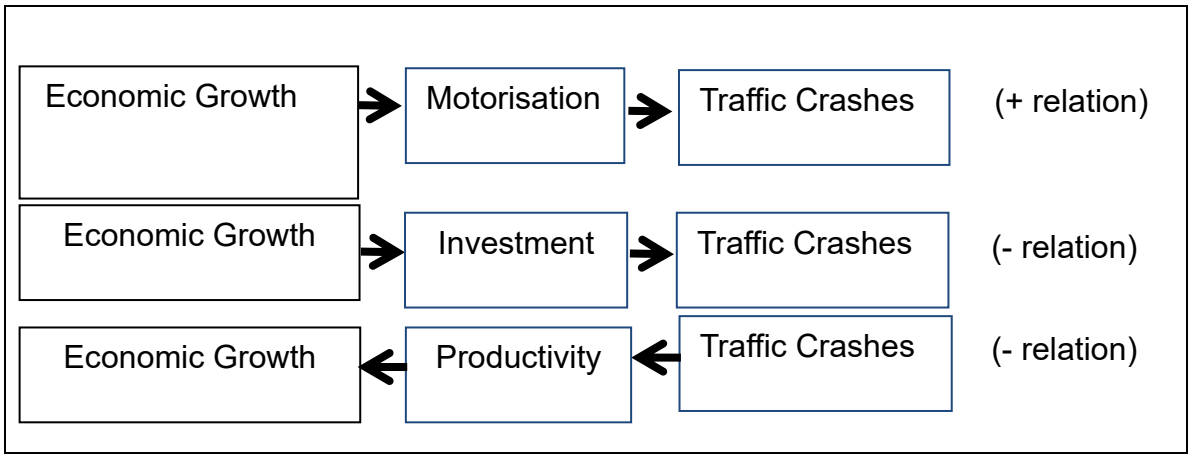


**Figure 2:** Relationship between economic factors and transport crashes
Source: Richard Tay (2011)

However, studies have simply assumed a one-way cause-and-effect relationship from economic activities to transport crashes through motorization. Tay (2011) without economic activities, living standards may decline as the population grows overtime.

## 2. LITERATURE REVIEW

This literature review is discussed in five different parts. The first part examines the trends in road transport crashes. The second part discusses socio-economic indicators and responses to crashes. The third part examines the measures directed at reducing road transport crashes while the fourth part examines the contributions and challenges of road transport safety related agencies and the last part discusses the view of geographical and regional planning approaches to road transport crashes.

### 2.1 Trends in Road Transport Crashes

Road transport and safety remains the pivot of growth and development in most parts of the world. In Africa, it plays a vital role in the socio-economic development of the continent particularly in facilitating movement of goods and services. However, while all parts of the world are vulnerable to road transport crashes, some regions are particularly very serious and alarming. This is the case with developing countries generally and those of the sub-Saharan African countries in particular. Moreover, while the developed countries that have attained advanced stages in their socio-economic and technological development have been able over the years to control the number of fatal crashes through a variety of counter measures, the developing countries are still facing the developmental challenges that impact on their abilities to develop counter measures. According to Kopits and Cropper (2005) the burden of transport casualties rises in developing countries in the early stages of economic development which witnessed increased motorization of the economy.

It is noteworthy that out of the estimated 1.2 million people killed in road transport crashes in 2002 throughout the world, 90 percent occurred in low- and middle-income countries. Peden et al. (2004) and Chen (2010) have shown that Africa has the highest fatality rate in relation to their population. Chen (2010) particularly posited that Africa with about 4 percent of the world's motor vehicles has the highest fatality rate.

The trend is still very alarming, and the crashes are increasing relatively in Nigeria. More recently for example in 2012, at least 473 persons were killed from a total of 1,115 vehicular crashes nationwide. However, in 2013, the month of April is likely to down as the worst month in terms of road transport crashes in Nigeria. According to reported cases,

(FRSC annual report 2013) April 3, 2013: A luxury bus and a smaller bus crashed on the Abuja-Lokoja Road, 18 people were killed. April 6, 2013: At Dazigan, 11 kilometers from Potiskum, Yobe State, 20 were killed in a crash. April 11, 2013: 10 were killed on the Damaturu-Gashua Road also in Yobe State. April 14, 2013: 7 people were killed on the Abuja-Lokoja road a car ran into an articulated vehicle. April 15, 2013: A petrol tanker set luxury bus and articulated vehicle ablaze at Ugbogui-village on Ore-Benin Expressway, 80 people were burnt beyond recognition. April 7, 2013: 5 people were killed on the Asaba-Onitsha Expressway. By the middle of April, 142 people have been killed from reported road transport crashes, 30 percent of the 473 deaths recorded in 2012 had been covered in only 15 days.

### 2.2 Socio-Economic Indicators and Responses to Road Transport Crashes

The growing road transport safety problems in low-income countries have been studied and discussed by a number of scholars. For example, Nantulya and Reich (2002) Largarde (2007), Grimm and Treibich (2010), and Chen (2010) have shown that the socio-economic implication of the impact of road transport crashes have continued to rise, and have been threatening the economic and human development initiatives of most countries.

In Nigeria few scholars have partially analysed the socio-economic implications of road transport crashes on the local economy. Some of these scholars include Onakomaiya (1977, 1988, 1991, 1992), Akpoghomeh (1996, 2000, and 2003); Badejo (1998) and Gbadamosi (2000). These scholars have all noted the negative socio-economic impacts of the crashes on the economy. Akpoghomeh (2003) in particular confirmed that almost 60 percent of road transport crashes in Nigeria involved the loss of at least one life in the last 10 years. More specifically, Bishai et al (2006) observed that transport fatalities increase with GDP per capita in lower-income countries and decrease with GDP per capita in wealthy countries. This is an alarming finding. It implies therefore, that as lower-income countries become richer, transport fatalities are expected to increase and indeed the WHO predicts that the current number of 1.3 million global road fatalities per year may rise to 1.9 million by 2020, WHO (2011).

However, there exists a noticeable gap in knowledge that needs to be filled through research, especially in the area of examining the National data of socio-economic development indicators on road transport crashes in Nigeria such as Gross Domestic Product, Foreign Direct Investment, Annual life expectancy, National Population growth, Number of motor vehicles registered, Number of telephone usage (Telecommunication and Post), Road Length, Agricultural output, Minimum Wage, Tonnage of Goods moved by road.

### 2.3 Measures Directed at Reducing Road Transport Crashes

In order to minimize exposure to high-risk transport scenarios that occasion injuries and fatalities, most counter measures are usually directed at planning and designing roads for safety, providing visible, crashworthy smart vehicles, setting road safety rules and securing compliance, delivering care after crashes and exploring extensive research activities on salient issues on road safety crashes.

### 2.4 Contributions and Challenges of Road Safety Related Agencies

Road transportation by the use of motor vehicle is one of the most flexible, as it accommodates the wide range of differences of its users and capacity making it the main carrier of the economy. It is the most important and dominant mode in the country. However, there are issues and challenges militating against the effectiveness of this mode as well as that of road safety related agencies.

The challenges of road transport safety related agencies should be viewed as appreciating that road safety is a shared responsibility. Reducing risk of road transport systems requires commitment and informed decision-making by governments at all levels,

non-governmental organizations, international agencies and individuals. It also needs the full participation of people from many different disciplines, which include road engineers, health professionals, educationists, motor vehicle manufacturers, law enforcement officers and community groups. As regards contributions to road transport crashes reduction by road safety related agencies, the developed economy has established great efforts at reducing crash risk on the roads.

### 2.5 Geographical and Regional Approach

Despite using various bodies of theories and models in social and behavioural sciences the study will also use a geographical and regional planning approach basing on geographical and regional matters such as Place, Time, Environment and Road Transport Crash as an additional conceptual implication in understanding land use, road element, width of the road, hilly area, topography and regional distribution in occurrence of road transport crashes in Nigeria. According to Cutter (1993), geographic scale is important in understanding technological hazards, their distribution, impacts and its reduction. Hence, the dictionary of human geography provides us with the application of graphical perspective and methods to the study of health, disease and health care Johnston (2000).

Road Transport Crashes bear strong elements of man-environment adjustments and maladjustment a well-known approach in geography Muhlrad and Lassarre (2005). Based on the logic of a modified human ecological model of a disease the approach can be transferred to studies of road transport crash. A model for transport crash as inspired by the ecological model of a disease was developed by Jorgensen and Abane (1999) who made a heuristic adjustment of this basic model to suit road transport crash analysis.

## 3. RESEARCH METHODOLOGY AND PROCEDURES

This research focused on methods adopted in data collection, handling and analysis. It also deals with the statistical methods used in the analysis of the data. In the same vein, sample size and sampling techniques as well as description of the statistical tools and instruments used for data collection and presentation are considered. Key variables used for the validation of the hypotheses were presented.

### 3.1 Sources of Data

Two major sources of data used for this study are secondary and primary sources of data. The secondary data and their sources used in this study: They are classified into published and unpublished. The published data include: (a) the reported national road transport crashes from 1960 -2010. Data were obtained from the Federal Road Safety Corps and the Nigeria Police Force (2010); (b) data on the countries' length of roads and Foreign Direct Investment were sourced from Central Bank of Nigeria (CBN) newsletter, 2011 and Federal Ministry of Works newsletter, 2011; (c) data on the countries' GDP, Life Expectancy, Agricultural Output, number of motor vehicles registered and number of telephone subscribers for 1990 – 2010 were sourced from the National Bureau of Statistics, (2011) and the Nigeria Communication Commission (NCC), Abuja; (d) other Economic Development information and data, such as population figures and Minimum wages were obtained from National Population Commission and National Salaries Wages and Income Commission; (e) data on the countermeasures adopted in this country were sourced from the Federal Road Safety Corps. The unpublished data are list of commercial drivers that had plied the selected routes (highways) across the six geopolitical zones of the country obtained from the National Union of Road Transport Workers (NURTW).

The primary sources required an extensive use of the following instruments of data collection. Two sets of questionnaires were prepared and were administered on the selected target population. The first set of the questionnaire was given to drivers (commercial and

private) plying the selected routes in Nigeria and the second set to the operational staff of Transport Administrators/Road Safety Management Related Agencies in Nigeria. The researcher carried out general observation on the Road Networks in Nigeria and that helped in determining the role of some drivers and other road users on the causes of road transport crashes. At the Road Transport Crash scene, thorough observations were carried out to determine causes of the crash. Photograph of specific road transport crashes were taken to showcase the physical effect of road transport crash on the immediate environment and items of various economic values.

In-Depth Interviews (IDIs) based on structured Interview guides were developed these were administered on the following; transport industry, road traffic management and the nation's economic handlers: (a) Head of Federal Highway Patrol, Nigeria Police Force (NPF); (b) Deputy Corps Marshal Operations, Federal Road Safety Corps (In charge of Highway Patrol and Rescue Operation) (FRSC); (c) Director, Land Transport, Federal Ministry of Transport (FMT); (d) Director, Fiscal Planning and Economic Development, Federal Ministry of Finance (FMF); (e) Director, Planning and Research, Central Bank of Nigeria (CBN); (f) Director, Research and Planning, Automotive Council of Nigeria. (NAC); (g) Director, Statistics and Demography, National Population Commission (NPC); (h) Director, ICT, National Bureau of Statistics (NBS); (i) Director, Planning and Evaluation, National Planning Commission (NPLC); (j) National President or National Secretary, National Union of Road Transport Workers (NURTW); (k) National President or National Secretary, National Association of Road Transport Owners (NARTO); and (l) National President, Road Transport Employer Association of Nigeria (RTEAN).

### *3.2* Sample Population and Sampling Technique

Drivers (private and commercial) that had plied the selected routes within three years (2008 – 2010) and operational staff of various road safety related agencies (Federal Road Safety Corps, Nigeria Police Force, Nigeria Security and Civil Defence Corps, Vehicle Inspection Officers, Federal Road Management Agency, National Emergency Management Agency, and, Non-governmental Organizations with road safety related activities in Nigeria) made up the sample population. The sample frame for the registered commercial drivers numbered 8,560 (Motor parks/terminals Reports of FRSC, 2012). Again, the private drivers that had plied the route, numbered 8293 (this was obtained from traffic count). Finally, the sample frame for the operational staff of road safety and traffic related agencies totaled 2,776 personnel. The operational staff are those staff that had direct link with road safety operations on the road aside the administrative staff. However, the total number of in these road safety and traffic related agencies totaled 644,104.

The sample size of this study was determined using two sampling size determination formula- Williams (1978) and Taro Yemane formula. The Williams (1978) formula as was adopted by Kerlinger and Lee (2000) was used to determine the sample size for the commercial drivers, while the Taro Yemane formula was used for the operational staff of road safety and traffic related agencies. The Williams (1978) formula is given as:

$$S = \frac{n}{1+(n/N)} \quad (1)$$

Where:

S = the sample size

n= the proportion of population that was sampled (0.1 percent).

N = the total number of people (commercial drivers).

### *3.3* Sampling Technique

Two sampling techniques were used in this study and these include: Multi-stage sampling and Simple random sampling technique. Using multi-stage sampling techniques, Nigeria, the study area was divided into the six major geo-political zones of the country (south-east, south-south, north-east, north west, north-central and south-west). Two states were randomly selected in each of the geo-political zone and two major road networks were considered in each of the zones. The following criteria were used to select the sample of roads for the purpose of this study:

a) Major city of regional influence per zones;
b) Oldest state capital territory as regards first state creation in 1976; and
c) Regional economic and administrative influence right from the colonial era.

In order to get the survey point in each of the selected major roads across the study areas, the busiest and the largest motor parks that service these roads were simple randomly selected and the names of these parks were obtained from unpublished document of the FRSC that shows the list of major parks in Nigeria. Table 1 gives detail of the presentation.

**Table 1:** Shows the Sample Size of the Road Traffic Related Agencies

| | Agencies | Total number of staff | Number of operational staff | Sample size |
|---|---|---|---|---|
| 1 | Nigeria Army | 184,000 | 304 | 171 |
| 2 | Nigeria Police Force | 371,800 | 487 | 210 |
| 3 | Directorate of Road Traffic Services (Vehicle Inspection Officer) | 750 (FCT) | 210 | 101 |
| 4 | Federal Road Safety Corps | 17,949 | 563 | 302 |
| 5 | Federal Road Maintenance Agency | 5,453 | 354 | 164 |
| 6 | Nigeria Security and Civil Defence Corps | 60,245 | 407 | 195 |
| 7 | NEMA | 2,442 | 333 | 189 |
| 8 | Non-Governmental Organizations on road safety related activities. | 1465 | 118 | 79 |
| **Total** | | 644,104 | 2776 | 1411 |

Source: Official website of each of the agencies

## RESULT

### Hypothesis One

**H0:** The trend of Road Transport Crashes does not differ significantly within the period (1960-2010) in Nigeria.

The result from the ANOVA statistics suggests that the trend of road transport crashes significantly different within the period (1960-2010) in Nigeria ($F = 25.666$, P-sig at 0.000, $P < 0.05$ significant level). The trends were decade 1 (1960 – 69), decade 2 (1970 – 79), decade 3 (1980 – 89), decade 4 (1990 – 99) and decade 5 (2000 – 10).The null hypothesis was therefore rejected. The details of this result were shown in Table 2 below. The test of homogeneity of variance shows a significant value of 0.128. This indicates that the ANOVA assumption was not violated.

**Table 2:** One-way Anova testing the trend of road transport crashes within the period (1960-2010) in Nigeria

**Descriptives**

crashes

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| decade1 | 10 | 15123.70 | 2313.82521 | 731.69578 | 13468.4892 | 16778.9108 | 12163.00 | 19835.00 |
| decade2 | 10 | 27660.00 | 7976.81543 | 2522.491 | 21953.7300 | 33366.2700 | 16666.00 | 40881.00 |
| decade3 | 10 | 29717.00 | 4139.80340 | 1309.121 | 26755.5630 | 32678.4370 | 23987.00 | 37094.00 |
| decade4 | 10 | 18997.00 | 2858.18225 | 903.83659 | 16952.3796 | 21041.6204 | 15865.00 | 22864.00 |
| decade5 | 10 | 12916.60 | 3857.54750 | 1219.864 | 10157.0768 | 15676.1232 | 8477.00 | 20530.00 |
| Total | 50 | 20882.86 | 8111.61232 | 1147.155 | 18577.5653 | 23188.1547 | 8477.00 | 40881.00 |

**Hypothesis Two**

**H0:** There is no significant relationship between Road Traffic Crashes and socio-economic development indicators as measured by the Gross Domestic Product, Annual Life Expectancy, Population Growth, Number of registered vehicles, Road Length, Minimum Annual Wage, Foreign Direct Investment, Agricultural Output, Telecommunications and Post and Tonnage of Goods moved by road in Nigeria.

The result of the second hypothesis suggests that there is a strong significant relationship between road traffic crashes and socio-economic development indicators as measured by the Gross Domestic Product, Population Growth, Number of registered vehicles, Road Length, Minimum Annual Wage, Foreign Direct Investment, Agricultural Output, Telecommunications and Post and Tonnage of Goods moved by road in Nigeria. (R2 = .956, Adjusted R2 = .937, Standard Error = 20.9387, F=50.892, P-sig = 0.000, P< 0.05 significant level). The null hypothesis was therefore rejected as detailed in Table 3.

**Table 3:** Regression Testing Relationship Between Road Traffic Crashes And Socio-Economic Development Indicators

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 8047.761 | 54695.756 | | .147 | .884 |
| | population | .000 | .000 | -.887 | -3.674 | .012 |
| | vehicle | -.005 | .034 | -.155 | -2.156 | .029 |
| | GDP | .041 | .042 | .928 | 4.970 | .000 |
| | FDI | 8.12E-007 | .000 | .235 | 2.601 | .022 |
| | wages | .016 | .036 | .117 | 3.448 | .013 |
| | telecom | .199 | .265 | .239 | 3.077 | .019 |
| | goods | -.001 | .001 | -.076 | -2.044 | .034 |
| | lifexpantan | 874.035 | 1223.719 | .222 | .714 | .483 |
| | roadlengt | -.388 | .160 | -1.543 | -2.432 | .024 |

a. Dependent Variable: crashes

**Hypothesis Three**

**H0:** The road traffic safety measure does not differ significantly in relation to the reduction of road traffic crashes.

**Result**

The result of the third hypothesis suggests that the road traffic safety measure does differ significantly in relation to the reduction of road traffic crashes. (KW value =153.9, P = 0.000,

P < 0.05 significant value). The null hypothesis was rejected. The detail of this result was shown in Table 4.

**Table 4:** Kruskal-Wallis Test Testing the road transport safety measure in relation to the reduction of Road Transport Crashes

**Ranks**

| | scores | N | Mean Rank |
|---|---|---|---|
| countermeasure | shoulders | 2494 | 48.45 |
| | pavements | 2494 | 65.55 |
| | speed limit signs | 2494 | 49.02 |
| | road signs | 2494 | 37.27 |
| | seat belt | 2494 | 94.61 |
| | speed breakers | 2494 | 63.55 |
| | child restraints | 2494 | 57.63 |
| | enlightenment | 2494 | 72.63 |
| | traffic laws | 2494 | 57.96 |
| | drivers licence | 2494 | 51.66 |
| | Total | 24940 | |

**Hypothesis four**

**H0:** There is no significant difference in the mean rating of the contributions and challenges of the road safety related agencies in the reduction of road traffic crashes among the various categories of respondents.

The result of the fourth hypothesis suggests that there was a significant difference in the mean rating of the contributions and challenges of the road safety related agencies in the reduction of road traffic crashes. (X2 value = 8.552, P = 0.023, P < 0.05 significant value). The null hypothesis was rejected. The detail of this result is shown in Table 5.

**Table 5:** Chi-square tests testing the mean rating of the Contributions and Challenges of the road safety related agencies in the reduction of road transport crashes

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 8.552(a) | 1410 | .023 |
| Likelihood Ratio | 8.466 | 1410 | .639 |
| Linear-by-Linear Association | .414 | 1 | .520 |
| N of Valid Cases | 390 | | |

a. 7 cells (58.3%) have expected count less than 5. The minimum expected count is .10.

## 4. DISCUSSION OF FINDINGS

The findings of the study are discussed under ten socio-economic indicators and incidences that are related to road transport crashes.

### 4.1 Socio-economic indicators and incidences that are related to road traffic crashes in Nigeria

In this study, ten (10) Socio-economic indicators were used and discussed. The indicators are as follows: (i) Gross Domestic Product; (ii) Foreign Direct Investment; (iii) Annual Life Expectancy; (iv) National population; (v) Number of motor vehicle registered; (vi) Number of telephone usage; (vii) Road length; (viii) Minimum wages; (ix) Tonnage of goods moved by road; and (x) Agricultural output. The discussions in this section were based on the regression results of hypothesis two. The result tables show the coefficient interpretation of

each of the socio-economic indicators. Table 5 below depict the regression description and the coefficient.

**Table 5:** Regression Results and its Coefficients

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | t | Sig. |
| 1 | (Constant) | 8047.761 | 54695.756 | | .147 | .884 |
| | population | .000 | .000 | -.887 | -3.674 | .012 |
| | vehicle | -.005 | .034 | -.155 | -2.156 | .029 |
| | GDP | .041 | .042 | .928 | 4.970 | .000 |
| | FDI | 8.12E-007 | .000 | .235 | 2.601 | .022 |
| | wages | .016 | .036 | .117 | 3.448 | .013 |
| | telecom | .199 | .265 | .239 | 3.077 | .019 |
| | goods | -.001 | .001 | -.076 | -2.044 | .034 |
| | lifexpantan | 874.035 | 1223.719 | .222 | .714 | .483 |
| | roadlengt | -.388 | .160 | -1.543 | -2.432 | .024 |

a. Dependent Variable: crashes

The study revealed the estimates for these b-values and these values indicate the individual contribution of each predictor to the model. If we replace the b-values from the values in the regression result.

The model of this study is defined as follows:

**Road Traffic Crashes = 8047.7 + 0.041(GDP) - 0.000000812 (FDI) + 0.0006 (population) - 0.0005 (vehicle) + 0.199 (telecom) – 0.388 (road length) + 0.016 (wages) – 0.001 (goods by road)**

The b-values tell about the relationship between road transport crashes and each predictor. If the value is positive, it shows that there is a positive relationship between the predictor (socio-economic variables) and vice versa. So as these socio-economic variable increases, the road transport crashes rate increases. The (b-coefficient values) highlights more than this. It gives the degree each of the independent variable affects the outcome of the effects of other variables which are held constant.

**Table 2;** Socio-Economic Characteristics of Pedestrians

| | Distribution by Gender | | Distribution by Age | | | | | Distribution by Occupation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | 1-15 | 16-30 | 31-45 | 46-60 | 61+ | Student | Traders | Self-Employed | Govt. Employed |
| No. of Respondent | 81 | 54 | 6 | 72 | 39 | 12 | 6 | 60 | 30 | 21 | 24 |
| Percent | 60 | 40 | 4.4 | 53.3 | 28.9 | 8.9 | 4.4 | 44.4 | 22.2 | 15.6 | 17.8 |

(Source: Field survey, 2016)

## 5. CONCLUSIONS

In conclusion therefore, several policy implications and new areas of knowledge emerged from this study. From the forgoing, available records and information revealed that the trend and pattern of road traffic crashes is reducing relatively socio-economic development indicators in Nigeria. This reduction in crash is still very unacceptable and its effect on socio-economic development indicators and incidences. The study has carefully outlined some socio-economic variables and it revealed for example that only one (1) out of the ten (10) variables is not significant (annul life expectancy), which shows that road traffic crashes has created great negative consequences while positive relationship shows that for every one

percent increase in the country's GDP, there is 41 percent increase in road traffic crashes. It is clear from this study and other related research work that new research frontiers may be embarked upon. This may include variables like educational facilities, its location, industrial facilities, its location and the component of demography (e.g. household population, household size, income, sex and literacy rate) using the national census database. All these variables and components can be used to establish their relationships with road traffic crashes in Nigeria.

The study also reveals that the issues of road traffic crashes and its effect on socio-economic environment require serious attention and approach towards ensuring effective preventive measures and efficient practice in a holistic manner. Therefore, government established the FRSC as the lead agency on road safety administration and traffic management in Nigeria. It was to handle the increasing and complexity situation on the rate of road traffic crashes and its attendance destruction of life and property. The agency introduced various measures, countermeasures, strategic policies and programmes with a view to bringing this trend to a barest minimum. Hence, relevant agencies such as NPF, VIO, NSCDC and the Army amongst others should synergise with the FRSC towards achieving safe motoring environment. This will create an interface, with very high degree of coordination that will bring about genuine solutions, effective implementation of programmes at reducing crashes and improving socio-economic development in Nigeria.

Finally, the study will provide information to policy decision makers as well as transportation planners and engineers on the socio-economic indicators affecting crashes at the national level. Moreover, the study reveals which of the indicators will increase the crashes. Based on this, information and guidelines to proper countermeasures can be developed for the reduction of road traffic crashes. The study is beneficial to developing countries, which are experiencing a significant number of road traffic crashes in recent times because of increase in population, motorization, improved foreign investment, less development in the road and highway sector of the economy.

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# SMART INNOVATION AND SUSTAINABLE TRANSPORTATION TECHNOLOGY TRANSFER FRAMEWORK FOR INTERCONNECTIVITY IN DEVELOPING COUNTRIES

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## ABSTRACT

Funding for research dissemination is increasingly uncertain which calls for trans-disciplinary and trans-sector research dissemination through collaboration in order to ensure that fundamental advances are made in the areas of focus for capacity building and sustainability of road infrastructure in Africa. Through dissemination of research, studies, publications on various disciplines, authoritative and non-partisan policy advice is being provided to decision makers in government, academia, and the private sector. Although, dissemination of research in road transportation is integral to our societies, there are persistent challenges to its sustainability. This paper proposes strategies for cooperation among academia, industry, and transport sector through transport research dissemination by establishment of transportation professional networking group to provide a platform for sharing of experiences and exchange of ideas amongst transport professionals and researchers. This group has organised four international conferences on transportation in Africa which required the dissemination of innovative researches and approaches that brought about safe and sustainable solutions. With proper coordination, transport experts are poised to help solve problems at this level of complexity and importance. The paper concludes by highlighting the availability of potentials and critical mass in academia, government and the private sector to attain global stature and tackle capacity building challenges in road transport sector which depends on how the research dissemination and publication ecosystem is nurtured.

**Keywords:** Sustainable development, road infrastructure dissemination, capacity building

## 1. INTRODUCTION

Globalization and rapidly evolving technologies are driving profound changes in the role of transportation in our society. Through research studies, publications on various disciplines, transport professionals continue to provide capacity building strategies, authoritative and non- partisan policy advice to decision makers in government, academia, and the private sector. This cooperation will enhance coordination of research within the transport sector in Africa, dissemination of research findings and innovations to transport professionals, promote uptake of research contributions amongst transport professionals, and provide a platform for sharing of experiences and exchange of ideas amongst transport professionals and researchers. Although research in transportation is integral to our societies, there are persistent challenges to the vitality of this sector. Funding for scientific research is increasingly uncertain which calls for trans-disciplinary and trans-sector research collaboration in order to ensure that fundamental advances are made in the areas of focus for capacity building and sustainability of road infrastructure in Africa.

Despite the challenges facing the transport sector, there are many promising avenues to strengthen this sector. New models of cooperation among academia, industry and government can better enable transport experts to meet the formidable challenge of dissemination of transport research. The world is increasingly faced with complex problems that require the adoption of innovative researches and approaches that will bring about lasting and sustainable solutions. For instance, the challenges facing communities from climate change, to providing adequate transport for the world's growing population are immense, urgent, and intimately connected. With proper coordination, transport experts are poised to help solve problems at this level of complexity and importance. Redesigning dated organizational structures and cultural attitudes within and across the sectors could dramatically accelerate the development of new approaches. I believe we now have the critical mass in academia, government, and the private sector to achieve this. To attain global stature and tackle critical societal challenges in transport sector will depend on how we nurture the research and publication ecosystem.

The objective of this paper is to develop capacity building strategies for sustainable development of cooperation among academia, industry and government through transport research dissemination by establishment of transportation professional networking group to provide a platform for sharing of experiences and exchange of ideas amongst transport professionals and researchers. This group has organised four international conferences on transportation in Africa which required the dissemination of innovative researches and approaches that brought about lasting and sustainable solutions. For instance, the challenges facing communities from climate change, to providing adequate transport for the world's growing population are immense, urgent, and intimately connected to the recent past theme. With proper coordination, transport experts are poised to help solve problems at this level of complexity and importance. The paper concluded by highlighting the availability of potentials and critical mass in academia, government and the transport sector to attain global stature and tackle capacity building challenges facing road infrastructure development which depends on how the research dissemination and publication ecosystem is nurtured.

