Volume 41 • Number 2 (ISSN 0511 5728) • January 2019

WEST INDIAN JOURNAL OF ENGINEERING

Editorial…… 2

A Comparison of Memetic Algorithms in a Generator Maintenance Scheduling Problem for Trinidad and Tobago …… 4

Determination of Best-fit Propagation Models for Pathloss Prediction of a 4G LTE Network in Suburban and Urban Areas of Lagos, Nigeria …… 13

Modular and 3D-Design of a Fluidised Bed Boiler with Agricultural Residue for Steam Energy Production …… 22

Assessing Residential Building Energy Efficiency in the Caribbean Environment: A Case Study of Trinidad and Tobago …… 31

Strengthening Geospatial Data Ecosystems in the Caribbean: A Role for Academic Institutions …… 43

Automated Identification of Vehicular Accidents from Acoustic Signals Using Artificial Neural Networks …… 55

Employee Perception of the Impact of Occupational Health and Safety Management on Organisational Commitment: A Case Study of an Energy Sector Organisation in Trinidad and Tobago …… 62

Modelling the Rehydration Characteristics of White Yam …… 70

Redesign of a Furniture Industry Component: A Sustainable Design Approach …… 77

Eur Ing Aldwyn Lambert Lequay (1927-2018): A Memorial …… 84

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2 **Editorial**

4 **A Comparison of Memetic Algorithms in a Generator Maintenance Scheduling Problem for Trinidad and Tobago**
by Neil Ramsamooj, Laura Ramdath, Sanjay Bahadoorsingh and Chandrabhan Sharma

13 **Determination of Best-fit Propagation Models for Pathloss Prediction of a 4G LTE Network in Suburban and Urban Areas of Lagos, Nigeria**
by Agbotiname L. Imoize, Augustus E. Ibhaze, Peace O. Nwosu, and Simeon O. Ajose

22 **Modular and 3D-Design of a Fluidised Bed Boiler with Agricultural Residue for Steam Energy Production**
by Muyideen B. Balogun, Clement O. Folayan, Dangana M. Kulla, Fatai O. Anafi, Samaila. Umaru and Nua O. Omisanya

31 **Assessing Residential Building Energy Efficiency in the Caribbean Environment: A Case Study of Trinidad and Tobago**
by Abrahams Mwasha and Joseph Ayoola Iwaro

43 **Strengthening Geospatial Data Ecosystems in the Caribbean: A Role for Academic Institutions**
by Bheshem Ramlal, Dexter Davis and Earl Edwards

55 **Automated Identification of Vehicular Accidents from Acoustic Signals Using Artificial Neural Networks**
by Renique Murray and Aaron D'Arbasie

62 **Employee Perception of the Impact of Occupational Health and Safety Management on Organisational Commitment: A Case Study of an Energy Sector Organisation in Trinidad and Tobago**
by Ruel L.A. Ellis, and Kareem D. Gordon

70 **Modelling the Rehydration Characteristics of White Yam**
by Akinjide A. Akinola, Stanley N. Ezeorah, and Ekene P. Nwoko

77 **Redesign of a Furniture Industry Component: A Sustainable Design Approach**
by Boppana V. Chowdary, Marc-Anthony Richards and Trishel Gokoolo

84 **Eur Ing Aldwyn Lambert Lequay (1927-2018): A Memorial**
by *Clément A.C. Imbert*

Editorial

This Volume 41 Number 2 includes nine (9) research/ technical articles and a memorial written for the late Eur Ing Aldwyn Lambert Lequay who was the past President of the Association of Professional Engineers of Trinidad and Tobago (1976-1977). The relevance and usefulness of respective articles are summarised below.

N. Ramsamooj et al., "A Comparison of Memetic Algorithms in a Generator Maintenance Scheduling Problem for Trinidad and Tobago", compared the uses of three search methods (hill climbing, tabu search, simulated annealing) against genetic and memetic algorithms in the solution of the generator maintenance scheduling problem in power generation companies. The paper demonstrates the use of metaheuristic optimisation techniques to approximate global optimum schedules in finite time. Results show that the techniques could improve the previously implemented solution of generator scheduling for a case company under study in Trinidad and Tobago.

In the article, "Determination of Best-fit Propagation Models for Pathloss Prediction of a 4G LTE Network in Suburban and Urban Areas of Lagos, Nigeria", **A.L. Imoize et al.** investigated the suitability of propagation models for path loss prediction of a fourth generation long-term evolution (4G LTE) network. These models were selected and developed using the least square regression algorithm. Promising prediction results with root mean squared errors (RMSEs) were recorded and compared with propagation measurement results reported in both urban and suburban areas. It was found that these models would better characterise radio coverage and mobile network planning, enhancing the quality of mobile services in the suburban and urban areas of Lagos, Nigeria.

M.B. Balogun et al., "Modular and 3D-Design of a Fluidised Bed Boiler with Agricultural Residue for Steam Energy Production", investigated the fuel distribution of a miniature fluidised bed boiler designed and constructed for steam generation. The investigation was carried in two-dimensional chamber. The results obtained with corncob at constant feed rate recorded stability of the saturation temperature. Saturation pressures were obtained, and the effect of fuel particle size on emissions and over all combustion efficiency of corncobs has proven to be efficient in a fluidised bed boiler.

A. Mwasha and J.A. Iwaro, "Assessing Residential Building Energy Efficiency in the Caribbean Environment: A Case Study of Trinidad and Tobago", explored the strategy for achieving sustainable building energy efficiency in warm humid regions. The impact of building envelope systems on the building energy efficiency was reported through experimental approach using three building physical models. The performance of the building envelope physical models was monitored in terms of energy consumption, cooling load, indoor temperature, indoor relative and humidity. It was found that short-term strategies could be applied and the insulated galvanised and standing seam roofing systems are more energy efficient and cost effective.

In the fifth article, "Strengthening Geospatial Data Ecosystems in the Caribbean: A Role for Academic Institutions", **B. Ramlal, D. Davis and E. Edwards**, explored the need toward the Sustainable Development Goals (SDGs), and examined the state of readiness of national geospatial data ecosystems (NGDE) in the region. They identified the major challenges in achieving functional systems, and proposed intervention strategies that could be implemented with indigenous support from academic institutions such as The University of the West Indies.

R. Murray and A. D'Arbasie, "Automated Identification of Vehicular Accidents from Acoustic Signals Using Artificial Neural Networks", developed an automated system for the identification of motor vehicular accidents. They utilised an artificial neural network approach to estimate the probability of occurrence, based on recorded acoustic signals, and then developd a dual layer artificial neural network. The system was built and tested in the MATLAB environment, utilising 22 sample signals in the design phase and a further 53 for testing. An evaluation of the system found it have an accuracy of 86% and a precision of 76%, with a 100% identification of actual accidents. The system also prioritises the time domain signal features over those of the frequency domain, in the identification process.

R.L.A. Ellis, and K.D. Gordon, "Employee Perception of the Impact of Occupational Health and Safety Management on Organisational Commitment: A Case Study of an Energy Sector Organisation in Trinidad and Tobago", spoke about the Occupational Health and Safety (OHS) dimension of the work environment. A cross-sectional case study was conducted using a group of non-managerial employees in the Petroleum Sector in Trinidad and Tobago (T&T). It was found that employee perception of managerial OHS support practices had a significant and positive correlation with affective commitment. Managerial OHS support would have an impact on employees wanting to remain employed in the organisation. It was concluded that the prioritisation of occupational health and safety in the workplace facilitates employees' organisational commitment, and recognition of workers perception of health and safety would demonstrate emotional attachment and commitment to the organisation.

In the eighth article, "Modelling the Rehydration Characteristics of White Yam", **AA. Akinola S.N. Ezeorah and E.P. Nwoko**, proposed a model describing

the variation in the rehydration ratio with rehydration time for yam slices. The model would describe the relationship between the moisture content of yam slices with time when rehydrated. It was claimed that the study would provide a better understanding of the rehydration characteristics of yam slices during the rehydration process. The results from rehydration process indicate that rehydration occurs very rapidly in the first few minutes of the rehydration process, and the process is faster as the rehydration temperature increases.

B.V. Chowdary, M-A. Richards and T. Gokool, "Redesign of a Furniture Industry Component: A Sustainable Design Approach", explored a sustainable product design for a furniture component using Design for X (DFX) tools and techniques. The efficacy of the approach was demonstrated through a case study involving the redesign of a component selected from the local Caribbean market. The SolidWorks package was used to generate computer-aided design (CAD) models which were further analysed by using the Simulation and Sustainability modules. The guidelines of Design for Manufacture and Assembly (DFMA) and Design for environment (DFE) were also utilised in the redesign. The research shows that DFX tools and techniques could be combined in a single platform to effectively redesign products to meet functional and environmental requirements.

C.A.C. Imbert, "Ing Aldwyn Lambert Lequay (1927-2018): A Memorial", speaks about the profession life, and recognises the commitments and contributions of late Eng Ing Aldwyn Lambert Lequay towards the development of mechanical and electrical engineering disciplines and professionals in Trinidad and Tobago and the wider Caribbean region.

On behalf of the Editorial Office, we gratefully acknowledge all authors who have made this special issue possible with their research work. We greatly appreciate the voluntary contributions and unfailing support that our reviewers give to the Journal.

Our reviewer panel is composed of academia, scientists, and practising engineers and professionals from industry and other organisations as listed below:

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A Comparison of Memetic Algorithms in a Generator Maintenance Scheduling Problem for Trinidad and Tobago

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Abstract: *Power generation companies have to meet consumer demand and reliability criteria. The maintenance of generators needs to be performed regularly to ensure a reliable supply of electricity. An increase in repair frequency will result in greater maintenance cost together with an expected decrease in capital loss due to generator failure. An optimal maintenance schedule is therefore needed to find the best suited trade-off and lower the overall operation cost. Maintenance scheduling is a combinatorial optimisation problem for which an exhaustive search is typically infeasible due to the large size of the solution space. Metaheuristic optimisation techniques are therefore used to approximate global optimum schedules in finite time. This paper compares the uses of the local search methods (hill climbing, tabu search, simulated annealing) against genetic and memetic algorithms in the solution of the generator maintenance scheduling problem. The solution methods improve the previously implemented solution of generator scheduling for the Power Generation Company of Trinidad and Tobago.*

Keywords: *Generator, maintenance scheduling, tabu search, simulated annealing, genetic algorithm, memetic algorithm*

1. Introduction

Regular maintenance of the generators is required for the stable operation of a power system. The scheduling of generator maintenance is central to power system planning as this schedule affects unit commitment, production cost, fuel scheduling, reliability calculations and other aspects of system planning. A non-optimal schedule will negatively affect these functions. The objective of a maintenance schedule is to minimise or maximise the reserve. The determination of an optimal generator maintenance schedule is a complex combinatorial optimisation problem which has been researched over several decades (Patton and Ali, 1972; Egan et al., 1976; Mukerji et al., 1991; Yellen et al., 1992; Burke and Smith, 2000; Dahal and Chakpitak, 2007).

We briefly outline the following sections of our paper. Section 2 outlines previous solution methods to the generator maintenance scheduling problem. Section 3 of this paper shows that the GMS problem may be modelled as an optimisation problem by specifying the constraints, objective function and solution space. In Section 4, the local search, genetic and memetic algorithms that are used to solve our GMS formulation are described. In Section 5, the results obtained from the different solution methods are compared. In Section 6, a case study is illustrated and a method is demonstrated to improve on a previously implemented solution of generator scheduling problem in industry in Trinidad and Tobago.

2. Solution Methods to the Generator Maintenance Scheduling Problem

The following summarises different solution methods to the generator maintenance scheduling (GMS) problem.

1) *Heuristic techniques* were among the first methods used to determine a generator maintenance schedule. Generators are first ranked by their power outputs and maintenance requirements. A typical heuristic method is a trial and error process that determines a maintenance schedule by applying a sequence of rules to this ranking of generators. Heuristic methods are best suited for small generator systems and cannot ensure a true optimal solution (Schlunz, 2011).

2) Dynamic programming is a general method of reducing a complex problem into sub-problems and using the storage of the sub-problem solutions to obtain a solution of the initial problem. The direct use of dynamic programming methods in the GMS problem is considered infeasible as the complexity of the resulting

models increases greatly with the number of generators. The *modification dynamic programming with successive approximations* (DPSA) has however been successfully applied to the generator maintenance scheduling problem (Ahmad and Kothari, 1998). The DPSA method provides close approximations to a global optimum solution.

3) An integer programming problem is an optimisation problem in which some of the solution variables are constrained to take only integer values (Rao, 2009). The maintenance durations of a GMS problem are specified in integers (weeks), and therefore generator maintenance scheduling problems are necessarily integer programming problems. The main techniques used to solve integer programming technique are the branch-and-bound, cutting plane and Balas methods (Rao, 2009). Of these, the branch-and-bound (Egan et al., 1976) and Balas methods (Mukerji et al., 1991) have been successfully applied to the GMS problem. These methods are computationally expensive (Schlunz, 2011) but provide true optimum solutions. Benders decomposition is an iterative approach to the above standard integer programming methods which has also been applied to GMS (Yellen et al., 1992).

4) A metaheuristic is a high level approach that may be applied to the solution of optimisation problems. These approaches have been widely applied to the GMS problem (Ahmad and Kothari, 1998) as they usually provide close approximations to a global optimum solution within acceptable time. Metaheuristics may be broadly classified as either local searches or as population based. These categories and their application to the GMS problem are discussed in Section 4.

3. Problem Formulation

The generator maintenance scheduling (GMS) problem is an optimisation problem, and therefore consists of the selection of an optimal solution chosen from a solution space. The solution space for the GMS formulation consists of *start time vectors*, subject to various constraints as discussed below. As with the optimisation problems, the choice of an optimal or best solution is achieved by the use of an objective function. We first define the variables in order to precisely describe the model constraints, solution space and objective function. These variables are:

I = number of generators
i = generator index
J = number of periods in planning horizon
j = period index
M_i = maintenance duration of generator i
X_i = start time of maintenance of generator i
ST_i = start time of maintenance window for generator i
ET_i = end time of maintenance window for generator i
C_i = operating capacity of generator i
D_j = demand at period j
R_j = reserve capacity at period j
P_{ij} = output of generator i at period i

$$y_{ij} = \begin{cases} 1 & \text{if generator } i \text{ is in maintenance at period } j \\ 0 & \text{otherwise} \end{cases}$$

ST_i = start time of maintenance window for generator i

Table 1 gives a simple example of input data used in the implementation of the solution of the GMS problem. We use this data example to illustrate the use of the variables given above.

Table 1. Sample Input Data

i	C_i	DS_i	ST_i	ET_i	M_i
1	40	1	2	4	1
2	50	1	1	6	5
3	45	1	3	5	2
4	55	1	2	5	2

In this case, the number of generators is $I = 4$. From further user input, we assumed that the start and end times of the planning horizon are 1 and 6, respectively, so that the number of periods (weeks) in the planning horizon is $J = 6$. Maintenance of generator i is assumed to start at the beginning of a period. Hence, we have:

$$X_i \in \{1,2, \ldots, J\}. \quad (1)$$

However, maintenance must also be done within a time window that is specified by periods ST_i and ET_i within the planning horizon. We therefore have the stronger condition that,

$$ST_i \leq x_i \leq ET_i \quad (2)$$

3.1 Model Constraints

The constraint (Equation 2) may be further strengthened as maintenance of generator i must continue for M_i weeks without interruption. This implies that,

$$ST_i \leq x_i \leq ET_i - M_i + 1 \quad (3)$$

which may be referred to as a *continuous maintenance constraint* for generator i. The input data (for example, see Table 1) in our implementation is validated, so that the constraints specified by Equation (3) are not vacuous, that is,

$$1 \leq ST_i \leq ET_i - M_i + 1 \leq J \quad (4)$$

for each i.

An illustrated example is given here. It is easily verified that $(x_1, x_2, x_3, x_4) = (2,1,3,4)$ is a potential schedule solution as it satisfies the constraint (3) for each generator $i = 1,\ldots,4$ where ST_i, ET_i and M_i are as specified in Table 1. This solution may equivalently be written as an $I \times J$ binary matrix,

$$(y_{ij}) = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \end{pmatrix}$$

where the variable y_{ij} is defined above.

A generator i that is undergoing maintenance may be capable of an output that is a fraction of its full operating capacity C_i. This partial output can be quantified by the use of the fraction,

$$0 < DS_i \leq 1 \quad (5)$$

where $DS_i = 1$ means that generator i is totally unavailable. The output P_{ij} of generator i during period j is, therefore,

$$P_{ij} = C_i(1 - y_{ij}DS_i) = \begin{cases} C_i(1 - DS_i) & \text{if in maintenance} \\ C_i & \text{if fully available} \end{cases} \quad (6)$$

The collective power output of all generators must satisfy the load demand D_j at each period j, and therefore

$$\sum_{i=1}^{I} P_{ij} \geq D_j \quad (7)$$

which from Equation (6) implies that

$$\sum_{i=1}^{I} C_i(1 - y_{ij}DS_i) \geq D_j \quad (8)$$

The Equation (8) describes a *load constraint* for period j.

3.2 Solution Space

As is illustrated in the example, any tuple

$$x = (x_1, x_2, \ldots, x_I) \quad (9)$$

where each x_i satisfies the constraints (Equation 3) may be equivalently written as an $I \times J$ binary matrix (y_{ij}). In this paper, **x** is called a *start time vector* if each x_i satisfies (Equation 3) and the equivalent matrix form (y_{ij}) of the tuple **x** satisfies the constraints (Equation 8). The set of all such start time vectors is the *solution space*, $\mathcal{S}$ of the formulation of the GMS problem. As each x_i is an integer that satisfies (Equation 3), it follows that the size of our solution space is finite and bounded above by the product

$$\prod_{i=1}^{I} (ET_i - M_i - ST_i + 2) \quad (10)$$

and hence the formulation of GMS is necessarily a combinatorial optimisation problem.

3.3. Objective function

Objective functions in most formulations of the GMS problem may be classified using one of three (3) criteria (Schlunz, 2011): *convenience*, *economic* or *reliability*. In this paper, we use the following reliability objective function.

$$\text{Minimise } \sum_j^J \{(\sum_i^I P_{ij}) - D_j\}^2 \quad (11)$$

Equation (11) is a standard objective function used in GMS formulations (Froger et al., 2015), and may be interpreted as the leveling of reserves on the horizon. We briefly explain this interpretation. The reserve capacity R_j is defined as total power output minus load demand for period j, that is,

$$R_j = (\sum_i^I P_{ij}) - D_j \quad (12)$$

and therefore Equation (11) may be rewritten as:

$$\text{Minimise } \sum_j^J R_j^2 \quad (13)$$

Recall from Function (7) that our solution space of start time vectors is constrained so that $R_j \geq 0$ for all periods j. We assume that load demand D_j that forms part of the input data incorporates a sufficiently large reserve margin in addition to actual forecasted load. The objective function (Equation 11) may therefore be viewed as reducing the variability of the reserve capacity R_j with change in period j by minimising the sum of squares as stated in Equation (13). A large value of the sum of squares (Equation 13) (given that each R_j is nonnegative) will usually be the result of a few large outliers together with several R_j values which are approximately zero – such a situation is clearly not desirable from a reliability viewpoint. Conversely, a minimal value for Equation (13) corresponds to the more reliable situation in which the reserves R_j are approximately equal and sufficiently nontrivial for each period j across the horizon.

4. Optimisation Methods

The discussion in Section 3 shows that the GMS formulation is a combinatorial optimisation problem or, more precisely, a nonlinear integer programming problem (Rao, 2009). There are formulations of GMS which have been solved by integer programming methods (Mukerji et al., 1991). For this study, we do not use these methods. Instead, the heuristic techniques are used to obtain optimal solutions of the formulation.

4.1 Local Searches

In any iterated local search method, an initial point x_0 in the solution space is chosen and is then assigned as the current solution point **x** of the first iteration. An improved subsequent point is then chosen from the neighborhood $N(\mathbf{x})$ of this current point **x** where improvement is measured by an objective function. This process is then iterated and this results in a walk through the solution space. A well-defined neighborhood $N(\mathbf{x})$ is therefore required by any local search method for each point **x** in the solution space $\mathcal{S}$.