## 2. LITERATURE REVIEW

In the field of Transport research, the academia, industry, and government are buffeted by common transport related problems and challenges. International Cooperation in Transport research is becoming an increasing priority aiming, primarily, at creating "critical mass" in moving collaboratively to solve critical 21st century transportation challenges (EUTRAIN, 2016). Developing countries have relied on researches carried out in the developed countries (Workman, 2013) which was strongly argued by O'Neil's and Greening (2010) that the capacity to develop innovative technology is an important part of the development process and a measure of a nation's ability to progress economically and identify solutions to local problems. TRB (2005) emphatically highlighted the benefits of research cooperation in accelerating growth of highway transportation if research studies and dissemination are best studied by highway departments in cooperation with their state universities and others through a coordinated program of cooperative research. This culminates into the establishment of African transportation professional networking group (AFTraP) to better enable transport experts to meet the formidable challenges by organising annual international conference on transportation in Africa. The main idea and objective were to establish through international cooperation in transport research dissemination; the free circulation of specialized knowledge, experience and know how in facing transport challenges. This has created through collaboration the conditions for more "breakthrough" research and achievements that would otherwise require more time and resources if faced individually and separately. The African transportation professional networking group (AFTraP) puts forward a framework for such international cooperation in Transport

research dissemination between the academia, industry and government, in order to ease existing barriers and limiting factors for such collaboration vis-à-vis a number of "focused" international cooperation issues such as achieving "global" research infrastructures; information and data sharing issues, intellectual property regimes; pre-standardization issues and means of harmonizing approaches and practices; research training and human resource issues (mobility of researchers and global networking); establishment of open research cooperation programmes (e.g. notably joint programming); differences in institutional cultures and research governance regimes.

It becomes incumbent upon road engineers to gain from the technology transfer developments of colleagues rather than "re-inventing the wheel" or making the same mistakes that others have made. In other words, the extent and efficiency of a country's technology transfer system could reveal the extent of that country's development. There has been recognition that informal sharing of experiences may no longer be the best approach to improve road transportation as the travel demands of modern society have increased exponentially. Technology transfer in the transportation sector is aimed at using the benefits of someone else's successful research, development, or experience to benefit roads locally – often at a fraction of the original development cost (PIARC, 2000).

The primary objective is to systematically and actively facilitate acquisition and dissemination of technology, practice and policy knowledge and know-how that is relevant to a local operating transportation environment. Technology transfer was explained by PIARC (2000) as the process of openly gaining and freely sharing experiences, workable solutions, technologies, and innovations. It was also emphasized by Logie (2007) that technology transfer occurs in many ways and different forms. Technology transfer happens at its simplest form, when someone reads about a "new" technique in a report or a technical magazine from another place. Furthermore, technology transfer operations were described by Pinard (2007) as a process of developing appropriate technology transfer mechanisms and activities ( newsletters and fact sheets; technical reports; news releases; journal and magazine articles; electronic bulletin boards); conveying well quantified success stories highlighting benefits over competing alternatives; carrying out well designed field tests, demonstration and pilot projects; producing well illustrated guidelines, reports and manuals in reader-friendly format; holding interactive conferences, workshops and seminars tailored to the differing requirements of segmented audiences at various stages of the technology transfer process.

## 3. RESEARCH METHODOLOGY

The African Transportation Professional Networking Group (AFTraP) is made up of transport professionals from the academic, business, and government sector with a commitment to proffer solutions to critical challenges facing transport in Africa. The goal of the group is to organise transportation professional conferences such as from country to country within Africa annually to provide a platform for experts and scholars to exchange ideas with each other, and also share the development and products in the field.

The goal of African Transportation Professional Networking Group (AFTraP) would be achieved in multiple steps and marked by three major deliverables

Deliverable 1 – Current challenges, practices, issues in international transport research cooperation

Deliverable 2 – Research areas, capabilities, and future priorities for international transport research cooperation

Deliverable 3 – Towards a framework and implementation for African international transport research dissemination.

The beneficiaries of the African Transportation Professional Networking Group (AFTraP) covered in a collective way all necessary aspects for the successful execution of an international cooperation in transport research project. As African Transportation Professional Networking Group (AFTraP) between the academia, government and the transport sector take shape and strength, international transport research collaboration can both help its further strengthening and internal cohesion as well as boost Africa's competitiveness in the global economy. However, enacting and fostering international research collaboration is faced with significant problems and difficulties today which should be researched, in order to provide the means of enacting solutions such as issues related to research infrastructures, intellectual property rights, and researchers' mobility.

The main objective was to produce a general framework related to international transport research cooperation, based on the reports of the three recent international conferences on transportation in Africa organised and the outcomes of related research topics presented. Other initiatives in the recent past as well as on the outcome of a thorough investigation of all different aspects of international cooperation such as current practices and more specifically gaps and barriers confronted in other international cooperation like European Transport Research Area International Cooperation activities (EUTRAIN) and Transportation Research Board of the National Academies (TRB) with the same field of interest, common characteristics, priorities and needs for international transport research and alternative models and tools for such research cooperation.

More specifically the AFTraP aimed:
(i) To contribute towards the establishment of a framework for international transport research cooperation and dissemination to be built upon the principles of knowledge sharing of transportation developments within African countries.
(ii) To investigate country research capabilities, future priorities, and potential for cooperation with the host countries in the prospect of mutual interest, in major regions of importance to AFTraP.
(iii) To consider and discuss current practices for research governance and management as well as barriers, gaps, and diversions for international transport research cooperation.
(iv) To assess the benefits or added value to AFTraP, as well as the prospective synergies from such closer international cooperation.
(v) To investigate alternative models and tools for carrying out such cooperation in the most effective and productive way and finally,
(vi) To disseminate, in the course of doing the above activities, African know how and practices in transport research.

## 4. KEY FINDINGS AND CONTRIBUTIONS

The first International Conference on Transportation in Africa was organised by the African Transportation Professional Group in collaboration with Ministry of Transport and Communications (Transport Hub, Botswana) themed "Improving Transport Systems and Sectors through Innovative Approaches", on December 15, 2014, at Gaborone Sun International Hotel, Botswana. During the opening ceremony, the Minister of Transport and Communications opined that to develop a safe, reliable, and sustainable transportation system for socio-economic development in Africa, the government needs to consider innovative approaches. Furthermore, the Minister emphasised that safe and reliable transport systems cannot be achieved without improved transport systems, adding that improved transport systems should form part of every government's top agenda. "In dealing with the broad set of issues facing transport sector particularly in Africa the conference should also tackle issues of safety, accessibility, and improved infrastructure, taking in consideration the environmental issues. It is also worth mentioning that in so doing, all

modes of transportation should be considered." The Minister stated that despite the considerable investments put in the road transport sector, problems of unmanageable and rough or periodically impassable roads are still quite common. "Government allocated funding for the provision of paved roads while maintenance lags behind, an improved balance between initial road investment and realistic assessment of maintenance capacity should lead to a better deployment of available resources."

Moreover, the minister said that transport might be considered as a vital missing link in the efforts to achieving the United Nations (UN) Millennium Development Goals (MDG) because without access to adequate transport infrastructure and services, the MDG's would not be effectively met and achievements made would be difficult to sustain. The Minister also added that research and publication will in turn help governments to come up with informed policies and appropriate interventions as urbanization increases, most cities and towns in Africa are faced with the problem of traffic congestion." This rapid increasingly congestion calls for definition and deployment of coherent and effective urban mobility plans and public transport policies. Africa needs to modernize its public transport systems. The minister assured the participants that the recommendations from the conference will be of immediate application to the transport sector and the whole of Africa as the representatives of governments and other stakeholders were urged to take the lessons from the conference seriously in formulating new strategies to take the transport sector forward.

**Figures 1:** Group picture of the Minister of Transport, Botswana with the 1st International Conference on Transportation in Africa participants (ICTA2014)

The 2nd International Conference on Transportation in Africa (ICTA2015) was successfully held on 25th - 27th November, 2015 at Majestic Five Hotel, Palapye, Botswana which indeed was a resounding Success. The conference was organised by the African Transportation Professional Networking Group and co-hosted by Botswana International University of Science and Technology, BIUST in collaboration with Transport Stakeholders, Private/Public sectors, Universities & Transport Professionals in Africa. The conference focused on how to optimally engage speakers and all stakeholders involved in the transport sector from African Countries, Australia, America, Europe to provide "safe and sustainable transport infrastructure in developing countries". The attendees gave the conference content an excellent satisfaction rating. It was an opportunity for Botswana International University of Science and Technology to be part of this outstanding program with International delegates from United Kingdom, Czech Republic, Ethiopia, Namibia, Zimbabwe, South Africa, Kenya, Tanzania, and Botswana as the host-country.


**Figure 2:** Group photo of 2nd International Conference on Transportation in Africa (ICTA2015)

The "African Transportation Professional Networking Group" is actually made up of transport professionals from the academic, business, and government sector that has a commitment to proffer solutions to critical challenges facing the transport sector by organizing transportation professional conferences, from country to country within Africa annually, to provide a platform for experts and scholars to exchange ideas and publish recent developments in the field of transportation. African Transportation Professional Networking Group in collaboration with Botswana International University of Science & Technology and the Ministry of Transport & Communications brought together practitioners and researchers from around the world to foster partnerships and collaboration. Technology transfer centres are now tasked with exploring ways in which research institutions, academia, industry and government will collaborate to bring about the effective dissemination and implementation of transportation research to the benefit of the public, locally, regionally and globally "to attain global stature and tackle critical societal challenges in the transport sector, which will depend on how the research and publication ecosystem is being nurtured.

### 4.1 Mitigating Current Challenges Facing Transportation in Africa

The 3rd International Conference on Transportation in Africa (ICTA2016) was successfully held on 26th - 28th October, 2016 at Ramada Resort, Accra, Ghana which indeed was a resounding success. The conference was organised by the African Transportation Professional Networking Group and co-hosted by Kwame Nkrumah University of Science & Technology, Kumasi, Ghana in collaboration with Ministry of Transport, Stakeholders, Private/Public sectors, Universities & Transport Professionals in Africa. The conference focused on how to optimally engage speakers and all stakeholders involved in the transport sector from African Countries, Australia, America, Europe to provide "mitigating measure towards the challenge of climate change facing transportation in Africa".

**Figure 3:** ICTA2016 Conference participants group photo with Transport Professionals

The 4th International Conference on Transportation in Africa (ICTA2017) was successfully held on 11th - 13th October 2017 at Sheraton Hotel, Abuja, Nigeria which indeed was a great success. The conference was organised by the African Transportation Professional Networking Group and co-hosted by The Nigerian Institution of Highway and Transportation Engineers, Abuja, Nigeria in collaboration with Ministry of Transport, Stakeholders, Private/Public sectors, Universities & Transport Professionals in Africa. The conference focused on how to optimally engage speakers and all stakeholders involved in maintenance from African Countries, Australia, America, Europe to provide "effective maintenance, safety and funding for sustainable transportation in developing countries".


**Figure 4:** ICTA2017 Conference participants group photo with Transport Professionals

The 5th International Conference on Transportation in Africa (ICTA2019) was successfully held on October 29th – 31st, 2019 at Morgan State University, Baltimore,

Maryland, USA which indeed was a great success. The conference was organized by the African - American Transportation Professional Networking Group and co-hosted by Morgan State University, Department of Civil Engineering in collaboration with Institute of Urban Research, Transportation Stakeholders, Private/Public sectors, Universities & Transport Professionals in America, and Africa. The conference focused on how to optimally engage speakers and all stakeholders involved in transportation from America and Africa to provide "sustainable transportation infrastructure and smart innovations".


**Figure 5:** ICTA2019 International Conference participants at Morgan State University, USA

## 5. CONCLUSION

Collaborative research dissemination and activities between the "advanced" - in terms of funding - countries or regions such as ASANRA, AFCAP, TRB, ARRB are now on the rise as the benefits from pulling of resources and commonly addressing the major issues and challenges in the transport field, seem to outweigh the traditional "competitive" positions taken by such countries and push towards more cooperation. This trend should be strengthened in the future by pursuing, at first, more easily achievable tasks such as multi-year technical personnel exchanges, agreements to further the exchanges of critical transport data, and so on. In the case of African countries, it is important to try and incentivize the private sector to contribute to international cooperative programmes and projects and compensate for existing funding restrictions and legislation for as long as these exist. Successes in collaboration should lead to larger projects and more extensive collaborative frameworks. These "advanced" research supporting countries should also explore in a more medium to long term horizon, more advanced models of international cooperation such as joint programming and funding of research, as well as use of more state-of-the-art technologies for new publications and dissemination that would highlight some existing best practices and success stories.

In the countries with "lesser research capabilities", for example African countries, there are considerable divergences of attitudes found towards international cooperation policies. Firstly, the factors hindering such cooperation are lack of timely information, lack of networking capabilities, as well as the substantial level of bureaucratic and cumbersome procedures and paperwork that is associated with establishing international cooperative proposals. Secondly, the attitudes were generally in favour of increasing the "reciprocity" in any future collaborative research programme, and a joint outreach to significant funding

sources and foundations to support sustainable (i.e. long term) ways of funding international collaborative transport research. Thirdly, there are a number of "critical" hindering factors which restrict researchers and research organisations in "lesser developed" countries to mobilise and benefit from international cooperative research programmes. These are due to the following observations: Lack of open, timely and reliable information about the various calls and networking with professionals from other countries; too cumbersome and complex administrative procedures; high co-funding percentages; lengthy turnaround times (proposals – evaluation – contract signature); need for capacity development for appropriate research personnel.

Recommendations for sustaining research dissemination and cooperation are:

(i) Observe "equal" standing as regards the focus and work programmes of international cooperation programmes and projects. In other words, the content of the call for paper as well as the criteria for selection and evaluation must not be simply aiming to promote the technologies, standards, and even commercial products of the "funding donor" countries.

(ii) Establishing effective and multi-channel communication processes has been stated as the key factor that will measurably enhance collaboration between developed and lesser developed countries internationally.

(iii) Foster international cooperation actions and human capacity building focusing on major global transport related problems and issues.

(iv) Relevance of research to the country's problems and policies. It is felt that some of the joint research programmes offered for international transport research cooperation are not of equal interest and importance to both sides and that they simply express the interests of the "funding donor" countries.

(v) Promote joint programming as a source of international Cooperation programme funding i.e. join forces between major research funder countries in order to provide greater funding opportunities for transport research dissemination in Africa.

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# DESIGN, FABRICATION AND TESTING OF A LAB-SCALE HYBRID MOBILE COOLING SYSTEM FOR OYSTER INDUSTRY

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## ABSTRACT

Cooling system is critical to maintain freshness of oysters and avoid contamination by bacteria. However, there is no persistent and efficient temperature control mechanism for cooling and storing of oysters in its supply chain from oyster farmer to the end consumers (e.g., market, restaurants). The aim of this project is to design, fabricate, and evaluate a lab-scale hybrid mobile cooling system for oyster aquaculture. This innovative hybrid cooling system integrated 110 volts AC cooling unit and 12 volts DC cooling unit with six individual chambers. These special features it to work under different power source. Even after power off, it can still run for several hours with battery (i.e., outage). So, it can be moved from boat to customers without change the storage condition of oysters. Six individual chambers have a potential to reduce energy loss and improve cooling performance because removing oyster baskets from one chamber will not affect temperatures in the other chambers. In this study, cooling system was fabricated in the laboratory based on the 2D design and 3D model. The performance of this cooling system was tested under various air circulation conditions (e.g., no vent open, two vents open, two vents open and air circulation fan on). Both cooling speed and the stand deviation of chamber temperature were used to evaluate the system cooling performance. Results indicated that the additional of air fan and two open vents in the divider has better cooling performance than the other two operating conditions. Hybrid cooling system with two vents and air circulation fan on can effectively cool down the oyster temperature from 21.1 ° C to 5.6 ° C within three hours. The stand deviation of the temperatures in six individual chambers can be reduced to 0.83 ° C in four hours.

**Keywords:** oyster aquaculture, hybrid mobile cooling system, air circulation, solar energy, thermal uniformity

## 1. INTRODUCTION

The Chesapeake Bay is famous for its oysters and oysters also play a vital role in the Bay ecosystem (Greenberg, 2012). The oyster industry has contributed millions of dollars to the region's economy since late nineteenth. However, oyster harvests of Chesapeake in 2008 declined to less than 2% of the historical peak in 1880 (Pelton, 2010). According to the conclusion of Rothschild et al. (1994), a century's overfishing is the key factor to the declination of oyster population. In 2009, Maryland's Oyster Restoration and Aquaculture Development Plan was announced that Maryland is trying to gradually shift oyster business from a fishing model to a farming model. According to the recent report of The Baltimore Sun, sales of farmed oysters jumped form 3,300 bushels in 2012 to more than 74,000 bushels in 2017, which making oyster aquaculture a roughly $5 million industry in Maryland (Dance,

2019). Oysters are usually sold and consumed alive. It may be stored for several weeks before consumption. However, the long storage time without appropriate cooling process might bring the risk of spoiling (Aaraas et al., 2004). For example, Vibrio parahaemolyticus (Vp) and Vibrio vulnificus (Vv) are associated with the consumption of raw oysters (Cole, 2015). From 1981-1992, seventy-two cases of Vv infection from raw oysters were reported and 36 (50%) patients died in Florida (Hlady et al., 1993). It has been proven that Vp levels significantly increase (p-value <0.05) over time with the storage temperatures (Mudoh et al., 2014). So that, regulations require oysters to be cooled and refrigerated after harvest in many countries. For example, Australian Shellfish Quality Assurance program requires oyster intended for consumption as raw product should be placed under ambient refrigeration at 10ºC or less within twenty-four hours of being harvested (Australian Shellfish Quality Assurance Advisory Committee, 2009). According to Code of Maryland Regulations for Vp Control, the internal temperature of oysters should reach 10°C or below within 10 hours or less after being placed under temperature control from June 1 through September 30.

Madigan evaluated one of Australian oyster cool chain from Smoky Bay, South Australia to the Sunshine Coast. He found that the ideal storage temperature all through the cool chain is not easy to achieve. As shown in Figure 1, oyster did not cool down to 10°C around 30 hours after harvest while the ambient temperature varies frequently from below 0°C to above 20°C (2008). Ice was widely used as cooling medium in the traditional boat cooling systems. However, it is not an ideal option for long time storage and long-distance transportation of oyster since ice will melt. There are different kind of on boat mechanical refrigerating system exists today (Dellacasa, 1987). However, its working ability is restricted by the horsepower of fishing boat and required large power consumption (Wang, 2005). Despite the fast development of refrigerate industry since its invention, there is no mobile cooling system specially designed for oyster industry on market.

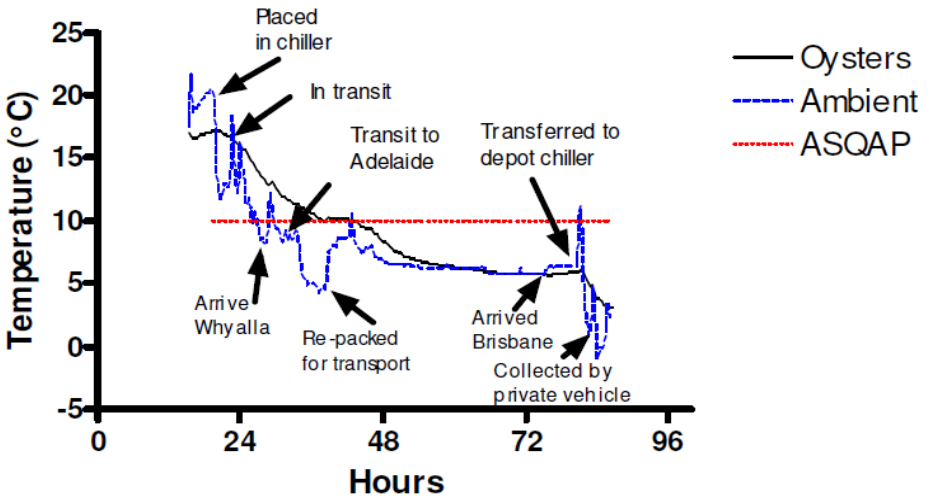


**Figure 1:** Temperature Profile of Oysters during Transportation (Madigan, 2008)

Solar energy is the cleanest and most abundant renewable energy source. A solar electric refrigeration system consists mainly of photovoltaic panels and an electrical refrigeration device. The biggest advantage of using solar panels for refrigeration is the simple construction, mobile, and high overall efficiency. As shown in Figure 2, a schematic diagram of a solar electric compressor air system is given (Kim and Ferreira, 2008). Torres-Toledo et al. (2016) built a solar icemaker and found that the icemaker can deliver the target ice production for 89% of the days of a typical year at the selected location. Zhang et al. (2010) developed and conducted performance test of photovoltaic-powered refrigerator in different

climate zones. Experimental results indicated that the refrigerator could work well in Shanghai area and has a stable performance in other different climatic regions. The above papers showed that solar energy is one of potential energy resources for refrigeration system.

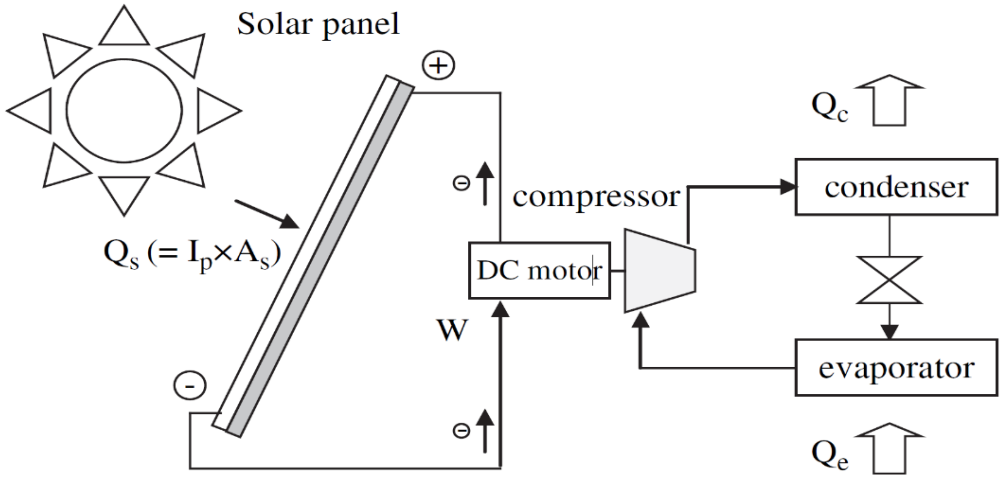


**Figure 2:** Schematic Diagram of Solar Electric Compression Air-conditioner

There are two technical challenges during oyster cooling. Firstly, rapid cooling is required to keep oyster fresh as the legal obligation. Secondly, even if the average temperature inside the refrigerator cabinet is adequate, local rise in temperature may damage oyster freshness. Thus, rapid cooling, thermal uniformity, and lower temperature variation inside the chambers of cooling system are required to keep oyster fresh (Fukuyo, 2003). Ding et al. (2004) found that the clearance between shelves and back wall as well as doors are important to reduce temperature variation and achieve uniform temperature distributions. In addition, a disturbing axial fan and an air duct were found to improve airfield and temperature uniformity in a refrigerator.

In summary, the current cooling system is not appropriate to provide ideal storage temperature of 10°C within specific cooling time required by law (10 hours or less). Solar energy is one of the best options to support a sustainable and energy efficient mobile cooling system. In addition, air circulation strategies can be used to reduce cooling time and improve thermal uniformity in a cooling system. The objective of this study is to develop, fabricate and evaluate a hybrid mobile cooling system which integrated 110 volts AC cooling unit and 12 volts DC cooling unit. Temperature changes within six individual chambers and cooling time of mobile cooling system were measured under various working conditions. It is believed that the hybrid mobile cooling system, which can move from boat, truck to final customer without any change of oyster storage condition will benefit the Chesapeake Bay oyster farmer.

## 2. METHODOLOGY

### 2.1 Effects of 4th IR on Education

The lab-scale hybrid mobile cooling system with two cooling units, 110 volts AC and 12 volts DC were designed and fabricated for the oyster farmers in the Center for Advanced Energy Systems and Environmental Control Technologies at Morgan State University. As shown in Figure 3, the frame of the cooling system was built from a heavy-duty shelf steel shelving material. The exterior wall was made from polystyrene foam board (R-value 10),

plus double bubble insulation reflective roll insulation (R-value 3). The 110 Volts AC cooling unit and 12 Volts DC cooling unit were installed and top mounted.


**Figure 3:** Raw Materials and Cooling Components for the Mobile Cooling System

As shown in Figure 4, a divider was vertically erected in the middle of the frame, which divided whole inner space into two sections. Each section is horizontally divided into three chambers by wire decking, the wire-mesh design can allow good air circulation while offering strong support. Thus, six individual chambers of cooling system, named from chamber 1 to chamber 6 individually. Chamber 1-3 belong to the left section and chamber 4-6 belong to the right section. Left section is operating with 110 volts AC cooling unit and forced convection air while right section is running with 12 volts DC cooling unit with natural convection air circulation. A DC battery was attached with this system to make sure the system can keep working even without energy source for a period. The clearance between the shelves and door was reduced to 0.5 inch to achieve uniform temperature distribution. Two vents, which can be open and close, was assembled at the top and bottom of the divider. The AC Infinity AIRTAP T4, Booster Fan can be mounted on the vent to offer air circulation. The ventilation system (vents and fan) was designed to ensure air circulation between two sections.

**Figure 4:** 3D Model of Mobile Cooling System with Two Sections and Six Chambers

### 2.2 Experimental Conditions and Instrumentations

In order to simulate the real oyster cooling process in the lab-scale hybrid mobile cooling system, oyster shell and equal amount of water was used to replace the missing oyster meat of the shell are used in this experiment. Table 1 indicates the weight of shells (in kg.) and water (in kg) in each chamber. The total amount of 95.2 kg of oyster shell plus 10 kg of water was put into the cooling system. Six set of Channel K Type Digital Thermometer were used to detect the temperatures of oyster in the center of each basket and ambient temperature in each chamber. The oyster temperature of each basket was recorded every 20 minutes. Temperature between 2 and 4 °C is the ideal storage condition for oyster. Thus, the desired cooling temperature in cooling system is set at 2 °C during this experiment. Cooling system performance include the cooling speed and temperature distribution were evaluated under three different operating conditions: working independently (two vents are closed); two vents open for air circulation between two units; two vents are opened and circulation fan on to strengthen the cooling air circulation.

**Table 1** Distribution of Oyster Shell and Water in the Cooling System

| 110 Volt Unit (Left Section) | | 12 Volt Unit (Right Section) | |
|---|---|---|---|
| Chamber 1 (kg) | | Chamber 4 (kg) | |
| 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water |
| Total: 21 shell+1 water | | Total: 21 shell+ 1 water | |
| Chamber 2 (kg) | | Chamber 5 (kg) | |
| 9.52 shell+1 water | 9.52 shell+1 water | 9.52 shell+1 water | 9.52 shell+1 water |
| Total: 42 shell+2 water | | Total: 42 shell+2 water | |
| Chamber 3 (kg) | | Chamber 6 (kg) | |
| 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water |
| 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water | 4.76 shell+0.5 water |
| Total: 47.6 shell+2 water | | Total: 47.6 shell+2 water | |

## 3. RESULTS AND DISCUSSION

Performance analysis of 110 Volt and 12 Volt cooling units working independently without and with load were performed and compared. Working independently means vents are closed while air circulation fan was off. In this experiment, it was assumed that two system were working independently because there is no vent between two sections. Figure 6 summarized the minimum, average and maximum temperature in the 110 volts and 12 volts sections without load. Results indicated that the temperature in the 110 volts section decreased from 21°C to 3.4 °C. While the temperature in the 12 volts section decreased from 20.6°C to 9.7°C within 5 hours cooling time. Figure 7 summarized the minimum, average and maximum temperature in the 110 volts and 12 volts sections with load. Results indicated that the temperature in the 110 volts section decreased from 20.8°C to 5.5°C while the temperature in the 12 volts section decreased from 20.8°C to 12.8°C within 7 hours cooling time. It can be seen that the cooling time was increased by the addition of cooling load. It was also found that 110 volts section has a better cooling performance than 12 volts section and air circulation may be required between two sections to achieve temperature uniformity.