In this paper, the neighborhood $N(\mathbf{x})$ of a point **x** is defined as those points in the solution space $\mathcal{S}$ that are at a Hamming distance of at most one from the point x, that is, $N(\mathbf{x})$ consists of the points of $\mathcal{S}$ that differ from $\mathbf{x} = (x_1, x_2, \ldots, x_I)$ in at most one position. For example, the point $\mathbf{x} = (x_1, x_2, x_3, x_4) = (2,1,3,4)$ can be shown to be an element of the solution space $\mathcal{S}$ for the input data specified by Table 1 and where demand $D_j = 30$ MW for each period j = 1,…,6. The neighborhood N(x) of this x consists of the start time vectors

(2,1,3,4), (3,1,3,4), (2,2,3,4)
(2,1,4,4), (2,1,3,2), (2,1,3,3)

Local search methods are used as solution techniques for the GMS formulation.

4.1.1 Hill Climbing

This iterated procedure is perhaps the simplest of the local search methods. Each iteration consists of selecting a most optimal point from the neighborhood of the

current point; this selected point becomes the current point in the following iteration. Hill climbing methods are sometimes not suitable for determining global optima as they may potentially become trapped at local optima (Michalewicz and Fogel, 2013).

Algorithm 1: Basic hill climbing pseudocode

```
1  select initial solution x_0
2  x := x_0; x* := x_0
3  while not (Termination criterion) do
4    identify neighborhood N(x) of current solution x
5    select local best solution x' of N(x)
6    replace current solution x with x'
7    update global best candidate solution x*
8  end
9  return global best candidate x*
```

4.1.2 Tabu Search

Consider the case in a hill climbing procedure in which the current point **x** in the iteration is locally optimal, that is, the most optimal solution in the neighborhood $N(\mathbf{x})$ is **x**. The subsequent point in the hill climbing iteration will remain as **x** and hence the procedure becomes trapped at this point. The tabu search method may be regarded as a modification of hill climbing that avoids such pitfalls by using a *tabu list* $\mathcal{T}$ as a memory device in which previously visited solution points are stored. A subsequent point in a tabu search iteration is chosen from $N(\mathbf{x})\setminus\mathcal{T}$, that is, it is chosen from neighbors of the current point **x** that have not been previously visited. In this way, iterations are not trapped at **x** and exploration of the solution space is encouraged.

Algorithm 2: Tabu search pseudocode

```
1  select initial solution x_0
2  initialise tabu list T: = []
3  x :=x_0; x* := x_0
4  while not (Termination criterion) do
5      identify neighborhood N(x) of current solution x
6      select local best solution x' of N(x)
7      replace current solution x with x'
8      insert x' into tabu list T
9      remove oldest entry from T if necessary
10     update global best candidate solution x*
11 end
12 return global best candidate x*
```

4.1.3 Simulated Annealing

In this local search method, exploration of the solution space is forced by the use of a parameter T called *temperature* which is reduced at a predetermined rate. Recall that in a hill climbing iteration, a subsequent point **x**' is necessarily an improvement on the current solution point **x**. However, in simulated annealing it is possible that a subsequent point **x**' may be worse than the current solution point **x**. This is done to encourage exploration of the solution space. The probability of deteriorating moves is higher for larger initial temperature values with a decrease in temperature resulting in this probability being lowered. At small temperatures, this probability is virtually zero with only improving moves being allowed and hence at low temperatures the simulated annealing procedure behaves as a hill climbing iteration.

Algorithm 3: Simulated annealing pseudocode

```
1  select initial solution x_0
2  initialise temperature T
3  set number of iterations l
4  x:= x_0; x* := x_0
5  while not (Termination criterion) do
6    for i = 1 to l do
7      randomly select x' from neighborhood N(x)
8      determine ΔC = cost(x') – cost(x)
9      if ΔC ≤ 0 then
10       replace current solution x with x'
11     else if rand [0,1] ≤ exp(-ΔC/T) then
12       replace current solution x with x'
13     end
14   end
15 update global best candidate solution x*
16 reduce temperature, T
17 end
18 return global best candidate x*
```

4.2 The Genetic Algorithm

In each of the local search methods considered above, a single initial point is chosen from the solution space. This single point is then used to generate a sequence of points with a global optimum candidate being selected from this sequence. A genetic algorithm (GA) differs from a local search in that multiple solution points (collectively referred to as a *population*) are initially selected. This initial population is then used to create a subsequent population via an improvement process that is analogous to the mechanism of natural selection from biology.

This process is then repeated for a predetermined number of iterations (called *generations* in the notation of genetic algorithms), hence creating a sequence of populations. A globally optimal candidate is then selected from these populations. In a genetic algorithm, the improvement process that is used to iteratively create subsequent populations may be subdivided into three (3) stages (Simon, 2013) – *selection*, *crossover* and *mutation*. The implementation of these stages in the solution of the GMS formulation via a genetic algorithm is discussed below.

4.2.1 Selection

In each generation, several solution points (called *parents*) are chosen from the current population; information from these selected points is used in the creation of the elements of the subsequent population (referred to as *children*). Two parents are used to produce two children via the crossover process. To achieve improvement in successive generations, more optimal solution points are chosen as parents with higher probability than those with lower optimal values – this is similar to the evolutionary process in biology in which less fit individuals are unlikely to reproduce.

4.2.2 Crossover

In this paper, we utilise the *single-point crossover* method in the formation of children from parents; other crossover methods are described in Simon (2013). The single point crossover method can be illustrated by the use of the following example. Assume that the input data is as given in Table 1 and consider the following two parents,

$$(2,1,4,3)$$
$$(4,2,3,2)$$

belonging to a population which is a subset of the solution space $\mathcal{S}$. A crossover point is then randomly chosen from $\{0,1,\ldots,I\}$; assuming that the chosen value (indicated by Δ below) is two.

A single point crossover is simply the formation of two children,

$$(2,1_{\Delta}3,2)$$
$$(4,2_{\Delta}4,3)$$

by switching all information of the above parents beyond the crossover point.

4.2.3. Mutation

Small random changes called mutations are made to children after the crossover process. This is done to introduce some measure of diversity between successive populations and to prevent premature convergence of solutions.

Consider the possible child

$$(x_1, x_2, x_3, x_4) = (2,1,3,4)$$

that is the result of crossover. Mutation of this solution point is achieved by changing each x_i with some small probability p (usually $p \approx 0.02$). If this probability occurs then x_i will be changed to a value such that the modified solution satisfies the constraints (Equations 3 and 8).

Algorithm 4: Genetic algorithm outline

1 select initial population P_0
2 choose best individual **x*** from P_0
3 set number of generations N
4 **for** $i = 0$ **to** $N - 1$ **do**
5 select parents from current population P_i
6 use crossover to determine children
7 apply mutation to children
8 form new population P_{i+1} from children
9 choose best individual from P_{i+1} and update global best **x*** if necessary
10 **end**
11 **return** *global best candidate* **x***

4.3. Memetic Algorithms

According to Dawkins (2006), a *meme* is a cultural replicator such as an idea, belief or song. Memes, in a manner similar to the genetic material of individuals, undergo replication, propagation and mutation. The notion of fitness or optimality may also be applied in that fitter memes are more likely to survive and propagate within a society. It follows that memes may be considered as being subject to a cultural evolutionary process (Heylighen and Chielens, 2009) with the goal of *memetic algorithms* being to model such processes.

A memetic algorithm usually carries the same replication aspects as a genetic algorithm but also incorporates problem specific or local data. The inclusion of local data may be done by hybridisation (Moscato and Cotta, 2003), and such hybrids form a subclass of memetic algorithms. Our method of hybridisation follows the method used by Burke and Smith (2000) in which a local search is applied to each member of the population generated after each of the i^{th} iterations of a genetic algorithm.

Algorithm 5: Memetic algorithm outline

1 select initial population P_0
2 choose best individual **x*** from P_0
3 set number of generations N
4 **for** $i = 0$ **to** $N - 1$ **do**
5 select parents from current population P_i
6 use crossover to determine children
7 apply mutation to children
8 form intermediate population $\acute{P}_i$ from children
9 use each optimal solution vector of the local search applied to each member of $\acute{P}_i$ to form new population P_{i+1}
10 choose best individual from P_{i+1} and update global best **x***
11 **end**
12 **return** *global best candidate* **x***

In this paper, we consider three (3) hybrids

Hybrid HC, Hybrid TS, Hybrid SA

that are formed by respectively applying the distinct local search methods of hill climbing, tabu search and simulated annealing to the populations generated by a genetic algorithm.

5. Results

Numerical results are presented below for the seven (7) solutions methods considered (see Section 4). These

solutions may be classified as local searches (hill climbing, tabu search, and simulated annealing) and evolutionary methods (genetic and memetic (Hybrid HC, Hybrid TS, and Hybrid SA)). We also compared the methods to Automated Optimised Generator Outage Scheduler (AOGOS) which is a previously implemented solution of the GMS problem by Sharma and Bahadoorsingh (2004). These solutions were implemented in MATLAB and were executed on a Precision 7710 laptop. Certain code segments of the solutions were derived from Simon (2015).

5.1 Validation

The size of the solution space $\mathcal{S}$ of the GMS formulation increases exponentially with increase in the number of generators I. Therefore, an enumeration of $\mathcal{S}$ is typically not feasible for realistic input data in which the number of generators I usually exceeds twenty (20). However, for sample input data with small I, it is possible to enumerate the solution space $\mathcal{S}$. An enumeration (with corresponding fitness values) was implemented for the sample input data given in Table 1.

Optimal solution vectors were easily obtained from this enumeration and these results were used to validate various implemented solutions of the GMS problem. Further validation may be noted in the case of large I as the optimal values obtained from each of the solution methods (for fixed input data) were approximately equal to each other within reasonable tolerance.

5.2. Comparison of Solution Methods

We use input data from the IEEE Reliability Test System (Power Market Subcommittee, 1979) to graphically compare the convergence of our solution methods. This data set (also used in Sharma and Bahadoorsingh (2004)) describes a $I = 32$ generator system with a $J = 52$ week horizon and has the same tabular form as the sample input data from Table 1. A constant load demand $D_j = 2700$ MW is assumed for each week; note however that our solution implementation may be easily modified to accommodate variable load demands. The minimum fitness value achieved from among all of our solution methods for this input data was 1.068547×10^7. This value was obtained by Hybrid SA after an execution time of 1479 seconds for a population size of 30 and a generation number of 25. This value is used as a baseline for the convergence of the solution methods, and heuristically considers fitness values less than 1.07×10^7 as acceptable for the above input data.

Figure 1 illustrates typical convergence of fitness values of the three (3) local search methods and AOGOS. These methods usually converge within approximately 25 seconds under the hardware conditions. Parameter tuning of three (3) local search methods by increasing the search depth in the cases of hill climbing and tabu search or increasing the number of iterations in the case of simulated annealing did not result in significant improvement in the convergence values. It is to note that the convergence values of

$$1.08 \times 10^7,\ 1.075 \times 10^7 \text{ and } 1.077 \times 10^7$$

for the examples of hill climbing, tabu search and simulated annealing (illustrated in Figure 1) improve on the convergence value of 1.125×10^7 for AOGOS. The bar chart shown in Figure 2 compares the convergence of Hybrid HC with the GA for varying numbers of generations and a fixed population size of 30 (where the input data described above is used).

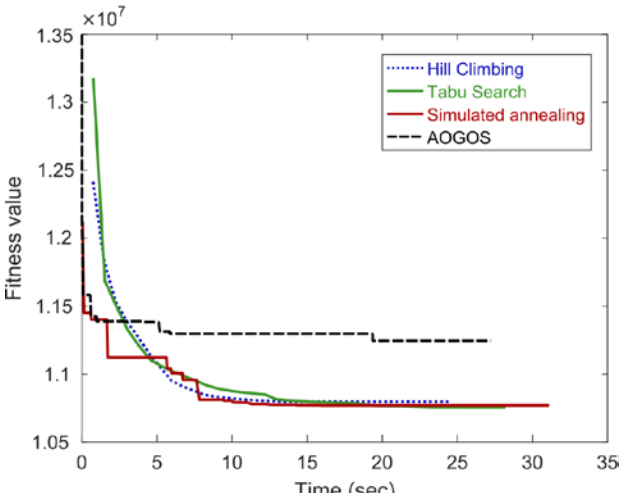

Figure 1. Comparison of local search methods with AOGOS

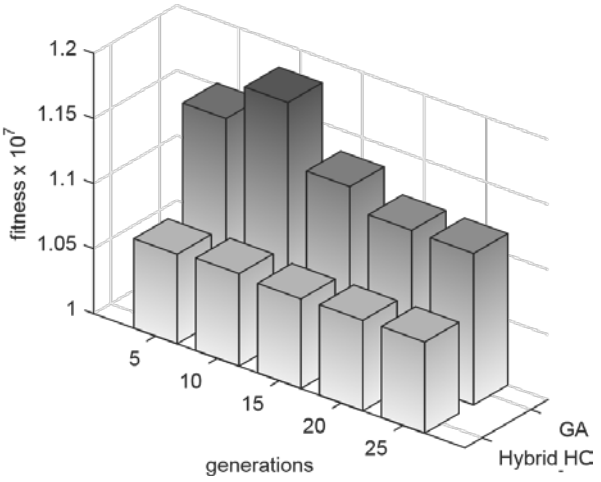

Figure 2. Comparison of fitness convergence values from Hybrid HC against the genetic algorithm (GA)

All convergence values of the GA for the given input data exceed 1.1×10^7 which is not acceptable when compared to the heuristic baseline of 1.07×10^7. It is to note that there is some marginal improvement in the GA convergence values with an increase in the number of generations. However, further increase in the number of

generations does not result in significant increase in the GA convergence values.

On the other hand, the performance of Hybrid HC is acceptable with the convergence values of all generation numbers being approximately equal to the baseline of 1.07×10^7. The cost of the improved convergence of Hybrid HC over the GA is execution time. The GA executes in 1.3 seconds for a generation number of five, while Hybrid HC requires 1285.4 seconds to complete for the same number of generations.

5.3. Adjustable Parameters and Execution Times

The execution time for each of the seven (7) solution methods will depend on the value of their associated variable parameters. These parameters include:

1) **search depth** in the case of the local search methods of hill climbing, tabu search and simulated annealing,
2) **initial temperature** and **cooling rate** in the case of simulated annealing ,
3) **population size** and **number of generations** in the case of the evolutionary methods of the genetic algorithm and the three (3) hybrids (discussed in Section 4.3).

The associated parameters of the local search component of a hybrid will also influence its execution time and performance. It is to note that, despite the previously discussed parameter influence, there is sufficient variance in the execution times of our seven (7) solution methods to allow a meaningful comparison to be made. The execution times stated in Table 2 correspond to the input data described in Section 5.2 and parameter values for which further modification does not result in significant improvement of convergence.

Table 2. Representative execution times in seconds for the GMS solution methods

Method	Execution Time
genetic algorithm	12.3
hill climbing	24.6
AOGOS	27.2
tabu search	28.2
simulated annealing	31.1
Hybrid SA	893
Hybrid TS	3625.4
Hybrid HC	3836.2

The representative execution times shown in Table 2 indicate that each of our local search methods generally executes in approximately 30 seconds. Recall that a hybrid method requires that a local search is performed for each element of each generation. These large number of subsidiary local searches for a hybrid method result in an execution time which is significantly higher than the local search times.

5.4. Parameter Independence of the Memetic Algorithm

As discussed in the Section 5.3 above, there are several parameters in the implementation of three (3) hybrid algorithms which may be adjusted as a possible means of improving the convergence of fitness values. It is to note that the performance of the hybrid solutions is good for relatively low population size and number of generations.

Further increase in these parameters does not significantly increase performance of the hybrid methods. An example of independence of convergence performance with change in parameter value may be seen in Figure 2. The optimal fitness for Hybrid HC does not improve with increase in the number of generations.

The optimal fitness values for Hybrid SA provide a second example of this relative parameter independence (see Table 3). These values illustrate that there is little change in convergence with increase in population and generation number after the thresholds of a population size of 30 and a generation number of 15 have been reached.

Table 3. Optimal fitness values $\times 10^7$ for Hybrid SA with respect to population size and number of generations

		Number of generations				
		5	**10**	**15**	**20**	**25**
Population	**10**	1.0703	1.0701	1.0723	1.0689	1.0691
	20	1.0717	1.0717	1.069	1.069	1.0689
	30	1.0731	1.0687	1.0686	1.0694	1.0685
	40	1.0686	1.0704	1.0697	1.0689	1.0696
	50	1.0731	1.0695	1.0689	1.0689	1.0689

6. Case Study

In this section, the GMS implementation is applied to obtain a maintenance schedule $\mathbf{x}^*$ that improves upon an actual schedule $\mathbf{x}$ utilised in 2013 (Sharma and Bahadoorsingh, 2004). Recall from Sections 3.2 and 3.3 that we may assign a fitness value to each schedule belonging to the solution space by the use of our objective function (Equation 11). Let F and F^* denote the respective fitness values of the schedules $\mathbf{x}$ and $\mathbf{x}^*$. If $F^* < F$ then (as Equation (11) is a minimisation problem), we regard the schedule $\mathbf{x}^*$ as an *improvement* of $\mathbf{x}$. This improvement may be interpreted as a reduction in the variability of the reserves, R_j (see Section 3.3).

In 2013, the Power Generation Company of Trinidad and Tobago (PowerGen) fulfilled the conditions of a Power Purchase Agreement to meet a constant forecast load demand D_j = 819 MW. The maintenance schedule $\mathbf{x}$ of the eighteen (18) PowerGen generators used in 2013 was recorded in (Sharma and Bahadoorsingh, 2004). As discussed above, we use the objective function given in Equation (11) to assign the fitness value of F = 282148 to this schedule $\mathbf{x}$.

In order to improve on this schedule, the requisite generator information as stated in Sharma and Bahadoorsingh (2004) forms the necessary input data for the GMS implementation (see Table 1 for an example of input data for a simple four generator case). Applying the Hybrid SA solution method to this input data gives an improved maintenance schedule $\mathbf{x}^*$ that is described in Table 4. The fitness value for this schedule is $F^* = 265496$ which is a 5.9% improvement on the fitness value $F = 282148$ of the actual PowerGen maintenance schedule **x** utilised in 2013.

Table 4. An improved generator maintenance schedule for PowerGen in the year 2013

Generator #	**Duration** (Week *i* to Week *j*)
1	30 to 33
2	21 to 28
3	44 to 52
4	1 to 5
5	6
6	37 to 43
7	8 to 20
8	44 to 46
9	28 to 33
10	48 to 52
11	47
12	34 to 36
13	21 to 23
14	2 to 4
15	none
16	24 to 27
17	6 to 7
18	52

7. Conclusion

The numerical results given in Section 5 indicate that the local search methods rapidly converge to acceptable solutions of the GMS problem. The hybrid methods converge to marginally better solutions than those obtained by the local searches at the cost of significantly longer execution times. This suggests the following methodology in the application of our solution methods – local searches should be initially applied to obtain estimates of the fitness values of optimal solutions. The hybrid methods would then be used to obtain improved solutions.

In addition, the performance of the genetic algorithm is generally unacceptable when compared to our local search and hybrid methods. A similar comparison is made in Dahal and Chakpitak (2007). It is possible that further tuning of crossover and mutation parameters may improve the performance of a GA solution of the GMS problem. These modifications would be considered in future work.

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Determination of Best-fit Propagation Models for Pathloss Prediction of a 4G LTE Network in Suburban and Urban Areas of Lagos, Nigeria

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Abstract: *Propagation measurements and modeling provide useful information for signal strength prediction and the design of transmitters and receivers for wireless communication systems. In order to deploy efficient wireless communication systems, path loss models are indispensable for effective mobile network planning and optimisation. This paper presents propagation models suitable for path loss prediction of a fourth generation long-term evolution (4G LTE) network in the suburban and urban areas of Lagos, Nigeria. The reference signal received power (RSRP) of a 4G LTE network was measured at an operating frequency of 3.4GHz, and measured data was compared against existing pathloss models. Among the candidate models, the COST 231-Hata and the Ericsson models showed the best performances in the urban and suburban areas with root mean squared errors (RMSEs) of 5.13dB and 7.08dB, respectively. These models were selected and developed using the least square regression algorithm. The developed models showed good prediction results with RMSEs of 6.20dB and 5.90dB in the urban and suburban areas, respectively, and compare favourably with propagation measurement results reported for similar areas. It was found that these models would better characterise radio coverage and mobile network planning, enhancing the quality of mobile services in related areas.*

Keywords: *4G LTE network; Path loss modeling; Propagation models; Suburban; Urban area, Least square regression*

1. Introduction

Propagation modeling has attracted major concerns in the industry and academia in recent years. Path loss models are essential tools for signal strength estimation, a key performance indicator for radio system installation within a wireless communication environment (Athanasiadou, 2009). As electromagnetic waves radiate through space, the signal strength degrades due to the signal path distance, and dynamic terrain characteristics. This results in signal scattering, absorption and reflection among others. It is worthy of note that these models are site specific and are designed based on the propagation terrain of the environment of interest (Mollel and Kisangiri, 2014).