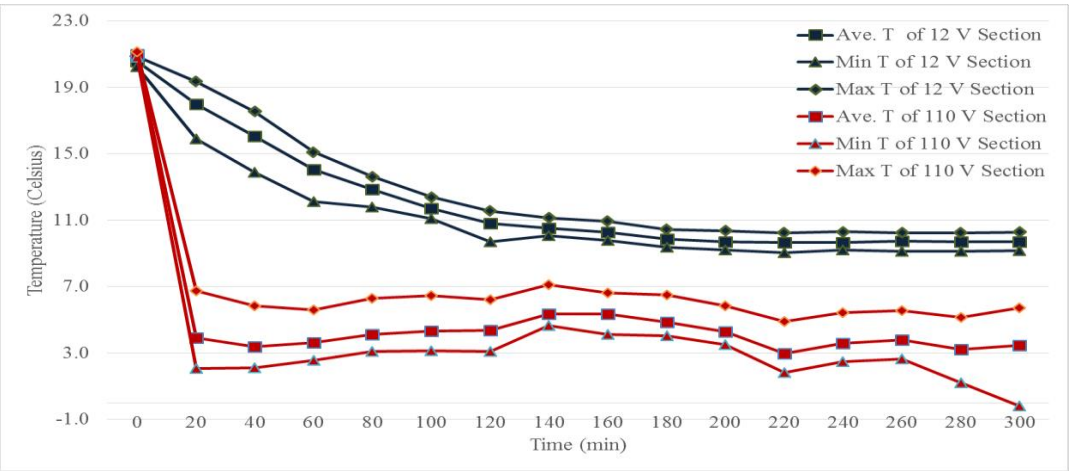


**Figure 6:** Cooling Speed and Minimum Average and Maximum Temperature without Load

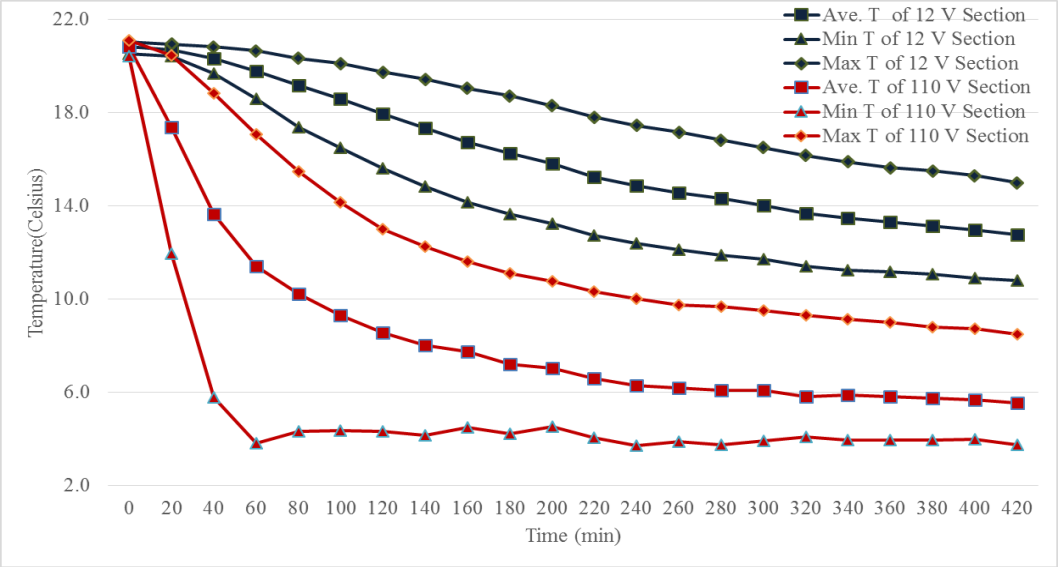


**Figure 7:** Cooling Speed and Minimum Average and Maximum Temperature with Load

Performance analysis of 110 Volt and 12 Volt units working with two vents open with load were further performed to improve the temperature uniformity. Two vents in the divider were expected to improve the air circulation and cooling performance. Figure 8 summarized the minimum, average and maximum temperature in the 110 volts and 12 volts sections. Results indicated that the temperature in the 110 volts section decreased from 20.9°C to 4.4°C while the temperature in the 12 volts section decreased from 20.8°C to 10.5°C within 7 hours. Compared with cooling performance on Figure 7, the cooling performance was improved by 1.2°C and 2.3°C in 110 volts and 12 volts chamber, respectively.

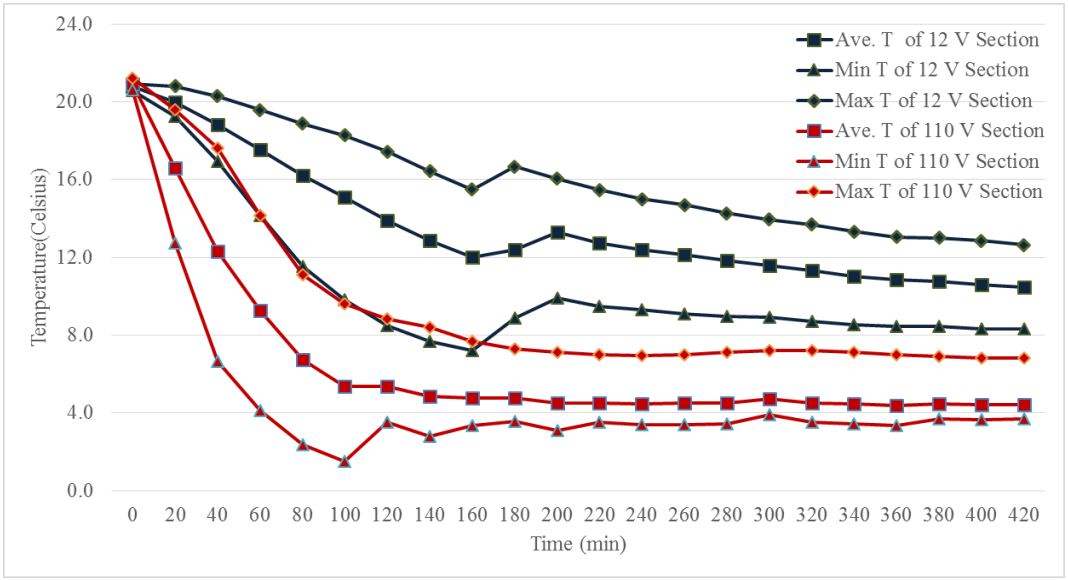


**Figure 8:** Cooling Speed and Temperature with Load and Vents Open

Under the condition of two vents open and circulation fan on, cooling performance of hybrid mobile cooling system were analysed. The cooling speed and temperature changes in the two chambers are recorded and summarized in Figure 9. It was found that average temperature of 12 volts chamber was decreased about 12.1°C within 280 minutes. However, the average temperature of 12 volts chamber in case of no vent has dropped 8°C within 7 hrs and while the case of two vents has dropped 10.3°C within 7 hrs. It was proved that there is significant improvement in both cooling speed and temperature uniformity for the hybrid mobile cooling system by adding the ventilation system (vents and fan). These results showed the importance of air circulation in the cooling system and necessary of future study on this area.

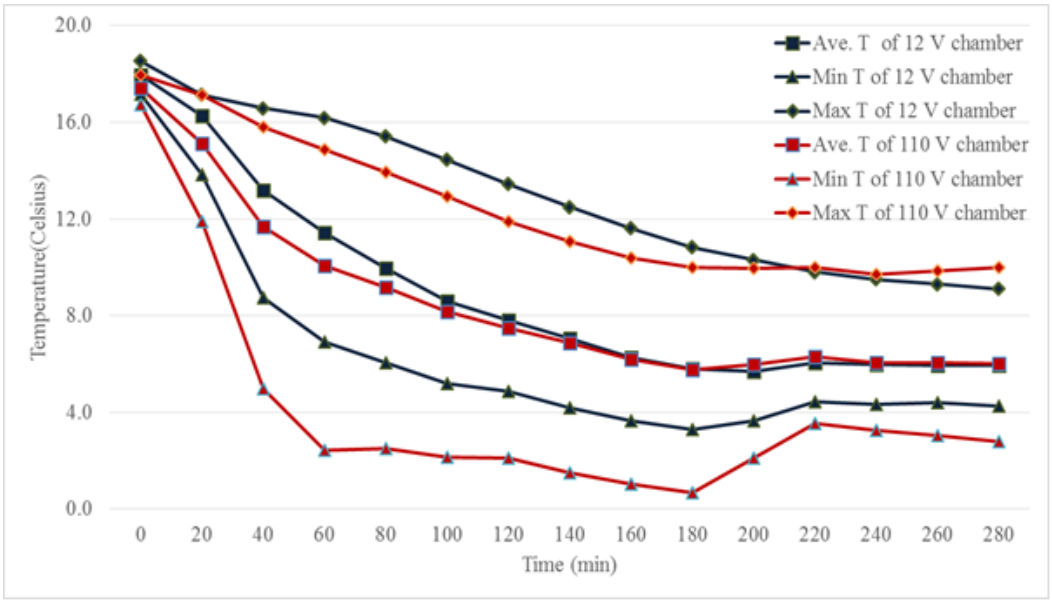


**Figure 9:** Summary of Cooling Speed and Temperature with Vents Open and Air Circulation Fan

**Table 2** Average and Standard Deviation of Temperature in Individual Chamber

| **3 Hours** | | | | | **4 Hours** | | | |
|---|---|---|---|---|---|---|---|---|
| 110V Cooling Section | | 12V Cooling Section | | | 110V Cooling Section | | 12V Cooling Section | |
| Chamber 1 | | Chamber 4 | | | Chamber 1 | | Chamber 4 | |
| Avg. T. | Std. D. | Avg. T. | Std. D. | | Avg. T. | Std. D. | Avg. T. | Std. D. |
| 2.06 | 1.94 | 3.72 | 0.56 | | 3.72 | 0.61 | 4.67 | 0.44 |
| Chamber 2 | | Chamber 5 | | | Chamber 2 | | Chamber 5 | |
| Avg. T. | Std. D. | Avg. T. | Std. D. | | Avg. T. | Std. D. | Avg. T. | Std. D. |
| 6.94 | 0.89 | 5.28 | 0.44 | | 6.67 | 0.78 | 5.67 | 0.33 |
| Chamber 3 | | Chamber 6 | | | Chamber 3 | | Chamber 6 | |
| Avg. T. | Std. D. | Avg. T. | Std. D. | | Avg. T. | Std. D. | Avg. T. | Std. D. |
| 8.33 | 1.28 | 8.39 | 2.17 | | 7.83 | 1.33 | 7.67 | 1.61 |

Table 2 shows the average temperatures and standard deviation of temperatures in each chamber of mobile cooling system to further investigate the temperature distribution and uniformity under the operating condition (two vents open and air circulation fan on). After the cooling system was operated for 3 hours, the lowest average temperature was found in Chamber 1 while the highest temperature was occurred in Chamber 6. For the standard deviation, the Chamber 1 and Chamber 6 has relatively higher value of standard deviation. Similar temperature distribution and standard deviation changes were found after 4 hours cooling. The possible reason can be the placement of evaporator and circulation fan in the chamber. In this study, the evaporator of 110 volts cooing unit was installed near the Chamber 1 and air circulation fan was placed in the Chamber 6, which significantly reduce cooling temperatures and generate a large variation of temperatures in the Chamber 1 and Chamber 6. In addition, it was found that temperature has an increasing trend in 110 volts section (from Chamber 1 to Chamber 3) as well as in 12 volts section (from Chamber 4 to Chamber 6). This explained that upper part of 110 volts and 12 volts section has better cooling performance. Thus, it was suggested to put fresh harvested oysters from bottom to top that increasing the cooling time and compensate the lower cooling performance of the lower chambers (e.g., Chamber 3 and Chamber 6). Moreover, it was found that the lab-scale hybrid mobile cooling system with best air circulation condition (two vent open and air circulation fan open) are efficient and capable to cool oysters from 18°C down to 6°C within 4 hours cooling time. These results provided a potential future study on the location of the air circulation fan inside the cooling system to further increase the cooling efficiency.

## 4. CONCLUSIONS

In this study, the lab-scale hybrid mobile cooling system was designed, fabricated and evaluated. Cooling time, temperature changes, and standard deviation of temperatures in the 110 volts and 12 volts cooling sections were collected and calculated. Cooling performance of system was investigated under three different operating conditions (no vents and air circulation fan off, two vents open with air circulation fan off, two vents open with air circulation fan on). Result indicated that the lab-scale mobile hybrid cooling system is able to cool oysters down to about 10°C within 7 hours. Among the different circulation strategies, two vents open with air circulation fan on in cooling system improved cooling performance and cooled oysters from 18°C down to 6°C within 4 hours cooling time. Temperature distribution in the cooling chamber indicated that cooling system has a better performance on the upper parts (temperature around 4°C) than lower parts (temperature around 8°C) of the cooling system. These results suggested to put fresh oysters from the

bottom parts to upper parts that lower parts may have longer cooling time than the upper parts. Results and findings from this study will assist to develop mobile cooling system and maintain fresh quality of oyster during the oyster farming process (e.g., harvesting, transporting). Moreover, hybrid cooling system will also help to utilize solar energy as energy resources for the 12 volts cooling unit and save additional energy consumption on the boats.

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# EVALUATION AND ANALYSIS OF THE SUSTAINABLE WASTE-TO-ENERGY SYSTEM PERFORMANCE FOR THE POULTRY FARM

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## ABSTRACT

Poultry litter is one type of biomass and waste generated from the poultry farms. However, excess land application of poultry litter caused eutrophication problems of surface waters coming from the watershed and destroyed the aquatic ecology. Co-combustion of poultry litter and coal were widely studied in fluidized bed combustor as an alternative disposal method during last two decades. However, there are severe environmental problems (i.e., gaseous emissions) and public health impact associated with the poultry litter and coal co-combustion process. In this study, poultry litter and natural gas co-combustion was investigated in the lab-scale waste-to-energy system to provide a sustainable and cost-effective disposal route for poultry farms. This waste-to-energy system integrates the Stirling Engine (SE), Shell-Tube Heat Exchanger (STHE) and the lab-scale Swirling Fluidized Bed Combustor (SFBC) with other systems (e.g., cyclone, air supply system, fuel feeding system). Measures of heat transfer effect, electricity output and gas emissions levels were used to evaluate the lab-scale waste-to-energy system performance. Results indicated that lab-scale waste-to-energy system can produce electricity (close to 1 kW) and hot water (57.2°C) while reducing NOx and SO2 emissions during the poultry litter and natural gas co-combustion process. In addition, energy flow analysis indicated that SE and STHE system might use 14.7% and 21.0% of total energy input in fuels, respectively, to generate useful energy. In addition, a sustainable life cycle of poultry litter was built and suggested to process poultry wastes in the poultry farms.

**Keywords:** sustainable energy systems, electricity, hot water, poultry litter, emissions

## 1. INTRODUCTION

Fossil fuel depletion and adverse environmental impacts (i.e., greenhouse gas emissions causing climate change) are stimulated to seek renewable energy sources that can replace fossil fuels during energy production process (Patel et al., 2016). Among all the renewable sources, there is an increasing interest in biomass utilization for energy production due to the benefits of CO2 neutral effect, and large availability and low cost of biomass fuels all over the world. Biomass is the name given to any organic matter which is derived from plants and animals (Saidur et al., 2011). Biomass energy sources are classified into five categories including woody biomass, agricultural biomass, aquatic biomass, animal and human waste, and industrial waste (Patel et al., 2016; Tripathi et al., 2016). Poultry litter is one type of biomass and animal waste during the poultry farming process. Using a litter production of 995 kg per 1,000 birds, a broiler house holds 23,400 birds/flock and produces 5.5 flocks/year

(6-7 week/flock, 5-6 flock/year) will produce about 128 tons/year of poultry litter (Chastain et al., 2012). Excluding states producing less than 500,000 broilers, poultry litter production were estimated about 10.8 million tons in 2008 and 10.3 million tons in 2009 from top poultry production states in U.S. (Perera et al., 2010). In most cases, the poultry litter is spread on cropland as an organic fertilizer due to its rich nutrients of nitrogen, phosphorous, potassium, sulfur and calcium (Henihan et al., 2003; Li et al., 2008). However, over-application of poultry litter to the soil can results in enrichment of water-soluble nutrient and eutrophication of water sources. When eutrophication occurs, algae living within the water will reproduce excessively under aerobic metabolism, effectively using large quantities of the dissolved oxygen in water, creating dead zones and destroying the aquatic ecology (Jia and Anthony, 2011). Eutrophication further degrades ground water quality, which is threating to human health. Due to excess production and associated problems of land application, it has stimulated interest into sustainable disposal options for poultry litter.

Kelleher et al. (2002) introduced an excellent review of alternative poultry litter disposal methods, include the compositing (or aerobic digestion), anaerobic digestion and combustion. Gasification is another main alternative disposal method of poultry litter (Topal et al., 2012). Among four main alternative disposal methods, one of the most widely used methods is combustion. Qian et al. (2018) collected higher heating values of the existing 49 poultry littler samples and found that higher heating value of poultry litter was between 6.78 and 27.90 MJ/kg with an average of 14.08 MJ/kg. With relative high energy content, combustion is able to provide a sustainable, cost-effective, environmentally benign disposal route for the poultry litter while providing for both space heating of poultry houses and large-scale schemes involving combined heat and power production (Li et al., 2008; Topal et al., 2012). However, there can be problems on maintaining steady and complete combustion of poultry litter due to the high moisture and ash contents, as well as low heating value of the poultry litter (Kelleher et al., 2002; Li et al., 2008). Therefore, co-combustion of poultry litter with fossil fuels (i.e., coal) has been considered to increase the heating value and solve technical challenges during the combustion process. Table 1 provides summary and major findings of poultry wastes and coal combustion studies in the last two decades. However, there are severe environmental problems (i.e., gaseous emissions) and public health impact associated with the poultry litter and coal co-combustion process.

**Table 1:** Summary of Co-combustion Studies of Poultry Litter and Coal

| Fuel Type | Major Findings | References |
|---|---|---|
| poultry litter + peat | Secondary air in two stages reduced $NO_x$ and CO emission. | Abelha et al., 2003 |
| chicken litter + peat | CO and volatile organic compound decreased with primary air/secondary air is 0.4. | Henihan et al., 2003 |
| chicken litter + coal | Increasing of chicken litter mass fraction in coal increased CO. | Li et al., 2008 |
| poultry wastes + coal | Excess air had a remarkable effect on CO and $CH_4$. | Topal et al., 2012 |

Co-combustion of poultry litter with natural gas has following advantages: (1) reduce gas emissions since natural gas is cleaner than coal; (2) reduce transportation cost because natural gas is available in most poultry farms; (3) reduction of the anaerobic release of CH4, NH3, H2S, volatile organic acids and other chemicals since the storage time is reduced (Zhu et al., 2005). Stirling Engine (SE) is an external combustion engine and used pressurized working fluids (i.e., helium) to convert residual heat energy into combined heat and electricity (CHP) (Thombare and Verma, 2008). In the previous studies, SE was observed to have the following advantages: smoothness, reliability, flexible external heat source, and high thermodynamic efficiency (Miccio, 2013). In addition, SE is capable of being manufactured in a low-power range of 1-10 kWe that is suitable for residential use. As a result, SE has

attracted increasing attention as an alternative option for micro-CHP systems (Corria et al., 2006; Miccio, 2013). Recently, SE has been integrated into fluidized bed combustor (Miccio, 2013), wood pellet burners (Cardozo et al., 2014), and combustion chambers (Damirchi et al., 2016) to produce heat with power for residential usage. Heat exchangers are used for transferring thermal energy between two or more fluids, or solid particulates and a fluid, at different temperature in thermal contact (Bichkar et al., 2018). Different types of heat exchanger are used worldwide that differ from each other because of their specific requirements, such as the double pipe, shell and tube, plate fin, plate and shell, pillow plate, etc. (Salahuddin et al., 2015). Shell and tube heat exchanger (STHE) are the one of the most common type of exchangers widely used in the industrial processes (Salahuddin et al., 2015; Zhang et al., 2009; Duan et al., 2016). According to Master et al. (2003), more than 35-30% of heat exchanger are the STHE type due to their robust geometry construction, easy maintenance and possible upgrades. In addition, STHEs are used in all sorts of industries because they have much lower production cost, can be easily cleaned and are considered more flexible with adaptability compared with other heat exchanger. There are limited studies on the integration of SE and STHE with swirling fluidized bed combustor during the poultry litter combustion process.

The objective of this study is to develop and evaluate the sustainable lab-scale waste-to-energy system. SE and STHE were integrated into the advanced lab-scale swirling fluidized bed combustor to generate useful energy, including electricity and hot water during the poultry litter and natural gas co-combustion process. Water temperatures, heat transfer effect, logarithmic mean temperature difference, gaseous emissions, and quantity of energy flow during the co-combustion process of poultry litter and natural gas were investigated and evaluated. In addition, the sustainable life cycle of poultry litter was designed and applied for this study.

## 2. METHODOLOGY

### 2.1 Materials

Poultry litter samples were collected from the poultry farm sheds (Bethel Farms, Salisbury, MD, USA). Then, poultry litter samples were tightly sealed, transported to laboratory, and stored in the room temperature condition. Before combustion testing, poultry litter samples were pre-sized by using sizer and crushed into smaller size while removing bulk samples, dead birds, and stones to prevent clogging and damaging of fuel feeder auger. Table 1 summarize the proximate analysis results and analysis methods of each composition for the poultry litter sample. Heating value of poultry litter was used to calculate the heat transfer and energy flow in the later section.

**Table 2:** Proximate Analysis of Poultry Litter Sample

| Composition (wt. %) | As Received | Dry Basis |
|---|---|---|
| Moisture (D3302/D3173) | 21.20 | N/A |
| Volatile Matter (D3175) | 50.40 | 63.96 |
| Fixed Carbon (diff., Calculated) | 9.44 | 11.98 |
| Ash (D3174) | 18.96 | 24.06 |
| Heating Value (D5865/5864) | 11.30MJ/kg | 14.34MJ/kg |

### 2.2 Experimental Setup

As shown in Figure 1, the sustainable lab-scale waste-to-energy system was developed. This system consists of the advanced lab-scale swirling fluidized bed combustor, air supply system, fuel feeding system, SE, STHE, cyclone, and instrumentations. Free-piston SE was acquired from Microgen Engine Corporation in the Netherlands and integrated into the

cylinder combustor at height of 120.0 mm above the primary air distributor. The lab-scale STHE was designed and fabricated along with six tubes, five segmental baffles and multiple tube connections and one shell. A cylinder carbon steel pipe was used as shell to cover tubes, baffles and connection parts. The fabricated lab-scale STHE system was inserted between combustion chamber and cyclone to capture residual heat from the hot flue gas and generate hot water during poultry litter combustion process. Then, hot water was sent to the radiators inside the mobile mini trailer house and returned to the lab-scale STHE system. During the co-combustion process, poultry litter and natural gas were supplied into the combustion chamber through the double concentric anger-based volumetric feeder (Acrison, USA) and natural gas pipe (Constellation, USA). Primary air and secondary air were supplied into the chamber via blowers. K-type thermocouple (OMEGA Engineering, USA), emission analyser (Enerac, USA) and water flow rate sensors (Ifm electronic, Germany) were used to measure inlet/outlet temperatures, gaseous emissions (e.g., CO, NOx, SO2), and water inlet/outlet flow rates along with temperatures. Heat transfer and logarithmic mean temperature were calculated using equations in the Section 2.3.

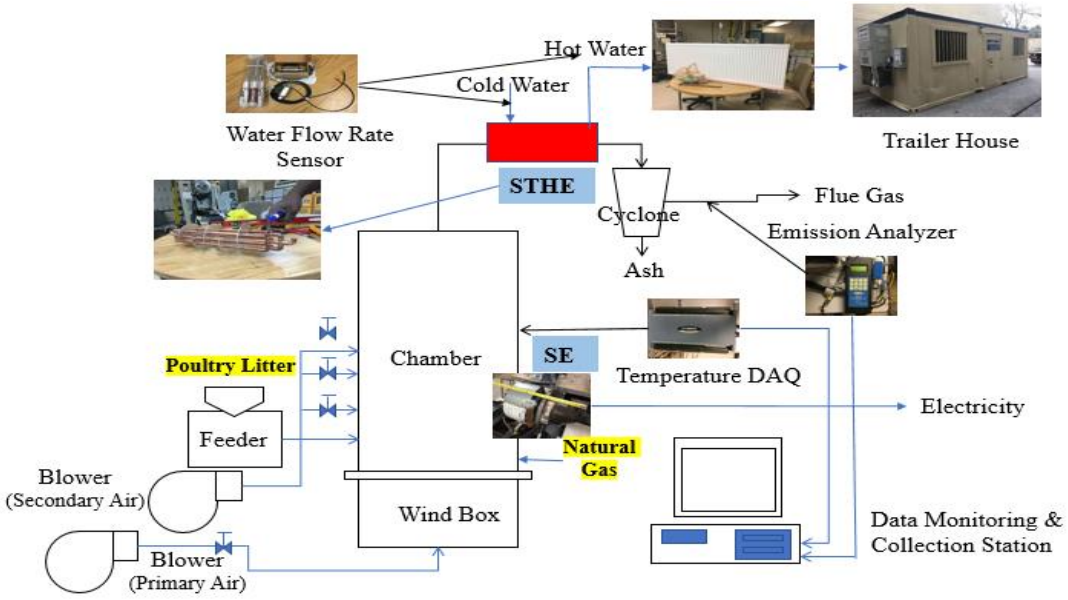


**Figure 1.** Schematic Diagram of Experiment Setup

### 2.3 Equations

Heat transfer is the measurement of the thermal energy transferred from one point to another and determined by specific heat, mass, and temperature change. The heat content, Q, is calculated as follows:

$$Q = m \times c_p \times \Delta T \quad (1)$$

where Q = heat content of medium, in Joules; m = mass, in kg; $c_p$ = specific heat, in J/g°C; and $\Delta T$ = change in temperature, in °C. Specific heat of flue gas and water were assumed as 2.01 J/g°C and 4.186 J/g°C, respectively. Heat capture efficiency was calculated by dividing of flue gas heat content by water heat content.

The logarithmic mean temperature difference (LMTD) is determined from two temperature differences $\Delta t_1$ and $\Delta t_2$ at each end of the heat exchanger.

$$LMTD = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} \qquad \Delta t_1 = T_1 - t_2 \quad \Delta t_2 = T_2 - t_1 \quad (2)$$

where $T_1$ = shell-side inlet temperature (°C), $T_2$ = shell-side outlet temperature (°C), $t_1$ = tube-side inlet temperature (°C) and $t_2$ = tube-side outlet temperature (°C).

## 3. RESULTS AND DISCUSSION

Performance of the lab-scale STHE system was evaluated under the various water flow rates (e.g., 1.89×10-5 m3/s, 2.90×10-5 m3/s, 3.78×10-5 m3/s, 5.05×10-5 m3/s, 6.31×10-5 m3/s) and fuel combinations (e.g., 2.52×10-4 m3/s natural gas, 2.83×10-4 m3/s natural gas, 2.83×10-4 m3/s natural gas and 7.08 kg/hr poultry litter). As shown in Figure 2, results indicated that the lab-scale STHE system can provide hot water (up to 42.8 °C from 20.6°C cold water) under various water flow rate and fuel combinations. It is obvious that hot water outlet temperature of the STHE system was decreased by increasing water flow rates from 1.89×10-5 m3/s to 6.31×10-5 m3/s under different fuel combinations. In addition, co-combustion of poultry litter and natural gas has relatively higher outlet temperature than the natural gas combustion because the total heat input were increased by adding the poultry litter into natural gas. System performance among the case of 113.6 L water tank, 37.8 L water tank, and no water tank between the lab-scale STHE system and mobile mini trailer were compared. Results indicated that the lab-scale STHE system without water tank is able to provide highest hot water (around 58.3 °C, from 20.6°C) than the other two cases with water tanks while increased room temperature of mobile trailer house from 16.7°C to 33.3°C within 120 minutes combustion process (outside temperature 13.9 °C).

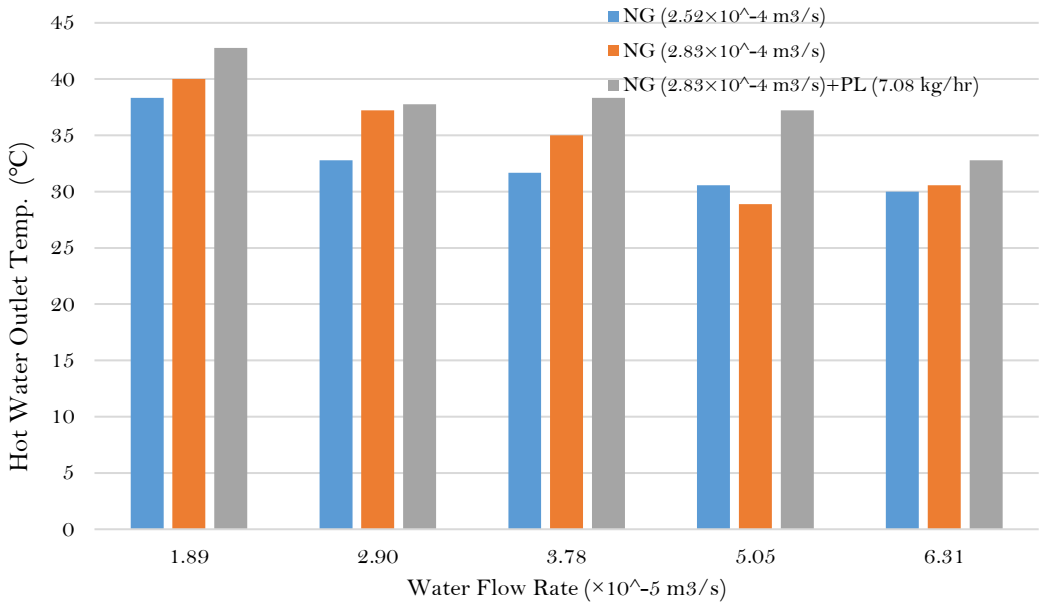


**Figure 2:** Hot Water Outlet Temperature of the STHE System

**Table 3**: Gas Emissions from Combustion Process

| Fuel Combinations | CO (ppm) | $NO_x$ (ppm) | $SO_2$ (ppm) |
|---|---|---|---|
| NG ($2.52\times10^{-4}$ $m^3/s$) | 80-100 | 28-50 | 10-22 |
| NG ($2.83\times10^{-4}$ $m^3/s$) | 126-240 | 32-60 | 15-30 |
| NG ($2.83\times10^{-4}$ $m^3/s$) + PL (7.08 kg/hr) | 300-480 | 10-35 | 8-15 |

Gaseous emission results under different fuel combinations were collected and summarized in Table 3. Results indicated that average emission of NOx were decreased from the 39 ppm to 22.5ppm. The possible reduction of NOx can be explained by the combination effect of decreased freeboard temperature to reduce small amount of thermal NOx formation and increased species, such as char and CO in the fuel bed region to form a reducing environment. Therefore, NO can be reduced by the char suspended within the freeboard, i.e., $2NO + 2C \rightarrow N_2+CO$. In addition, NOx reduction appears when a large amount of CO emissions splashed and entrained into the freeboard and interact with NO emission ($2NO+2CO \rightarrow 2CO_2+N_2$). There is small amount of $SO_2$ emission during the natural gas combustion because the sulphur containing mercaptan may be existed in natural gas for the leakage detection and lead to small amount of $SO_2$ emissions. However, it was observed that $SO_2$ emission decreased with an addition of poultry litter into natural gas. Two possible reasons may cause this fact. First, poultry litter ash has strong retention for sulphur due to relatively high Ca and Mg present in poultry ash. Second, high volatile in poultry litter creates strong reducing atmosphere above the bed that inhibits the oxidation of $H_2S$ to $SO_2$ (Li et al., 2008).