In addition, slight deviations in the characterisation of the area under investigation could affect the efficiency of propagation models designed for the area. This implies that the adoption of models in environments other than those designed for their application could result in severe planning and performance issues. Fourth generation long-term evolution (4G LTE) technology has an undeniable capacity for wireless broadband services due to its enormous benefits. The key features of 4G LTE include higher data rates, greater spectral efficiency, low latency, scalable bandwidth, reduced network complexity and improved quality of service, resulting in user satisfaction (Song and Shen, 2010; Shabbir, et al., 2011; Ramiro and Hamied, 2011; Dahlman, Parkvall, and Skold, 2013; ElNashar, El-Saidny and Sherif, 2014).

However, it is quite challenging to decide on the path loss model applicable to the environment of interest. There are very few proposed models for the 4G LTE contest with a focus on the 3.4 GHz frequency band, but we have not seen any elaborate study on propagation modeling of 4G LTE network with a focus on the Nigerian environment. Therefore, the focus of this paper is to investigate the relationship between measured pathloss and existing propagation models, with a goal to determining the best models for a commercial 4G LTE network in the suburban and urban areas of Lagos, Nigeria. This would be very useful to mobile network planners and engineers in ensuring greater accuracy and better quality of service deployment in the suburban and urban areas of Lagos, Nigeria. The results presented in this paper could be very useful in predicting and characterising propagation path loss in the Nigerian environment, and our future work will focus on providing correction factors to ease the applicability of the proposed models in different areas.

This paper is organised as follows. Section 2 presents an overview of related works on propagation

measurements and channel modeling. Section 3 covers the measurements campaigns, experimental set-up, and modeling parameters. Section 4 presents the results of the study and useful discussions. Finally, the conclusion to the paper is given in Section 5.

2. Related Work

Long Term Evolution, a 3rd generation partnership project (3GPP), has been designed and developed to meet the requirements of mobile network operation at data rates up to 100Mbps (Dimou et al., 2009). This will enable operators to provide high data rate applications with low latency, thereby culminating into an increased market penetration by mobile operators (Sesia, Baker and Toufik, 2011). Different propagation models have been adapted to different terrains at different frequencies, and the classification of models into urban, suburban and open (rural) areas has been reported in (Abhayawardhana et al., 2005; Ajose and Imoize, 2013). These models include the free space model, Okumura Hata model, COST 231 model, Walfish-Ikegami model, Lee model, Stanford University Interim (SUI) model, ECC-33 model and others (Milanovic, Rimac-Drlje and Beyuk, 2007; Aragon-Zavala, 2008; Molisch, 2012).

The performance efficiency of the existing models when applied to wireless terrains other than those they were designed for falls far from ideal (Chebil et al. 2011). Thus, this prompts the need to determine the models that best predict the signal strength of the wireless channel. Several studies conducted in Nigeria and other parts of the world have revealed that a number of path loss models perform efficiently when tuned with respect to measured data.

On propagation measurements and channel modeling, Ajose and Imoize (2013) reported extensive propagation measurements, and presented a modified COST 231 Hata model for improved pathloss prediction in Lagos, Nigeria. Similarly, Ibhaze et al. (2016) conducted measurement campaign at 1800 MHz in Ikorodu, Nigeria, and proposed the modification of SUI and COST 231 models for signal prediction and network planning in the investigated area.

Chebil, Lawas, and Islam (2013) carried out a set of measurements at frequencies ranging from 1800 MHz to 1900MHz and compared the measured pathloss with six empirical propagation models. It was reported that the SUI and the lognormal models showed superiority over other models, and could be used to estimate the predicted path loss in microcell mobile coverage, in the Malaysian environment.

Kamboj, Gupta and Birla (2011) reported that the SUI path loss model provides the minimum path loss among other path loss models compared under specified conditions, using propagation measurements at 3.5GHz. Similarly, Kale and Jadhav (2013) performed analysis of empirical models for WiMAX in an urban environment in India. It was reported in the study that the Ericsson and the SUI models showed a better performance in the investigated urban environment.

Bola and Saini (2013) carried out measurement campaigns using different empirical models for WiMAX in urban areas. The analysis showed that all models experienced higher path loss due to multipath and non-line of sight (NLOS) environments. It was concluded that there is a slight change in path loss when the operating frequency was changed. Further studies on LTE, WiMAX, WLAN design, and performance analysis are reported in (Korowajczuk, 2011; Katev, 2012).

In another related study, Podder et al. (2012) reported an analytical study on propagation models at 2.5GHz. The comparative analysis revealed that increased multipath in the urban and suburban areas favored the SUI model, which experienced the lowest path loss compared to the rural area. In the rural area, the COST-Hata model provided the lowest path loss compare to the SUI model, and the results showed that no single propagation model is well suited for all the tested areas.

On performance analysis of diverse models for wireless network in different environments, Khan, Eng, and Kamboh, (2012) reported that all models under study in urban areas, due to increased multipath effect and NLOS, experienced higher path loss compared to suburban areas, and that no single model could be recommended for all environments.

Famoriji and Olasoji (2013) used Friis and Okumura - Hata models to predict broadcasting signal strength for a television station in Akure Ondo State, Nigeria. The authors concluded that the performance of Okumura–Hata model showed its suitability for good signal prediction and the mean deviation errors were added to the Okumura-Hata model in order to derive the modified Okumura-Hata model suitable for deployment in the Akure metropolis.

Furthermore, Ibhaze et al. (2017) proposed the modification of Ericsson model at 2100MHz for the Alagbado axis of Lagos, Nigeria. Here, higher degree polynomial was fitted to measured data and the results were compared with some empirical models. Although this model was used earlier in predicting lower frequency ranges other than the investigated spectrum, it predicted the investigated wireless channel with less probability of error in contrast to the previously used Okumura-Hata model, and inappropriate model application was seen to have resulted in marked quality and coverage issues.

3. Measurement Campaigns

Measurement campaigns at 3.4 GHz using a personal computer with Genex probe, a data collection software interface and a GPS unit for the receiving device tracking is presented in the experimental set-up as shown in Figure 1, and a typical eNodeB site is as shown in Figure. 2.

Figure 1. Experimental set-up inside a drive test vehicle

Figure 2. Pictorial view of a typical eNodeB site located in Ajah area of Lagos, Nigeria

The reference signal received power measurements were taken and stored on a personal computer (PC) which had GENEX probe drive test (DT) software installed on it, and a Huawei Model E392 (4G compatible). The operating frequency is set from the PC and other readings such as transmitter-receiver distance, received signal level, location (latitude and longitude) are read from the PC. Here the personal computer with GENEX software installed on it, the Huawei modem and the GPS system were set-up in the drive test vehicle. The channel frequency was set to 3.4GHz, and the reference distance used for the measurements is 100m from the fixed base station. Transmitter to receiver distance was varied between 0.1km to 1.0km in steps of 50m at a near constant receiver antenna height of 1.5m. The transmitter-receiver distance was limited to 1km, in order to limit the impact of interference from neighboring transmitting antennas.

3.1 Suburban Areas

Propagation measurements were carried out at two eNodeB sites located in Ajah, typical of a suburban area in Lagos, Nigeria. Ajah is located on Latitude 6.4670N and Longitude 3.5670E. This area is dominantly residential and moderately congested. In addition, there are several schools, banks, and religion worship centers in this area. A typical Ajah area on a Google map is shown in Figure 3. The tested eNodeB sites are as shown in Figure. 4 and for simplicity, these are labelled as eNodeB 1 and eNodeB 2.

Figure 3. Google map showing Ajah (suburban) area of Lagos Nigeria

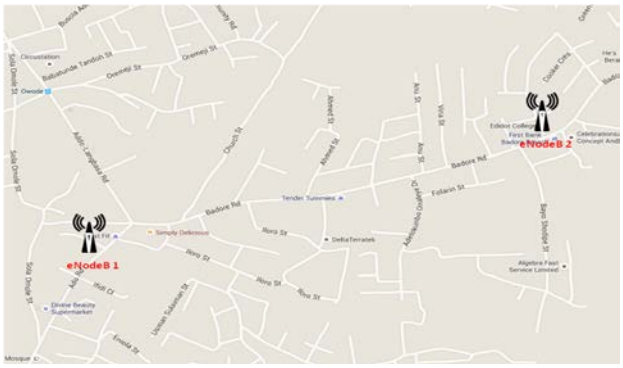

Figure 4. Google map showing the location of eNodeBs in the suburban areas

3.2 Urban Areas

Field measurements were carried out at two sites in Lagos-Island typical of an urban area in Lagos. Lagos-Island is located on Latitude 6.4500N and Longitude 3.4000E and is classified as an urban area. This area is dominantly a business hub with high density of high-rise buildings. A typical Lagos-highland area on a Google map is shown in Figure 5. The eNodeB sites location are as shown in Figure 6 and for convenience, these are denoted as eNodeB 3 and eNodeB 4.

Figure 5. Google map showing Lagos-highland (urban) areas of Lagos Nigeria

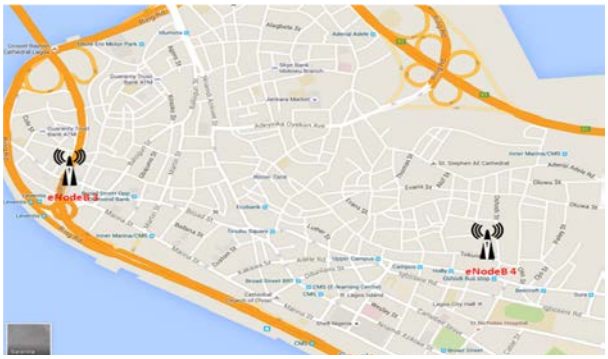

Figure 6. Google map showing the location of eNodeBs in the urban areas

4. Modelling Parameters

In this study, the operating frequency is fixed at 3400 MHz, distance between the transmit antenna and the receiver is limited to 1km with a transmitter height of 20m in urban area and 24m in sub-urban areas. Evidence shows that 1km is a reasonable antenna separation distance to limit the impact of interference from adjacent base stations (eNodeBs). For the Lagos environment, average inter-building distance is about 20m and street width is about 10m. Correction factors for shadowing effects are given as 10.6 dB in urban and 8.2dB in sub-urban areas, respectively (Sesia, Baker and Toufik, 2011; Shabbir et al., 2011). The modeling parameters are as shown in Table 1.

Table 1. Modeling Parameters

Parameters	Values	
	Suburban area	Urban area
Transmitter power	43 dBm	43 dBm
Operating frequency	3.4GHz	3.4GHz
Max. distance between Tx and Rx	1km	1km
Transmitter antenna height	20m	24m
Receiver antenna height	1.5m	1.5m
Building to building distance	20m	20m
Average building height	9m	18m
Street width	10m	10m
Street orientation angle	40^o	30^o
Correction for shadowing	8.2dBm	10.6dBm

5. Results and Discussion

The mean reference signal received power measured from the suburban and urban areas was converted to the equivalent pathloss values for further analysis. Results shown as tests eNodeB 1 and eNodeB 2 are used for analysis to reflect a suburban area, and tests eNodeB 3 and eNodeB 4 are typical of an urban area. The path loss is calculated using Eq. (1) as in Rappaport (1996).

$$PL(dB) = P_T + G_T + G_R - P_R - L_T - L_R \quad (1)$$

where,

$$P_T + G_T + G_R - L_T - L_R = EIRP \quad (2)$$

From Equations (1) and (2),

$$PL(dB) = EIRP - P_R \quad (3)$$

Equation (1) gives the gains and losses in the signal strength from the transmitter to the receiver, and Table 2 presents the LTE downlink gains and losses (Mishra, 2004). The total effective isotropically radiated power (EIRP) includes the transmitter EIRP, and other gains and losses. The values of the test eNodeB parameters are observed from the equipment manufacturers' manual, actual measurements and from the data reported in (Mishra, 2004; Holma and Toskala, 2007). From Table 2, the total EIRP is given as shown in Eq. (4). Hence, from Equations (3) and (4), the corresponding path loss at a distance d km from the transmitter is given by Eq. (5). Correspondingly, the calculated path loss in the suburban and urban areas, compared with free space loss is as shown in Figure 7. Here, it is observed that the pathloss for the urban setting is higher than the suburban setting for about 80% of the measurements period. This is expected because pathloss in suburban area is supposed to be less compared with pathloss in the urban area.

$$EIRP = 58.75\ dB + (-22.5)\ dBm = 36.25 dBm \quad (4)$$

$$PL = 36.25 dBm - P_R \quad (5)$$

Table 2. Base stations (eNodeBs) downlink parameters

Parameters	Values
Maximum Transmitter Power	43dBm
Multi-Antenna Combining Gain	3dB
Transmitter Antenna Gain	17dBi
Radio Frequency Filter + Cable Loss	3dB
Pilot Power Boosting	3dB
Transmitter Duplexing Loss	0dB
Loss Due to Pilot Powers	-1.25dB
Total Transmit EIRP	58.75dBm
Handoff Gain	2.5dB
HARQ Gain	3dB
Coding Gain	0dB
Interference Margin	2dB
Penetration Loss	20dB
Log normal Fading Margin	6dB
Other Losses and Gains	-22.5dB

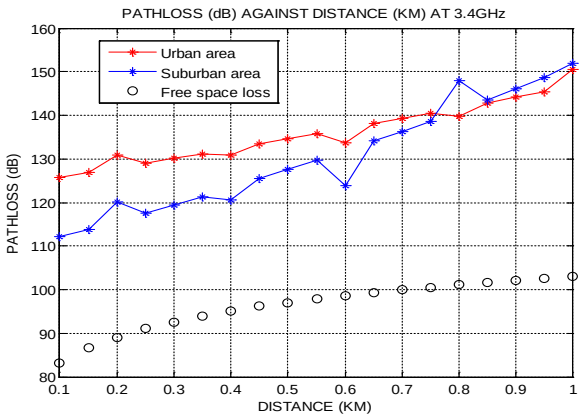

Figure 7. Comparison of path loss of measured data in suburban and urban areas

5.1 Results - Typical of a Suburban Area

The mobile receiver height was maintained at 1.5m, Tx-Rx distance increases in steps of 50m from 100m to 1.0km and a transmitter antenna height of 20m was used. Results typical of a suburban area are as shown in Fig. 8. Here, the predicted and the measured path loss vary logarithmically with propagation distance. It can be seen from Figure 8 that the SUI and the COST 231/WI models showed alarming deviations from the measured path loss. On the other hand, the Ericsson model showed the best match to measured data whereas the COST 231-Hata and ECC-33 models show close agreement with measured data.

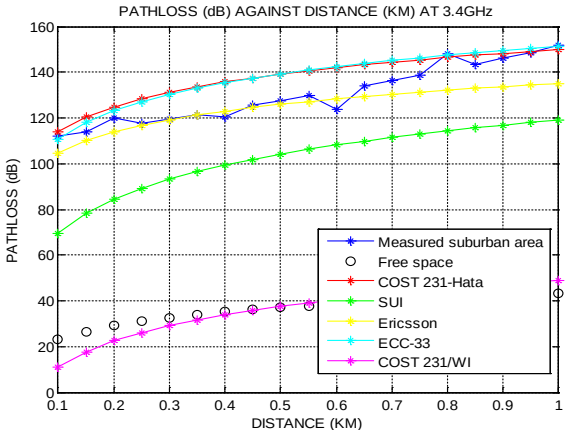

Figure 8. Predicted and measured pathloss in a suburban area

5.2 Results - Typical of an Urban Area

In the urban area, the operating frequency was set at 3400 MHz, the transmitter height at 24 m, transmitter (Tx)-receiver (Rx) distance was varied between 0.1km to 1.0km in steps of 50m at a near constant receiver antenna height of 1.5m. Variations in the predicted and measured path loss values are as shown in Figure 9. It shows that the COST-231 Hata model is the best fit to measured pathloss, and the Ericsson model show close relationship

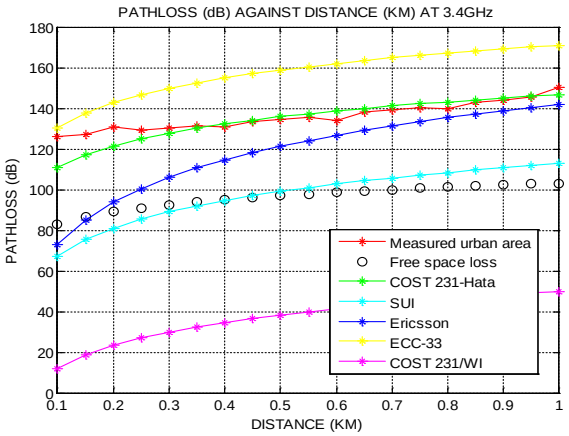

Figure 9. Predicted and measured path loss in an urban area

with the measured data, while the COST 231 Walfisch Ikegami (COST-231/WI), SUI and the ECC-33 models showed reasonable deviations from the measured data.

5.3 Root Mean Squared Error Analysis

The root-mean-squared error (RMSE) is used for error estimation between measured data and referenced or standardised data set. The RMSE represents the mean standard deviation between the measured and predicted values (Chebil et al., 2011; Ajose and Imoize, 2013).

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{\left(PL_{M,i} - PL_{P,i}\right)^2}{N}} \quad (6)$$

Where,

$PL_{M,i}$ is the actual sample values
$PL_{P,i}$ is the predicted sample values
N is the number of data points

From Eq. (6), the RMSE for the measured and predicted path loss is given as shown in Eq. (7);

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{\left(PL_{measured,i} - PL_{predicted,i}\right)^2}{N}} \quad (7)$$

where

$PL_{measued,i}$ = Path loss of measured data in dB
$PL_{predicted,i}$ = Predicted path loss measured in dB
N = 19 depicting the number of measured data points

The RMSE values follows directly from Eq. (7) with the resulting values for the suburban and urban areas are as shown in Table 3.

Table 3. Root mean squared errors in suburban and urban areas

Pathloss models	**Root mean squared errors (dB)**	
	Suburban area	Urban area
Free Space	34.9108	39.6194
COST 231 Hata	9.9103	5.1343
SUI	57.3672	48.4570
Ericsson	7.0797	15.1728
ECC -33	8.6927	18.9087
COST 231 W/I	13.8730	5.2496

5.4 Best Model Selection

Measured pathloss at 3400 MHz in Ajah and Lagos-highland areas of Lagos State, Nigeria have been compared against predicted path loss. From Table 3, the minimum value of the RMSE observed is 5.1343dB in the urban area. This corresponds to the RMSE of the predicted pathloss for the COST-231-Hata model. The COST-231-Hata model, which satisfied the RMSE closest to zero, is taken as the best candidate for predicting the pathloss in the urban area.

Similarly, the minimum value of the RMSE as observed from Table 3 is 7.0797dB, for the suburban area. This corresponds to the RMSE of the pathloss predicted for the Ericsson model. Hence, the Ericsson model is the most suitable model for predicting the pathloss of measured data in the suburban area.