In order to increase the water outlet temperature of the STHE system, poultry litter was fed at rate of 7.07 kg/hr and natural gas was increased to $2.83 \times 10\text{-}4$ m3/s. LMTD under different flue gas and water temperature changes were calculated by using the equation (2) and used to evaluate the heat transfer of the STHE system. Results indicated that the LTMD was increased from 409.0 °C to 482.2 °C when the flue gas inlet was increased from 588.4°C to 701.2°C. This trend infer that the larger flue gas inlet temperature will increase LMTD and more heat is transferred from flue gas in the shell to water in the twisted tubes. Therefore, co-combustion of poultry litter and natural is preferred to increase total heat output and improve the heat transfer process of STHE system as well as the overall efficiency of the waste-to-energy system.

**Table 4:** LMTD Summary of the STHE System

| Flue Gas Inlet ($T_1$, °C) | Flue Gas Outlet ($T_2$, °C) | Water Inlet ($t_1$, °C) | Water Outlet ($t_2$, °C) | LMTD (°C) |
|---|---|---|---|---|
| 588.4 | 321.5 | 27.2 | 38.3 | 409.0 |
| 618.8 | 357.6 | 31.7 | 44.4 | 438.5 |
| 658.4 | 372.9 | 38.3 | 51.1 | 457.8 |
| 691.2 | 387.8 | 40.6 | 53.9 | 477.7 |
| 701.2 | 399.2 | 48.3 | 57.2 | 482.7 |

As shown in the Figure 3, energy flow during the poultry litter and natural gas co-combustion process was calculated and analysed. Heating value of poultry litter and natural gas are 11.30MJ/kg and 46.52MJ/kg, respectively. Density of natural gas (0.8 kg/m3) and air (1.225 kg/ m3) were used to calculate the total mass of fuels and air. Total energy generated from the combustion chamber was divided into the flue gas stream (60.3%), SE (14.7%) and heat loss in chamber surface (25.0%). Total heat of 18.0MJ/hr was required to produce electricity (about 1 kW) during the poultry litter co-combustion process. Then, the STHE system was used to collect 21.0 % of residual heat from the flue gas stream to produce hot water (about 57.2 °C). There was 57.2 % of residual heat from the flue gas stream was sent to the chimney. Thus, additional heat transfer devices can be used to collect this waste heat.

Based on the farm visits, farmer interviews, literature reviews and lab-scale implementations, a sustainable life cycle of the poultry litter was developed. As shown in the Figure 4, poultry litter originally produced from poultry house and cleaned out to the poultry farm sheds for short period storage before utilization and conversion process. Large quantity and volume of poultry litter caused high transportation cost along with severe environmental

problems during the land application. This study found that poultry litter could be burned in the combustor to produce useful energy (electricity and hot water) and biochar with lower gaseous emissions. Reduced volume of biochar with high nutrient concentration may help to reduce transportation cost and assist plant growth on cropland.

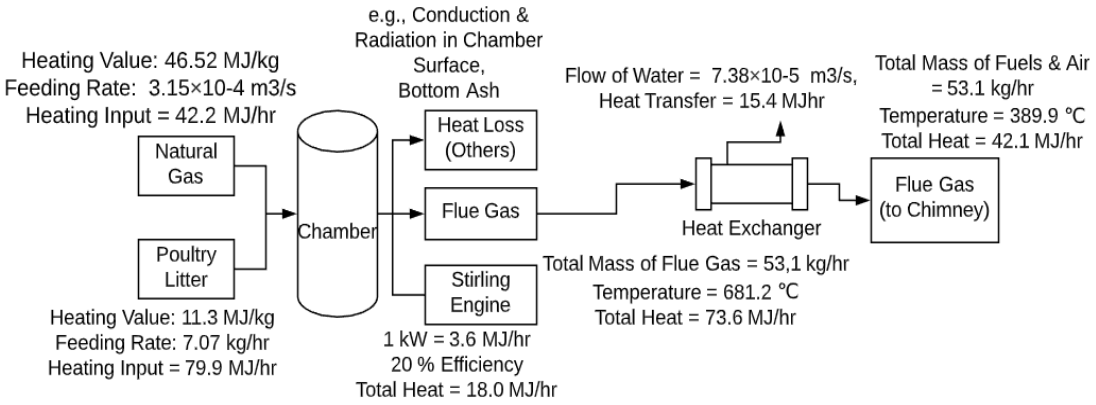


**Figure 3.** Energy Flow Analysis of Poultry Litter and Natural Co-combustion Process

The feeding materials (i.e., corn) will be returned into the poultry house as feeding materials of chickens. SE could be used to produce on-farm electricity and compensate partial electricity consumption on the ventilation fan and lighting. In addition, STHE system can be used to produce hot water, which will be sent to the radiators in the poultry house for space heating. Conventional propane-based space heating systems produced a high concentration of CO2 and moisture as well as room-relative humidity (Smith et al., 2016). Increased air moisture and room-relative humidity content can react with poultry litter, resulting in increased ammonia production and potentially negative effects on both bird health and welfare (Estevez, 2002). High concentrations of ammonia (above 70 ppm) can reduce growth performance, which result in lower body weight gain and higher feed conversion ratios (Yi et al., 2016). Thus, using poultry litter as a source of space heating can reduce propane consumption and address the run-off issues while providing a drier heat to mitigate ammonia concentration in poultry house. It is believed to save energy cost and also provide effective yield of chickens based on the sustainable waste-to-energy system in the poultry farm.

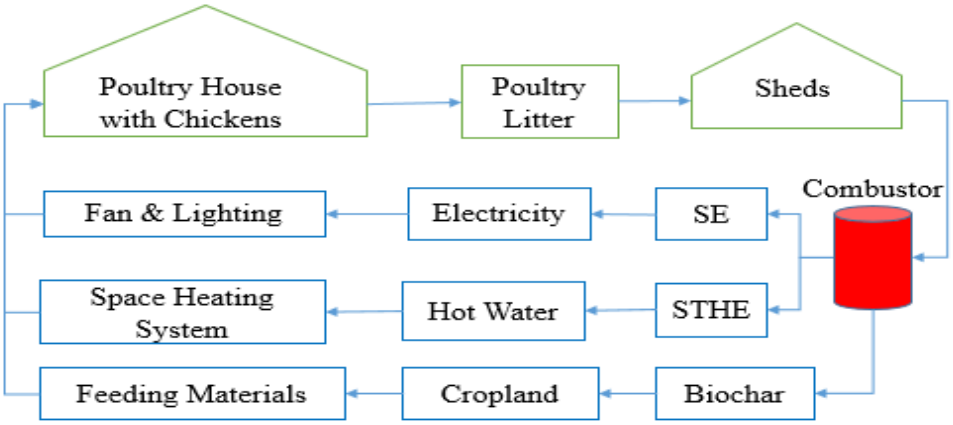


**Figure 4.** Sustainable Life Cycle of Poultry Litter in Poultry Farm

## 4. CONCLUSIONS

The sustainable waste-to-energy system was developed by integration of the existing lab-scale swirling fluidized bed combustor, SE and innovative STHE. System performance, such as electricity output, hot water temperature and gaseous emissions was investigated and evaluated under various operating conditions. Results indicated that electricity from SE was close to 1 kW and hot water from was close to 58.3 °C in the lab-scale sustainable waste-to-energy system during the poultry litter and natural gas co-combustion. Both SO2 and NOx emissions were decreased by addition of poultry litter in the natural gas combustion. It was found that co-combustion of poultry litter and natural gas was increased total heat output and flue gas inlet temperature. This inlet temperature increased LMTD and more heat was transferred from flue gas in the shell to water in the twisted tubes. In addition, a sustainable life cycle of poultry litter in poultry farm was designed and applied for this study. It is believed to reduce environmental problems of poultry litter and save energy cost by using the sustainable waste-to-energy system in poultry farm.

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# ABIOTIC STRESS RESPONSE-ASSOCIATED PROTEINS IN A SALT TOLERANT STRAIN OF THE CYANOBACTERIUM FREMYELLA DIPLOSIPHON: A POTENTIAL BIOFUEL AGENT

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## ABSTRACT

Cyanobacteria have gained great significance as a clean green alternative to fossil fuels as they are renewable and sustainable. Fremyella diplosiphon is a potential biofuel-producing cyanobacterium that efficiently captures light energy for photosynthesis. Efforts in our laboratory have been aimed to identify salt response pathways in this organism to develop strategies to enhance halotolerance in this model organism. In this study, protein expression in wild type and halotolerant mutant F. diplosiphon strains was compared using two-dimensional polyacrylamide gel electrophoresis and matrix-assisted laser desorption/ionization time of flight mass spectrometry. Of the 16 up-regulated proteins identified in the mutant, tripartite ATP-independent periplasmic (TRAP) transporter solute receptor was found to assist in salt-stress response with a significant hit to a corresponding spot with a score of 669 and 21% sequence coverage. Another protein, elongation factor Tu, linked to enhanced abiotic stress tolerance was significantly matched to a spot with a score of 1358 and 52% sequence coverage. Results of our study indicate that TRAP transporter solute receptor likely assists in enhancing halotolerance of the mutant, while elongation factor Tu is up-regulated in response to heat shock. These findings enable better understanding of F. diplosiphon salt-stress response paving the way for novel approaches in enhancing its halotolerance, leading to viable options leading to biofuel production.

**Keywords:** renewable energy, heat mutagenesis, polyacrylamide gel electrophoresis, MALDI/TOF mass spectrometry

## 1. INTRODUCTION

The use of fuels in a productive and economic way is a major challenge that we face today. While fossil fuels such as oil, coal and natural gas provide about 85% of our energy needs, the main concern of using fossil fuels is that it is a non-renewable resource, which will be depleted in the near future. In addition, continuous use of petroleum-based fuels is unsustainable because of the contribution of these fuels to atmospheric pollution and climate changes. Biofuels, which includes fuels derived from biomass conversion, as well as those from vegetable oils or animal fats, is one of the most important alternatives to fossil fuels that has gained great importance in recent years. These biofuels can be used as a fuel for vehicles in its pure form or can also be used as an additive to reduce levels of particulates, carbon monoxide and hydrocarbons in diesel-powered vehicles.

As third generation biofuels agents, photosynthetic cyanobacteria, the oldest known group of organisms on Earth offer immense potential for 'green' energy. These organisms

are amazingly productive and produce roughly 100 times the amount of clean fuel per acre compared with other biofuel crops (Abed et al. 2009) and convert light energy into chemical energy through photosynthesis using special pigments called phycobilisomes. To inhabit a wide range of environmental conditions, these organisms have evolved different mechanisms to sustain their photosynthesis (Gutu and Kehoe 2012). Thus, cyanobacteria have been found unique environmental applications such as the production of photosynthesis-derived biofuel (Ducat et al. 2010).

Recently, the potential of Fremyella diplosiphon as a production-scale biofuel agent has been recently unearthed in our laboratory. Theoretical biodiesel properties in F. diplosiphon transesterified lipids have revealed extremely high cetane number and oxidative stability, exceeding the minimum fuel standards (Tabatabai et al. 2018). Values for density, viscosity, iodine cold filter plugging point, cloud point and pour point were also above the minimum or within the acceptable range for both American and European fuel standards, with abundant C16:1 and C18:1 fatty acids indicating high-quality biodiesel. This breakthrough along with other unique capabilities of the organism such as fast growth in 7-9 days in a wide range of light wavelengths makes biofuel derived from F. diplosiphon attractive for large-scale production.

Salinity of the hydrosphere caused by man-made and environmental factors is a significant limitation for the survival of this organism which has an immense potential as a biofuel agent (Bhadauriya et al. 2007; Srivastava et al. 2008, Tabatabai 2017a). Genetic manipulation of F. diplosiphon to increase salt tolerance through biotechnological approaches has enabled our team to uncover unique environmental applications of this species (Tabatabai 2017b). Adaptation strategies in cyanobacteria in response to high salinity have been identified as well. Prior studies in cyanobacteria have reported that a major salt stress response pathway in these organisms is divided into three phases. First, an immediate rise in cellular concentration of sodium chloride (NaCl) occurs, including an accelerated invasion of sodium and chloride into the cytoplasm after turgor collapse. This is followed by the exchange of sodium with potassium resulting in the elimination of toxic impacts of high sodium concentration on cell metabolism. In the final phase, the synthesis of compatible solutes occurs to further stabilize osmotic potential in the cytoplasm and maintain the structure of cellular proteins and membranes. In short, these microorganisms adapt to salt stress by protecting the mechanisms for repair of the respiration process in photosystem I and cytochrome oxidase activity (Allakhverdiev et al. 2000).

The impact of salt stress on photosynthesis, growth, and pigmentation in F. diplosiphon has been documented (Tabatabai et al. 2017a; Singh and Montgomery 2013a,b). Our effort to enhance salt tolerance in this organism via heat mutagenesis has resulted in a mutant that thrives in 20 g L-1 NaCl (Tabatabai et al. 2017a). A three-fold increase in tripartite ATP-independent periplasmic (TRAP) solute receptor gene was detected in this mutant suggesting that it assists in cellular salt stress response in F. diplosiphon. However, further analysis of additional proteins involved in halotolerance will provide a better understanding of the molecular basis in this species. In cyanobacteria, synthesis of proteins which induces by the salt stress is distinguished to the specific salt stress and general proteins groups Berntsson et al. 2010). The objective of this study was to identify up-regulated proteins in the halotolerant strain Fd33-M25 via two-dimensional polyacrylamide gel electrophoresis (2D-PAGE) and matrix-assisted laser desorption/ionization time-of-flight/time-of-flight mass spectrometry (MALDI/TOF/TOF MS) for potential use as a biofuel agent.

## 2. METHODS

### 2.1 Strain and Culture Conditions

Halotolerant F. diplosiphon strain (Fd33-M25) isolated by subjecting the short filamentous wild type strain (WT-Fd33) to heat mutagenesis (Tabatabai et al. 2017a) were used in this study. Cultures were grown in liquid BG-11 medium (Allen 1968) containing 20 mM HEPES (hereafter BG-11/HEPES) under fluorescent white light with continuous shaking at 170 rpm at 28 °C for seven days. Light fluence rate was adjusted to 30 µmol m-2 s-1 using a LI-190SA Li-Cor quantum Sensor connected to a LI-250 Li-Cor light meter (Li-Cor, USA). Wild type strain WT-Fd33 not treated with heat mutagenesis served as the control in this study (Tabatabai et al. 2017a).

### 2.2 Sodium Dodecyl sulfate–polyacrylamide Gel Electrophoresis (SDS-PAGE)

Total proteins in the wild-type and mutant strains were separated using SDS. Proteins were isolated using Cell Lytic B reagent (Sigma-Aldrich, USA) supplemented with lysozyme, benzonase, and protease inhibitors according to the manufacturer's protocol. SDS-PAGE was performed in a Mini-Protean Tetra gel system using a 10% precast polyacrylamide gel (Bio-Rad, USA). Samples were mixed with Laemmli sample buffer supplemented with ß-mercaptoethanol (BME), heated to 95 °C for 5 min and run on a 10% polyacrylamide gel at 150V for 60 min. The gel was washed three times for 5 min in distilled water to remove excess SDS and protein bands were visualized using Simply Blue stain (Life Technologies, USA).

### 2.3 Two-dimensional Polyacrylamide Gel Electrophoresis (2D-PAGE)

Further separation of proteins was carried out using 2D-PAGE according to the carrier ampholine method of isoelectric focusing (IEF) of O'Farrell (1975) by Kendrick Labs (USA). WT-Fd33 and mutant F. diplosiphon cultures (300 mL) grown at culture conditions mentioned above were centrifuged at 5,515 x g for 8 min. Pelleted cells (100 mg) were lysed in 500 µl of osmotic lysis buffer (10 mM Tris, pH 7.4, and 0.3% SDS) containing 10X nuclease (50 µg mL-1 RNase and 100 µg mL-1 DNase in 5 mM MgCl2 and 10 mM Tris-Cl, pH 7.0), phosphatase inhibitors I and II (EMD Millipore, USA) and 100X protease inhibitor (20 mM AEBSF, 1 mg mL-1 leupeptin, 0.36 mg mL-1 E-64, 500 mM EDTA, and 5.6 mg mL-1 benzamidine) stocks. SDS boiling buffer without BME (5% SDS, 10% glycerol and 60 mM Tris, pH 6.8) (500 µl) was added and samples heated in a boiling water bath for 5 min before protein concentrations were determined using the BCA Assay (Thermo Fisher Scientific, USA). Samples were lyophilized and re-dissolved at 4 mg mL-1 in 1:1 ratio of diluted SDS boiling buffer (5% SDS, 5% BME, 10% glycerol and 60 mM Tris, pH 6.8.): urea sample buffer (9.5 M urea, 2% w/v IGEPAL CA-630, 5% (BME), and 2% ampholines consisting of 1.6% pH 5-7 and 0.4% pH 3.5-10) prior to loading on a 10% acrylamide gel. Isoelectric focusing was performed in a glass tube using 2.0% Servalyt at pH 3-10 (Serva, Germany) for 9600 volt-hours. Tropomyosin (1 µg) was added to each sample as an IEF internal standard. Tropomyosin migrates as a doublet with the lower observed spot exhibiting a molecular weight (MW) of 33,000 Da and a pI of 5.2. Six proteins, myosin (220,000), phosphorylase A (94,000), catalase (60,000), actin (43,000), carbonic anhydrase (29,000) and lysozyme (14,000) were used as MW standards in IEF (Sigma, USA). These standards appear as bands at the basic edge of the acrylamide gel stained with Coomassie Brilliant Blue R-250.

### 2.4 Identification of Proteins Using MALDI/TOF Mass Spectrometry

Differential protein expression in the WT-Fd33 and mutant was identified using MALDI-TOF mass spectrometry (MS). Protein spots from two biologically replicated 2D-PAGE gels were manually excised, digested using modified porcine trypsin (Promega, USA) in ammonium bicarbonate, and purified as described by Natarajan et al. (2014). Samples were spotted on a MALDI plate and co-crystallized with a 5 mg mL-1 concentration of α-

cyanohydroxycinnamic acid matrix prepared in 70% acetonitrile containing 0.1% trifluoroaceticacid.

### 2.5 Identification of Proteins in Wild Type and Mutant F. diplosiphon

Protein identification was performed using the Mascot search engine (http://www.matrixscience.com) against the NCBI non-redundant database with the taxonomy filter "other bacteria". The parameters for database searches included: monoisotopic mass, trypsin as the digestive enzyme with allowance for 1 missed cleavage, peptide tolerance of 50 parts per million (ppm), MS/MS tolerance of 0.6 Da, allowance of 1+ peptide charge, fixed modification for carbamidomethylation of cysteine residues, and variable modifications for oxidation of methionine residues as well as N-terminal pyroglutamic acid resulting from glutamic acid or glutamine. Positive identification of proteins by MS/MS analysis required a single peptide having a significant ion score.

## 3. RESULTS AND DISCUSSION

### 3.1 SDS-PAGE of Wild Type and Mutant F. diplosiphon Total Protein Extracts

Comparison of total proteins using SDS-PAGE revealed differential expression in the wild type and mutant strains ranging from 35 to 130 kDa, indicating widespread changes in the proteome associated with salt tolerance in Fd33-M25. SDS-PAGE has been used to identify alterations in protein expression induced by heat mutagenesis and salinity stress (Sato et al. 2010).

### 3.2 Identification of Substrate Binding Proteins (SBPs)

Up-regulation of proteins was further confirmed by 2D-PAGE (Fig. 1), which identified proteins representing 32 spots in the wild type (Table 1) and 24 spots in the halotolerant strain (Table 2). Of these spots, 16 were found to be up-regulated in the mutant strain, indicating that heat mutagenesis significantly altered expression of these proteins. Several overexpressed proteins in the mutant were found to be substrate-binding and associated proteins (SBPs), a class of protein domains that are often associated with membrane protein complexes for transport or signal transduction (Berntsson et al. 2010). Specifically, a SBP exclusive in the mutant was identified as a TRAP type transporter solute receptor by MALDI-TOF MS (spot #1) (Fig. 1).

Differentially expressed proteins were identified by matrix-assisted laser desorption/ionization time of flight mass spectrometry. Substrate-binding and associated proteins up-regulated in Fd33-M25 are marked with black arrows representing the following: spot #1: Tripartite ATP-independent periplasmic TRAP-type transporter solute receptor, spot #2: bicarbonate-binding protein, spot #3: phosphoglycerate kinase, spot #4: Fe(3+) ABC transporter substrate-binding protein, spot #5: phosphogluconate dehydrogenase. A Mascot search of NCBI non-redundant databases revealed a TRAP-type protein of interest (GI: 662703514) as the most significant match with a MOWSE score of 669. Other Mascot information for this protein revealed a theoretical isoelectric point (pI) of 4.9, molecular weight (Mr) of 41206 Da, 6 peptides matches, and 21% sequence coverage. TRAP solute receptors could enhance the ability of the mutant to uptake compatible solutes when grown in 20 g L-1 NaCl. The uptake of these solutes is a preferred mechanism since it is less energy-intensive than de novo synthesis of osmoprotectants (Mulligan et al. 2011). In Synechocystis sp. strain PCC 6803, the TRAP transporter complex GtrABC is a Na+-dependent transporter for the uptake of glutamate in response to osmotic stress.

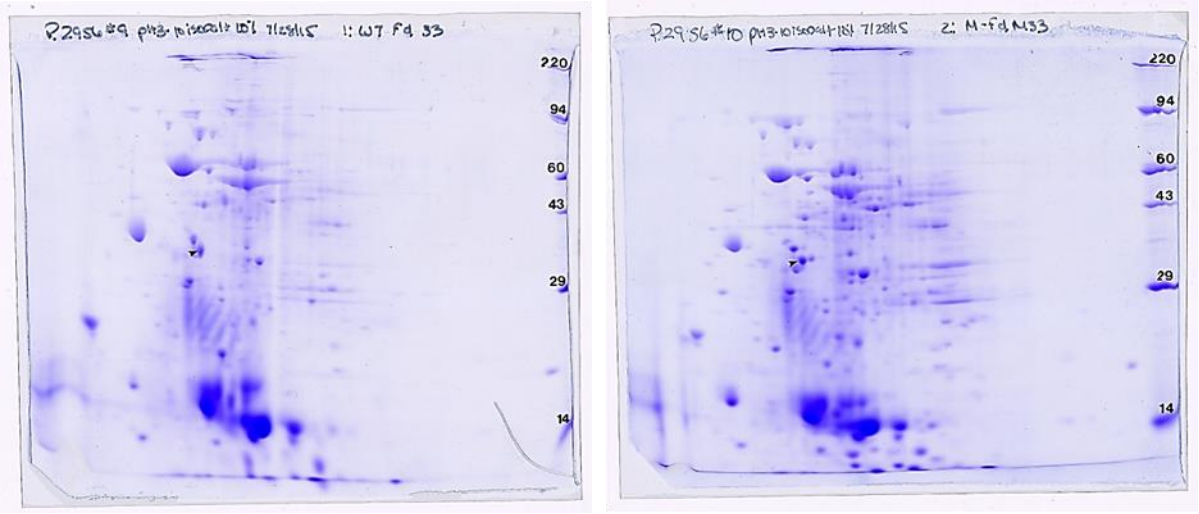


**Figure 1.** Two-dimensional polyacrylamide gel electrophoresis of Fremyella diplosiphon (A) wild type (WT-Fd33) and (B) halotolerant mutant (Fd33-M25) run on a 10% acrylamide gel.

Another known compatible solute is glycine betaine which has been reported in several phototrophic bacteria (Grammann et al. 2002). A glycine betaine/choline ATP-binding cassette transporter system in F. diplosiphon has been reported to assist in glycine betaine uptake (Singh and Montgomery, 2013a) suggesting that this organism can uptake compatible solutes in response to salinity stress. Accordingly, the TRAP transporter system could serve as a secondary glycine betaine transporter in concert with an ABC transporter. These results indicate that alterations in the regulation of the TRAP transporter complex could be a potential source of halotolerance in the mutant. In addition, a six-fold overexpression of a TRAP-type C4-dicarboxylate transport system resulted in the exclusion of sodium ions from the cytoplasm at high salinity in the halotolerant bacterium Tistlia consotensis (Rubiano-Labrador et al. 2015). Similar systems have also been found in the moderately halotolerant cyanobacterium Synechocystis sp. strain PCC 6803, where a Na+-dependent TRAP transporter for L-glutamate was reported (Quintero 2011).

**Table 1:** Proteins identified in Fremyella diplosiphon wild type strain (WT-Fd33) via 2D-PAGE and MALDI-TOF/TOF.

| **Identified Protein** | **Accession #** | **MW** | **pI** | **# PM** | **% Seq cov** | **MOWSE** |
|---|---|---|---|---|---|---|
| Membrane protein | gi\|655653826 | 67591 | 4.52 | 10 | 22 | 1148 |
| S-layer protein | gi\|655729225 | 65072 | 5.09 | 8 | 20 | 851 |
| Elongation factor Tu | gi\|655669450 | 43764 | 5.1 | 11 | 49 | 1073 |
| Fructose-bisphosphate aldolase | gi\|499175825 | 39119 | 5.46 | 5 | 30 | 710 |
| Elongation factor Ts | gi\|655690303 | 24414 | 5.5 | 7 | 34 | 573 |
| Phosphate ABC transporter substrate-binding protein | gi\|655646357 | 35287 | 9.89 | 7 | 34 | 785 |
| Chain B, X-ray Crystal structure of phycocyanin | gi\|459358656 | 18283 | 4.98 | 5 | 50 | 684 |
| Membrane protein | gi\|655653826 | 67591 | 4.52 | 7 | 19 | 656 |
| ATP synthase subunit beta | gi\|655670889 | 51841 | 4.95 | 12 | 32 | 938 |
| Elongation factor Tu | gi\|655669450 | 43764 | 5.1 | 9 | 41 | 740 |
| Fe(3+) ABC transporter substrate-binding protein | gi\|655641475 | 38156 | 5.82 | 10 | 47 | 1047 |
| Phosphate ABC transporter substrate-binding protein | gi\|655646357 | 35287 | 9.89 | 6 | 27 | 629 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Elongation factor Ts | gi\|655690303 | 24414 | 5.5 | 3 | 30 | 385 |
| Molecular chaperone groel | gi\|499174454 | 57731 | 5.01 | 9 | 29 | 874 |
| ATP synthase subunit beta | gi\|655670889 | 51841 | 4.95 | 12 | 37 | 1490 |
| Elongation factor Tu | gi\|662705204 | 43764 | 5.1 | 9 | 43 | 750 |
| Hypothetical protein D082_28000 | gi\|662705353 | 60433 | 5.47 | 9 | 31 | 1114 |
| ABC transporter substrate-binding protein | gi\|655741293 | 41206 | 4.9 | 6 | 21 | 669 |
| Elongation factor Tu | gi\|655669450 | 43764 | 5.1 | 15 | 52 | 1358 |
| Bicarbonate-binding protein | gi\|655714980 | 47823 | 5.57 | 7 | 25 | 722 |
| Elongation factor Tu, partial | gi\|909637040 | 34530 | 5.06 | 3 | 23 | 500 |
| Fructose-bisphosphate aldolase | gi\|499175825 | 39119 | 5.46 | 8 | 33 | 912 |
| Chain B, X-ray crystal structure of phycocyanin | gi\|459358656 | 18283 | 4.98 | 3 | 46 | 456 |
| Phosphoglycerate kinase | gi\|655666522 | 42010 | 4.99 | 7 | 37 | 899 |
| Phosphoribulokinase | gi\|655688149 | 38101 | 5.14 | 9 | 37 | 791 |
| Fe(3+) ABC transporter substrate-binding protein | gi\|655641475 | 38156 | 5.82 | 12 | 47 | 1265 |
| Photosystem I reaction center subunit XII | gi\|655705579 | 32581 | 9.45 | 10 | 37 | 903 |
| Phycocyanin alpha subunit | gi\|2673718 | 11319 | 9.3 | 1 | 19 | 140 |
| Photosystem I reaction center subunit XII | gi\|655705417 | 30870 | 9.51 | 9 | 46 | 1010 |
| Phosphate ABC transporter substrate-binding protein | gi\|655646357 | 35287 | 9.89 | 9 | 34 | 958 |
| Phosphate ABC transporter substrate-binding protein | gi\|655646357 | 35287 | 9.89 | 4 | 39 | 751 |
| Elongation factor Tu | gi\|655669450 | 43707 | 5.1 | 7 | 43 | 893 |

In addition to TRAP solute receptors, other SBP spots were identified as bicarbonate-binding protein (spot #2), phosphoglycerate kinase (spot #3), Fe(3+) ABC transporter substrate-binding protein (spot #4), and phosphogluconate dehydrogenase (spot #5) (Fig. 1) suggesting that heat mutagenesis significantly affects SBP regulation. This is interesting to note since SBPs are not only involved in TRAP-type transporter systems, but several mechanisms of salt-stress response. Members of this protein class are key components of ABC transporter systems that uptake compatible solutes such as glycine betaine that can be used as osmoprotectants in bacteria such as Listeria monocytogenes and Escherichia coli (Roeßler and Müller 2001; Ko and Smith 1999). This indicates that heat mutagenesis could result in enhanced robustness of multiple salt-stress response pathways. This is supported by recent transcriptomic analysis in mutant halotolerant strains of the microalgae Chlorella sp., which revealed up-regulation of sorbitol/mannitol transport system substrate-binding proteins relative to wild type salt-sensitive strains (Li et al. 2018).

### *3.3* Elongation Factor Tu

In addition to SBPs, several proteins that differentially accumulated in Fd33-M25 and WT-Fd33 spanning a wide range of isoelectric points and molecular weights were identified. One of these up-regulated proteins identified was the elongation factor Tu, which is known to be highly conserved in bacteria (Jiang et al. 2016). MALDI-TOF/TOF revealed this protein of interest (GI: 655669450) as the most significant match with a MOWSE score of 1358 via Mascot search of NCBI non-redundant databases. Other Mascot information for this specific protein revealed a theoretical pI of 5.1, Mr of 43764 Da, 15 peptides matches, and 52% sequence coverage (Table 1). This membrane-bound protein is involved in translation and protein biosynthesis and plays a role in various abiotic stress response pathways (Barbier et al. 2013; Fu et al. 2013). Specifically, overexpression of this protein in E. coli has been

reported to enhance heat tolerance, enabling survival when exposed to high temperatures up to 55 °C (Bhadula et al. 2001). This suggests that up-regulation of the elongation factor Tu in F. diplosiphon is a response to heat shock treatment in the mutagenesis process. While accumulation of this protein has been linked to a more robust heat, drought, and UV light stress response (Shrivastava et al. 2015; Fu et al. 2013; Bhadula et al. 2001), to our knowledge there exist no studies to discuss its potential effect on salinity stress. Thus, additional studies to determine if elongation factor Tu up-regulation assists in salt stress response in addition to heat tolerance.

## 4. CONCLUSIONS

Protein expression in wild type and heat-transformed F. diplsosiphon strains using 2D-PAGE and MALDI-TOF MS was ascertained in this study. The results indicate up-regulated SBPs in theFd33-M25 strain obtained by heat mutagenesis, which are typically key components of bacterial salt-stress response mechanisms such as compatible solute uptake via TRAP-type and ABC transporters. While the elongation factor Tu was also overexpressed likely in response to heat stress, further studies are required to determine its role in halotolerance. In future studies, comprehensive characterization of proteins associated with salt-stress response pathways in F. diplosiphon will be pursued. This will enable development of efficient strategies to further enhance halotolerance of this strain as a potential biofuel agent.

## 5. ACKNOWLEDGEMENTS

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# THERMAL PERFORMANCE EVALUATION AND ANALYSIS OF THE EFFICIENT and SUSTAINABILITY SHELL AND TUBE HEAT EXCHANGER SYSTEM

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## ABSTRACT

Shell and tube heat exchanger (STHE) is one of the most attractive heat exchanger types and widely used in many industrial processes, power generation, and chemical process industries because of the STHE suits the high-pressure applications and harsh environment. STHE porotype consists of a shell with a bundle of tubes and several baffles inside it. The objective of the study is to model and analysis of thermal performance and heat transfer in the advanced STHE system by using ANSYS Fluent along with the experiment. The advanced computational simulation tool, ANSYS Fluent, and AutoCAD were used to model the STHE system along with the one shell (8" diameter), five tubes (1" diameter) and four baffles. In this study, steel was selected for shell materials, copper and brass was compared to select better performance materials for tubes. The constructed STHE model has meshed and analyzed under two mediums (water and biogas) with different thermal conditions. Besides, the experiment results from the STHE prototype were used to investigate conversion efficiency and analyze heat transfer. The analysis of variance (ANOVA) method was used to analyze the significant effect of hot water flow rate and inlet temperature on heat transfer of the STHE prototype. Results from simulation and Karen's method indicated the heat release of the brass is lower than the copper in the system. Under various operating conditions, experimental results showed the conversion efficiency of the lab-scale STHE is a high range of 0.80-0.86. In addition, ANOVA results indicated that the hot water inlet temperature has a significant effect on heat transfer of STHE prototype.

**Keywords:** Shell and tube heat exchanger, heat transfer, conversion efficiency, ANOVA

## 1. INTRODUCTION

The Heat exchanger is an equipment, which used to transfer energy from a hot fluid to cold fluid while the fluid is passing through the heat exchanger, the temperature of fluid changes along the length of heat exchanger (Duan et al., 2016; Salahuddin et al., 2015). The shell and tube heat exchanger (STHE) consist of a shell (a large pressure vessel) with a bundle of tubes inside it. Heat exchangers are used in a wide variety of engineering applications, such as power generation, waste heat recovery, manufacturing industry, air-conditioning, refrigeration, space applications, and petrochemical industries (Duan et al., 2016). Large ratio of heat transfer area to volume is provided by the STHEs. Thus, STHE can be easily cleaned and has great flexibility to meet almost any service requirements. STHE can also be designed for high pressure relative to the environment and high-pressure difference between the fluid streams. In the previous studies, authors paid attention to analysing this problem both

experimentally and theoretically during design and development of shell and tube heat exchangers.

Kern's method presented the correction factor as a function of two variables R and S, which depends on the inlet and exit temperatures of the heat exchanger of both the fluids. Then, corrected effective mean temperature difference (CMTD) was calculated by multiplication of the correlation factor (F) and the logarithmic average of the temperature (LMTD) to evaluate the heat transfer performance (Nitsche and Gbadamosi, 2015). LMTD is used to calculate the heat transfer coefficient and critical to the heat transfer process because inlet fluid temperature affects both LMTD values and Reynold number (Singh, 2013). Surface area, correction factor, LMTD, and heat content are used to obtain the overall heat transfer coefficients and evaluate the performance of the STHE (EI-Said and Al-Sood, 2019). Water is utilized as a working fluid for both hot and cold streams and experiment results indicated that hybrid segmental baffle enhanced the energy efficiency by 1.27 to 1.4 times compared to conventional single segmental baffle. Recently, Kasmir and Joshi (2015) compared performance under the counter flow arrangement and parallel flow in the experimental study of STHE. Experiment results indicated that counter flow arrange gave better results that parallel flow while hot water supplied from boiler to the shell side and cold water came from main storage tank to tube side.

During the simulation studies, computational fluid dynamics (CFD) analysis of STHE has been widely performed to study temperature gradients, pressure distribution and velocity vectors. Ozden and Tari (2010) performed shell side CFD analysis of a small STHE to flow and temperature fields under a variable number of baffles and turbulent flow. In this study, water was used as medium inside the shell and simulation results showed 23% baffle cut gives slightly better results than the 25% and 36%. Singh and Kumar (2014) considered hot water is flowing inside the tube and cold water runs over the tube in the STEH model. It is concluded that the temperature of the experiment results and simulated values in CFD model are fair agreement and CFD can help to design and predict the heat performance of the STHE model. Ma (2012) conducted CFD and heat transfer simulation in a novel shell-tube type heat exchanger. The agreement between the predicted 3D flow structure in ANSYS model and particle image velocimetry (PIV) flow visualization results from experiment also verified that the CFD model is appropriated to study flow fields. Bogale (2014) conducted simulation for the heat transfer between the two fluids is analyzed using the concept of CFD in Gambit and Fluent software's. Simulation results indicated that redesigned STHE cam efficiently work to achieve required outlet temperature of 340˚C to make beer for customer use. However, there is limited study to investigate the STHE performance by using biogas as a medium in the shell section.

The objective of this study is to understand the effect of operating factors, such as hot water inlet temperature and hot water flow rates on the system performance during the experimental in STHE porotype. Mixed level and ANOVA method were used to perform statistical analysis and analyze the system performance. Then, CFD simulation of the STHE model was performed to study the temperature and velocity distribution in the STHE. In this simulation, biogas and water were used as medium in the shell and tube to investigate the heat transfer between gas and water in the STHE. It is believed that the combination of experimental and simulation study will help to better understand and overall performance of STHE.

## 2. METHODOLOGY AND SCIENTIFIC APPROACHES

### 2.1 Effects of 4th IR on Education

As shown in Figure 1, the STHE prototype was designed and installed to analysis the temperature changes and heat transfer between one medium in shell and another medium in tube section. The principle of operation is simple that two fluids of different temperatures are

brought into close contact, but they are not mixing with each other. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. Temperature of two fluids will tend to equalize and the heat is simply exchanged from one fluid to the other and vice versa. Multiple pipes were used to connect between STHE, water pump, faucet, and water tank. The cold-water inlet was connected between faucet and STHE while cold water outlet was pointed to the water sink and STHE. For the cold water, inlet was connected between hot water tank and pump while outlet was connected between STHE and water sink. The inlet cold water connection is connected to the normal room temperature tap water and flow is control by the value and cold-water outlet is directly flow through the basin. The hot water inlet is taken in a large basin and water flow is controlled by another value. Three different hot water flow rates (e.g., 5.0 in3/s, 6.6 in3/s, and 8.2 in3/s) and four different hot water inlet temperatures (e.g., 95F, 105F, 115F, and 125 F) were selected and used to investigate the system performance of STHE under this experimental setup. Analysis of variance (ANOVA) method was used to identify the effect of hot water inlet temperature and flow rate on cold water outlet temperature and hot water outlet temperature while cold water inlet temperature of 66.8 F and cold water flow rates of X were kept.


**Figure 1.** Schematic Diagram and Experimental Setup of STHE Prototype

### 2.2 2D Design, 3D Modelling, and Simulation

Table 2 summarizes the detailed geometric dimensions of STHE system for the 2D design and 3D modeling. As shown in Figure 2, 2D design and 3D model of the STHE were designed using AutoCAD software and ANSYS software.

**Table 1:** Geometric Dimensions of STHE

| | |
|---|---|
| Heat exchanger length, L | 0.762 m |
| Shell inner diameter, $D_i$ | 0.2032 m |
| Tube Outer diameter, $d_o$ | 0.0254 m |
| Tube bundle geometry and pitch | 0.0381 m |
| Number of the tube, $N_t$ | 5 |
| Number of the baffle, $N_b$ | 4 |
| Central baffle spacing, B | 0.1016 |
| Baffle inclination angle, $\theta$ | 90 $^{\circ}\theta$ |

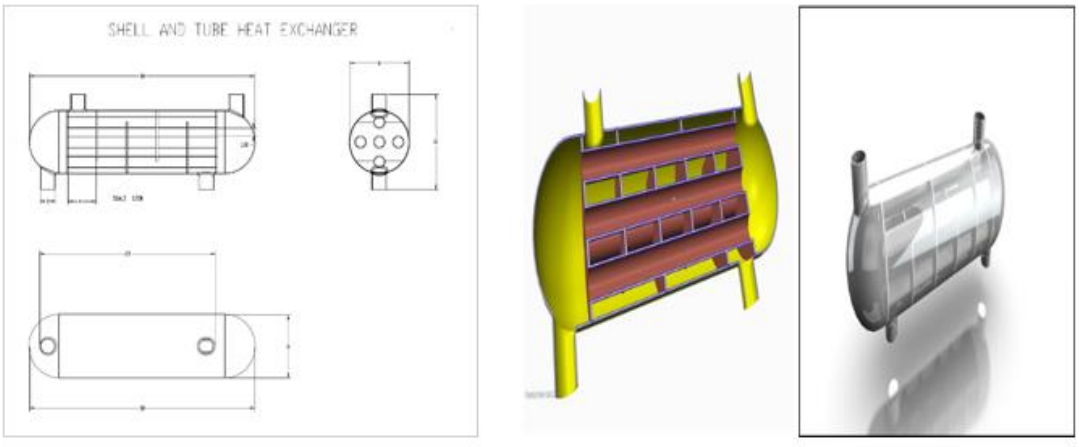


**Figure 2:** Schematic Diagram and Experimental Setup of STHE Prototype

**Table 2:** Thermal Properties of Materials and Medium in STHE Modelling and Simulation

| Thermal Properties | Copper | Brass | Steel | Fresh Water | Biogas |
|---|---|---|---|---|---|
| Thermal Conductivity (W/(m°C) | 140 | 125 | 45 | 0.604 | 0.026 |
| Density (kg/m$^3$) | 8940 | 8600 | 7872 | 997.4 | 1.2 |
| Specific Heat (J/kg°°C) | 385 | 62 | 481 | 4179 | 3493 |

Then, the 3D model is meshed by using the hexahedra mesh elements. Before meshing, fluid and the solid domain was created to have better control over the number of nodes. The simulation was carried out in the ANSYS® FLUENT® v18.1 software. During the simulation, absolute velocity formation, steady time, standard k-epsilon turbulence model, standard wall function and pressure-based solver were used. Water and biogas were selected as the medium for the copper tubes and shell section. Inlet velocity of biogas and water are 10 m/s and 2 m/s while the inlet temperature of biogas and water are 726.85°C and 26.85°C, respectively. Each shadow wall should be select in boundary condition and have to make couple with the wall thickness of 0.03 m. Together with the continuity and momentum equations, the two equation of k-ε model will be solved with the SIMPLE algorithm. Solution initialization was standard method and solution was initializing from inlet with 26.85°C. Under the above boundary conditions and solution initialize condition, the simulation was set for 300 iterations and Navier-Stokes Equations were to analyse the temperature and velocity distribution in the STHE prototype.

## 3. RESULTS AND DISCUSSION

Table 4 represents the inlet/outlet temperature, volume, mass flow rate of the hot water and cold water during the experiment in the STHE prototype. Then, temperature differences, mass flow rate and specific heat were used to calculate the heat in and heat out for hot water and cold water. The overall efficiency was calculated by diving the heat out and heat in. Results indicated that the conversion efficiency of STHE system is a range of between 80% to 86%. Thus, the STHE prototype has good conversion efficiency and can be used to capture residual heat for the combustion process.

**Table 3:** Thermal Properties of Materials and Medium in STHE Modelling and Simulation

| Hot Water | | | | Cold Water | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Temp In (°C) | Temp Out (°C) | Volume (L) | Mass Flow Rate (kg/sec) | Temp In (°C) | Temp Out (°C) | Volume (L) | Mass Flow Rate (kg/sec) | Heat In (kW) | Heat Out (kW) | Eff. |
| 34.8 | 31.61 | 18.2 | 0.182 | 13.16 | 20.11 | 7.2 | 0.072 | 2.450 | 2.090 | 0.85 |
| 37 | 33.5 | 17.4 | 0.174 | 13 | 18.88 | 8.3 | 0.083 | 2.551 | 2.052 | 0.80 |
| 40.05 | 34.77 | 20.6 | 0.206 | 15.61 | 24.51 | 10.2 | 0.102 | 4.549 | 3.80 | 0.84 |
| 43.94 | 39.27 | 22.0 | 0.220 | 13 | 24.61 | 7.6 | 0.076 | 4.288 | 3.679 | 0.86 |
| 8.88 | 5.55 | 23.8 | 0.238 | -10.6 | -3.24 | 8.7 | 0.087 | 3.322 | 2.711 | 0.82 |
| 53 | 46.77 | 22.7 | 0.227 | 15.61 | 27.94 | 9.5 | 0.095 | 5.915 | 4.885 | 0.83 |

As shown in Table 4, cold water inlet temperature and flow rate was set as constant of 19.3°C and 0.16 L/s during the test. Mixed level factorial design method was applied to identify the effect of hot water inlet temperature and flow rate on the cold water and hot water outlet temperatures in STHE prototype. There are 3 individual levels for the hot water flow rate while 4 individual levels for hot water inlet temperature. There are 3 replications for each test run. Average temperatures were collected for each condition in the last column of cold water outlet temperature and hot water outlet temperature. Mixed level method and ANOVA test were used to analyse the differences among the group mean under different operating condition (Qian et al., 2014; Qian et al., 2018). Table 5 summarizes the ANOVA results, include a degree of freedom (DF), adjusted sum of squares (Adj SS), adjusted mean square (Adj MS), F-value and P-value. From the ANOVA table, results indicated that the hot water inlet temperature has a significant effect on the cold water outlet temperature because the P-value is smaller than 0.05.

**Table 4:** Summary of Hot and Cold Water Outlet Temperatures at Variable Operating Conditions

| Hot Water Flow Rate | Hot Water Inlet Temp. (°C) | Cold Water Outlet Temp. (°C) | | | | Hot Water Outlet Temp. (°C) | | | |
|---|---|---|---|---|---|---|---|---|---|
| (L/min) | ( °C ) | #1 | #2 | #3 | Avg. | #1 | #2 | #3 | Avg. |
| 5 | 35.00 | 21.11 | 21.17 | 21.28 | 21.17 | 30.17 | 30.11 | 30.22 | 30.17 |
| 5 | 40.56 | 24.89 | 24.67 | 24.89 | 24.83 | 29.72 | 29.56 | 29.72 | 29.67 |
| 5 | 46.11 | 27.28 | 27.33 | 27.28 | 27.28 | 29.00 | 28.89 | 29.06 | 29.00 |
| 5 | 51.67 | 29.17 | 28.89 | 29.06 | 29.06 | 35.72 | 35.78 | 35.83 | 35.78 |
| 6.6 | 35.00 | 22.89 | 22.94 | 23.00 | 22.94 | 34.67 | 34.56 | 34.50 | 34.56 |
| 6.6 | 40.56 | 25.06 | 25.11 | 25.06 | 25.06 | 34.17 | 34.11 | 34.22 | 34.17 |
| 6.6 | 46.11 | 28.17 | 28.06 | 28.00 | 28.06 | 38.50 | 38.56 | 38.61 | 38.56 |
| 6.6 | 51.67 | 29.39 | 29.50 | 29.33 | 29.39 | 38.06 | 37.94 | 38.00 | 38.00 |
| 8.2 | 35.00 | 23.06 | 23.17 | 23.22 | 23.17 | 37.00 | 36.94 | 36.89 | 36.94 |
| 8.2 | 40.56 | 25.78 | 25.56 | 25.67 | 25.67 | 40.22 | 40.33 | 40.22 | 40.28 |
| 8.2 | 46.11 | 27.61 | 27.28 | 27.22 | 27.39 | 39.61 | 39.56 | 39.67 | 39.61 |
| 8.2 | 51.67 | 28.61 | 29.00 | 29.06 | 28.89 | 39.17 | 38.89 | 39.06 | 39.06 |

**Table 5:** Summary of ANOVA Results

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 5 | 253.293 | 50.6587 | 52.11 | 0.000 |
| Hot Water Inlet Flow Rate | 2 | 4.727 | 2.3633 | 2.43 | 0.169 |
| Hot Water Inlet Temperature | 3 | 248.567 | 82.8556 | 85.22 | 0.000 |
| Error | 6 | 5.833 | 0.9722 | | |
| Total | 11 | 29.127 | | | |

Contour plot represented cold-water outlet temperature change as response variable from two predictor variables, hot water inlet temperature on x-axis and hot water flow rate on y-axis. In this contour plot, cold water inlet temperature = 19.3°C, cold water inlet flow rate = 0.16 L/s, and hot water inlet flow rate = 0.11 L/s. Results indicated that if the desired cold water temperature in the STHE prototype is above 26.7 °C (80 °F), the hot water inlet temperature should be at least 44.3 °C (110 °F).

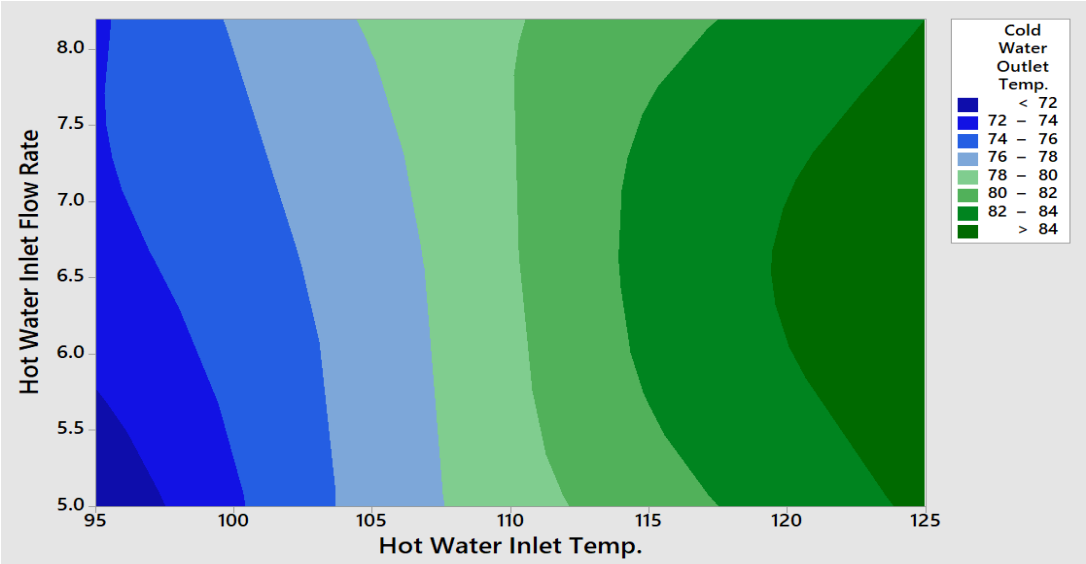


**Figure 3.** Contour Plot of Cold-Water Outlet Vs Hot Water Inlet Temp and Flow Rate

Figure 4 illustrates the temperature distribution in the STHE model. In this simulation, cold water was passed through the tube side and hot biogas was passed through the shell side. The initial temperature of water in tube side is assumed to be 22 °C and biogas temperature is set at 150 °C. As shown in Figure 4, the temperature of cold water is increased from 26 °C (299.1 K) to 658°C (931.1 K) in the tube section and the heat is transferred from biogas to the cold water. The temperature contours plot across the cross section of the baffle along the length of heat exchanger provided an idea of the flow direction. It was found that cold water was transported from upper right of tube to the bottom left of tube side while the hot biogas was entered from the upper right and exited from down left in the STHE prototype.

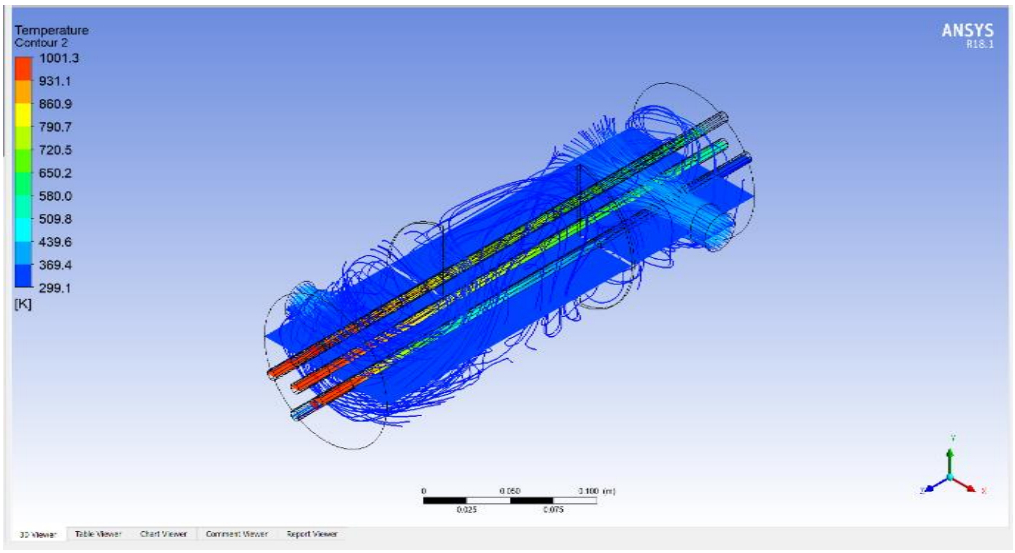


**Figure 4.** Variation of Temperature in the STHE Model

As shown in Figures 5 and 6, the transient thermal models were used to analyze and compare the heat transfer between the tubes and shell. Stainless steel was used as shell material while heat transfer was compared between the copper tube and brass tube. Engineering data of materials (copper, brass and stainless steel) and fluids (biogas, water) were created by using ANSYS thermal analysis. Results indicated that the copper has a higher temperature around the tubes and better heat transfer than the brass tube. This study also indicated that the possibility of using biogas as a heat source to provide hot water for space heating in residential and commercial buildings.

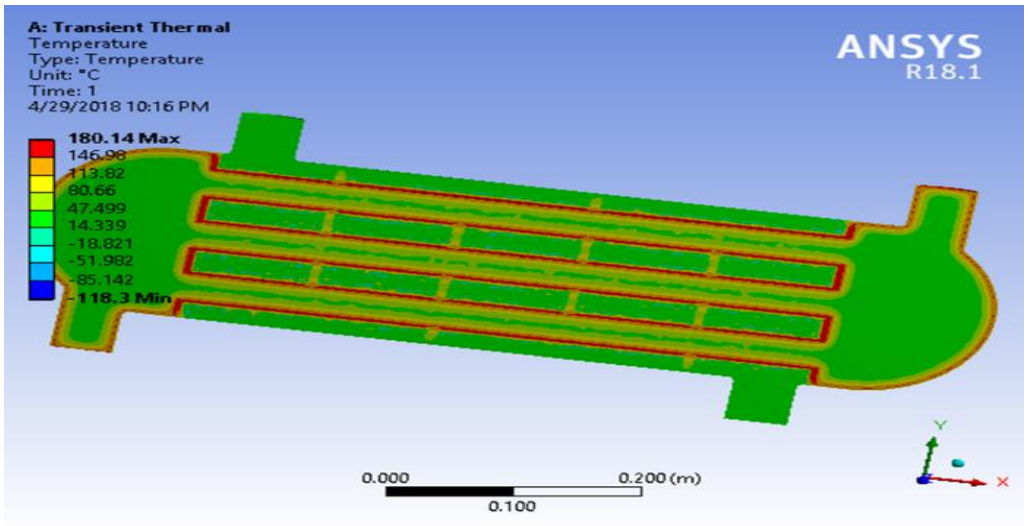


**Figure 5.** Thermal Analysis of STHE Model with Copper Tubes

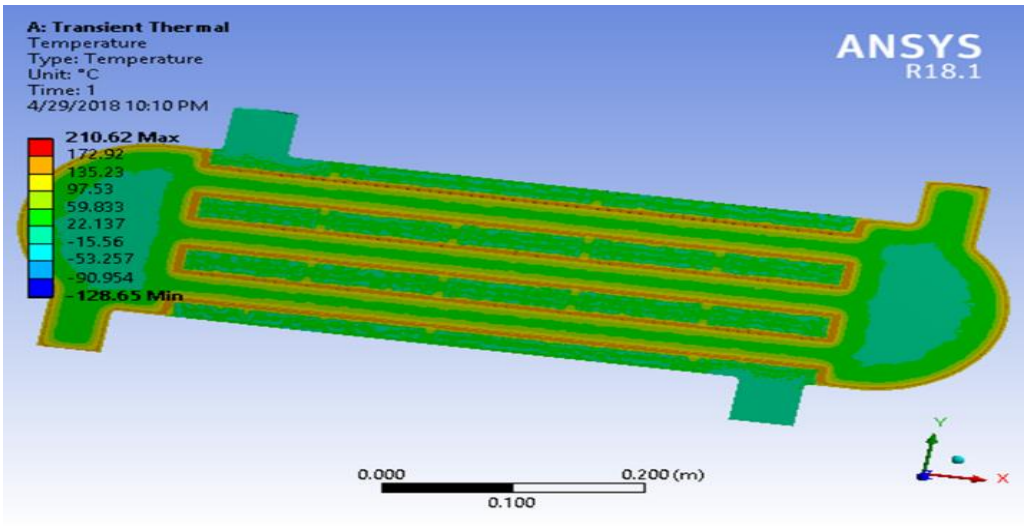


**Figure 6.** Thermal Analysis of STHE Model with Brass Tubes

### 3.1 Document Search

bibliometric study further considered specific parameters, namely subject topic and document types. The results were limited to the Computer Science, Education science, Social Science, Environmental and Engineering subjects, and although the documents in the research results were limited to the Final peer-review conference processing and journal articles published in English only, there was no restriction on the date of publication of the documents. As the next step, it was feasible to combine the results from the two databases (Scopus 301 documents and Web of Science 427 documents). After re-evaluating the alignment of the titles and keywords of the resultant 728 documents to the research theme, 146 articles were excluded, leaving the authors with a portfolio of 582 relevant articles.

## 4. CONCLUSIONS

System performance of the shell and tube heat exchanger was evaluated by both experimental and computational method. The modelling and meshing of STHE were done by using the ANSYS Fluent software. Results indicated that various operating conditions have a significant effect on the performance of the lab-scale STHE. It was found that the STHE prototype has good conversion efficiency is a high range of 0.80-0.86. In addition, ANOVA results indicated that the hot water inlet temperature has a significant effect on heat transfer of STHE prototype. CFD simulation and analysis results showed copper tube has a better heat transfer than brass tube to transfer the heat from biogas into water. These results confirmed that the STHE with copper tubes are very effective tube material in STHE model. Experimental and simulation study will help us to develop new heat exchanger system that can capture the residual from hot flue gas and provide hot water for residential and commercial buildings.