5.5 Modification of Selected Model for Urban Areas

The COST-231 Hata model has been selected as the best candidate for path loss prediction in the urban area. This is because it gives the best prediction (a value closest to zero) when compared with other contending models. However, there is a need to modify the model to improve its prediction accuracy. A modification of the COST 231 model can be achieved by adding the value of the corresponding RMSE to the model (Ajose and Imoize, 2013; Ogbeide and Edeko, 2013; Famoriji and Olasoji, 2013).

$$PL = 46.3 + 33.9.\log_{10} f - 13.82.\log_{10} h_b - 3.20[\log_{10}(11.75\, h_r)]^2 - 4.97 + [44.9 - 6.55.\log_{10} h_b].\log_{10} d + C_m \quad (8)$$

where,
f_c = 3400MHz; h_b = 24m
h_r =1.5m; C_m = 3 dB for urban
d = distance between transmitter and receiver in meters

Adding the value of RMSE to Eq. (8) results in Eq. (9) in terms of d.

$$PL = 46.3 + 33.9.\log_{10}(3400) - 13.82.\log_{10}(24) - 3.20[\log_{10}(11.75 * 1.5)]^2 - 4.97 + [44.9 - 6.55.\log_{10} 20].\log_{10} d + 3 + RMSE \quad (9)$$

Here, it should be noted that the modification is aimed at giving better performance to the model, when compared to the actual predicted pathloss, hence the sign of the RMSE is important. By applying Eq. (7) in Eq. (9), we have;

$$PL = 46.3 + 33.9.\log_{10}(3400) - 13.82.\log_{10}(24) - 3.20[\log_{10}(11.75 * 1.5)]^2 - 4.97 + [44.9 - 6.55.\log_{10} 20].\log_{10} d + 3 + (-5.1343) \quad (10)$$

$$PL = 145.929 + 36.38.\log_{10}(d) \quad (11)$$

where d = 0.1, 0.15, 0.2 … 1.0 *km*

Equation (11) shows a simplified and modified COST-231 Hata model for the selected urban area at 3400 MHz. The comparison of the measured pathloss, modified and predicted COST 231 Hata model is as shown in Figure 10.

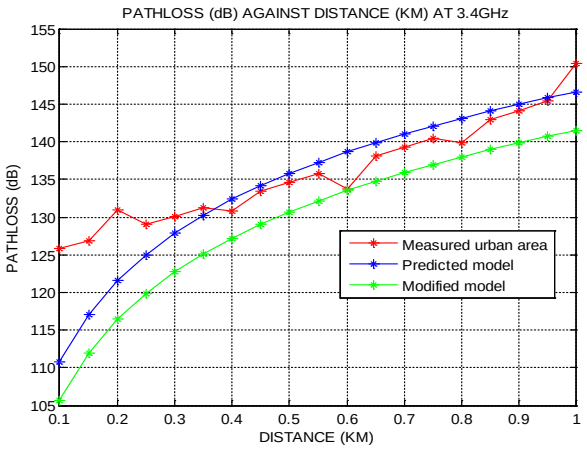

Figure 10. Comparison of measured pathloss, modified and predicted COST 231 Hata model for urban areas

5.6 Modification of Selected Model for Suburban Areas

The Ericsson model gives the best prediction in relation to the measured path loss in the suburban area, with an RMSE of 7.0797dB. The modification to the Ericsson model can be achieved by adding the value of the corresponding RMSE (± 7.0797dB). The Ericsson model is given (Ibhaze et al., 2017) as shown in Eq. (12).

$$PL = a_0 + a_1.\log_{10}(d) + a_2.\log_{10}(h_b) + a_3.\log_{10}(h_b)\log_{10}(d) - 3.2(\log_{10}(11.75h_r))^2) + g(f) \quad (12)$$

$$PL = 36.2 + 30 * \log_{10}(d) + 12 * \log_{10}(20) + 0.1 * \log_{10}(20)\log_{10}(d) - 3.2 * (\log_{10}(11.75 * 1.5))^2) + 44.49 * \log_{10} 3400 - 4.78 * (\log_{10} 3400)^2 + RMSE \quad (13)$$

Applying Eq. (7) in Eq. (13), gives;

$$PL = 36.2 + 30 * \log_{10}(d) + 12 * \log_{10}(20) + 0.1 * \log_{10}(20)\log_{10}(d) - 3.2 * (\log_{10}(11.75 * 1.5))^2) + 44.49 * \log_{10} 3400 - 4.78 * (\log_{10} 3400)^2 + (-7.0797) \quad (14)$$

$$PL = 137.2683 + 30.33.\log_{10}(d) \quad (15)$$

where, d = 0.1, 0.15, 0.2 … 1.0 *km*

The results showing a comparison of the measured pathloss, predicted and modified Ericsson model is as shown in Figure 11.

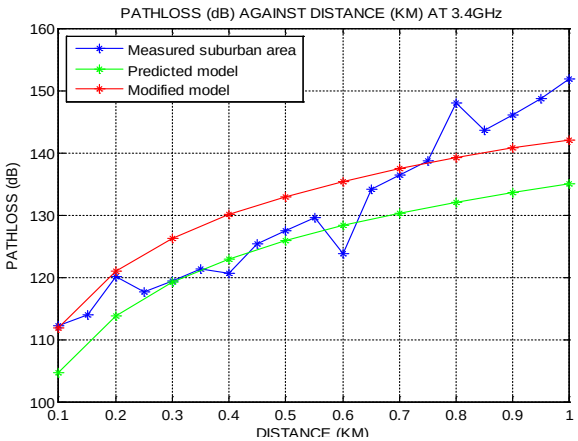

Figure 11. Comparison of the measured pathloss, modified and predicted Ericsson model for suburban areas

5.7 Development of Best Curve for Measured Pathloss

The least square regression method is generally adopted to fit a straight line or a curve to a set of data points (Hoffman and Frankel, 2001; Hamming, 2012; Stroud, and Booth, 2013). A second order polynomial of the form $y = a + bx + cx^2$ has been chosen to fit the measured path loss data. Generally for a j^{th} order polynomial of the form of Eq. (16) (Stroud and Booth, 2013);

$$f(x) = a_j x^j + a_{j-1} x^{j-1} + a_{j-2} x^{j-2} + \ldots + a_0 \quad (16)$$

Polynomial equations of the best fit are given as;

$$a_0 N + a_1 \sum x_i + \ldots + a_j \sum x_i^{\,j} = \sum x_i f(x)_i \quad (17)$$

$$a_0 \sum x_i + a_1 \sum x_i^{\,2} + \ldots + a_j \sum x_i^{\,j+1} = \sum x_i^{\,2} f(x)_i \quad (18)$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$a_0 \sum x_i^{\,j} + a_j \sum x_i^{\,j+1} + \ldots + a_1 \sum x_i^{\,2j} = \sum x_i^{\,j} f(x)_i \quad (19)$$

where

N = number of data points

i = position of each of the data points

j = order of the polynomial

Equations (17) – (19) can be written in matrix form as shown in Eq. (20).

$$\begin{bmatrix} n & \sum x_i & \ldots & \sum x_i^{\,j} \\ \sum x_i & \sum x_i^{\,2} & \ldots & \sum x_i^{\,j+1} \\ \vdots & \vdots & \vdots & \vdots \\ \sum x_i^{\,j} & \sum x_i^{\,j+1} & \ldots & \sum x_i^{\,2j} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_j \end{bmatrix} = \begin{bmatrix} \sum x_i f(x)_i \\ \sum x_i^{\,2} f(x)_i \\ \vdots \\ \sum x_i^{\,j} f(x)_i \end{bmatrix} \quad (20)$$

In terms of the path loss of measured data $PL_{measured}$ and the distance between the transmitting and the receiving antennas, Eq. (20) can be re-written as in Eq. (21);

$$\begin{bmatrix} n & \sum d_i & \ldots & \sum d_i^{\,j} \\ \sum d_i & \sum d_i^{\,2} & \ldots & \sum d_i^{\,j+1} \\ \vdots & \vdots & \vdots & \vdots \\ \sum d_i^{\,j} & \sum d_i^{\,j+1} & \ldots & \sum d_i^{\,2j} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_j \end{bmatrix} = \begin{bmatrix} \sum d_i PL_{measured,i} \\ \sum d_i^{\,2} PL_{measured,i} \\ \vdots \\ \sum d_i^{\,j} PL_{measured,i} \end{bmatrix} \quad (21)$$

A resultant second order polynomial in terms of the fitted values for the measured path loss PL_{fitted} and the distance d is of the form of Eq. (22);

$$PL_{fitted} = a + b * d + c * d^2 \quad (22)$$

Comparing Eq. (16) to Eq. (22), $a_0 = a$, $a_1 = b$, $a_2 = c$. The least square regression data for measured path loss in the suburban and urban areas are as shown in Table 4, and Eq. (23) follows directly from Eq. (21) and Table 4.

Table 4. Least square regression data for measured path loss in suburban and urban areas

Parameters	Suburban Area	Urban Area
d	10.45	10.45
d^2	7.1725	7.1725
D^2	5.1524	5.1524
d^4	4.5169	4.5169
$PL_{measured}$	2478.8	2582.6
$d * PL_{measured}$	1425.6	1453.7
$d^2 * PL_{measured}$	1006.1	1012.8

$$\begin{bmatrix} 19 & 10.45 & 7.1725 \\ 10.45 & 7.1725 & 5.1524 \\ 7.1725 & 5.1524 & 4.5169 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 2582.6 \\ 1453.7 \\ 1012.8 \end{bmatrix} \quad (23)$$

As shown in Eq. (23), the constants a, b and c are solved using a third order determinant method in MATLAB (Hoffman and Frankel, 2001). The results are highlighted as shown in Eq. (24);

$$a = 126.2429,\ b = 8.0496,\ c = 13.9272 \quad (24)$$

Now, we substitute the values in Eq. (24) into Eq. (22), resulting in the curve that best fit the measured data in the urban area as shown in Eq. (25);

$$PL_{fitted} = 126.2429 + 8.0496d + 13.9272d^2 \quad (25)$$

Similarly, we derive a suitable equation for the suburban area, following the same approach for the urban area. From Table 4, and applying Eq. (21), the values of a, b and c are computed for the suburban area by solving Eq. (26);

$$\begin{bmatrix} 23 & 10.45 & 7.1725 \\ 10.45 & 7.1725 & 5.1524 \\ 7.1725 & 5.1524 & 4.5169 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 2478.8 \\ 1425.6 \\ 1006.1 \end{bmatrix} \quad (26)$$

Similar to Eq. (24), the values of a, b, and c are as shown in Eq. (27);

$$a = 111.1971,\ b = 20.5984,\ c = 21.0234 \quad (27)$$

The equation of the curve that best fit the measured path loss in the suburban area is given in Eq. (28).

$$PL_{fitted} = 111.1971 + 20.5984d + 21.0234d^2 \quad (28)$$

The comparison of the fitted data for the urban and suburban areas is as shown in Figures 12 and 13, respectively. The results depicted in Fig. 12 and Fig. 13 show that the least square (LS) curve fitting, approximately fits the measured data points with smaller error bound.

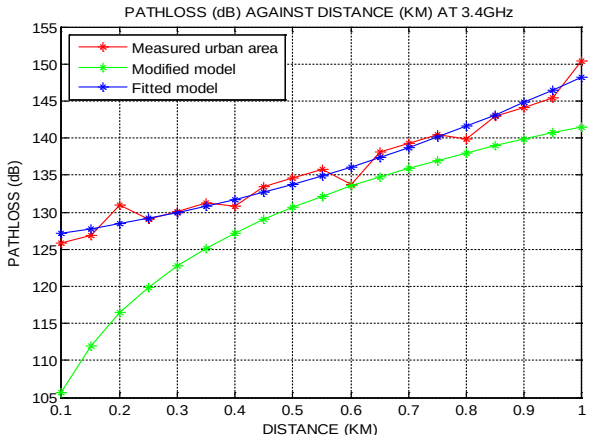

Figure 12. Comparison of measured pathloss, modified and fitted models for urban areas

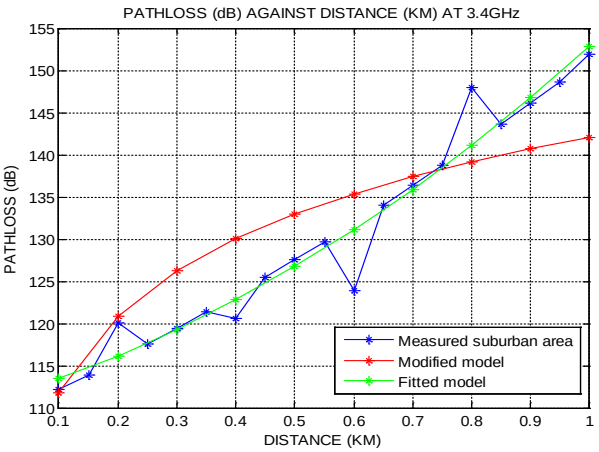

Figure 13. Comparison of measured pathloss, modified and fitted models for suburban areas

5.8 Validation of Models

In order to test the validity of the developed models for applicability in related environments, the RMSE analysis have been used to determine the error ratio based on the developed COST 231 Hata and the Ericsson models for urban and suburban areas, respectively. Applying Eq. (7), the results of the RMSE values are given as 6.20dB and 5.90dB for urban and suburban areas, respectively.

The developed models are found suitable for the investigated areas. This is because the RMSEs between the fitted, measured and predicted path loss values fall reasonably in the acceptable range of up to 6dB (Wu and Yuan, 1998; Ajose and Imoize, 2013; Ogbeide and Edeko, 2013; Famoriji and Olasoji, 2013, Popoola et al., 2018). However, the excess pathloss of 0.20dB observed for the urban area may be due to other dynamic factors such as high-density vehicular movements.

6. Conclusion

Path loss of propagation measurements taken from four eNodeBs of a 4G LTE network in the suburban and urban areas of Ajah and Lagos highlands in Lagos State, Nigeria, have been compared against well-known empirical models. Results revealed that the COST-231 Hata model outperformed other contending models in the urban area with an RMSE value of 5.13dB, and the Ericsson model showed the best performance in the tested suburban area, with an RMSE value of 7.08dB.

These models were selected and developed for the urban and suburban areas, respectively. The development was necessary to further reduce the RMSEs for improved path loss prediction in the areas. The developed models showed improved RMSEs values within the acceptable range of up to 6dB. Overall, the results compare favourably with related works reported for similar areas, and future work will focus on providing correction factors to ease the applicability of the models to other environments.

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Modular and 3D-Design of a Fluidised Bed Boiler with Agricultural Residue for Steam Energy Production

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Abstract: *In this study, a miniature fluidised bed boiler for steam generation was designed and constructed. The boiler is made up of a steam drum, combustion chamber, downcomer and riser tubes as a heat exchanger, a non-return valve and superheater tube. Experimental investigation on the fuel distribution was carried in two-dimensional chamber with cross-section of 500 mm x 1000 mm and bed height of 77 mm, 47 mm and 27 mm. The results obtained from the performance evaluation of the fluidised bed boiler operated with corncob at constant feed rate of 6kg/h for various bed heights of 77 mm, 47 mm and 27 mm recorded stability in the saturation temperature of 121 ^oC at 50 minutes, 144 ^oC at 45 minutes and 153 ^oC at 30 minutes, respectively. In additional, saturation pressures of 2.0 bar from 50 to 55 minutes for bed height of 77 mm, 2.1 bar from 45 to 50 minutes for bed height of 47 mm and 3.6 to 3.7 bar from 45 to 55 minutes for bed height 27 mm were obtained. The effect of fuel particle size on emissions and over all combustion efficiency of corncobs has proven to be efficient in a fluidised bed boiler as the emission analysis of the flue gas has shown to be low in various percentages of 0.0003% of NO_x, 0.001% HC, 0.02% of CO and 0.93% of Nitrogenm, respectively.*

Keywords: *Solid fuels, Bed height, Heat transfer, Steam, Saturated temperature, Saturated pressure, Flue gas*

1. Introduction

Fluidised bed combustion (FBC) is a combustion technology that offers many unique advantages such as large interfacial surface areas between the fluid (gas or liquid) and particles, high fluid-particles contact efficiency, excellent heat transfer, uniform bed temperature and the ability to handle wide range of solid fuels (Thenmozhi and Sivakumar, 2013; Zhou et al., 2008). In its most basic form, fuel particles are suspended in a hot, bubbling fluidity bed of ash and other particulate materials (sand, limestone, etc.) through which jets of air are blown to provide the oxygen required for combustion. The resultant fast and intimate mixing of gas and solids promotes rapid heat transfer and chemical reactions within the bed. FBC plants are capable of burning a variety of low-grade solid fuels, including most types of coal and woody biomass, (Thenmozhi and Sivakumar, 2013) at high efficiency and without the necessity for expensive fuel preparation (e.g., pulverising).

According to American Society of Mechanical Engineers (ASME), a steam generating unit is defined as a combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporised (Rajput, 2010). Boilers are pressure vessels designed to heat water or produce steam, by combustion of fuel which can then be used to provide space heating and/or service water heating to a building (Odigure et al., 2005). Steam is preferred over hot water in some applications, including absorption cooling, kitchens, laundries, sterilisers, and steam driven equipment. Steam is therefore important in engineering and energy studies. Boilers are classified into different types based on their working pressure and temperature, fuel type, draft method, size and capacity, and whether they condense the water vapour in the combustion gases.

Boilers are also sometimes described by their key components, such as heat exchanger materials or tube design. Two primary classifications of boilers are Fire tube and Water tube boilers. In a Fire tube boiler, hot gases of combustion flow through a series of tubes surrounded by water. On the other hand, in a water tube boiler, water flows in the inside of the tubes and the hot gases from combustion flow around the outside of the tubes. Steam generator is a complex integration of

furnace, superheater, reheater, boiler or evaporator, economiser and air preheater, along with various auxiliaries such as pulverises, burners, fans, stokers, dust collectors and precipitators, ash-handling equipment, and chimney or stack. The boiler (or evaporator) is that part of the steam generator where phase change (or boiling) occurs from liquid (water) to vapour (steam), essentially at constant pressure and temperature (Nag, 2008).

Biomass is an intriguing alternative fuel as it is readily available in various forms throughout the world, is renewable and can be harnessed by agricultural means. Though biomass is a renewable source, the growth of some materials, such as wood, is a very long process and cannot be rapidly grown, while other crops are perennial, such as corn, straw and switch grass (Saidur et al., 2011). Growth rate as well as availability must be considered while selecting a viable crop. It is also necessary to replace nutrients that are absorbed from the ground by plant growth or biomass production will be depleted over time (Christensen, 2011).

A wide variety of techniquesis available to utilise biomass resources, but the most efficient have been to burn them directly for heat in a controlled environment. The crop residues that are commonly used as sources of energy includes rice husks, sugar cane fiber, groundnut shells, maize cobs, coconut husks, and palm oil fibre. (Kyauta et al., 2015). The use of biomass as alternative sources of energy is attractive because it addresses both problems of waste disposal and fuel wood shortages (Armesto et al., 2002; Varol et al., 2014). The extraction of useful energy from biomass could contribute to sustainable development and bring very significant social and economic benefits to both rural and urban areas (Khan et al., 2009). Folayan et al. (2015) investigated the environmentally friendly methods of extracting biomass energy for rural use, one such means is energy recovery using fluidised bed combustors. This system uses agricultural waste as fuel source to produce heat energy as an alternative to power rural community for light load applications. Test results recorded high flue gas and bed temperatures of over 300°C and 850°C respectively, suitable for rural application including grain drying and water boiling.

Martínez et al. (2011) presented the conceptual design of a three fluidised beds combustion system capturing CO_2 with CaO. In their work, three fluidised bed reactors are interconnected in such a way that it is possible to perform the $CaCO_3$ calcination at a temperature of 950 ^oC with the energy transported by a hot solid stream produced in the circulating fluidised bed combustor operating at 1030 ^oC. They presented that the stream rich in CaO produced in the calciner was splited into three parts. The reported result shows that due to high temperatures involved in all the system, it was possible to recover most of the energy in the fuel and to produce power in a supercritical steam cycle. A case study was studied and it was demonstrated that under these operating conditions, 90% CO_2 capture efficiency can be achieved with no energy penalty further than the one originated in the CO_2 compression system.

Ohijeagbon et al. (2013) reported on the design of laboratory fire tube boiler for eventual construction and use as teaching aid and for research purposes, the design enables the availability of portable and affordable steam boiler for steam generation in school laboratory and to enhance research and students' learning process in area of thermodynamics, heat transfer and energy studies.

The objective of this work seeks the utilisation of locally sourced materials to design, develop and test the fluidised bed boiler for steam generation by carrying out technical feasibility of using corncob as fuel and varying the bed height while keeping the superficial velocity of fluidising gas constant. More so, the characteristic of the steam generated was used in the selection of an applicable steam turbine.

2.0 Material and Methods

2.1 Description of the Fluidised Bed Boiler

The physical geometry of the fluidised bed water tube boiler was developed and a 3-D model diagram is shown in Figure 1. The boiler consists fundamentally of the fluidised bed combustion chamber and steam drum, other parts such as; steam tubes, steam trap, steam tap, downcomer, exhaust pipe, air blower and insulations were designed in the geometry of the miniature water-tube steam boiler.

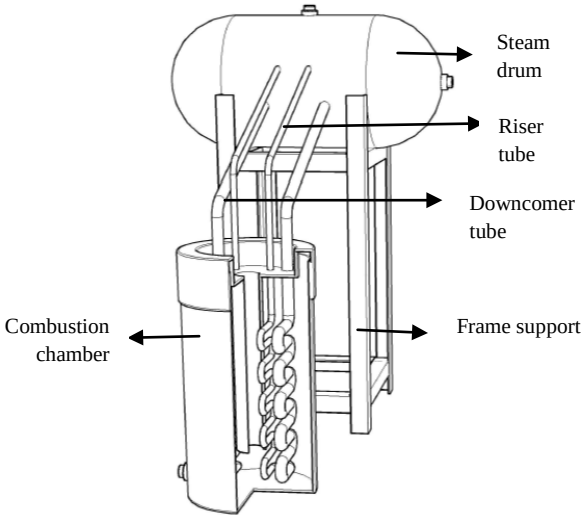

Figure 1. 3-D Model of the Developed Boiler

2.2 Design Considerations

The systematic approached to the design, fabrication, experimental procedure and testing of the (Boiler and Code, 1989) developed bubbling fluidised bed boiler for energy generation are as follows:

i. Steam pressure of 2 bar to 5 bar
ii. Steam temperature of 120 ^oC to 180 ^oC
iii. Steam capacity of 2 kg/h to 10 kg/h

iv. Stoichiometric air-fuel ratio
v. Calorific value of corncob as fuel

2.3 Material Selection

The suitable materials selected for the fabrication of the fluidised bed boiler were selected based on the physical and mechanical properties, and their availability. The materials include the following:

i. Galvanised plate was used for the steam drum because it can withstand high temperature applications and resistivity to corrosion.
ii. Galvanised pipes were used for steam tubes due to its hollow shape.
iii. Mild steel plate was used for fluidised bed combustion chamber because of its high melting temperature resistance.
iv. Mild steel used as the grate and distributor plate because of the reaction that is expected to occur during combustion.
v. Safety valve and Non-return valve were made of brass
vi. Granular Material (Sand)
vii. Pipes and Fittings were made of galvanised materials

2.4 Design Theories and Calculations

The boiler is a vessel that operates under pressure; hence, the design theories are the basic principles considered to evaluate the various parameters, dimensions and the performance of the boiler under internal pressure.

2.4.1 Internal Designed Pressure of a Boiler

The design pressure higher than operating pressure with 10% or more will satisfy the requirement. The maximum allowable working pressure is the maximum permissible pressure at the top of the boiler in its normal operating position at specific temperature. This pressure is based on the nominal thickness. The internal design pressure is given by (Ohijeagbon et al., 2013).

$$P_d = \frac{\sigma_u \times t}{R_i \times f_s} \quad (1)$$

where, P_d = Internal design pressure on inside of drum or shell (N/m^2)
σ_u = Ultimate strength of plate (N/m^2)
t = Thickness of plate (m)
R_i = Internal radius of drum (m)
f_s = Factor of safety (ultimate strength divided by allowable working stress)

Tensile stress, σ_{ut} = 385 MN/m^2

Compressive stress, σ_{uc} = 665 MN/m^2

Shear stress, τ = 308 MN/m

2.4.2 Stresses in Tubes and Drums

Stresses are induced in different parts of an operating boiler by the temperatures and pressures of hot flue gases, feed water and steam respectively. The magnitudes of these stresses must be known so that the boiler will be operated under safe conditions. Thus, the wall of the boiler subjected to internal pressure has to withstand two types of tensile stress, namely, 1) Circumferential or hoop stress and 2) Longitudinal stress (Khurmi and Gupta, 2005)

$$\sigma_{t1} = \frac{P_d \times D_i}{2t} \quad (2)$$

where, P_d = Internal design pressure of the drum or shell (N/m^2)
σ_{t1} = Circumferential or hoops stress (N/m^2)
t = Thickness of plate (m)
D_i = Internal diameter of drum (m)

$$\sigma_{t2} = \frac{P_d \times D_i}{4t} \quad (3)$$

where, σ_{t2} = Longitudinal stress (N/m^2)

2.4.3 Design of the Steam Drum

The design of this component must be strong enough to contain steam or hot water that was generated and to mechanically hold the boiler tubes as they expand and contract with changes in temperature. Hence, its volume is of importance and is written as (Balogun et al., 2016).

$$V_{dru} = A_{dru} \times L_{dru} \quad (4)$$

where, A_{dru} = Cross sectional area of the drum (m^2)
L_{dru} = Length of the drum (m)

2.4.4 Design of the Steam Tube

Materials which can withstand high temperature and resistance to corrosion such as galvanised steel material was selected to form tubes.

$$V_{st} = A_{st} \times L_{st} \quad (5)$$

where, A_{st} = Cross sectional area of the tube (m^2)
L_{st} = Length of the drum (m)

2.4.5 Design Height of the Combustion Chamber

This is given by the ratio of volume to combustion chamber area of the boiler (Balogun et al., 2016).

$$H_{com} = V_{com} / A_{com} \quad (6)$$

where, H_{com} = Height of the combustion chamber (m)
V_{com} = Volume of the combustion chamber (m^3)
A_{com} = Cross sectional area of the combustion chamber (m^2)

2.4.6 Minimum Wall Thickness of Tubes and Drum

The minimum required wall thickness of a boiler is a value beyond which the boiler wall cannot be easily damage by the operation pressure in a boiler. The formula is given as (Ohijeagbon et al., 2013).

$$t_w = \frac{P_d \times R_i}{\sigma \times \eta_E - 0.6P_d} \quad (7)$$

where, σ = Allowable working stress of the material (N/m^2)

t_w = Minimum wall thickness (m)

η_E = Ligament efficiency of the welded joint

Therefore, the minimum wall thickness of the tubes is given as:

$$t_{w\,tubes} = \frac{P_d \times r_i}{2 \times \sigma \times \eta_E + 0.8P_d} + C \quad (8)$$

where, C = Corrosion allowance

2.4.7 Velocity of Fluid inside Tubes, Pipes and Drum

To control the boiler operation, it is necessary to determine the velocity of fluid. It is given as (Ganapathy, 2003)

$$V = 0.05 \times M_w \times \frac{v}{D_i^2} \quad (9)$$

where, V = Velocity (m/s)

v = Specific volume of liquid (m^3/kg)

M_w = Mass of water in the steam drum (kg/hr)

D_i^2 = Square of inner diameter of the drum (mm)

For steam, v can be obtained from steam table.

2.4.8 Quantity Flow Rate of Fluid inside Tubes

The quantity of fluid to be delivered depends upon the inside diameter of the tube, and is given as:

$$Q_d = \frac{\pi}{4} d_i^2 \times V \quad (10)$$

where, Q_d = Quantity flow rate (m^3/h)

Therefore, in boiler design the operating pressure of a boiler must be determined in order to make other important calculations required for effective functioning of the boiler. Table 1 shows the summary of the design calculation.

2.5 Construction Procedures

The techniques followed in order to achieve the modular construction of the developed fluidised bed water-tube boiler and evaluation of the materials that were used are as follows:

2.5.1 Combustion Chamber

The combustion chamber was fabricated from mild steel of thickness 3 mm, which was rolled into shape to form a diameter of 0.5 m and 1 m long (see Figure 2), was adopted for the fluidised bed combustion chamber. A perforated distributor grate that was made from mild steel was also adopted for the combustion of fuel and the whole combustion chamber was enhanced by air blower rated as 0.28 kW which provides the air for combustion.

2.5.2 Steam Drum

The steam drum was fabricated from a galvanised steel of 3 mm thick and welded together by gas welding to form the drum of 1m long and 0.6 m in diameter (see Figure 2), in which water was feed in at top through a valve, and steam tubes and downcomers was also be welded to it. The downcomer which convey water from the drum into combustion chamber where it was heated to form steam due to density differences of water in both steam tubes and downcomers results into natural circulation. Lastly, it was designed to hold up to 40 liters of water, steam pressure of 5 bars was also anticipated and steam capacity of 10 kg/h was also being desired.

Figure 2. Combustion Chamber at Early Stage of Fabrication with Coiling of Tubes

Figure 3. Steam Drum at Early Stage of Fabrication (Gas Welding)

2.5.3 Steam tubes

Materials which can withstand high temperature and resistance to corrosion such as galvanised steel materials were selected to form tubes. The steam tubes of 0.0127 m diameter were achieved after machining processes. Both downcomer and riser tubes were fabricated from a ¾" and ½" galvanised pipe of 3 m long that was cut and then bent it into 3" curvature (see Figure 3), which was 76.2 mm. Two (2) downcomer and riser tubes were achieved in line with these design specifications, welded to front of the steam drum, and went through the top of the combustion chamber. The curvature of tubes at the bottom bend was allowed to suspend at a height of 0.3 m just above the distributor plate.

Table 1. Summary of the Design Calculation

Initial Data	Calculations	Results and Remarks
Type of boiler	Bubbling fluidised bed boiler	
Internal designed pressure of the boiler		
σ_{ut} = 385 MN/m^2 t = 0.003 *m* R_i = 0.3 *m* f_s = 5	$P_d = \frac{\sigma_u \times t}{R_i \times f_s} = \frac{385 \times 0.003}{0.3 \times 5}$ $P_d = 0.77\ MN/m^2 \cong 770{,}000\ N/m^2$ Hence, $P_d = 7.7\ bar$	The design pressure was calculated as: $P_d = 7.7\ bar$
Stresses in the tubes and drum		
For the Drum P_d = 7.7 *bar* t = 0.003 *m* D_i = 0.6 *m*	$\sigma_{t1} = \frac{P_d \times D_i}{2t} = \frac{0.77 \times 0.6}{2 \times 0.003}$ $\sigma_{t1} = 77\ MN/m^2$ $\sigma_{t2} = \frac{P_d \times D_i}{4t} = \frac{0.77 \times 0.6}{4 \times 0.003}$ $\sigma_{t2} = 38.5\ MN/m^2$	σ_{t1} = Circumferential or hoops stress (N/m^2). Calculated as $\sigma_{t1} = 77 \times 10^6\ N/m^2$ σ_{t2} = Longitudinal stress (N/m^2). Calculated as $\sigma_{t2} = 38.5 \times 10^6\ N/m^2$
Design of steam drum		
$D_i = 0.6\ m$ L_{dru} = 1 *m*	Volume of steam drum or boiler shell $\frac{\pi}{4} \times 0.6^2 \times 1 = 0.283\ m^3$	For this design specification, the volume of steam drum was calculated as V_{dru} = 0.283 m^3
Design of steam tubes		
$d_i = 0.0127\ m$ L_{st} = 3 *m*	Volume of tube $\frac{\pi}{4} \times 0.0127^2 \times 3 = 0.038\ m^3$	Babcock and Wilcox, stated that the minimum and maximum allowable tube diameter are 0.01 m and 0.0635 m. Therefore, the volume of the steam tube was calculated as V_{st} = $0.038\ m^3$
Design of combustion chamber		
$D_i = 0.5\ m$ H_{com}= 1 *m*	Volume of combustion chamber $V_{com} = \frac{\pi}{4} \times 0.5^2 \times 1 = 0.196\ m^3$	For this design specification, the volume of combustion chamber was calculated as V_{com} = 0.196 m^3
Types of feed Bed material	Agricultural waste (chipped corncob and charcoal) Sand	The corncob was from Shika community, Zaria. Sand material of 250 µm and particle density of 2.659 g/cm^3 was used with bed height of 0.027 *m*, 0.047 *m* and 0.77 *m* were adopted.
Design of minimum wall thickness		
For the Drum $P_d = 0.77 MN/m^2$ D_i = 0.6 *m* η_E = 1 $\sigma_{t1} = 77\ MN/m^2$	$t_w = \frac{P_d \times R_i}{\sigma \times \eta_E - 0.6P_d} = \frac{0.77 \times 0.3}{77 \times 1 - 0.6 \times 0.77}$ $t_w = 3.0181 \times 10^{-3}\ m$ $t_w = 3.018\ mm$	$t_w = 3.018\ mm$ Take $t_w = 3.0\ mm$
Also, for the tube $d_i = 0.0127\ m$ $C = 3$	$t_{w\ tubes} = \frac{P_d \times r_i}{2 \times \sigma \times \eta_E + 0.8P_d} + C$ $t_{w\ tubes} = \frac{0.77 \times 0.00635}{2 \times 77 \times 1 + 0.8 \times 0.77} + 3$ $t_{w\ tubes} = 3.0312\ mm$	$t_{w\ tubes} = 3.0312\ mm$ Take $t_{w\ tubes} = 3.0\ mm$
Velocity of fluids in tubes, pipes and drum		
From steam table; v = 0.3427 m^3/kg of water @ 155 ^oC M_w = 48 kg/hr	$V = 0.05 \times M_w \times \frac{v}{D_i^2} = 0.05 \times 48 \times \frac{0.3427}{0.6^2}$ $V = 2.284\ m/s$	For this design specification, the velocity of fluids in the steam drum is calculated to be $V = 2.284\ m/s$
Quantity flow rate of fluid inside tubes		
$V = 2.284\ m/s$ d_i = 0.0127	$Q_d = \frac{\pi}{4} d_i^2 \times V = \frac{\pi}{4} \times 0.0127^2 \times 2.284$ $Q_d = 2.8933 \times 10^{-4}\ m^3/h$	Q_d= 0.000289 m^3/h $Q_d = 4.817 \times 10^{-6} m^3/min$
Design of frame support		
L = 0.6 *m* B = 0.3 *m* H = 1.5 *m*	Area of frame support $A_{fs} = 0.6 \times 0.3 \times 1.5 = 0.270\ m$	$A_{fs} = 0.270\ m$

2.6 Experimental Procedure

Fine sand of 250 µm was fed evenly onto the distributor plate through the manhole opening up to a desired static bed height of 77 mm, 47 mm and 27 mm respectively. An air blower with capacity of 0.7 MPa rated 0.28 kW, 60 Hz was used to provide the buoyant forces for fluidisation and in addition provides the oxygen for combustion. Some charcoal in small pieces was fed onto the bed for pre-heating of the system. Additionally, 1 kg of the corncob waste samples from Shika community, Zaria as the raw biomass fuel was cut into pieces with 3 ± 0.5 mm in diameter and 10 ± 0.5 mm in length to equalise their sizes and was feed in at 10 minutes' interval through the hopper.

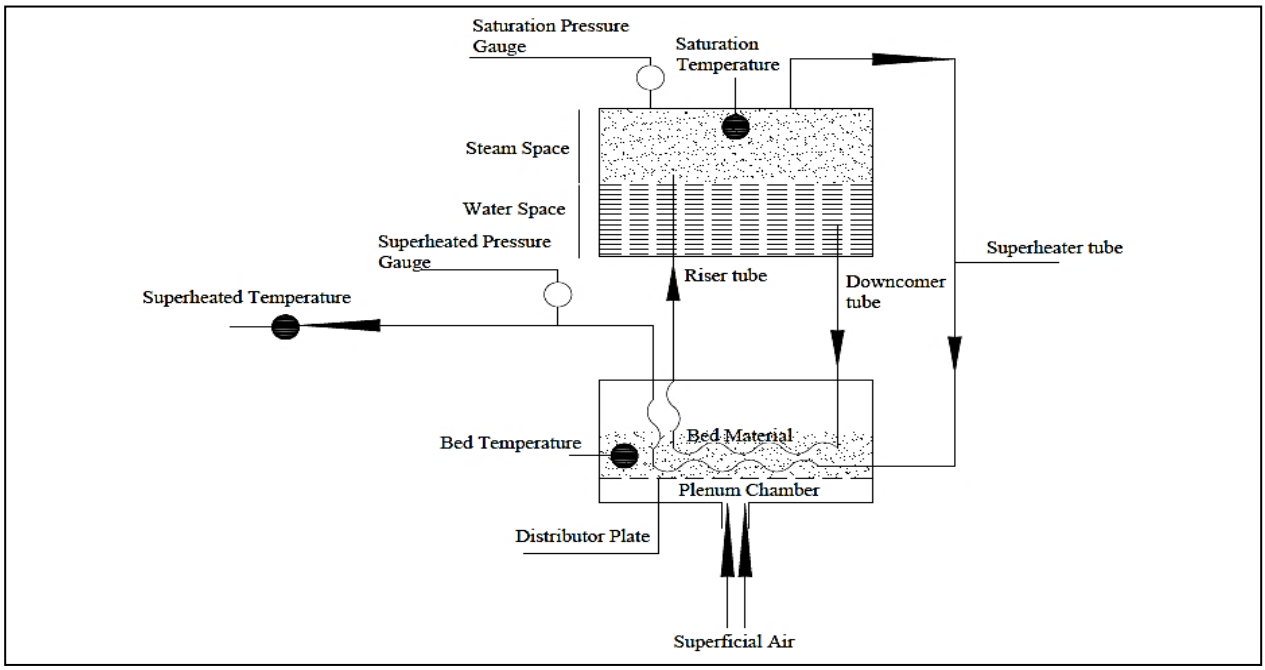

Figure 4. Schematic Flow Diagram of the Developed Boiler

Figure 4 shows three temperature-measuring devices that were used to determine temperatures at various points; mercury in glass thermometer ranging from 0 ^{o}C-360 ^{o}C was used to determine the ambient temperature as well as the initial temperature of the water. Two digital thermometers (Kane-May and MASTERTECH multipurpose clamp meter) with thermocouple wire props having one connected to the outlet of the super-heater tube, one buried in the bed to determine the bed temperature, one inserted in the steam drum to determine the saturated temperature and the last one connected to the exhaust pipe to determine the temperature of the flue gases at every 5-minutes interval.

3. Results and Discussion

The combustion of agricultural residue (corncobs) in the developed fluidised bed boiler are described in this section. The influences of operating parameters such as; the effect of pressure, effect of temperature as a function of time, steam generated with respect to bed heights, and emission characteristics are discussed.

3.1 Saturation Temperature of Steam

The temperatures of the steam at the steam drum with respect to time were taken at 5 minutes' interval. According to literature, a denser material and larger volume of bed height required more bed pressure to equalise the gravity force for fluidisation (Hilal et al., 2001). It was deduced from Figure 5 that the saturation temperature of water in the steam drum increases with increase in time; subsequently, from the bed heights of 77 mm, 47 mm and 27 mm. There was a noticeable change at 10 minutes in the temperature. This can be said to be attributed to heat gain by the water.

In addition, there was a rapid change in temperature at 25 minutes this is attributed to phase change of water from liquid to vapour. Temperature stability was attained in the bed height of 27 mm at 30 minutes from temperature ramp of 153 ^{o}C to 155 ^{o}C compare to bed height of 47 mm and 77 mm which were at 40 minutes and 45 minutes which were in temperature ramp of 142 ^{o}C to 144 ^{o}C and 117 ^{o}C to 121 ^{o}C, respectively. This behavior is attributed to complete bubble fluidisation of the crystalline material and the specification of the blower being able to provide enough buoyant force of fluidization (see Figure 5).

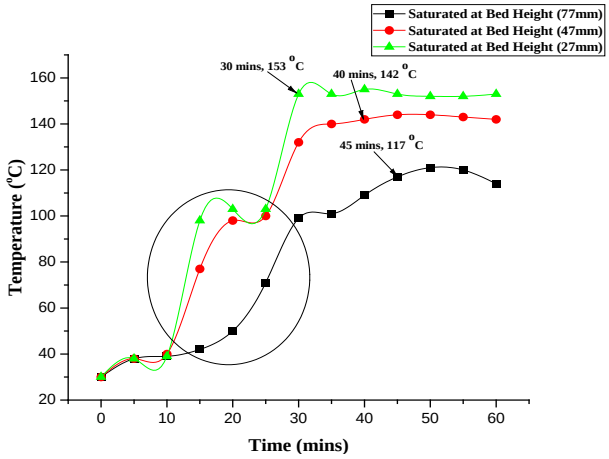

Figure 5 Saturation Temperature of Steam/Bed Height as a Function of Time

3.2 Saturation Pressure of Steam

Pressure developed is a major parameter in any designed boiler (Zhong et al., 2006), Figure 6 presents the saturated pressure obtained which revolve round the designed pressure. Saturation pressures of the steam from steam drum at 5 minutes' interval were taken. It shows that the maximum saturation pressure obtained from the three experiments carried out was 3.7 bar.

The pressures obtained are 2.0 bar from 50 to 55 minutes for bed height of 77 mm, 2.1 bar from 45 to 50 minutes for bed height of 47 mm and lastly, 3.6 to 3.7 bar was obtained from 45 to 55 minutes for bed height 27 mm.