### 4.1 Future Studies

Future scope from my study is that different baffle angle can be used in the STHE exchanger so as to increase more heat transfer inside the heat exchanger. This work can be extended by using same working fluid for heat exchanger. Analysis can be done in ANSYS workbench by varying the baffle angle and change the flow position for a given heat exchanger.

## 5. ACKNOWLEDGEMENTS

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# COMPARATIVE STUDY OF A SUSTAINABLE HYBRID HEATING SYSTEM IN A GREEN INFRASTRUCTURAL BUILDING

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## ABSTRACT

Traditional energy production from fossil fuel conversion process creates negative environmental impact and affects human health. Thus, the usage of solar space heating piques the interest of several countries and organizations because it can reduce fossil energy consumption and is environmentally friendly. This paper conducted a comparative study between the advantages and impacts of using a sustainable Hybrid Heating System (HHS) and a Conventional Heating System (CHS) in an infrastructural building. The Centre for the Built Environment and Infrastructure Studies (CBEIS), a GOLD LEED-certified building of Morgan State University (MSU) is currently using an HHS for heating and cooling of electricity production. Several testing and analysis were used to compare and evaluate the performance and advantages of the HHS. The results showed that HHS has a significant edge over the CHS and was able to reduce the annual cost of the electric bill for almost $25,000. The statistical results and Analysis of Variance (ANOVA) confirmed that there was a significant difference during the months of winter and summer season in determining how much Kilowatt (kW) produced during the process.

**Keywords:** solar energy, heating system, sustainability, renewable energy, regression model

## 1. INTRODUCTION

The demand for energy is constant and will require newer and more plentiful sources in the future as demand continues to rise. The current practice of using non-renewable resources in the form of natural gas and oil is not sustainable long term. Therefore, it is very prudent to begin the development of other sources of energy. The energy production field requires a massive amount of innovation and vast improvements in technology. Until those alternative fuel sources can be created or discovered, there needs to be the development of readily available sources of energy that can provide sustainability (Bonetti et al., 2017).

The purpose of this research was to compare, evaluate, and analyze data obtained from the sustainable hybrid heating system in the CBEIS building to determine their energy and cost efficiency properties that can be seen in Figure 1. Furthermore, this also aimed at weighing the benefits and advantages of using renewable energy compared to fossil fuel in commercial applications such as residential heating buildings. An increase in renewable energy usage can lead to the improvement of technology in green energy fields and a subsequent reduction in emissions that cause environmental hazards. Future work can be conducted on the topic to compare other systems that use renewable energy to systems that

do not. That work can translate to improvement and optimization of renewable energy systems so that they can produce as effectively and efficiently as conventional or traditional systems.

**Figure 1.** CBEIS Sustainability Hybrid Heating System Diagram (The Freelon Group, 2012)

Heating water at the national levels is how people minimize their expenses. Most of the water heaters usually use two known systems which are solar heating systems and conventional heating systems. In a solar heating system, PV arrays collect solar energy from that sun and convert that energy to heat the water for different applications. Figure 2 shows that other equipment such as pressure gauge, pumps, storage tank, heat exchanger, compressors, and expansion valves which require incorporation into the design process. This extra equipment, in turn, makes the solar water heater expensive to build.

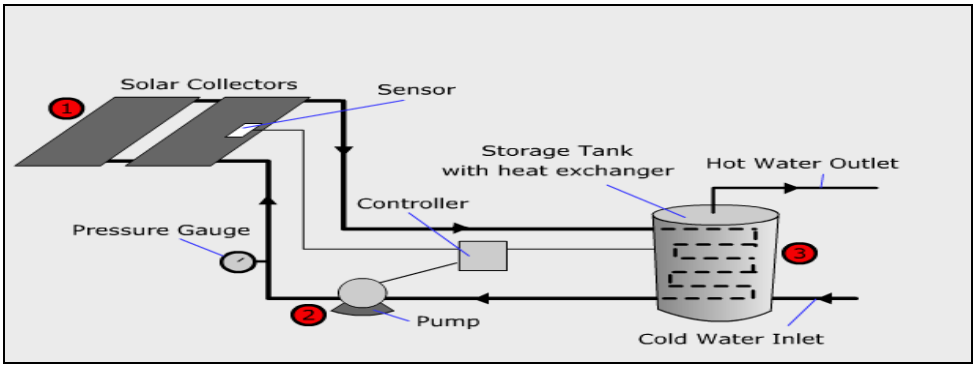


**Figure 2.** Diagram of a Solar Water Collective System (Bonetti et al., 2017)

Whereas the conventional heating system, it uses fossil fuels to heat the water. Burning fossil fuels emits several air pollutants that are harmful to both the environment and public health. Sulphur dioxide emissions, primarily the result of burning coal, contribute to acid rain and the formation of harmful particulate matter. Thus, with the increased demand for electricity by consumers has impacted the growth of the solar energy sector to explore and venture out different renewable areas that have a minimum environmental impact. Due to the advantages of solar energy, it has received overwhelming support between politician and environmentalists. The article by Huseyin, Benli, and Aydın Durmus (2009) discusses the use of solar collectors and thermal storage to provide adequate heating for a greenhouse. Due to the rising costs of fossil fuels, climate change, and the abundance of solar radiation, the need for a renewable energy source has increased. The rise in fuel costs makes it expensive when heating the greenhouse on severe freezing days. However, due to the limited amount of renewable resources, companies in both public and private are suffering.

Several authors have explored the issue of solar heating and made a comparison of an Electrical Heating System (EHS) and Solar Heating System (SHS) (Lazaar et al., 2015). In the end, they concluded that the SHS was better overall. They carefully analysed the heating conditions at a greenhouse setting. They observed that the Electrical Heating System was able to provide a much higher temperature of 40 ºC, whereas the Solar Heating System was only able to offer 20 ºC. However, although the heating obtained from the SHS is lower compared to EHS, it was deemed to be more economically viable since it was able to lower the energy cost. These findings support the research done by Chaturvedi et al., 2014, who conducted a life cycle analysis of the heat pump in the two systems. They concluded that solar pump was more economically viable and cheaper than an electric pump. These findings by these authors confirm that solar-powered systems for domestic purposes for domestic applications are more financially feasible than electrically powered systems.

The cost of solar-assisted equipment also depends on other expenses, such as the initial costs, installation, and maintenance charges. According to Abdur-Rehman (2016), a typical passive solar water heater requires at least a solar collector; this is aimed to show that there are prerequisite requirements of any solar equipment that is necessary for any project. The authors also identified the need for evacuated tube collectors on top of the project that they were presenting (Chaturvedi et al., 2014).

## 2. METHODOLOGY

### 2.1 Solar Panel Placement

The installation of the angles (tilt and azimuth) of the solar panels are facing plays a significant role in how much efficiency of energy is collected. As much as possible, the alignment to where the sun's radiation is binding to quickly achieve of collecting the maximum amount of the sun's energy. The azimuth angle gives the degrees of the solar panel and diverges from the south. The placement is in the Northern Hemisphere facing direction whereas the tilt angle gives the divergence from the horizontal in degrees (Turski & Sekret, 2016). Furthermore, Table 1 is the photovoltaic module used in the CBEIS building is a GEPVp-210-M, which is a 210-watt photovoltaic module for 600-volt applications. There are two main reasons why CBEIS building chose this system. (1) The photovoltaic module has a power tolerance of +/-5% and (2) it has a robust and clean anodized aluminium frame with pre-drilled holes for quick installation. The system has the following characteristics:

a) 54 poly-crystalline cells connected in series
b) Peak power of 210 watts at 27.3 volts
c) Designed for optimum use in residential and commercial grid-tied applications
d) 20-year limited warranty on power output, a 5-year limited warranty on materials and quality
e) Junction box and 1.8-meter cable with easy-click SOLARLOK® connectors included

**Table 1:** Performance Characteristics of the PV Module

| **Peak Power (Wp)** | **Watts** | **210** |
|---|---|---|
| Max. Power Voltage (Vmp) | Volts | 27.3 |
| Max. Power Current (Imp) | Amps | 7.7 |
| Open Circuit Voltage (Voc) | Volts | 3.3 |
| Short Circuit Current (Isc) | Amps | 8.3 |
| Short Circuit Temp. Coefficient | mA/ºC | 5.6 |
| Open Circuit Voltage Coefficient | V/ºC | -0.12 |
| Max. Power Temp. Coefficient | %/ºC | -0.5 |
| Max. Series Fuse | Amps | 15 |
| Max. System Voltage | Volts | 600 |
| Normal Operating Cell Temperature (NOCT) | ºC | 50 |

### 2.2 Energy Cost Equation of the CBEIS Building

The average commercial rate of a unit of electricity is above the national average. This warrant and makes economic sense for installation of a Solar Heating System. By multiplying the electricity units with the price of one unit of electricity in Maryland it can easily calculate the total electricity units in kilowatt-hour consumed by the buildings system. The average cost of energy is also calculated using the same computer programs. According to Electricity Local, the commercial electricity rates in Maryland for a commercial building is 10.43c/kWh, which ranks 16th in the United States. Additionally, the average commercial electricity rate of 10.43c/kWh in Maryland is 3.37% greater than the national average commercial rate of 10.09c/kWh. Moreover, the approximate range of commercial electricity rates in the United States is 6.86c/kWh to 34.88c/kWh. Thus, the cost of solar energy per unit of electricity is 7.8c/kWh. The cost of energy tabulated below gives the total cost that potentially incurred if the building used electricity only and if the building used solar energy only. In this case, the governing system of equations can be written as follows:

Energy Cost for Electricity = Price of Electricity per unit * Meter Reading

$$Cost = \frac{\frac{10.43}{100}}{kWh} * Meter\ Reading\ (kWh) \quad (1)$$

$$Cost = \frac{\frac{7.8}{100}}{kWh} * Meter\ Reading\ (kWh) \quad (2)$$

Energy Cost for Solar = Price of Solar per unit * Meter Reading

The governing system of equations by the cost of energy in CBEIS building, can be written as follows:

Energy Cost for Electricity = Price of Electricity per unit * Meter Reading

$$Cost = 0.3 * \frac{\frac{10.43}{100}}{kWh} * Meter\ Reading\ (kWh) \quad (3)$$

Energy Cost for Solar = Price of Solar per unit * Meter Reading

$$Cost = 0.7 * \frac{\frac{7.8}{100}}{kWh} * Meter\ Reading\ (kWh) \quad (4)$$

The cost of energy in the CBEIS building without solar is simply the total cost assuming that the building was using electricity at 100% with the same meter readings.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Cost Analysis

A hybrid system is a combination of both solar and electric, whereas, on the hand, a conventional system is just a pure electric heating system. The meter readings and monthly costs were collected from MSU's Physical Plant Office last 2018. Figure 3 shows the monthly readings collected from the power plant at Morgan State University in kilowatts per hour (kWh). Results indicated that the highest reading was 123,882.79 in July whereas the lowest reading was in January, which was only 77,820.24 kWh. Morgan's CBEIS building paid more during the summer than the Winter season. In certainty, most buildings in cold states (e.g., MD) are paying more energy bills in the winter than the summer. Additionally, this coincides

with the research of Xu et al., when their analysis indicated that the influence of building energy efficiency was a factor in a Hot Summer and Cold Winter (HSCW) zone (2013). Notwithstanding, due to the structure and HVAC insulation of the CBEIS building, the data indicated that it has a higher summer bill. Al-Sanea and Zedan's results had a similar finding that the dynamic thermal characteristics of insulated building walls were affected through the usage of one, two and three layers of insulation, and the locations of which they are placed (Al-Sanea et al., 2011). During Winter season, CBEIS does not require that much heat energy to raise the temperate up and make it comfortable to the workers and students. The materials used during its construction phase were carefully planned out to maintain the comfortability of the workers and students while still considering the most effective way to save costs.

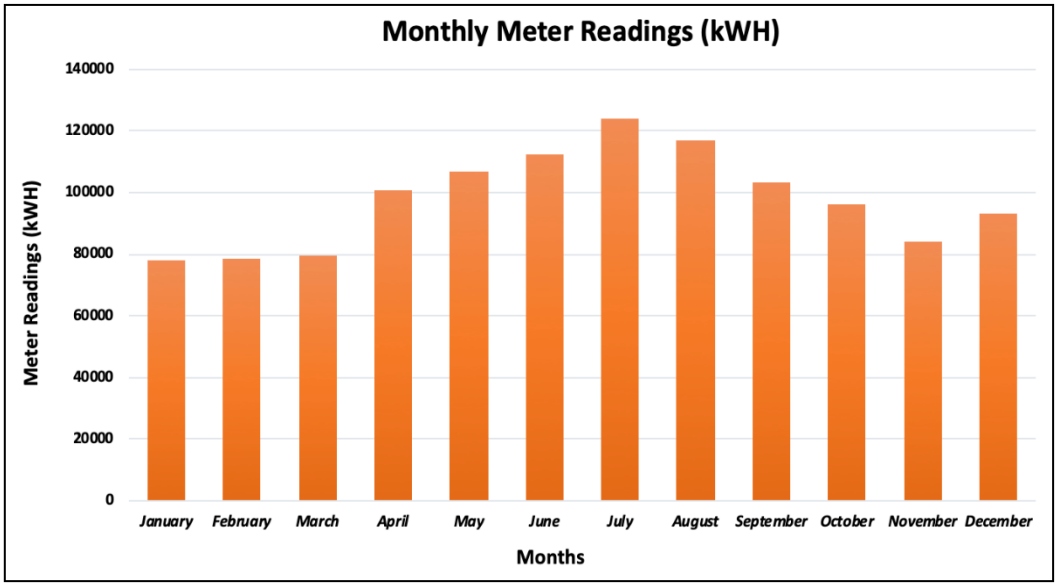


**Figure 3.** Monthly Meter Readings (kWh)

Last 2013, CBEIS received a Gold Award for Leadership in Energy and Environmental Design (LEED) certification from the U.S. Green Building Council (USGBC) and is now aiming for the Platinum Certification. Certainty, solar power is energy harnessed from the sun and transformed into different types of energy, including thermal and electricity. Figure 4 shows the graph of the Hybrid Heating System of its monthly cost distribution between 70% Solar and 30% Electric. The graph breaks down on how much price and energy that the solar system contributed. Whereas the electric system of CBEIS was only partially working throughout the year. Thus, it indicated that the CBEIS building profoundly practiced in utilizing renewable energy to decrease greenhouse gas emissions and air pollution.

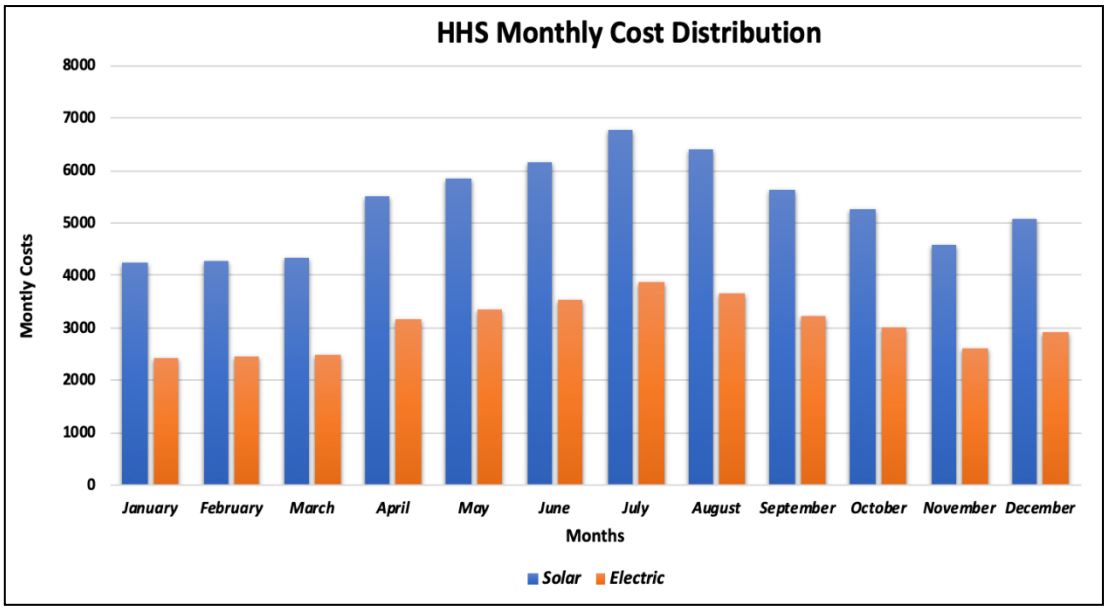


**Figure 4.** HHS (70% Solar and 30% Electric) Monthly Cost Distribution

The graph in Figure 5 depicts the price comparison between the Hybrid System of the CBEIS building and if ever the CBEIS was using full electric, which is the Conventional Heating System. The orange line in the graph is for the CHS while the blue line is for the HHS. Results indicated that the HHS had some significant edge over the CHS in terms of monthly costs. There is a vast difference in price per month. Based on the analysis of the data collected, the HHS was able to save almost $25,000.00 annually. The CBEIS serves as the ideal and standard building for any upcoming sustainable projects of MSU. The building itself has a vast number of laboratories intended for sustainability in design and engineering. Until now, the Administrators, Architects, and Engineers of the CBEIS building still continually seek for future improvements and look for resources to meet sustainability goals. Currently, the CBEIS building is using multiple forms of daylight harvesters, which are the two green roof systems and a traditional rooftop Photo Voltaic (PV) Panels with curtain wall integrated PV collectors.

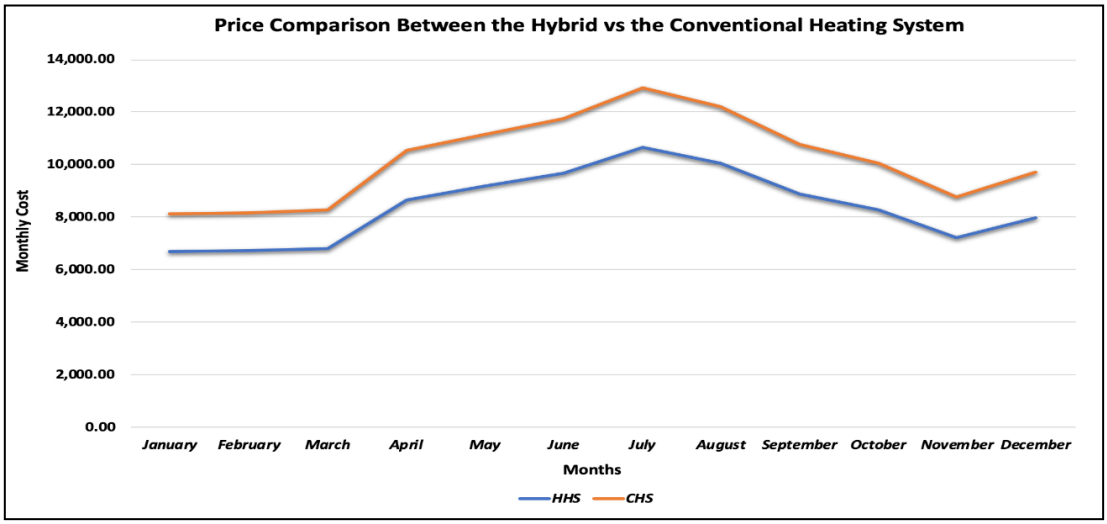


**Figure 5.** Price Comparison Between the HHS and the CHS

### 3.2 Descriptive Statistics

As previously mentioned, the two angles, which are the tilts and azimuth, identified the sun's position in the sky and played a significant role in the efficiency and energy captured of the solar panels. Figure 6 shows the mean, the standard deviation, and the range of the hybrid and conventional heating system.

| Variable | Total Count | Mean | StDev | Variance | Minimum | Q1 | Median | Q3 |
|---|---|---|---|---|---|---|---|---|
| Meter Reading | 12 | 97807 | 15729 | 247393234 | 77820 | 80588 | 98718 | 111152 |
| Sustainable Hybrid System | 12 | 8401 | 1351 | 1825226 | 6683 | 6922 | 8479 | 9547 |
| Conventional System | 12 | 10201 | 1641 | 2691259 | 8117 | 8405 | 10296 | 11593 |

| Variable | Maximum |
|---|---|
| Meter Reading | 123883 |
| Sustainable Hybrid System | 10640 |
| Conventional System | 12921 |

**Figure 6.** Descriptive Statistics of Meter Readings, SHHS, and Conventional Heating System

Afterward, a Normal Probability Plot (NPP) was made. It is a graphical technique for assessing whether a data set is approximately normally distributed (Chambers et al., 1983). Based on the graphs in Figure 7, the data collected in both systems do not have any outliers, which means that there are only two following conclusions from the above plot, which are:

1. The NPP shows a strongly linear pattern. There are only minor deviations from the line fit to the points on the probability plot.
2. The normal distribution appears to be a good model for these data.

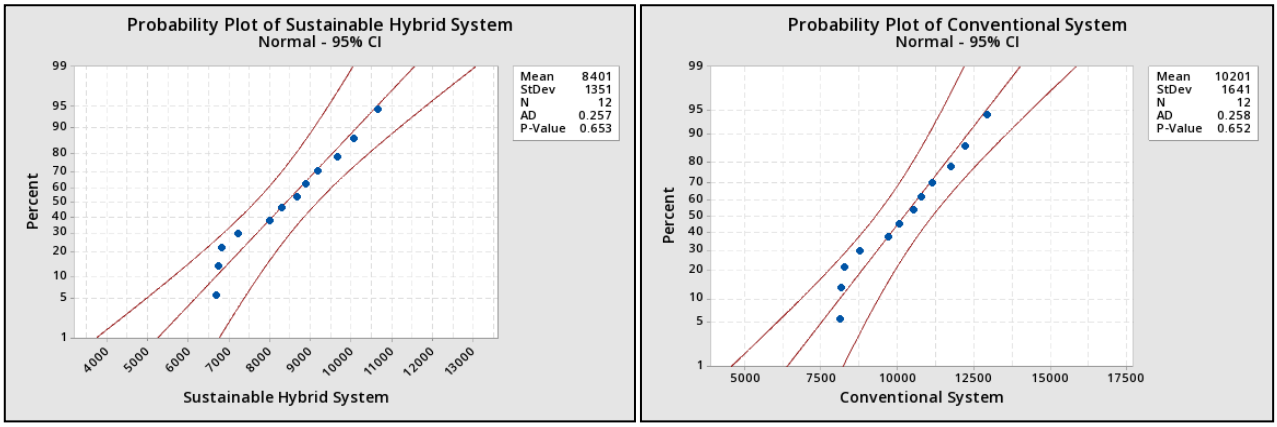


**Figure 7.** Normal Probability Plot of SHHS and Conventional Heating System

### 3.3 Inferential Statistics

Figure 8 shows the ANOVA results of the CBEIS building with its theoretical and calculated assumptions. Based on the given results of the ANOVA, the P-value is less than 0.05 in both factors – months and type of systems. Thus, it concludes that there is a significant difference between the factors and the response variable.

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Months | 11 | 49220382 | 4474580 | 106.78 | 0.000 |
| Types of Systems | 1 | 19454439 | 19454439 | 464.26 | 0.000 |
| Error | 11 | 460945 | 41904 | | |
| Total | 23 | 69135766 | | | |

**Figure 8.** ANOVA of HHS and CHS

Figure 9 shows the linear regressions for the two systems. Linear regression is used to study the linear relationship between a dependent variable Y, which in this case is the total costs and the independent variables X, which are the types of systems and months. The dependent variable Y must be continuous, while the independent variables may be either continuous or categorical. The initial judgment of a possible relationship between two continuous variables should always be made on the basis of a scatter plot that can be seen above. With that said, the given equation that was made is able to predict the meter reading and costs that is needed to quantify the unknown costs in the future.

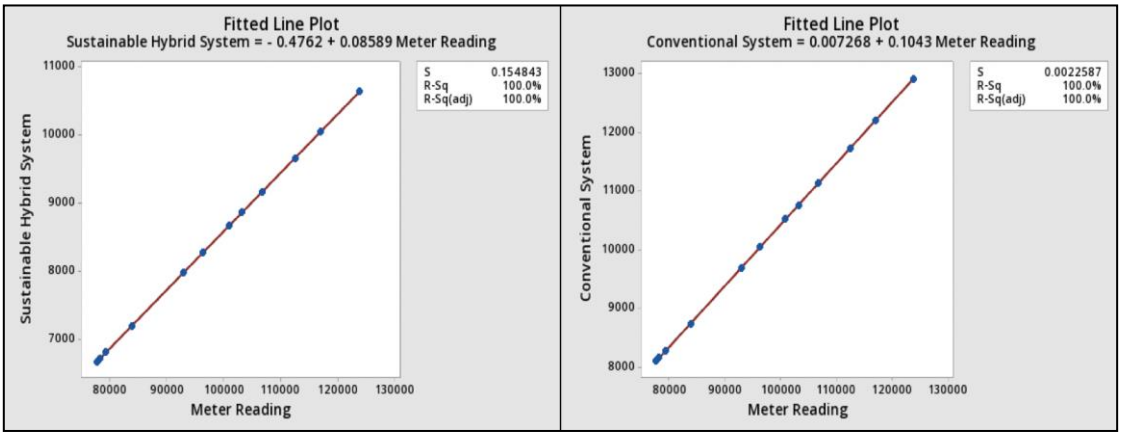


**Figure 9.** Regression Analysis Equation of the HHS and CHS

## 4. CONCLUSIONS

In conclusion, the data collected was able to differentiate the results and examined the advantages of using the HHS than the CHS. Based on the data comparison of energy consumption, it indicated that the HHS was more economical and cost-efficient. The results showed that HHS has a notable edge over the CHS and was able to reduce the annual cost of the electric bill for almost $25,000. The results from ANOVA confirmed that there was a significant difference during the months of winter and summer season in determining how much Kilowatt (kW) was produced during the process. Lastly, as the data collected where further analysed and evaluated, it is safe to assume that the factors heavily influenced the response variable. The regression equation was formulated to predict the total costs based on the energy given.

## 5. ACKNOWLEDGEMENTS

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# CASE STUDY: DEVELOPING TANZANIA'S TRANSPORT INFRASTRUCTURE MANAGEMENT SYSTEM (TIMS)

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## ABSTRACT

This case study profiles the steps taken to develop a process for developing a transportation information management system protype. The case study was initiated in response to a pattern of growth whereas, Tanzania is increasingly becoming a mobile society that suffers severely from traffic congestion, delay and mobile source pollution. Meeting the challenges of greater mobility, accessibility, land use development, economic growth and revenue constraints requires that transport investment and maintenance strategies be optimized. In this case study we define transportation information management system (TIMS), in the context of the Tanzania 2014 transportation network. In doing so an argument is made for developing a base line digital transport network analysis, as a starting point. In doing so, we identify a suite of decision-making tools and a stable of performance variables. As well, this case study presents a draft: work plan which emerged during this effort.

Developing effective congestion relief strategies requires going beyond the collection of geotechnical like shoulder width, guardrails, vegetation, road length and width, culverts, volume, drainage, terrain, rail crossing, number of lanes, bridges locations, and type of terrain. A comprehensive analysis of congestion requires a fully loaded transportation database with the following characteristics: regional, trunk line, and local roads; travel, time, ADT, population, employment, landuse, and income data at the regional and ward level and; transit line and multi modal infrastructure data. To test multiple congestion mitigation strategies advanced analysis tools are helpful to analyze the impact that network connectivity, pedestrian flows, population growth, travel demand, landuse, and community have accessibility. Equally important is the need have a skilled professional, and technical workforce that has not only the theoretical knowledge but also the technical training to use buffer, proximity, travel demand and simulation tools to assess the impacts of population concentrations, vehicle travel and goods movement.

## List of Acronyms and Abbreviations

| | |
|---|---|
| GIS | Geographic Information System |
| JISR | Joint Infrastructure Sector Review |
| NBS | National Bureau of Statistics |
| PMO-RALG | Prime Minister's Office Regional Administration and Local Government |
| SUMATRA | Surface and Marine Transport Regulatory Authority |
| TAA | Tanzania Airports Authority |
| Tan T2 | Tanzania Transportation Technology Transfer |
| TANROADS | Tanzania National Roads Agency |
| TIMS | Transportation Infrastructure Management System |
| TMS | Transportation Management System |

## 1. INTRODUCTION

Traffic congestion in Tanzania stems from limited capacity in any multi-modal network, where roads are the main mode of transport. In Tanzania roads support approximately 80% of the travel demand.

While it is well known that a variety of measures to deal with congestion available, Meyer (1997), states that no single measure can completely "solve" traffic congestion problems. However, there is a recognition of the need to find solutions that reduce traffic delays while increasing mobility and accessibility. Resolving this "horn of a dilemma" requires an examination of how congestion management measures complement one another and how over the long term these measures will influence future travel patterns, mitigate traffic congestion, and enhance economic development.

In the absence a transport management system, traffic congestion unmitigated will grow the transport infrastructure needs. In 2008, Dar es Salaam had 74,000 private vehicles. By 2015 there will be 180,000, and near 515,000 by year 2030. During that same period vehicle ownership, will more than triple from 25 cars per 1,000 persons in the year 2007, to 89 cars per 1,000 persons by year 2030. Dares Salaam as a major commercial and government activities center has more than 120,000 private vehicles outstripping the road network supply. There are over 6000 commuter buses serving a daily demand of 43% and a new Bus Rapid Transit (BRT). Still congestion persist.