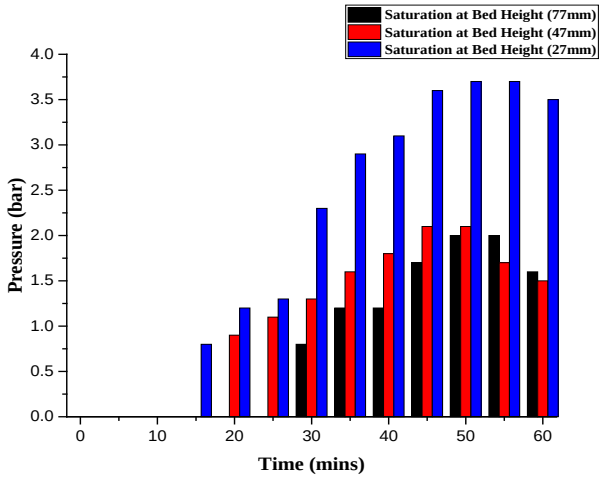

Figure 6. Saturation Pressure of Steam/Bed Height as a Function of Time

3.3 Amount of Steam Generated

Figure 7 shows the plot of the amount of steam generated in kg/h in the steam drum of the developed fluidised bed boiler. The figure revealed that 5.6 kg/h of steam was achieved from bed height of 77 mm, 6 kg/h was achieved from 47 mm and 6.6 kg/h as maximum capacity of steam achievable from the bed height of 27 mm and this is capable to run a small steam turbine, sterilisation of medical equipment, laundry and soil steaming for pest control.

3.4 Flue Gas Temperature at Exhaust Pipe

Figure 8 shows the flue gas temperature of the developed fluidised bed. The initially measured temperature of the bed at the onset of fluidisation was 51 ^{o}C for bed height of 77 mm, 86 ^{o}C for bed height of 47 mm and 89 ^{o}C for bed height of 27 mm respectively. Conversely, it increases with increase in time (Folayan et al., 2015) up to 45 minutes, at 50 minutes a drop in temperature begins to set in and this is because of fuel stoppage.

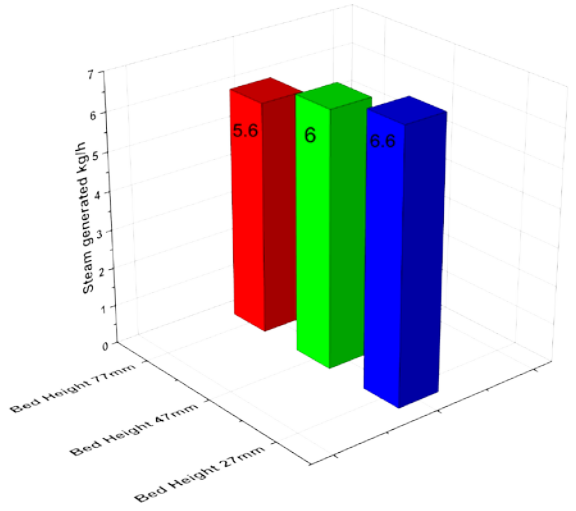

Figure 7. Steam Generated as a Function of Bed Height

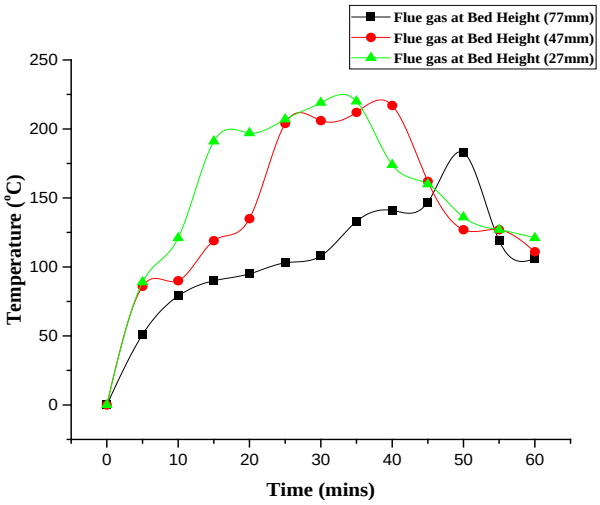

Figure 8. Flue Gas Temperature as a Function of Time

3.5 Analysis of Flue Gas Emission

The exhaust flue gas of the developed boiler is presented below after being analysed with a flue gas analyser. Figure 9 presents the exhaust emission in their percentages to be 0.001% of hydrocarbon, 0.0003% for oxides of nitrogen, 0.02% of carbon monoxide, 0.04% of carbon dioxide.

The harmful emissions were very low and this is attributed to granular material which is crystalline in nature that absorbs the harmful gas within it (Thenmozhi and Sivakumar, 2013). The excess nitrogen that was present for the combustion was found to be 0.93%. In conclusion, the oxides of Sulphur were found to be zero and this can be said to be attributed to low contents of Sulphur in biomass fuel.

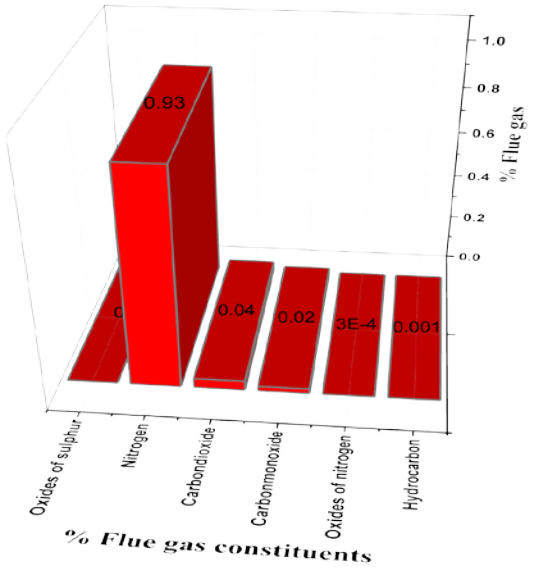

Figure 9. Percentage Composition of the Flue Gas Constituent

4. Conclusions

Fluidised bed technologies are proving to be the most practical option for biomass conversion. The fabrication of the boiler was successfully accomplished based on the design specifications of length of steam drum to be 1 m, diameter of 0.6 m, the length of the steam tubes of 3 m and diameter of 0.0127 m, respectively. Local mild steel and galvanised steel were sourced for the fabrication owing to the fact they have heat resistance and corrosion resistance.

The result of the performance evaluation showed that the bed height of 27 mm gives a better fluidisation result. Stability in the saturation temperature of steam was observed at 30 minutes up to 60 minutes with corresponding temperature ramp of 153 ^{o}C to 155 ^{o}C. The efficiency of the boiler was found to be 53.69% for bed height of 77 mm, 57.42% for bed height of 47mm and 61.72% for bed height of 27 mm. This shows that the developed fluidised bed boiler has its application in medium capacity steam turbine.

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Assessing Residential Building Energy Efficiency in the Caribbean Environment: A Case Study of Trinidad and Tobago

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Abstract: *The energy performance of building is closely linked to the energy performance of the building envelope. Buildings in the Caribbean countries are experiencing high heat, humidity, rainfall, and extreme weather events. Compared with "Temperate Regions", humid tropical climates can affect buildings through higher rates of deterioration and uncomfortable conditions for the occupants. The transfer of building technology and policies developed in temperate regions that are sometimes irrelevant and often inappropriate for hot and humid regions, therefore there is acute need to initiate rigorous models in order to develop typical sustainable buildings for warm humid regions such as in the Caribbean countries. As such, the current research was undertaking to investigate and recommend effective passive strategy for achieving sustainable building energy efficiency in warm humid regions. In order to achieve this aim, an investigation was conducted on the impact of building envelope systems such as roof and wall design solutions on the building energy efficiency through experimental approach using three building physical models attached with air-conditioning system each. Subsequently, the performance of the building envelope physical models in terms of energy consumption, cooling load, indoor temperature, indoor relative and humidity was monitored through Lascar EasyLog USB-2-LCD data logger sensors and Multifunctional Mini Ammeter. The findings derived from this study have proved that, the short term strategies could be applied for achieving sustainable building energy efficiency for humid warm climatic zones. Specifically, it was found that, the insulated galvanised and standing seam roofing systems are more energy efficient and cost effective, while in the longer terms, flat slab concrete roofing system is more energy efficient and cost effective.*

Keywords: *Energy Performance; Building Envelope; Cooling Load*

1. Introduction

According to State of the tropics report (2017) published by the James Cook University, it reported that the buildings in the "Tropics" are usually exposed to environmental conditions, including high heat, humidity, rainfall, and extreme weather events, not experienced elsewhere. Compared with temperate regions, tropical climates can affect infrastructure through higher rates of deterioration. The transfer of infrastructure, technology and policies developed in other parts of the world are therefore often inappropriate for tropical conditions, pointing to the need for increasing opportunities, capacity and investment for developing and scaling up local infrastructure design and innovations.

In India, the Energy demand had traditionally been dominated by the buildings (India Energy Output, 2015). In the buildings sector, a key driver of consumption in both rural and urban areas has been rising levels of appliance ownership, especially of fans and televisions, and an increase in refrigerators and air conditioners over the latter part of the 2000s. As a result, electricity demand in the buildings sector grew at an average rate of 8% per year over 10 years. The interaction between building envelope and the external environment is an important issue in developing sustainable tropical residential structures. Considering the urgency of saving the world's energy reserve, energy-conscious buildings are becoming an important part of design helping to minimise demands on non-renewable resources while providing better natural ventilation than was previously possible (Brown and Herendeen, 1996). As such, it is important to understand the energy saving potential of the building envelope in energy conscious building design (Mwasha, et. al. 2011; Iwaro and Mwasha 2013).

The energy performance of building envelope has direct influence on the level of energy consumption of building. It is therefore necessary to consider building envelope as effective sustainable passive strategy for achieving sustainable building energy efficiency especially in hot humid regions of the world (Iwaro 2016). As such, this paper investigated the impact of sustainable envelope design in warm humid region such as Trinidad and Tobago and other Caribbean countries.

2. Literature Review

2.1 Energy Efficiency Strategies

According to Hoffman, and Pienaar (2013) the awareness of energy inefficiency and global climate change has significantly impacted the construction sector in recent years. In warm and humid regions such as Caribbean countries, the building envelopes are the largest component of building which consumes large amount of energy at each stage of its development from design, construction through to operation and final demolition. In Trinidad and Tobago, the residential sector consumes 29% of total electricity (Natacha et. al. (2015). The average household consumption is the highest in the CARICOM region, and it is considered that there is a large potential for energy savings through efficiency in the sector. The energy consumption at each stage in the building envelope development is largely influenced by how the envelope was constructed, building orientation, outside temperature, window areas, light systems, air conditioning and ventilation, level of insulation and the thermal characteristics of building envelope i.e. walls and roofs (Cole and Rousseau (1992); Spence and Mulligan (1995), Hui (2001); Ding (2004); Jamie (2007)).

In warm humid regions, the cooling energy needed by building can be significantly reduced with the use of cool materials as suggested by Santamouris, Synnefa and Karlessi (2011) and Vincenzo, Gianpiero and Luigi (2013) as well as proper insulation of building envelope through wall and roof components as suggested by Irene and Robert (2007). Moreover, improving the energy efficiency of the building envelope glazing system will bring about reduction in energy consumption and improvement in building energy efficiency (Stansfield 2001). Building envelope can also impact overall building energy consumption through its shading devices (Irene and Robert 2007). In the study conducted by Cheun et al. (2005) using the passive thermal building envelope design strategies such as insulation, colour, glazing system and shading devices, they found that, on using passive energy efficient strategies, the annual required cooling energy was reduced from 3056 KWh to 2252 KWh. The passive energy efficient strategies include adding extruded polystyrene (XPS) thermal insulation in walls, white washing external walls, reflective coated glass window glazing, 1.5m over hangs and wing wall to all windows (Cheung et al. 2005).

According to Sharma (2013) energy savings of 31.4% and peak load saving of 36.8% were recorded for high rise buildings by implementing passive energy efficient strategies. In another study, the energy effective building envelope design was found to have saved as much as 35% and 47% of the total energy and peak cooling demands respectively (Chan and Cow 1998). In Greece, the thermal insulation in walls, roof, floor, and low infiltration strategies were found to reduce energy consumption by 20-40% and 20% respectively. According to the same study, light colored roof and external walls reduced the spaced cooling load by 30% and 2-4% respectively (Balaras et al. 2000). However, the effectiveness of building envelope on energy consumption in hot humid regions is still not well elaborated in the literature reviewed. In order to understand the effectiveness of building envelope on energy consumption in warm humid zones, a small scaled building envelope physical model was used to simulate building performance in a natural environment in order to actually justify the benefits of the proposed envelope design options in hot climatic regions. Hence, the current research was undertaking to investigate and recommend effective sustainable passive strategies for achieving sustainable building energy efficiency in hot climatic regions.

2.2 Building Envelope as Environmental Load Regulator in Warm Humid Regions

According to Irene and Robert (2007), building envelope has been described as the first line of defence against the undesirable external impacts on building such as Carbon emission, pollution, climate change, and also provides indoor conditions suitable for human comfort (Lucuik 2005). Building envelope serves as a thermal barrier and plays an important role in regulating interior temperatures and determines the amount of energy needed to maintain thermal comfort (Centre for Climate Change and Energy Solution 2015). In addition, building envelope was defined as a dynamic system that responds to the variability in surrounding environments such as external radiation, climate conditions and internal requirements for occupant's comfort (Mary 2010). As shown in Figure 1 the environmental loads on building envelope include the loads generated within the natural and built environment, industrial and urban environment, geo environment and indoor environment (Aksamija 2009) and Aksamija (2013). Besides, the impact of environment on building envelope and the impact of building envelope on the environment necessitated the need to make building envelope sustainable (Iwaro and Mwasha 2013). However, making building envelope systems sustainable to undertake these regulatory and protection tasks for tropical residential structures in most developing countries has been the major challenge.

Figure 1 illustrates the regulatory and protective functions of the building envelope in building against these environmental loads. As suggested by Hegger et al. (2008); DFW (2011a) and (DFW 2011b) building envelope interacts with: exterior environment, interior environment. Also the building envelope system interacts with the physical system of building in the process of separating the interior environment from the exterior environment, comfort and building sustainability. Therefore, the sustainable performance of building depends on the geometrical dimensions of the building envelope components. As such, the building envelope and its components are the major determinants of the amount of heat gain or loss in a building (ECBC 2013a). It means that in order for the residential building

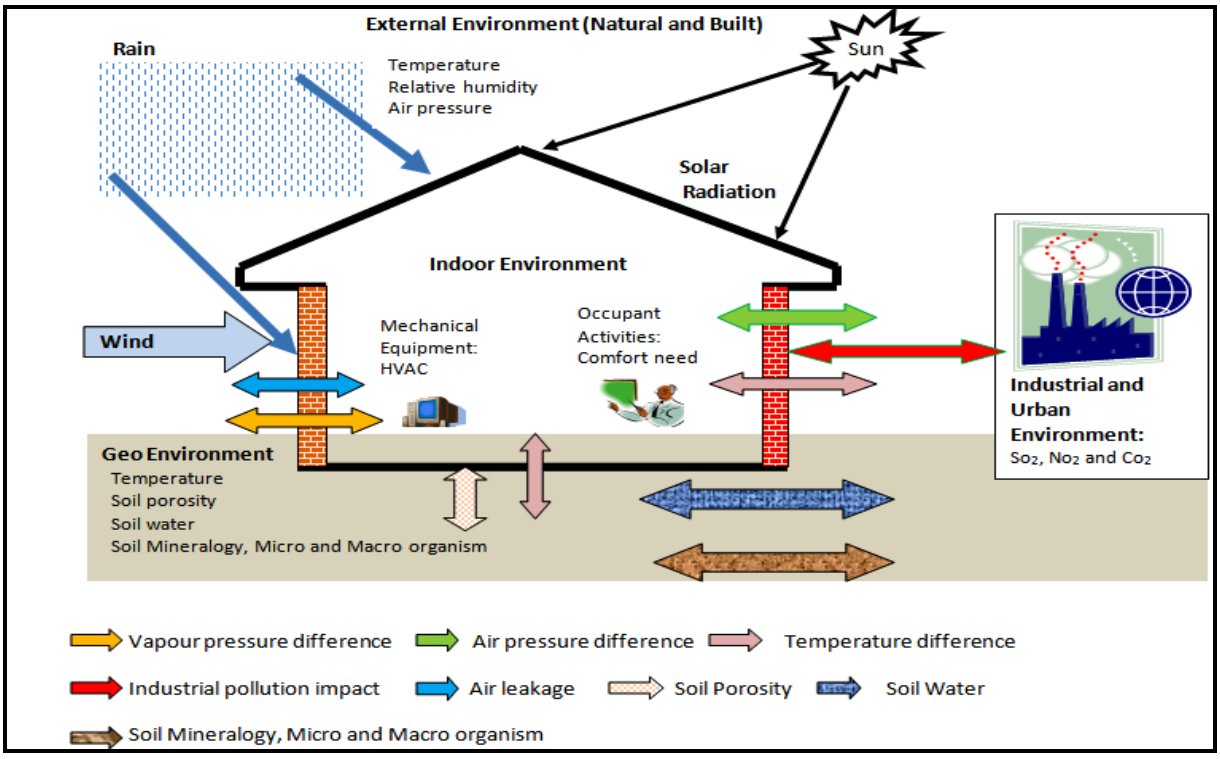

Figure 1. Environmental loads on building envelope

structures in warm tropical climatic region to be sustainable in view of the numerous environmental loads, it is necessary that the building envelope systems be made sustainable.

2.3 Heat Exchange and the Mechanism of Control in Building Envelope in Warm and Humid Regions

Solar radiation is the main source of heat loading in the tropics and one of the main functions of building envelope is to prevent the solar radiation from reaching the indoor environment. According to Szokolay et al. (2010), the conduction of heat may occur through the walls either inwards or outwards, the rate at which it occurs was denoted as Q_c (convective and radiant components in the transfer of the same heat at the surfaces are included in the term 'transmittance). Also, the effects of solar radiation on opaque surfaces can be included in the above by using the solar-air temperature concept, but through the transparent surfaces, the solar heat gain through the windows must be considered separately denoted as: Q_s.

While, the heat exchange in either direction may take place with the movement of air, i.e. ventilation denoted as Q_v. An internal heat gain may result from the heat output of human bodies, pets, lamps, motors and appliances is denoted as Q_i. The flow rate of such mechanical controls is denoted as Q_m and if the evaporation is taking place on the surface of the building envelope and the vapours are removed, this will trigger a cooling effect denoted as Q_e. The cooling and heating of the building envelope can be expressed in equation 1

$$Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m - Q_e = 0 \quad (1)$$

This cooling effect brings about the cool temperature being experienced inside the building by the occupants. Moreover, in view of the importance of removing heat from the indoor environment, there may be need to introduce other passive solar control measures to reduce and control the solar radiation load on the walls, windows and roof of the building envelope using solar heat control mechanism.

2.4 Solar Control of Heat Gain in Warm and Humid Regions

Glass windows are one of the greatest sources of heat gain into the building. In this case, the magnitude of solar-air temperature is influenced by factors such as absorbance and surface conductance. Since the window glasses are practically transparent for short-wave infrared radiation emitted by the sun. However, almost opaque for long wave radiation is emitted by irradiated objects in the room. The consequence of this is that the radiant heat, once it has entered through a window, is trapped inside the building causing solar overheating snags. As such, there are four methods recommended for the reduction of solar heat gain through windows. These are: Orientation and window size, internal blinds and curtains, special glasses and external shading devices.

Using these strategies, the transmittance (t) through the window glasses may be reduced from t = 74% to less than t = 42%. However, one difficulty is that the reduction in transmittance is accompanied by a corresponding increase in absorbance. Absorbed heat will be re-radiated and converted partly to the outside and partly to the inside. Hence, the net improvement will not be as great as the reduction in transmittance.

2.5 Thermal Insulation

According to Balaras et al. (2000), in Greece, thermal insulation in walls, roof and floor reduced energy consumption by 20-40%. Also, external shading and light coloured roof and external walls were found to reduce the space cooling load by 30% and 24% respectively. This means that building envelope with a low U-value will reduce all forms of conducting heat transfer through the building envelope. Thermal insulation of building envelope plays an important role in meeting the demands of improving the energy efficiency of residential building (Sharma 2013). This requires using insulation materials with low thermal conductivity and overall thermal heat transfer resistance, U-value in buildings. However, in the case where there is a big heat gain into the building with a strong solar radiation, it is the solar-air temperature value that will be evaluated to find the temperature difference. In case, the temperature difference is small, the actual motion force for heat flow may be large thereby suggesting the importance of insulation in buildings.

2.6 Thermal Capacity and Thermal Mass Effect

Some studies have referred to the effect of thermal capacity as capacitive insulation provided by low conductivity materials and low transmittance construction (Szokolay et al. 2010). For instance, the variation of climatic conditions produces a non-steady state, consequently, diurnal variations produce an approximately repetitive 24-hour cycle of increasing and decreasing temperatures. As such, the effect of this variation in buildings is that, in the hot period heat flows from the environment into the buildings, where some of it is stored and at night during the cool period, the heat flow is reversed from the building to the environment. Moreover, as the outdoor temperatures increase, the heat starts entering the outer surface of the wall. Subsequently, each particle in the wall absorbs a certain amount of heat for every degree rise in temperature, depending on the specific heat of the wall material.

The heat to the next particle will only be transmitted after the temperature of the first particle has increased. Consequently, the corresponding increase of the internal surface temperature will be delayed as shown by the broken line in Figure 2. As such, the outdoor temperature will have resulted in its peak and started decreasing before the inner surface temperature reached some level. From this point, the heat stored in the wall will be dissipated partly to the outside and only partly to the inside. This slowing of the flow of heat is called "thermal lag" (or time lag), and is measured as the time difference between peak temperature on the outside surface of a building element and the peak temperature on the inside surface. Some materials, like glass, do not have much of a thermal lag. But the thermal lag can be as long as eight or nine hours for constructions with high thermal mass like double-brick or rammed earth walls.

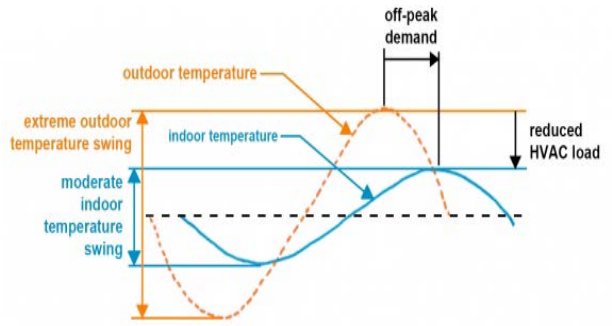

Figure 2. Lag-time and moderation of temperatures due to thermal mass
Source: Based on Autodesk (2016)

It may be several hours, however, before this temperature “spike” is seen at the inside surface of the wall. The reason is that some heat is being stored in the wall material. This heat is stored in the wall material until it has absorbed as much as it can (saturated). Heat will then flow to the inside, based on the conductivity of the material. As the outdoor temperature cools, an increasing proportion of this stored heat flows outwards.

The lag-time shown in Figure 1 does not represent the behavior of building envelope in hot humid climate regions since in these regions there are minimum variation of high and low temperatures. The air temperature during the day is between 27^{o}C and 32^{o}C. The relative humidity remains high, at about 75% for most of the time, but it may vary from 55% to almost 100%. The vapour pressure is also steady in the region with 2,500 to 3,000 N/m^{2}. In this paper the models are created to investigate the effects of varying building envelope components on fluctuation of the external and internal environment.

3. Modelling of Building Envelope Systems’ Performance in Warm and Humid Climate

3.1 External Environment in Warm and Humid Climate Regions

The interaction of solar radiation with the atmospheric gravitational forces together with the distribution of land and sea masses, gives rise to the infinite variety of climates. According to Szokolay et al. (2004), the tropical regions of earth comprise of warm-humid equatorial climate, hot-dry desert climate and monsoon

climate. The same authors pointed out that the warm humid equatorial climates are found in a belt near the equator which extends to about 15°C N and S. Surprisingly most of the developing countries such as Africa, Asia, Pacific and the Caribbean Islands are found within this region.

In this warm humid climatic region, there are little seasonally variations throughout the year. The air temperature during the day is between 27°C and 32°C. The relative humidity remains high, at about 75% for most of the time, but it may vary from 55% to almost 100%. The vapour pressure is also steady in the region with 2,500 to 3,000 N/m^2. Furthermore, the solar radiation is partly reflected and partly scattered by the cloud cover on the high vapour content of the atmosphere, hence, the radiation reaching the ground is diffused and strong. Typically for these regions, the wind velocities are typically low, with frequent calm periods.

On the other hand, the islands within the equatorial belt and in the trade wind zones belong to warm humid island climate type. The countries within this region include the Caribbean, Trinidad, Philippines and other islands in the Indian and Pacific Ocean. The air temperature i.e. (Dry bulb Temperature) DBT ranges between 29 °C and 32°C, while night time is normally between 18 °C - 24 °C. The relative humidity varies between 55% and 100%, while the vapour pressure varies between 1,705 and 2,500 N/m^2. The solar radiation is strong and mainly direct, with a very small diffuse component. The predominant trade wind blows at a steady 6-7 m/m and provides relief from heat and humidity. However, the much higher velocities occur during hurricane seasons. Different from most of the Caribbean Islands, the Trinidad's geographical location put it on the Southern periphery of the North Atlantic hurricane basin.

3.1.1 The Local Climate in Trinidad and Tobago

According to the Trinidad Meteorological Office Information (Metrological Office 2017), Trinidad and Tobago's close proximity to the equator enables the country to have two climate types producing two opposing seasons differentiated by characteristic dry and wet seasons. The dry season which occurs during January to May symbolises a tropical maritime climate that is characterised by moderate to strong low level winds, warm days and cool nights, with rainfall mostly in the form of showers. Also, a moist equatorial climate that is characterised by low wind speeds, hot humid days and nights, an increased rainfall which results mostly from migratory and latitudinal shifts at equatorial weather systems. This climate symbolises the wet season during June to December. During the wet season is the hurricane seasons which runs from June to November, peaking between August and October. Trinidad's geographical location puts it on the Southern periphery of the North Atlantic hurricane basin. As such, Trinidad is not directly affected by storms as frequent as Tobago. However, peripheral weather associated with tropical storm systems normally impact Trinidad and Tobago. Their annual maximum and minimum temperatures are 31.3°C and 22.7°C, respectively with a mean daily temperature of 26.5°C. These external environmental data will be used to assess the energy efficiency of the building envelope models.

3.2 Model Description

This experimental method used in this study has been extensively used in other studies, such as Cabeza et al. (2010) in an experimental study showing the performance of insulation materials in construction, where they used the concrete columns with reinforced steel bars as envelope frame structure. Similarly, In Dimdina et al. (2013)'s study on measuring the influence of building envelope materials on energy efficiency and indoor environment, five identical small envelope models with external walls of different composite building materials were used. Also, studies from Sakipova et al. (2013) on energy efficiency and sustainability of low energy houses in Latvian climate conditions used five identical small envelope models. Likewise studies by Borodinecs and Zemits (2012) and Ozolinsh and Jakorich (2012) successfully used small envelope models. In all these studies, the results from their physical envelope models studies were extrapolated to the full scale residential building.

3.2.1 Building Envelope Systems Insulated with Fibre Glass

The study investigated the impact of building envelope systems such as roof and wall design solutions on the building energy efficiency through experimental approach using three (3) building physical models attached with air-conditioning system each.

The three (3) identical small-scale test models (1.524 m long x 1.219 m wide x 1.524 m high) as shown in Figure 3 were built to determine the effect of the different envelope design solutions in the building energy efficiency performance. The difference between the models is the type of masonry wall and roof materials used. In the process, eleven (11) different model designs were used. The testing was done in two phases: Phase 1- building envelope insulation, and Phase 2 - roof system insulation.

In the Phase 1, three model design solutions were tested. The models include: Models A, B and C as shown in Figure 3, they were constructed with 100 mm concrete block, 150 mm concrete block, 100 mm clay, clay tile roofing system, corrugated standing steam roofing system, galvanised iron roofing system, steel frame structure, wood roof frame structure, 100mm concrete slab, 12,000 BTU Panasonic air conditioning system and 1.5 inches Fibre glass insulation for wall and ceiling.

Figure 3. Physical building envelope models

The envelope design solutions, were compared with each other to determine their benefits and impacts to the building energy efficiency and impacts to the building energy efficiency.

3.2.2 Roof Systems with Fibre Glass Insulation

In the second phase, five (5) model designs were tested based on three identical models as shown in Figures 4, 5 and 6. The models were constructed with 150mm concrete block, 100 mm clay, corrugated standing steam roof, corrugated galvanised iron sheet roof, 100mm concrete roof, steel frame structure, wood roof frame structure, 100 mm concrete slab, 12,000 BTU Panasonic air conditioning system and ceiling insulated with 1.5 inches Fibre glass.

Figure 4. Model 1 - 100mm Clay block walls and corrugated galvanised iron sheeting roof

The models were tested with and without insulation, with and without air conditioning system to develop baseline conditions which would be used to determine the benefits of the roof materials, roof system and the insulator to building energy efficiency. Table 1 shows a summary of the insulations and materials used for the different masonry unit walls tested.

Figure 5. Model 2 – 150mm Concrete block walls and corrugated standing seam roof

Figure 6. Model 3 - 150mm Concrete block masonry walls and concrete roof

Table 1. Components and material used in the envelope physical models

Components	**Model A**	**Model B**	**Model C**
Roof Sheeting	Red clay tile	26G corrugated standing seam sheeting	26G galvanised aluminium sheeting
Roof Frame	2" X 4" Timber	2" X 4" Timber	2" X 4" Timber
Structural Frame	4" steel RHS	4" steel RHS	4" steel RHS
Ceiling	6mm plywood ceiling board and 1.5"fibre glass sheet	1.5" fibre glass sheet	1.5" fibre glass sheet
Floor Floor finishes	4" concrete slab Carpet	4" concrete slab Terrazzo	4" concrete slab Wood
Wall	100mm x 200mm x 400mm concrete block	100mm x 200mm x300mm clay block	150mm x 200mm x 400mm concrete block
Wall insulation	1.5"fibre glass sheet	1.5"fibre glass sheet	1.5"fibre glass sheet

4. Experimental Methodology and Procedures

The models in each phase were tested at same times and subjected to same environmental conditions. Subsequently, the performance of the building envelope physical models in terms of energy consumption, cooling load, indoor and outdoor temperature was monitored through Lascar EasyLog USB-2-LCD data logger sensors and Multifunctional Mini Ammeter. This was aimed at monitoring the impact of outdoor temperature and humidity on the envelope energy consumption and indoor temperature. Also, these parameters were monitored in January, March and June with A/C and without AC. In the process of monitoring, each envelope model was tested for 2 days with air conditioning (A/C) for three months, while the mini ammeter measured the cumulative energy consumption in kWh at interval of 2 hrs. Air conditioning unit was incorporated into the experiment in order to investigate the impact of building envelope materials on the envelope energy efficiency performance. This was done by measuring the energy consumption associated with each envelope model tested.

Along with the Multifunctional Mini Ammeter reading, Lascar EasyLog USB Data Logger sensors were also installed on the outside roof, outside west wall and inside west wall of the models to monitor outdoor and indoor humidity and air temperature. The logger sensors were set to record humidity and air dry bulb temperature information at the time interval of 5 min for 2 days continuous reading with air conditioning cooling.

Moreover, the parameters related to type of external walls and their insulation that influenced the internal environment were identified as Relative Humidity and DBT. For each model, these parameters were tested every 5 minutes for 2 days over a period of 48 hours, both with and without Air Condition. The energy consumption was measured every 2 hours over the 48-hour period for two days in three months when the models were tested with Air Condition. This would enable correlations with the insulation and the energy consumption necessary to achieve energy efficiency.

The data collected for concrete and clay masonry unit walls were analysed and compared to determine which insulation performed the best for each wall. Likewise, the data collected from these roof systems were analysed and compared to determine which insulation performed the best for each roof. Each model was tested for two days with Air Condition and two days without Air Condition. The models were tested at same time period under same external environment conditions. The research parameters were monitored using the Lascar Easy Log USB-2-LCD Humidity, Temperature and Dew point USB data logger sensors.

The energy efficiency performance of each physical envelope model was measured using Multi-functional Mini Ammeter. The U values and area of the components used are shown in Tables 2, 3 and 4.

Table 2. Envelope design alternative A

Load components	Area(m^2)	U-value (m^2K/W)
Roof	98.8	1.208
Wall	99.1	3.021
Floor	77.8	0.860
Window	15.1	3.700
Door	3.9	2.612
Infiltration	-	-

Table 3. Envelope design alternative B

Load components	Area(m^2)	U-value (m^2K/W)
Roof	98.8	0.573
Wall	99.1	3.876
Floor	77.8	0.940
Window	15.1	2.700
Door	3.9	3.129
Infiltration	-	-

Table 4 Envelope design alternative C

Load components	Area(m^2)	U-value (m^2K/W)
Roof	98.8	0.571
Wall	99.1	3.071
Floor	77.8	0.840
Window	15.1	7.370
Door	3.9	4.117
Infiltration	-	-

5. Data Analysis and Results

5.1 Energy Efficiency Performance of Insulated Building Envelope

The average energy consumption data for the models were collected at two hours' interval over a 48 hours (2 days) period. The result shows in Figure 7 that the energy consumption of the models increases as the outside temperature increases and decreases as the levels of the sun exposure decrease. The result further shows that the energy consumption of the models was at the peak between the hours of 10.00 am to 4.00 pm. In these specified periods, the average energy consumption of Model "B" was the lowest with 0.3420 kWh while Model "C" has the average energy consumption with 0.4683 kwh. This indicates higher energy efficiency performance in Model "B" when compared with other two models.

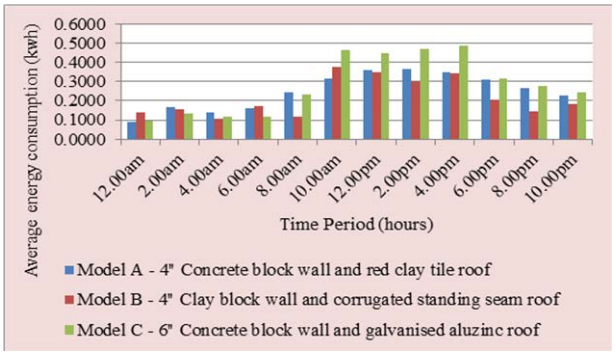

Figure 7. Average energy consumption at two-hour interval for 2 days (48hours)

It can be seen that more energy was consumed between the periods of 6.00 pm - 10.00 pm than the periods of 12.00 am - 8.00 am. This is because the building envelope stores heat energy during the period of 6.00 pm - 10.00 pm, and releases the heat energy during the periods of 12.00 am - 8.00am for cooling and temperature stabilisation. Moreover, the energy consumed between the periods of 12.00 am - 8.00 am was lower due to the absence of solar radiation from sun and low heat gain into the envelope indoor environment. The result further revealed that energy consumption was the greatest in Model 'C" during the day with the highest thermal mass of 150 mm (6") concrete block wall, while Model "A" has the highest energy consumption during the night due the presence of thermal mass in the100mm (4") concrete block wall and red clay tile roof. This means that more energy is stored at night in model "A" than the other two models.

Moreover, given the set indoor temperature at 24 ^{o}C, model B recorded the lowest indoor temperature when compared with other two models indoor temperature profile performance. The Figure 8 shows that, within the peak period between 10.00 am – 4.00 pm, the indoor temperature of model B was the least among the three models tested with about 2^{o}C above the 24 ^{o}C set indoor temperature at its peak temperature. Besides, model B consumed the least amount of energy to cool the outdoor temperature to the indoor temperature of 26 ^{o}C at its peak temperature when compared to the other two models. This suggests better energy efficiency performance of model B. This is because the model was able to reduce the impact of outdoor temperature. In addition, model B continues to maintain the least temperature even after the outdoor temperature and sun radiation started to decline between 8.00 pm – 12.00 am.

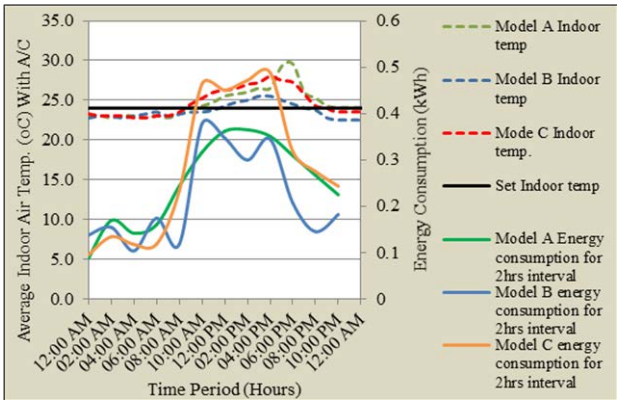

Figure 8. Energy consumption and indoor air temperature

5.1.1 Energy Consumption and Relative Humidity Performance of the Models

Indoor relative humidity represents the percentage of the available energy that has been used for cooling. In model C, the indoor relative humidity was as high as 90% during the peak period of 10.00 am to 4.00 pm, while model A was relatively at 62 % and model B was at 60 % as shown in Figure 9. This means that significant percentage of the available energy from electricity has been used for air cooling in model C as compared to mode A and B where lesser amount of energy was used for cooling. Moreover, given the recommended set indoor relative humidity of 60% with A/C, model B recorded better performance when compared with model A. This suggests better indoor thermal comfort conditions in model B in terms of indoor temperature and indoor relative humidity (as shown in Figure 8).

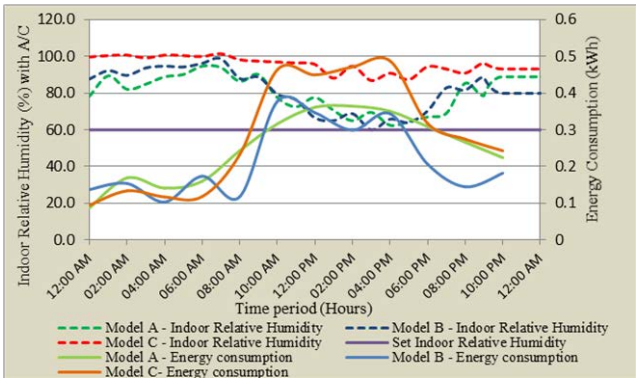

Figure 9. Energy and Indoor relative humidity

Figure 9 also shows the relationship between the outdoor relative humidity and the energy consumption. In this case, the outdoor relative humidity represents the percentage of the available energy for cooling. Figure 10 shows that between the periods of 12.00 am to 8.00 am, the average outdoor relative humidity of the three models was high ranging from 80 % - 100% while the energy consumption rate of the three models was low, ranging from 0.1 to 0.2 kWh. This means that the percentage of the available energy for cooling is very high between the periods of 12.00 am to 8.00 am.

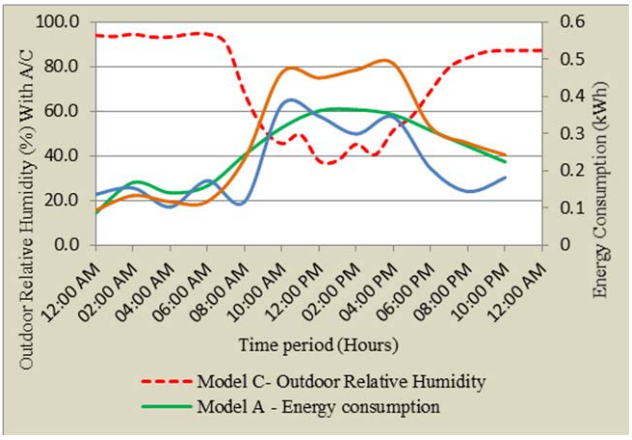

Figure 10. Energy and Outdoor relative humidity

Moreover, as the solar radiation increases, the outdoor temperature increases and the energy consumption also increases, while the outdoor relative humidity decreases. Thereby it reduces the available energy for cooling between the periods of 10.00 am to 6.00 pm. Within these periods, model B recorded the lowest energy consumption, compared to the other two models with 40% outdoor relative humidity. This means that Model B has more energy available for cooling than models A and C. This suggests that model B is more sustainable in terms of energy efficiency and relative humidity performance.