The goal of this project is to implement a process which will lead to the development of an efficient and effective multi-modal information system, that will enable the Ministry of Works, Transport, and Communication to meet the recommendations and targets of Joint Infrastructure Sector Review (JISR), and Transport Sector Investment Program (TSIP), to improve transportation investment decision making. Thus, increasing the number of preserves improve, and expansion projects that modal agencies can initiate and retire in an environment of scarce revenue and budgetary constraints. As the Tanzania government expands to meet the challenges of global warming and other environmental stressors it is critically important to ensure that multi-modal infrastructure is equitable distributed and environmentally friendly. Equally important is the need to addresses the need to develop advance project prioritization intelligence.

The objectives of this project are:

1.) To clearly define national multi-modal management procedures that will integrate the modal data that can adequately address the policy and system level analysis requirements of the department.

2.) To develop a first-generation Tanzania multi modal transportation infrastructure management system (TIMS) which will provide modal agencies with information to improve transportation investment decision making.

3.) To integrate the transportation infrastructure procedures to demonstrate how TIMS will help Tanzania optimize investment strategies that combat congestion, reduce travel time delay, improve vehicular safety, broaden accessibility, and increase mobility.

4.) To inform short range (Phase II) and long-range work plans that guide future upgrades to the (TIMS)

5.) To develop a web-based GIS-T tool and procedures defined in Phase I, refined and expanded in Phase II and III for use in the development of modal long-range transportation plans.

## 2. SCOPE OF DEVELOPMENT

The scope of this case study is layout the architecture for developing a functional prototype. The prototype will be used to seek additional funding for the full development and full roll out of a comprehensive and interactive decision making and data analysis tool

that will support the development of a growing Tanzania's transport infrastructure. The objective of this work is to develop baseline inventory needs assessments tools that can help advance operational awareness and the development of strategic transport funding and maintenance strategies. The geographic scope of this project will include national, regional and local highway network and its associated multi-modal linkages. Based on best practices,

Phase I of this work will develop a Tanzania TIMS prototype with proximity overlay to assess funding and to identify project selection criteria to analyze and evaluate the following components: transportation and infrastructure operations, transportation management system development, intermodal connectivity operations control, academic and professional development and technology transfer.

Phase II expands the architecture developed in Phase I to include all modal data that has been capture. Phase II will conduct sensitivity analysis, additional research, and data collection to ensure the fidelity of the application and to detail the logistics for a proportional roll-out and advance the Tanzania TIMS prototype developed in Phase I into a fully developed application. This will include attributing a highway, transit, rail, water, and air mode compliant application and infusing it into the governmental decision-making fabric.

Phase III implements a full-scale roll out and will expand the application to include attribution of the bridge mode. This is the sustainability phase and involves integrating TIMS into the decision-making process across the Ministry of Works, Transport and Communication, President's Office Regional Administration and Local Government, TANROADS DART, TRL, TAZARA, TPA, TAA, TCAA and all other implementing agencies.

## *3.* METHODOLOGY

This case study describes the Tanzania's 2014 transportation problem and makes an argument for the need to conduct a base line transport network needs analysis. In addition, it identifies a suite of decision-making tools and a stable of performance variables. In doing so, this case study presents a draft: work plan, financing, project management schema, and the institutional organizational structure which emerged during this effort. This work is a direct outcome of the Link Agreement between the University of Dar es Salaam (UDSM) in Tanzania and Morgan State University (MSU) of USA signed in April 2009 and extended in 2014 to 2019 is the development of blueprint to establish a TIMS. The development of TIMS is a response to a pattern of growth whereas, Tanzania is increasingly becoming a mobile society that suffers severely from traffic congestion, delay and mobile source pollution. In the face of constant revenue constraints expected economic growth across Tanzania will require a new way of doing business to optimize transport investment development and maintenance strategies to meet the challenges of greater mobility, accessibility, and land use development.

The Government of Tanzania through the Ministry of Works, Transport and Communication in collaboration with the College of Engineering and Technology, University of Dar es Salaam, Morgan State University of USA and other 12 key stakeholder institutions representing all modes of transport have been working together since FY 2011/2012 in advancing the development of Tanzania's Transport system. As shown in Table 1, through these efforts, the project on development and implementation of Tanzania's Transport System and Inter-Modal Linkages has evolved. The Development and implementation of this Tanzania's Transportation Infrastructure Management System (TIMS) Project capitalize on the existing Link Agreement between the University of Dar es Salaam (UDSM) in Tanzania and Morgan State University (MSU) of USA signed in April 2009 and extended in 2014 to 2019 and demonstrates the value of Technology Transfer.

**Table 1:** Phase I and Phase II Products.

| Phase I | Phase II |
|---|---|
| 1.) Multi-modal Inventory<br>2.) Refined Regions, Districts, Wards Boundary Files, and land use point files.<br>3.) Developed Link, Node, Point, Transportation Analysis Zones, and Intermodal Layers<br>4.) Multi-modal data variables to support TIMS (TT, Dist. matrix & Speed table. Milepost, and Functional Classifications<br>5.) Link modal data sets into a National GIS-T Database.<br>6.) Prototypical Accessibility Graphical User Interface<br>7.) Phase II proposal | 1.) Enhanced project selection criteria based on modal: inventory, needs, and performance data<br>2.) Integrated multi networks, zone structure and socio-economic databases to compliant with development of the web- based decision-making analysis tool.<br>3.) Enhanced accessibility graphical user interface<br>4.) Capability to conduct sensitivity, connectivity, and scenario retesting<br>5.) Advanced managerial training and functional assessment of TIMS<br>6.) Fine Tune, continue buildout, and develop Phase III proposal. |

In the face of increasing regional competition the need to capture market share for: commodities, agriculture, tourism, industry, mining, and oil refining it is helpful to have in place a strengthen infrastructure intelligence. What has emerged are a number of geotechnical database for managing programs such as the introduction of commuter train, road expansion, introduction of bus rapid transit (BRT), and improving intersections operations. While the appending of new operational data to existing geotechnical data is necessary, however when it is combined with travel demand performance metrics it improves highway planning. This useful technique when used can quickly prove to be a valuable congestion impact tool for evaluating impacts associated with travel delay, emergency response, air quality, noise, safety, and vehicle operating cost at a granular level.

To address this stark reality the Government of Tanzania through the Ministry of Works, Transport and Communication in collaboration with the College of Engineering and Technology, University of Dar es Salaam, Morgan State University of USA and other 12 key stakeholder institutions representing all modes of transport have been working together since FY 2011/2012 in advancing the development of Tanzania's Transport system. The Development and implementation of this Tanzania's Transportation Infrastructure Management System (TIMS) Project capitalize on the existing Link Agreement between the University of Dar es Salaam (UDSM) in Tanzania and Morgan State University (MSU) of USA signed in April 2009 and extended in 2014 to 2019 and demonstrates the value of Technology Transfer.

### 3.1 System Needs: Current Problems, Weaknesses and Shortfalls in Transport Sub-sectors

Because of the constant threat of projected revenue and budget shortfall the Ministry of Works, Transport, and Communication, its associate ministries involved in the transportation planning and programming process require advanced analysis tools to ensure that maintenance needs are met given current and future budgetary constraints.

The Transportation Infrastructure Management System (TIMS) project anticipates the planning, operational, and maintenance needs and challenges of a growing and expanding Tanzania's multi- modal transportation network. Since 2012 several new projects have been built to address the growing needs of Tanzania expanding local and national economy and require innovative system wide approaches to determining strategic needs and to allocate transportation infrastructure expenditures by mode.

The following reports address the magnitude of Tanzania's transport problems, weaknesses and shortfalls and confirm among others that rural roads provide limited access, urban roads are congested, modal infrastructure is below capacity, and rail system is not competitive and old, and transit service is inefficient and unsafe.

- Current Tanzania Transport sector reviews conducted by the Joint Infrastructure Sector Review (JISR) Meetings
- Transport Sector Investment Program (TSIP), Phase I (2007/08 – 2011/12) Main Report April 2008 and TSIP Phase II (FY2012/13 - FY2016/17) Final Draft Report, March 2013
- The project on Capacity Building of the Transport Sector in Tanzania funded by the European Union, and
- Tanzania Transport Sector Review report of September 2013 funded by African Development Bank.
- Effectively addressing these cross-sector infrastructure challenges require advanced data management tool sets and a skilled professional transport workforce.

### 3.2 Key Benefits

A key benefit of building and maintaining TIMS is shown in figure 3. It is an example of the type of a customized interactive information displays that would be generated by TIMS's dashboard. It also shows that unlike optimized strategies associated with TIMS 's the traditional "worst first" maintenance approaches are more expensive over a 10-year time frame. A fully implemented TIMS's saves money.

Another key benefit is on the job training which will produce a cadre of Tanzanian transportation professionals. The "Tanzanian Work Force Development and Transportation Infrastructure Capacity Building and Congestion Relief Solutions Boot Camp" training, submitted on 16 March 2014 is supplemental and not included in this case statement.

### 3.3 Transportation Infrastructure Management System (TIMS) Solution Components

Tanzania's TIMS will be a comprehensive multi -modal asset management decision making support system made up of a database repository and complementary performance-based infrastructure analysis, risk assessment and decision-making tools. As envisioned the repository will include high-quality and topological line and polygon GIS data structures suitable for sophisticated transportation analysis; and will make quality multi – modal transportation travel demand, inventory, needs, and assessment performance data easily and readily accessible and usable for decision making. The TIMS will create an efficient and productive means of acquiring and working with the data. In its broadest sense TIMS involves managing all the activities related to multi-modal highway network. These activities include, but are not limited to, planning and programming, design, construction, maintenance, and rehabilitation. A TIMS provides effective tools and methods that can assist decision makers in formulating optimum strategies for providing and maintaining a serviceable multi-modal network over the planning horizon. TIMS will help transportation planners, engineers, and top management work together in initiating cost-effective decisions relative to the "what," "where," and "when" of multi-modal system operations, maintenance and rehabilitation.; for example what improvement is cost effective, and where and when to schedule needed enhancements.

### 3.4 Data Base Configuration

Figure 1 shows the output of Phase 1: a TIMS prototype with travel demand forecasting model inputs, enhanced multi-modal planning network, national GIS-T data base (highway network and Transport analysis zones), web-based accessibility calculator prototype, and an accompanying multi-modal screenshots (Bridge, Highway, Ports, Air, Transit, Rail, Air, Road

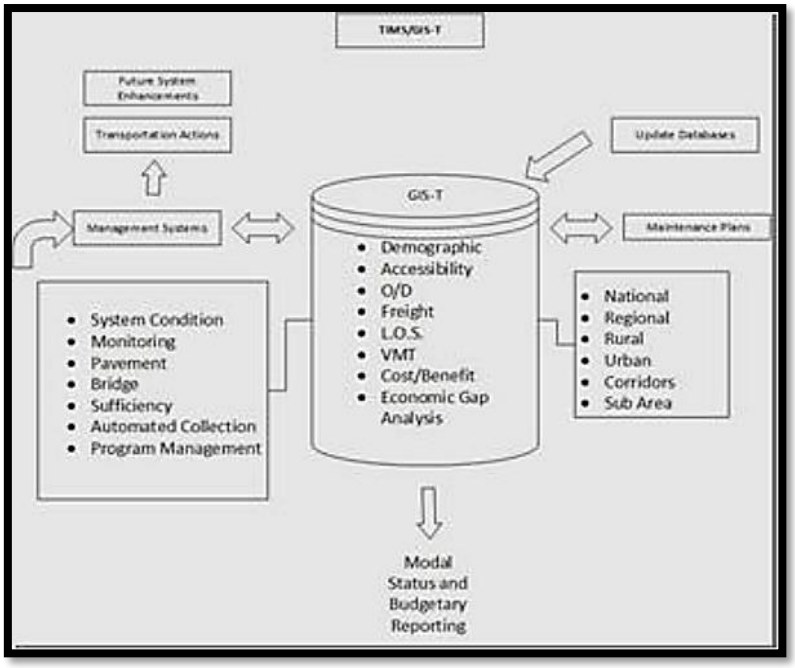
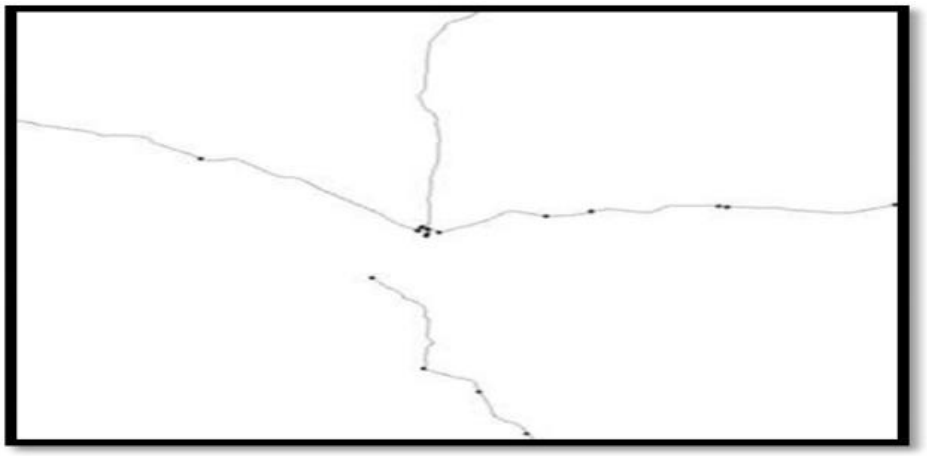



**Figure 1.** Proposed National GIS-T Database Structure and Outputs. Source: Michigan Department, 2012

*3.4.1 Baseline Network Needs Assessment*

A baseline needs assessment data is functional requirement for an optimal transportation management system (See Table 2). Our approach is to repair the network problems shown below in Figure 1; in advance of merging transport, demographic, land use and economic factors into a national GIS_T database architecture that adheres to best practices and complies with Tanzania transportation system requirements. After a brief review of the existing GIS line data for Trunk and Regional Roads in Tanzania, several serious discrepancies were noted. The illustration below demonstrates the lack of trunk line connectivity in the current line structures. Such critical Proceeding of the 5th International conference on Transportation in Africa-America (ICTAA2019)



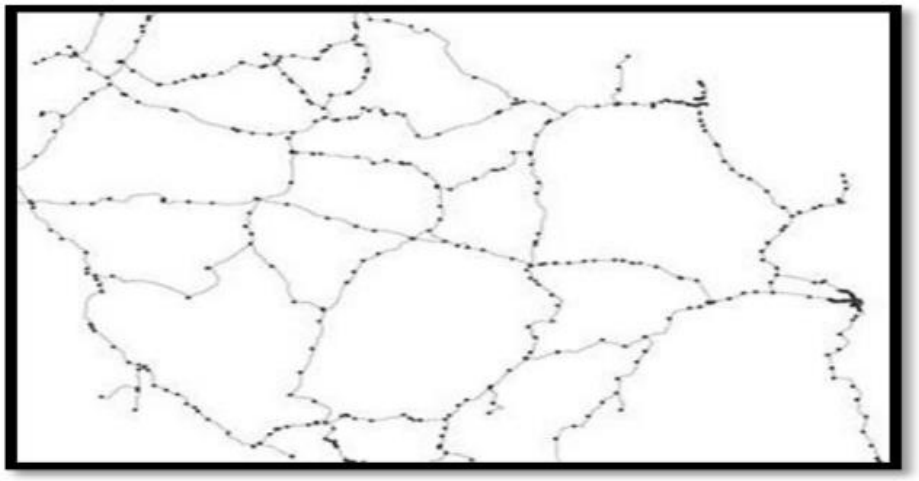


**Figure 2.** Illustration of Network Problems. Source: Morgan State University, Baltimore, Maryland, USA

Deficiencies are noted in every line segment. The line layer appears to be connected, however when viewing it at a zoomed-out scale, but a closer examination reveals the problem clearly. As shown in figure 2 zooming into the center of the map reveals disconnected links. The cost of traversing these line segments cannot be quantified if the road segments are not routable. As it stands, they are not suitable for network analysis.

**Table 2:** Tanzania Network Attributes and Decision-Making Variables

| Inventory | Area Datum | Line and Point Datum | Point Datum |
|---|---|---|---|
| Modal Condition, Need and Sufficiency Data | Transportation TAZ Social Economic Variables | Infrastructure, Geo., &Travel Demand | Activity Centers |
| Demographic | TAZ area | Link length | |
| | Total Population | Link Lat. and Lon. | |
| | Sub Jurisdiction Population Within TAZ | Node Lat. and Lon. | |
| | TAZ and Sub Jurisdiction | Link Jurisdiction | |
| Housing | # of Housing Units by TAZ | Node Jurisdiction | |
| Economic | Total Employment | Link Speeds | |
| | Retail Employment | | |
| | Non-Retail Employment | | |
| | Auto Dwelling per Unit | | |
| | Census Data on Income | | |
| Inter modal | Modal Facilities by Type | Choke Points | Node Lat/Lon |
| | | | Activity Centers |
| | | | # of Interchanges |
| | | | O/D |
| | | | Wait time |

*1. Travel Demand Model Inputs and Modeling Capability*

The TIMS will provide a basis for the development of travel demand modeling capability. The capability and its complexity will ultimately depend on the reliability of the collected socioeconomic and demographic data, along with the employment data. Ideally, the modeling capability would allow Ministry of Works, Transport and Communication to produce origin-destination matrices sufficient for assigning to a transportation network. The modeling capabilities will be incorporated into a tool that interactively allows Ministry of Works, Transport, and Communication, and staff from other implementing agencies to work together effectively and efficiently.

*2. Network Analysis*

Once a topologically correct and connected line database is created, staff of the Ministry of Works, Transport and Communication and other implementing agencies will be able to perform various levels of network analysis. Network analysis will include such applications as generating travel time bands with polygon overlay, analyzing travel effects for major construction both for system improvement and during construction. Network analysis capabilities are envisioned at the local, regional, and national levels.

### *3.5* Accessibility Calculator Overlays

As stated earlier TIMS is a series of planning tools. TIMS as envisioned by the project team would provide an interactive proximity analysis tool that when combined with the example shown in figure 3, will enable staff from the Ministry of Works, Transport and Communication and other implementing agencies to analyze road inventory through a lens of accessibility to transit and highway modes to or from point locations. In addition, non-motorized modes of travel will be considered, such as walking and biking. The underlying data will support all available modes in a region, provided that the data can be reliably collected and generated for those regions. The accessibility calculator will utilize a similar dashboard approach described above for interaction with TIMS.

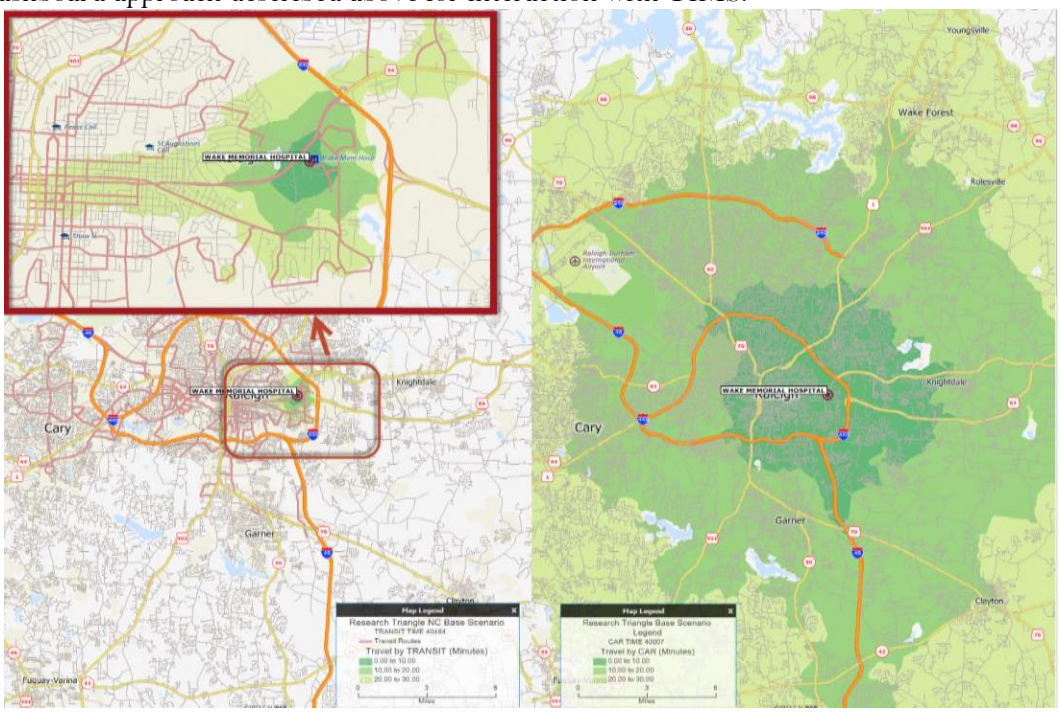



**Figure 4:** Interactive Map Overlays. Source: Caliper Corporation

30 Minutes from WAKE MEMORIAL HOSPITAL, DUKE RALEIGH HOSPITAL by CAR: TriangleBase

| Minutes | 0–5 | 5–10 | 10–15 | 15–20 | 20–25 | 25–30 | Overall |
|---|---|---|---|---|---|---|---|
| Population | 72,641 | 204,697 | 193,281 | 185,713 | 221,661 | 216,998 | 1,094,991 |
| Population 2040 | 98,785 | 302,087 | 357,535 | 333,551 | 436,833 | 411,550 | 1,940,341 |
| Households | 30,256 | 83,064 | 76,467 | 69,962 | 77,552 | 79,121 | 416,422 |
| Households 2040 | 41,811 | 130,041 | 141,626 | 128,612 | 163,658 | 155,959 | 761,707 |
| Jobs | 105,802 | 230,211 | 141,860 | 164,435 | 194,347 | 140,909 | 977,564 |
| Household Income | 53,255 | 48,896 | 70,239 | 78,389 | 67,587 | 53,676 | 62,007 |
| Family Income | 60,516 | 67,980 | 80,916 | 88,841 | 76,956 | 61,088 | 72,716 |
| Per Capita Income | 30,120 | 29,271 | 32,378 | 36,395 | 30,293 | 25,224 | 30,614 |
| Hispanic Origin | 11,784 | 25,625 | 19,736 | 13,752 | 18,287 | 22,017 | 111,201 |
| Black | 28,782 | 63,751 | 43,508 | 23,877 | 36,533 | 60,396 | 256,847 |
| White | 29,500 | 104,862 | 116,448 | 135,790 | 146,355 | 122,142 | 655,097 |
| American Indian | 266 | 902 | 1,023 | 981 | 1,234 | 1,136 | 5,542 |
| Asian | 1,716 | 7,855 | 10,988 | 9,921 | 17,562 | 9,583 | 57,625 |
| Other Race | 116 | 508 | 474 | 468 | 488 | 511 | 2,565 |
| Multiple Races | 447 | 1,070 | 995 | 826 | 1,045 | 1,112 | 5,495 |
| College/Univ | 1 | 6 | — | 1 | — | 2 | 10 |
| Grocer | 0 | — | — | — | — | — | 0 |
| Hospital | 1 | 1 | — | — | — | — | 2 |
| Hospital Beds | 870 | 266 | — | — | — | — | 1,136 |

30 Minutes from WAKE MEMORIAL HOSPITAL, DUKE RALEIGH HOSPITAL by TRANSIT: TriangleBase

| Minutes | 0–5 | 5–10 | 10–15 | 15–20 | 20–25 | 25–30 | Overall |
|---|---|---|---|---|---|---|---|
| Population | 668 | 1,497 | 2,468 | 4,714 | 9,665 | 16,996 | 36,008 |
| Population 2040 | 1,306 | 2,373 | 3,313 | 6,828 | 14,111 | 23,594 | 51,525 |
| Households | 169 | 494 | 978 | 2,104 | 4,469 | 7,441 | 15,655 |
| Households 2040 | 500 | 960 | 1,388 | 3,028 | 6,324 | 10,725 | 22,925 |
| Jobs | 5,213 | 6,499 | 8,075 | 11,100 | 15,622 | 56,233 | 102,742 |
| Household Income | 39,158 | 36,877 | 42,897 | 45,505 | 53,213 | 45,097 | 43,791 |
| Family Income | 30,392 | 30,477 | 42,276 | 49,526 | 63,858 | 76,962 | 48,915 |
| Per Capita Income | 23,271 | 21,899 | 25,028 | 26,240 | 30,507 | 29,486 | 26,072 |
| Hispanic Origin | 329 | 564 | 798 | 1,131 | 1,305 | 1,860 | 5,987 |
| Black | 164 | 528 | 1,052 | 1,931 | 3,126 | 6,089 | 12,890 |
| White | 153 | 362 | 550 | 1,491 | 4,937 | 8,508 | 16,001 |
| American Indian | 3 | 6 | 9 | 17 | 33 | 74 | 142 |
| Asian | 12 | 21 | 36 | 96 | 190 | 327 | 682 |
| Other Race | 2 | 3 | 4 | 7 | 16 | 31 | 63 |
| Multiple Races | 2 | 7 | 16 | 35 | 54 | 96 | 210 |
| Hospital | 1 | — | — | — | — | — | 1 |
| Hospital Beds | 870 | — | — | — | — | — | 870 |
| Grocer | — | 0 | — | — | — | — | 0 |
| Locale | — | — | 1 | — | — | 1 | 2 |

### 3.6 Work Plan

Phase 1: develops prototype to fine-tune the TIMS's framework, decision-making dashboard, refines the Phase II proposal, and establishes a training program.

Task 1 - Create multi-modal Inventory

Task 2 - Refine Regions, Districts, Wards Boundary Files, and landuse point files. Develop Link, Node, Point, Transportation Analysis Zones, and Intermodal Layers

Task 3 - Develop multi-modal data variables to support TIMS (TT, Dist. matrix & Speed table. Milepost and Functionally Classify National GIS-T Database.

Task 4 - Develop and Test Prototypical Accessibility Graphical User Interface

Task 5 - Develop Phase II Proposal

Phase 2: Conduct careful review of the phase 1 work effort and develop proposals which seek funding support for its full development and rollout in phase 2 and phase 3 as originally envisioned. Additional research is conducted to support a proportional roll-out and refines the Phase III proposal

Task 1: Performance and connectivity sensitivity testing

Task 2: Identify and repair application gaps

Task 3: Fine Tune and continued buildout of application

Task 4: Conduct user training and functional assessment of TIMS

Task 5: Expand training to include manager and executive training

Task 6: Fine tune Phase III proposal

Phase 3: Implement a full-scale roll-out. This is the sustainability phase and involves integrating TIMS into the decision-making process across the Ministry of Works, Transport and Communication, President's Office Regional Administration and Local Government, TANROADS DART, TRL, TAZARA, TPA, TAA, TCAA and all other implementing agencies.

## 4. RESULTS AND OUTCOMES

TIMS ach are more expensive over a 10 years' time frame. Strategically connecting the modal pieces-bikeways, pedestrian facilities, transit services, and roadways into an intermodal, interconnected system saves money and offers key benefits which include the development of high-quality public transportation that foster economic development.

TIMS is a decision support system that is designed to offer community, residents, and workers the full range of transportation choices. Arterial management systems can potentially reduce delays between 5% and 40% with the implementation of advanced control systems and traveler information dissemination. Freeway management systems can reduce the occurrence of crashes by up to 40%, increase capacity, and decrease overall travel times by up to 60%. Freight management systems reduce costs to motor carriers by 35% with the implementation of the commercial vehicle information systems and networks.

## 5. CONCLUSIONS

This case study concludes that the development of a TIMS is needed to build a robust decision –making platform. Its three interrelated components: coordinated communications, data retrieval, and data exchange tools are customized to establish budgetary efficiency. As shown in the above figure 2 they include a graphical user interface for modal systems, GIS-T database, and a graphical user interface for national planning and systems management. This agency shared control platform supports operational and service delivery for the modal agencies. Modal data pushed to the GIS-T data base and deployed for national, regional, rural, urban, corridor, and sub area analysis. The result of this work will be a fully loaded Transport network with a broad array of Transport, planning, engineering, equity, and transport economic development datum which is required for the Phase 2 attribution per mode and Phase 3 buildout of the bridge mode to complete the rollout. The outcome of Phase 1 will be a functional TIMS architecture that supports: travel demand forecasting model inputs, enhanced multi-modal planning network, national GIS-T data base (highway network and Transport analysis zones), web-based accessibility calculator prototype, and accompanying multi-modal screen shots. As well, the phase I work for development of a Transportation Infrastructure Management System will result in a cadre of administrative decision makers, planners, analysts, and technicians with advanced knowledge and capability to enable the deployment of powerful analytical transportation management system (TMS) tools that will: support, improve, and sustain transportation infrastructure development, maintenance, and management.

## 6. ACKNOWLEDGEMENTS

Special thanks to representatives of all Development Partners attending a Stakeholders' Meeting organized by the Ministry of Works, Transport and Communication on Development and Implementation of the Proposed Project on Advancing and Managing Tanzania's Transport System and Inter-Modal Linkages held on 27 February 2014 at Double Tree by Hilton Hotel in Dar es Salaam endorsed this project and have pleaded to help, support, participate and finance the initiative and the project. However, the Representative of all Development Partners expressed the importance for the government of Tanzania to allocate counterpart funds towards implementation of the TIMS project.

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# EFFICIENT BIOMASS CONVERSION PROCESS TO SUSTAINABLE ENERGY

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## ABSTRACT

A greener approach to sustainable energy production is by processing and burning biomass. Readily abundant across the globe, biomass can be obtained largely from agricultural, domestic and industrial processes. The growing concern for an energy source that is environmentally friendly, socially acceptable, and economically feasible, prompts researchers to explore the conversion of everyday biomass wastes in the form of municipal solid waste (MSW) and agricultural wastes (such as poultry litters, wood pellets) to useful energy(i.e., heat or electricity). This research work studied the two broad biomass conversion processes-thermochemical and biochemical. A comparative study was performed using poultry litter as the biomass feedstock in both conversion processes. The obtained data was justified considering the environmental, economic and social impacts of the biomass-to-energy source. At an industrial scale, biochemical processes are capital intensive as pre-treatment and post-treatment of both feedstocks and products are required. In addition, more reaction time is required for product formation and high volume of secondary wastes (sludge) are generated during the process. On the other hand, burning of biomass waste has been largely considered as a better approach due to the fact that the CO2 generated during the process is being balanced by an equivalent amount that plants capture through photosynthesis while they are growing, thus making biomass a carbon-neutral energy source. However, raw biomass possesses low density (30–50 kg/m3) and high moisture content that limits its usage for thermochemical processes. Therefore, the inclusion of a pelletizing process which allows easier economic storage, transportation, and energy conversion characteristics, is considered as an efficient and sustainable approach to biomass-to-energy conversion.

**Keywords:** Biomass, Biochemical, Thermochemical, Poultry litter, Municipal Solid Waste (MSW), Greenhouse gases (GHG).

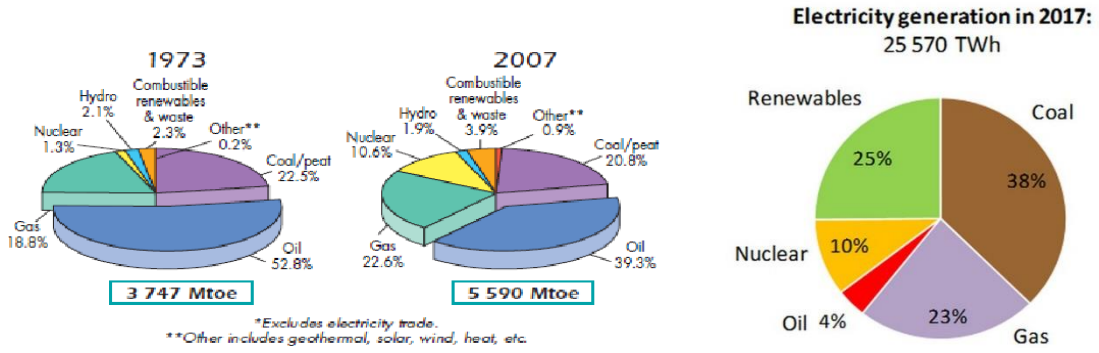
## 1. INTRODUCTION

Owing to the ever-increasing release of gaseous pollutants that impacted the atmosphere greatly, there have been continuous efforts by researchers to provide lasting solutions through biomass conversion to energy. Biomass is made up of plant and animal materials-wood, animal dungs, solid waste, poultry litters, sawdust among others. Biomass has been proven to be a good alternative to energy production and a source of heat energy since the discovery of fire by the first man. More than 3 billion people in the world today are still burning wood as their primary source of cooking and heating because it is relatively cheap and affordable for low-income earners (WHO, 2015). Biofuels (i.e., bioethanol, biodiesel, and biogas) made from biomass are alternative energy sources to fossil fuels (e.g. coal, petroleum,

and natural gas). The use of biofuels, such as ethanol, has been around for some time as well. It was used as lamp fuel in the United States in the 1800s as well as the first Model-T Fords until 1908 (Solomon et al., 2007).

The fast advance in biomass conversion technologies for energy production arises from the need to meet the growing energy demand worldwide as a result of dwindling in petroleum supplies. Figure 1 shows the proportional ratios of different sources of world electricity generation for over 40 years (1973-2017) according to the International Energy Agency (IEA). Renewable Energy has gained more popularity as the world seeks an energy sources that are environmentally friendly, easily accessible and less expensive. Renewable energy sources include solar, hydropower, wind, geothermal and biomass. Biomass contributes about 68 % of the total energy generated from renewable resources in the European Union (EU) in 2009 (Tomasz and Zenonin, 2012). In 2016, IEA recorded total primary energy supply of 13.7Mtoe of which slightly above 80% came from fossil fuels (in the form- 31.3% from oil, followed by coal (28.6%) and 21.2% from natural gas), 14.1% renewable energies (14.1%), and lastly nuclear power (4.8%). Of this total production, only 18% was in the form of electricity while the remaining 82% was used for heating and transportation. This means that larger percent of energy impacts on the climatic condition in terms of pollutants is from both industrial and transportation activities.

Burning either fossil fuels or biomass releases carbon dioxide ($CO_2$), a greenhouse gas (GHG). However, the plants that are the source of biomass capture a nearly equivalent amount of $CO_2$ through photosynthesis while they are growing, which can make biomass a carbon-neutral energy source. Using wood, wood pellets, and charcoal for heating and electricity generation can replace fossil fuels and may result in lower $CO_2$ emissions overall.




A] Source: IEA 2008 B] Source: IEA 2017

**Figure 1.** World Electricity Generation (IEA 2008 and2017)

A large amount of agricultural and MSW are produced annually across the globe. In 2015, a total of 262.4 million tons of MSW was generated in USA, among which 52.5% was used in landfill, 25.8% recycled, 12.8% burnt for energy recovery, and the rest 8.9% was composted (EPA, 2015). MSW materials can be broadly categorized into three as: biomass (such as paper, food waste, grass clippings, leaves, wood, and leather products); Non-biomass combustible materials (plastics, petroleum-based); and Non-combustibles materials (glass, metals). Burning MSW produces gas emissions (that is, releases chemicals and substances into the air). Some of these chemicals can be hazardous to people and the environment if they are not properly controlled. The U.S. Environmental Protection Agency (EPA) applies strict environmental rules to waste-to-energy plants, which require thermal plants to use pollution

control devices such as scrubbers, fabric filters, and electrostatic precipitators to capture air pollutants. Direct industrial CO2 emissions rose 0.3% to reach 8.5 GtCO2 in 2017 (24% of global emissions), a rebound from the 1.5% annual decline during 2014 16 (IEA, 2019).

Agricultural wastes, on the other hand, can be segmented into several categories: crop waste (such as wood waste, corn hubs, bagasse, paddy husks); animal wastes (e.g., animal excreta such as poultry litters, cow dungs; and animal carcasses); processing waste (e.g., packaging materials); and environmental harmful wastes (such as pesticides, herbicides, insecticides, and fertilizers). Out of the total global primary energy (230 exajoules), about 56 exajoules (one-fourth of the global primary energy) are utilized for agricultural purposes (WEC 1994). Suitable for energy production among these wastes are the crop and animal wastes. These wastes have been widely used in the production of biofuels through biochemical processes and heat energy through thermochemical processes.

This research paper seeks to increase societal perspectives of huge investment in renewable energies as a means to mitigate pollutions from largely used energy sources, by comparing the thermochemical and biochemical conversion processes of biomass for sustainable energy production in terms of environmental, economic and social impacts.

## 2. BIOMASS CONVERSION PROCESSES

### 2.1 Thermochemical Processes

Thermochemical processes involve the burning of biomass fuels (e.g., wood, sawdust, poultry-litter, biomass pellet) at various temperatures mostly greater than 400oC to produce the desired end products. These processes include pyrolysis, gasification, and combustion. Pyrolysis involves heating of organic materials at high temperatures (i.e., >430oC) in the absence of oxygen. The resulting products are solids and liquids in the form char and bio-oil respectively. Gasification is a process of heating organic materials with some amount of oxygen at elevated temperatures above 700oC. This process is referred to as Partial oxidation as biomass is burnt in air with activation energy to produce syngas (CO+H2) and gives off heat. On the other hand, combustion is a complete oxidation process that involves the burning of organic materials with excess oxygen at very high temperatures (i.e., >800oC) to produce excess heat, CO2 and water with other emitted pollutants.

### 2.2 Biochemical Processes

The biochemical processes involve the decomposition/breaking down of organic materials by the activity of micro-organisms in both aerobic and anaerobic conditions. These processes include extraction, fermentation and anaerobic digestion. Oil-based plants (such as soybean, groundnut) undergo extraction process to remove the oil content of the plants to be further used in the transesterification process for production of biodiesel. An alternative to biodiesel production is the use of marine biomass (algae) to convert carbon into a record amount of energy-rich fat, which can then be processed into biodiesel. Root crops (such as cassava, potatoes); grains (such as corn, wheat, sorghum); and sugar-based crops (sugarcane, molasses, sugar beets) are used in the production of Bioethanol. Upon breaking down the complex sugar of the biomass crops through milling (dry or wet process), the fine particles are then undergone hydrolysis prior to the fermentation process (i.e., conventional or Simultaneous Liquefaction Saccharification Fermentation- SLSF) to produce bioethanol. Anaerobic digestion is the microbial digestion of feedstock releasing heat, methane, hydrogen sulphide, carbon dioxide and under specific conditions hydrogen gas. This process takes place over several days in large tanks where the ideal conditions are maintained. After the process, the remaining solid digestate is suitable for use as fertilizer and the gases released are collectively referred to as biogas. The biomass to energy conversion processes are shown in Figure 2.

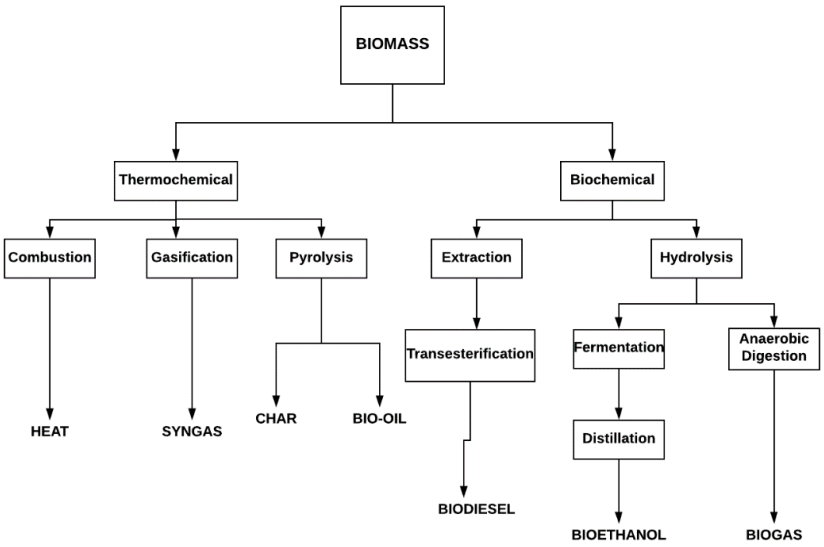



**Figure 2.** Biomass-to-Energy Conversion Pathways

## 3. POULTRY LITTER AS A SOURCE OF ENERGY

In general, waste from the poultry industry includes a mixture of excreta (manure), bedding material (e.g. wood shavings or straw), waste feed, dead birds, broken eggs and feathers removed from poultry houses. Other wastes include those from cages, conveyer belts and water flushing systems (Kelleher et al., 2002).

Poultry litter refers to a mixture of poultry manure (excreta), bedding materials (e.g., wood shavings, sawdust, straw, and pine or rice husk), spilled feed, and feathers (Lynch et al., 2013). In 2009, assuming 1.4 ton of litter per 1,000 birds, a total of about 25 million tons of poultry litter was generated by the US and the EU (Lynch et al., 2013). According to a U.S. Department of Agriculture estimate, the population of broilers, layers and turkeys in the U.S. (about 10.7 billion birds in total) produce about 550 million tons of manure annually (Coker, 2017). Due to its rich nutrient contents (e.g. N, P, K), most poultry litter have traditionally been utilized as a source for organic fertilizer on agricultural land (Kelleher et al., 2002). However, the environmental consequences of applying poultry litter include the release of ammonia and nitrous oxide (a GHG) together with contamination of ground and surface water with nitrate, phosphate and pathogens (Seidavi et al, 2019). As a result, excess application of poultry litter poses a risk to the health and wellbeing of humans, animals, and the aquatic ecosystem (Abelha et al., 2003; Li et al; 2008).

Poultry production is associated with greenhouse gas (GHG) emissions but at a much lower extent than other livestock. In a study by Seidavi et al (2019), it was stated that poultry waste is contributing 33.7 million metric tons of $CO_2$ eq./year or 0.0337 gigatons (Gt) $CO_2$ eq per annum. This represents only 0.64% of agricultural GHG emissions, if 2% of the nitrogen contained is lost as nitrous oxide with a global warming potential (GWP) of 298 $CO_2$ equivalents (eq.) per unit as GHG.

### 3.1 Poultry Litter to Biogas

Anaerobic digestion is used worldwide as a unit treatment for industrial, agricultural and municipal wastes. This is a biochemical process of decomposing organic materials under the influence of microbial organisms in the absence of oxygen, leading to the formation of methane as main product alongside other inorganic products as shown in equation 1.

$$\text{Poultry Litter} + H_2O \longrightarrow CH_4 + CO_2 + NH_3 + H_2S + \text{heat} \quad (1)$$

The organic components of poultry litter can be classified into broad biological groups: proteins, carbohydrates and lipids or fats. The poultry litter contains a higher fraction of biodegradable organic matter than other livestock wastes, and this includes high levels of organic nitrogen due to the high content of protein and amino acids. (Kelleher et al., 2002). Anaerobic digestion of poultry litter involves two stages- Hydrolysis and Fermentation. The former involves dilution of the organic wastes with water at a ratio depending on reactor size and then homogenized. Under the activity of anaerobic bacteria, the products of hydrolyses undergo fermentation to yield methane gas and CO2 as major products. The produced methane gas can be converted to electricity using a generator, used as fuel for boilers in place of natural gas (to heat up poultry houses) or used as fuel for cooking stoves. The spent sludge can be further processed into fertilizers as shown in Figure 3. This in return can generate more income for farmers and reduce the overall production cost of poultry farming.

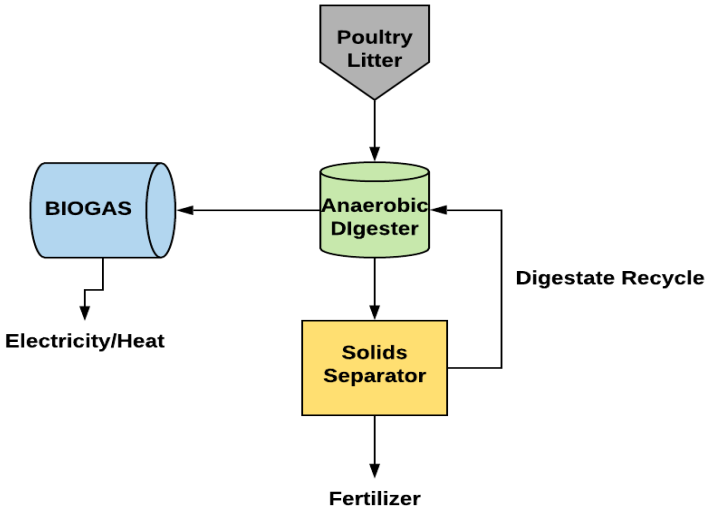



**Figure 3.** Biochemical Process Flowchart of Poultry Litter Digestion

Anaerobic digestion of poultry litter produces a collectable biogas mixture with an average methane content of 60%. The amount of methane gas produced, and its quality potential can be increased through the process of co-digestion with other substrates. Babaee et al. (2013) evaluated co-digestion of poultry litter and straw, and found highest gas yield (0.12 m3 CH4/kgVS) and highest methane content (70.2%) at loading rates of 3.0 kgVS/m3-d, hydraulic retention time of 15 days and operating temperatures of 35°C (95°F), but that yield and quality dropped off significantly at higher loading rates and at lower temperatures. Another study on co-digestion of poultry litter with hog shows that higher yield of methane was produced, up to 200 +/- 30 mL/g volatile solids destroyed, and methane, up to 130 +/- 20 mL/g volatile solids destroyed when using either waste alone (Magbanua et al., 2001). Biogas contains 50-60% of methane gas and has a heating value of 5-6KW with 30 to 45% carbon dioxide (CO2), traces of hydrogen sulphide (H2S) and hydrogen (H2), and fractions of water vapor. Every kg of organic matter yields 0.5m3 of biogas. It takes 30 days for complete digestion of poultry litter. A 1000kg of poultry litter with 55% dry matter

containing 42% organic matter has a capacity to yield 200m3 of biogas, which can generate 420KW of electricity (Bijman, 2014).

A major concern in anaerobic digestion of poultry litter is the presence of ammonia, which inhibits the process. To eliminate ammonia inhibition, the 25-30% total solids waste must be diluted with water to achieve a <10% total solids waste. However, this reduction in total solids percentage takes 5-8 times the volume of water, and therefore creates a subsequent water disposal problem after the digester (DVO, 2019). Thereby, making the process economically non-viable. The environmental hazard posed by burning biogas in engines is the presence of H2S which on reaction with water vapor form Sulphuric acid (H2SO4). In large concentrations, hydrogen sulphide is toxic and poses health hazard. Prior to burning of raw biogas in engines, hydrogen sulphide and Carbon-dioxide must be removed using activated carbon.

### 3.2 Thermochemical Processes

Direct combustion has been another major alternative for production of useful energy (e.g., heat, electricity) from poultry litter. It has the potential to provide space heating for poultry houses and on large scale production of steam heat for running a turbine to generate electricity. As shown in Figure 4, thermochemical process of converting poultry litter to useful energy involves burning of the litters in excess air at a temperature >800oC in a Fluidized Bed Combustor (FBC). There are three main types of fluidized beds, bubbling, turbulent or circulating bed types. All designs consist of a bed of sand in a refractory-lined chamber through which primary combustion air is blown from below. Adjusting the airflow fluidizes the sand particles. Cyclones are placed after the furnace to separate the bed particles from flue gas, and then recirculate the particles to the furnace. FBC facilitates the dispersion of incoming fuel, where it is quickly heated to ignition temperature, and provides enough residence time in the reactor for complete combustion (Kelleher et al., 2002). The equation 2 below shows the poultry litter combustion process resulting into generation of heat, ash and gaseous products (such as carbon-dioxide, nitrogen oxides (NOx), sulphur-dioxide, and particulate matters).

$$\text{Poultry Litter} + O_2 \longrightarrow CO_2 + H_2O + \text{heat} \qquad (2)$$

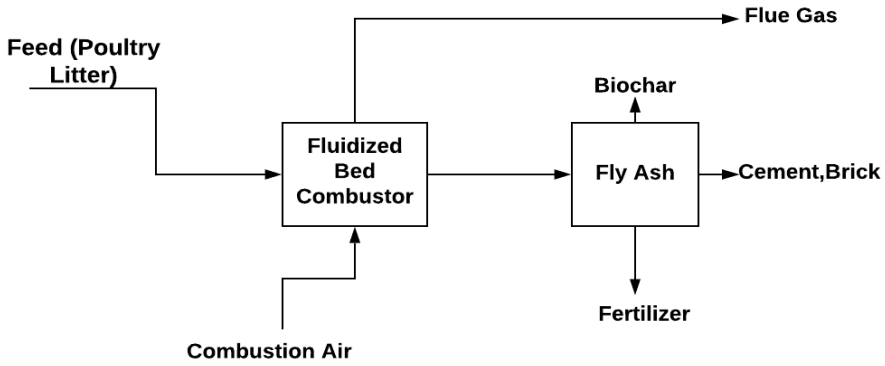



**Figure 4.** Flowchart of Poultry Litter Combustion

High moisture content present in raw poultry litter is a major setback in converting the waste to energy. The calorific value of the litters reduced with increasing moisture content. Poultry litter has a heating value between 6.78 and 27.90 MJ/kg with an average of 14.08 MJ/kg (Qian et al., 2018) Lower Heating Values (LHVs) on a wet basis range are much lower

(mean values of 2664 kJ/kg) due to the high moisture content of poultry manure (Quiroga et al., 2010). Overcoming the 35-40% moisture content requires additional technology to dry the litters to lower moisture content (<10%) prior to the combustion process. High volume of ash generated during the combustion process of poultry litter poses environmental hazards alongside other gaseous pollutants. Therefore, researchers across the globe work continuously on converting the high-volume ash to useful products in different fields. The ash is generally a valuable fertilizer, high in phosphorous, potassium and other micronutrients (Echols et al., 2006). Fly ash can be used as prime material in many cement-based products, such as poured concrete, concrete block, and brick (Rodriguez, 2019). A similar use of fly ash is as biochar and substrates for bioremediation of soil (Sitarz-Palczak and Kalembkiewicz, 2012). Fine particulate matters produced in the combustion process of poultry litter are handled by installing cyclone and electrostatic precipitator (ESP). On a large scale, energy conversion of poultry litter via combustion process is economically not feasible as technologies needed for an efficient and environmentally friendly production are expensive and impact the overall cost of operations. A way of improving poultry litter conversion to heat energy is via co-combustion process. Co-combustion is defined as the combustion of renewable fuel (i.e., biomass) along with the primary fuel (coal, natural gas, furnace oil, etc.) (Sami et al., 2001). Co-combustion of poultry litter with natural gas has the following advantages: (i) reduction in fuel costs since biomass is cheaper than fossil fuel; (ii) minimization of waste and reduction of soil, water, and air pollution; and (iii) reduction of the anaerobic release of CH4, NH3, H2S, volatile organic acids and other chemicals since the storage time is reduced (Sweeten et al., 2003).

A case study of improved thermochemical conversion of poultry litter to heat energy via the co-combustion process is the facility provided in Centre for Advanced Energy Systems and Control Technologies (CAESECT) lab in Industrial and Systems Engineering Department, Morgan State University, Maryland, USA (Qian et al., 2019). Figure 5 shows the lab-scale FBC used in the CAESECT lab having a diameter of 304.8mm and a height of 1500mm. The chamber was fabricated with a carbon steel pipe covered inside with a 12.7mm thickness refractory ceramic. The primary air for combustion is supplied at the bottom of the chamber at varying speeds. Above this line, the feed (poultry litter) is introduced from a screw feeder at a varying rate and the secondary air lines are introduced tangentially to the bed at heights 650mm, 850mm and 1100mm respectively (Zhu et al., 2005; Qian et al., 2019). The heat recovery system installed involves the use of shell and tube heat exchanger to condense the total heat generated, which passes through a set of connected pipes to four radiators placed in an empty mobile trailer for space heating. Poultry litter is being collected from poultry farms in Chesapeake Bay's Delmarva area of Maryland. The collected waste with 20-25%moisture content, is combusted with natural gas in the lab-scale bubbling FBC at 80:20 percent ratio. At 4.5-5.5% feeding rate, 20-25cfm of primary air with low amount of secondary air, the maximum chamber temperature was observed to be 850-950oC, resulting in a temperature of greater than 90oF in the mobile trailer. According to the study by Qian et al. (2019), 905 W of electricity was reached under a water flow rate of 13.1 L/min and an engine head temperature of 584 °C. It was found that excess air (EA) ratios between 0.79 and 1.08 can relatively produce more electricity with lower emissions (under acceptable standards).

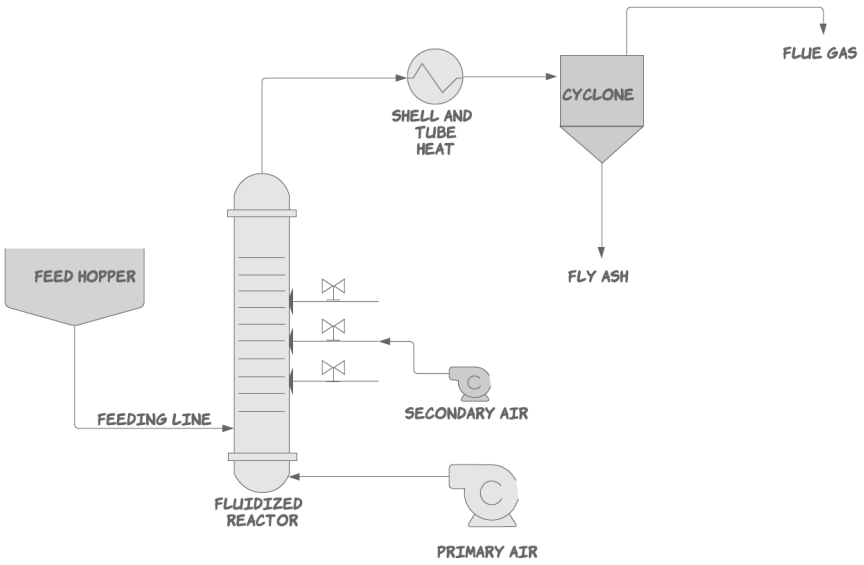



**Figure 5.** CAESECT Lab-Scale Fluidized Bed Combustor

## 4. BIOMASS-TO-ENERGY SUSTAINABILITY

Sustainable energy over the years has been defined as development of energy system which meets the need of the present without compromising the future's ability to meet its needs. Sustainability has been repeatedly explained by several researchers as an act of designing and developing a system that is environmentally friendly, economically viable and socially impactful as shown in Figure 6. The previous section compares the two processes under this study using poultry litter. Biochemical conversion process of biomass is said to be a clean, pure and efficient process among other processes (Chen and Wang, 2016), but cannot be said to be sustainable, balancing the three elements-environment, economy and society. The process generates primarily methane gas and a secondary waste in form of sludge with both requiring further processing to become environmentally safe. Furthermore, biochemical process requires pre-treatment (physical or chemical) of the biomass material; fully depends on particular strains of microbes and enzymes for large scale production; and requires longer reaction time for products formation (biomass fermentation takes 3-4 days before alcohol distillation, biomass digestion takes 15-30 days before biogas production). These reasons explain its economic non-feasibility.

On the other hand, thermochemical conversion process can be effectively applied to any biomass feedstock with or without pre-treatment process. Some feedstocks require pre-treatment (such as drying of poultry litter, sorting of MSW) to improve their products quality. Wood can be burnt directly without any pre-treatment, thereby making thermochemical processing more flexible. In addition, the thermochemical process requires less reaction time as the product in form of heat energy is formed immediately. Biomass resources can play a major role in reducing the reliance on fossil fuels by making use of thermochemical conversion technologies. However, raw biomass possesses low density (30–50 kg/m3) and its high moisture content limits its usage for thermochemical processes. The inclusion of a pelletizing process in thermochemical processes, allows easier economic storage, transportation, and energy conversion characteristics, and thus makes the process an efficient and sustainable approach to biomass-to-energy conversion. Burning of biomass

waste has been largely considered as a better approach in that the CO2 generated during the process is balanced by an equivalent amount plants capture through photosynthesis while they are growing. As a result, the biomass is considered a carbon-neutral energy source, thus making the process environmentally sustainable. Furthermore, the increased utilization of biomass-based fuels will be instrumental in safeguarding the environment, generation of new job opportunities, sustainable development and health improvements in rural areas. Biomass Energy and Alcohol Fuels Act (1980), Energy Policy Act (EPA 1992) and Energy Independence and Security Act (EISA 2007) among others are governmental policies to address sustainability in the use of biomass for energy production.

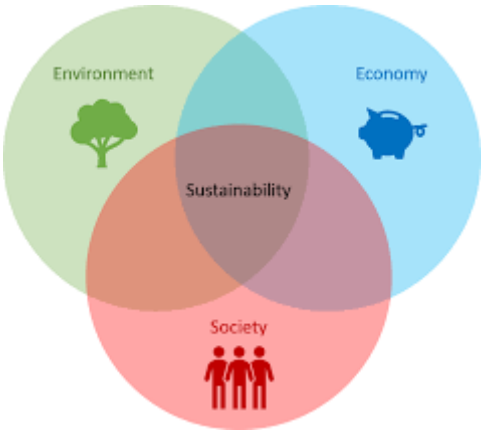



**Figure 6.** Elements of Sustainability (Deirdre, 2018)

## 5. CONCLUSIONS

The continuous overdependency on fossil fuel and its impact on climatic change has led researchers across the globe to design and develop energy system that is renewable, environmentally friendly, socially acceptable and economically feasible. In this study, the use of biomass feedstocks for energy production has been reviewed and the two mostly adopted biomass conversion processes have been compared using poultry litter as a case. Biochemical processes require pre-treatment of feedstock as well as post-treatment of products which increases the production cost, thereby making the process economically unstainable. Thermochemical processes require less reaction time (products formed immediately) while biochemical conversion requires 15-30 days for complete digestion prior to the formation of products. Furthermore, the thermochemical process has the capacity to generate more electricity with less emissions as the amount of CO2 produced is balanced out by the equivalent amount the biomass feedstock captured through photosynthesis. In addition, the biochemical process investigated in this study, generates high amount of ammonia which inhibits the process and, in a bit, to reduce the ammonia formation, a high volume of waste is generated. This renders the process economically non-viable. Therefore, thermochemical processing can be considered as an advantageous and viable means for energy production, offering an efficient and sustainable conversion process for biomass.

## 6. ACKNOWLEDGEMENTS

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