5.2 Energy Efficiency Performance of Insulated Roof Systems

From this data set, average energy consumption over a 24-hour period was computed. The results for the five (5) models in Figure 11 show relatively similar trend-lines for progression of energy consumption throughout the 24hrs time period. For the period 6-12 (morning) consumption consistently increased along exponential trends, peaking between 12 and 15 (midday to mid-afternoon), after which consumption gradually decreases along a gentler inverse exponential trend into the nighttime period, up to approximately 24 (midnight). Between 24 (midnight) and 30 (sunrise) consumption remains constant.

Considering the energy consumption for the 18-24 period, it can be inferred that the models still require a significant amount of cooling after sunset to achieve thermal acceptability of the internal environment. Moreover, with the aid of the thermal mass of the material components of the envelope, heat energy produced by the sun is absorbed and stored by the models during the day and released to the internal and ambient at night when external temperatures drop.

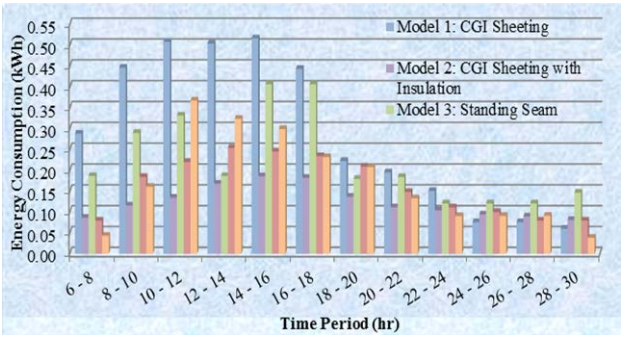

Figure 11. Average Energy Consumptions for Tested Roofing System over a 24-hr period

Besides, the consistency of consumption between 24 and 30 (midnight to sunrise) indicates that the heat source (building envelope) has dissipated most of the heat energy stored during the daytime period and a state of relative thermal equilibrium was achieved, thereby necessitating minimum and consistent function by the air conditioning. Further analysis of data presented in Figure 10 shows that the bulk energy consumption (approximately 60% - 70%) for each model was engaged during the 6-18 period (daytime period) where cooling requirements are most significant. Upon removal of an external heat source (i.e. the sun), the models, were seen to engage the remaining 30% - 40% of the total energy consumed for the 24 hr. period. This is attributable to lower external air and surface temperatures, and the relatively minimal heat gains from the environment.

In the case of the findings displayed in Figure 12 on the model energy consumption performance ranking, it can be seen from Figure 11 that daytime (6-18) consumptions for each model are consistently greater than those for the nighttime periods (18-30). Ranking of each model with respect to efficiency of cumulative energy consumption shows model 2 with corrugated galvanised sheeting roof system and insulation consumed the least energy and emerged the most efficiency. It can be seen in the cumulative energy consumption performance that the roofing systems with insulation (Models 2 and 4) are more energy efficient than their counterparts without while concrete (Model 5) that deemed a relative mid-range performance. Considering the insulated systems, Corrugated Galvanised Iron (C.G.I) (model 2) outperforms Standing Seam roofing system (model 4).

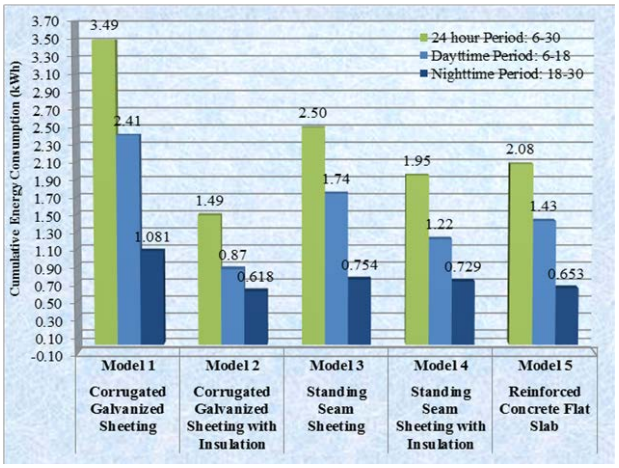

Figure 12. Cumulative average energy consumption for tested roofing systems

In Figure 13, the reverse is shown for the un-insulated counterparts as Standing Seam is proven to outperform the C.G.I. system. Moreover, in terms of the average rate energy consumption (Iwaro, 2016), Model 4 with standing seam sheeting roof system was more energy efficient than Model 2 with insulation. Energy consumption rates during the daytime period can be seen to be significantly greater than at night as the required cooling load is greater in the daytime than at night.

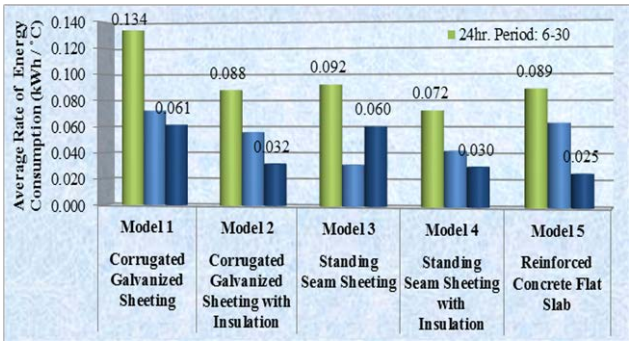

Figure 13. Average Rate of Energy Consumption for Tested Roofing Systems

Moreover, the energy consumption at night is not solely a function of required cooling load, but also minimum operating requirements of the air-conditioning. With respect to their energy efficiency (rate of energy consumption) the insulated roof systems are observed to outperform all other roof systems tested; Standing Seam with insulation (0.072 kWh/°C) followed by C.G.I Sheeting with Insulation (0.088 kWh/°C). Reinforced Concrete Flat Slab is deemed the mid- range performer (0.89 kWh/°C) followed by the un-insulated models, whereas with their insulated counterparts, Standing Seam (0.092 kWh/°C) was rated more efficient than C.G.I. (0.134 kWh/°C). Overall, both C.G.I Sheeting with Insulation and Standing Seam with insulation performed best in terms of impact on the building energy efficiency. These roofing systems can be recommended as effective and sustainable passive strategies for residential building energy efficiency.

6. Discussion

The difference in temperature between the external and internal environment for the tested envelope systems, without the function of air-conditioning is termed the "Baseline Thermal Variation". This value is a direct measure of the thermal efficiency of each building envelope system. The ability of the envelope system limits energy transference from the generally warmer to the cooler environment (along the temperature gradient); thus positively contributing to achieving acceptable levels of thermal comfort for the interior.

The baseline thermal variation is the amount by which the building envelope was able to keep the internal temperature cooler by in comparison to the external during the 6-18 (daytime) period and vice versa for the 18-30 (nighttime) period. Given external temperatures during the daytime within the upper limit or in excess of the acceptable comfort range, a decrease in temperature is deemed desirable.

Besides, ranking of Baseline Thermal Variations and energy consumption rate for the 6-18 (daytime) period for envelope roofing systems show that the insulated models proved the most thermally and energy efficient, with the Standing seam system with insulation (Model 4) followed by the C.G.I. System with insulation (Model 2) being the top performances, affecting the largest reductions of internal temperatures, more energy efficient and thermal acceptability. Reinforced concrete flat slab system (Model 5) was the middle performer, seeming to achieve a balance between the performance of the insulated and un-insulated metal sheeting systems. The un-insulated systems were observed to have affected the smallest temperature differentials, with the Standing Seam system (Model 3) outperforming the C.G.I. System (Model 1), which was the least efficient of all tested systems. The rated relative efficiencies of the envelope roofing systems were found to be in direct correlation, with the findings of the literature review (Sharma 2013) and subsequent theoretical calculation.

Moreover, the building envelope systems would function to limit the transference of energy from the warmer external ambient (presence of the sun) to the cooler interior during the 6-18 (daytime) period. However, during the 18-30 (nighttime) period, when external temperatures drop lower than the internal, the building envelope would function at the same rated efficiency but in reverse, limiting dissipation of the stored heat energy (attributable to the thermal mass of the model) from the internal to the external ambient.

Evidence of the consistent performance of each roofing system is evidenced as follows: for any model the magnitude of internal temperature decrease observed for the 6-18 (daytime) period, is near equal to the magnitude of internal temperature increase observed for the 18-30 (nighttime) period. It can thus be deduced that the insulation utilised for the metal sheeting systems provides beneficial thermal regulation during the daytime and has an inverse effect at night. For rating purposes, the 6-18 (daytime) period is determined to be the dominant efficiency rating of Baseline Thermal Variation, as it is given a heavier significance rating. The significance weighting of the 6-18 (daytime) period out ranked that of the 18-30 (nighttime) period. This is because the magnitude of external temperatures during the day was significantly higher than those at night. This meant that the effect of insulation was more critical towards achieving thermal efficiency during the 6-18 (daytime) period compared to the 18-30 (nighttime) period, where external temperatures are comparatively closer to achieving acceptable values for thermal comfort.

It is very important for passive housings and eco-friendly building concepts such as sustainable envelope, wall and roof passive strategies to be implemented. According to this study, the tested passive sustainable strategies have been found to be effective in the realisation of the building energy efficiency. Prominent among them include: Standing Seam roofing sheet insulated with fibre glass, corrugated galvanised roofing sheet insulated with glass fibre, reinforced concrete flat slab roof, concrete block wall internally insulated with

fibre glass, clay block wall internally insulated with fibre glass, and building envelope systems insulated with fibre glass such as Clay block wall insulated with fibre glass, corrugated standing seam sheet insulated with fibre glass, Terrazo floor finishing, and 100mm concrete slab.

Based on the above analyses, these passive strategies were found to be the most effective energy saving strategies for realising building energy efficiency. According to Sharma (2013), there is over 50% energy saving potentials in building sector. As such, building sector should be considered as a potential sector to address the issues of global energy crisis and climate change. Besides, building worldwide is the main drive of the world economy and account for up to 40% of total energy use. The green building market in both the residential and non-residential sectors was estimated to have increased from $36bn in 2009 to $60bn by 2013 (Zhang and Cooke 2010). This shows that the market potential for green building is high.

It is important to implement sustainable passive strategies established in this study where the residential building energy efficiency, such as sustainable building envelopes, wall and roof passive strategies tested.

7. Conclusion

The findings derived from this study have proved that the utilisation of insulation in residential building envelope in warm humid regions, will significantly reduce heat transfer between the internal and ambient environment, thus reducing the energy demand of the structure and the relative carbon footprint of a structure per unit area over its lifetime. In addition, it has been proved that the utilisation of a flat slab concrete roofing system as opposed to the roof sheeting alternative systems, will be comparatively more cost effective for longer time and yield similar energy demand reductions.

In the short terms, insulated galvanised and standing seam roofing systems are more energy efficient and cost effective, while in the longer terms, flat slab concrete roofing system is more energy efficient and cost effective. Also, this study concludes that the fibre glass fibre insulated masonry walls, roofs and envelope can reduce the energy consumption associated with thermal cooling making structures more energy efficient. The insulated envelope model, walls and roof system recorded the lowest relative humidity, indoor temperature values and hence performed the best in terms of energy consumption. In addition, the energy consumption values of the models tested showed that the fibre glass insulation utilised less energy to achieve thermal comfort.

Hence, these results have showed that sustainable envelope, wall and roof passive strategies such as corrugated standing seam roof sheeting system with fibre glass insulation, corrugated galvanised roof sheeting system insulated with glass fibre, reinforced concrete flat slab roof, and insulated building envelope systems (Clay block wall insulated with fibre glass, corrugated standing seam sheet insulated with fibre glass, Terrazo floor finishing, and 100mm concrete slab) can be used to improve the energy efficiency of the residential building structures in hot dry climatic region. The implementation of these strategies is intended for low cost residential buildings in a hot dry climate.

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Strengthening Geospatial Data Ecosystems in the Caribbean: A Role for Academic Institutions

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Abstract: *Developing and implementing strategies to achieve, monitor, and measure progress toward the Sustainable Development Goals (SDGs) requires robust and functional national geospatial data ecosystems (NGDE). However, most countries in the Caribbean region are yet to achieve a high level of geospatial data ecosystem readiness. Several factors account for this situation including a lack of resources, infrastructure, policies, and standards, and an absence of clear and consistent leadership. In this study, we examined the state of readiness of geospatial data ecosystems in the region, identify the major challenges in achieving functional systems, and propose intervention strategies that can be developed and successfully implemented with indigenous support from academic institutions such as The University of the West Indies.*

Keywords: *Geospatial Data Ecosystems, Caribbean Data Ecosystem Readiness*

1. Introduction

Successful development, implementation, monitoring, and measurement of the 232 indicators for the Sustainable Development Goals (SDGs) are contingent on the availability of current and reliable data through a functional data ecosystem. The United Nations (UN), through the Partnership in Statistics for Development in the 21st Century, initiated the "Informing a Data Revolution" (IDR) project in 2014 to ensure that countries are able to develop such data ecosystems (PARIS21, 2018). An ecosystem is a system or group of interconnect elements formed by the interaction of a community of organisms with their environment (Dictionary.com, 2018). A data ecosystem is focused on the data and related support systems and stakeholders that foster interaction among the various elements of the environment (Heimstadt, Saunderson, and Heath, 2014).

As part of an effort to improve the use of national geospatial data ecosystems (NGDEs) in the Caribbean as a means of developing and implementing strategies in achieving and monitoring the Sustainable Development Goals, the Government of Mexico (GOM), through the United Nations Global Geographic Information Management Americas (UN-GGIM Americas), partnered with the Association of Caribbean States (ACS) and The University of the West Indies (UWI) to improve the NGDEs in the region. The project leaders successfully secured funding by arguing that more than ninety percent of all data needed to achieve the SDGs is geospatial in nature. This allows the project to focus on NGDEs, stay within the scope of the UNGGIM Americas, and significantly benefit the region. The first step of the project was to conduct an assessment of NGDE readiness to identify challenges and opportunities. The results would be used to identify specific needs in terms of human capacity development, infrastructural improvements, and data collection support, as well as to develop strategies for sustainability of NDGEs (UNGGIM Americas, 2016). Sometimes, sustainability failures can occur when there are design-actuality gaps (Heeks, 2002) caused by a lack of contextual understanding. Therefore, it was decided that the UWI, as an indigenous regional institution, would be involved in the design and execution of the project (Iaaly et al., 2016). In 2016, an agreement was formalised among the partners for the UWI to provide technical support to the regional NDGEs on a long-term basis.

This paper reports on research completed on the adaptation and the application of the Data Ecosystem Readiness Assessment Framework (DERAF) developed by the Independent Expert Advisory Group to the United Nations General Secretary (IEAG, 2014) to undertake an assessment of NGDE readiness for Caribbean countries. Based on the results of the NGDE readiness assessment, we propose strategies that can be developed and implemented with support from academic institutions and other international and regional stakeholders toward addressing current geospatial data ecosystem challenges facing the Caribbean.

2. Geospatial Data Ecosystem Readiness Assessment Frameworks

Several frameworks exist for assessing different aspects of data ecosystems readiness. These include, but are not limited to: the Open Data Barometer (ODB, 2016); the Open Data Readiness Assessment (ODRA) (World Bank 2018); various indices developed by the International Telecommunications Union to assess ICT development (ITU, 2017); the Global Open Data Index (Open Knowledge International 2018); the UN E-Government Survey (UN, 2014); the Open Data Monitor (EU, 2018); the Open Data Certificate (ODI, 2018); the Open Government Data Framework developed by the OECD (2018); the Open Data 500 for assessing the value of open data in the private sector (Govlab, 2018); and the Networked Readiness Index (WEF, 2015). However, these assessment frameworks are by design, focused on a few specific aspects of open data ecosystems rather than providing comprehensive assessment rubrics (Welle Donker and Loenen, 2017).

A spatial data infrastructure (SDI) is defined as a framework of technologies, policies, and institutional arrangements that facilitate the creation, exchange, and use of geospatial data and related information resources across an information-sharing community (OMB, 2002). Several assessment frameworks specifically focused on SDIs were developed and applied by many researchers (for example, Fernández et al. (2005), Steudler et al. (2008), Rajabifard et al. (2006), Fernández and Crompvoets (2007), and Holland, Rajabifard and Williamson (2010)). The major limitation of these frameworks is their focus on the assessment of well-established SDIs (Makanga and Smith, 2010). Most Caribbean countries do not have well-established SDIs and therefore, these frameworks are not suitable for assessing NGDEs in this context.

In 2016, a framework for assessing national data ecosystems (DERAF) was developed by the United Nations Development Programme (UNDP, 2016) to assess the readiness of national data ecosystems. The DERAF was used in eight countries including several developing countries: Trinidad and Tobago (Ramlal, 2016), Bangladesh, Moldova, Senegal, Mongolia, and Swaziland (UNDP, 2017). All aspects of the data ecosystem were assessed in a single framework providing an overall strategy to assess the readiness and functionality of national data ecosystems.

3. Adapting the Data Ecosystem Readiness Assessment Framework for NGDEs

The UNDP data ecosystem readiness assessment framework (DERAF) is guided by nine key principles (IEAG, 2014). These principles underscore the need for the provision of current, detailed and reliable data to support timely decision-making and policy formulation whilst protecting the privacy and human rights of individuals, and the national security of countries (see Table 1).

Five major components (namely, Infrastructure, Capacity, Stakeholders, Processes, and Legislation) are fundamental to the success of a data ecosystem (Figure 1). Each component is composed of several sub-components that must work in concert to allow for the provision of current and reliable data (IEAG, 2014).

Data ecosystems function through interactions amongst stakeholders. Stakeholders may be local, regional and international individuals, and organisations and are categorised into: data producers or those

Table 1. Key principles of the Data Ecosystem Readiness Assessment Framework

Key Principle	Description
Data Quality and Integrity	The quality and reliability of data significantly impact the decision-making process. The quality determines fitness for purpose and therefore the level of trust that can be placed on the data. The integrity of the data can be assessed based on the available metadata.
Disaggregated or Detailed Data	The greater the detail of the data, the more localised is the applicability of the data. While recognising the privacy of individuals and national security issues of a country, it is important to provide disaggregated data so that policy and targeted interventions are applied in addressing the challenges at hand.
Current or Timeliness of Data	Technology has made it possible to generate data quickly and more efficiently than ever before. Data needs to be made available in the shortest possible timeframe that affords timely decision-making, planning, and policy formulation.
Openness and Transparency	Data is a national asset in a country and should be shared in an open and transparent way; so that all decisions would be based on the most current and reliable data that is available to these organisations.
Usability of Data	All data that are to be shared must be presented in easy-to-understand formats and with interfaces that allow users to easily access and use the data that is made available.
Data Protection and Privacy	Policies, regulations, and legislation are needed to ensure personal privacy and national security protection while still ensuring that the public good is served
Data Governance and Independence	Data producers need to be well resourced and have the autonomy to collect, analyse, and disseminate data without political interference and influence. The data produced should meet both national and international standards and engender public confidence and satisfaction.
Resources and Capacity	The resources and capacity need to be made available to support data producing organisations to fulfil their mandates. This requires data management systems, information technology infrastructure, human capacity, and legal infrastructure to support this effort.
Data Rights	Human rights need to be at the centre of all considerations with respect to data usage. Measures are needed to minimise the misuse of data to cause harm to individuals. Protection through enacted legislation and appropriate policies and processes is required.

Source: Abstracted from IEAG (2014)

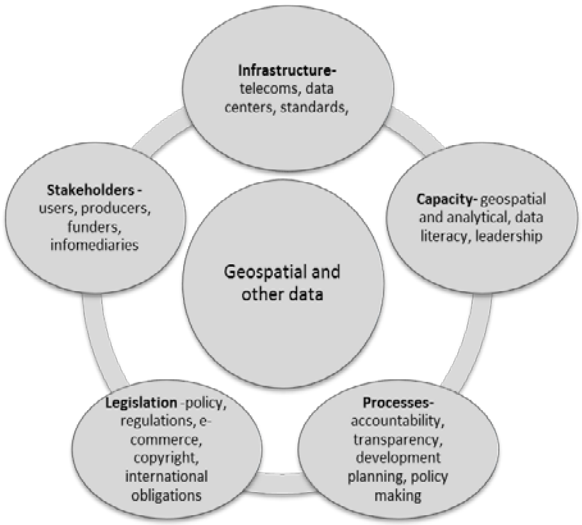

Figure 1. Components of a Geospatial Data Ecosystem
Source: Adapted from UNDP (2016)

involved in data conversion, collection, acquisition, and pre-processing; data users or those involved in data manipulation, analysis and the use of data to support decision-making processes across a number of applications; data "infomediaries," or those who use raw data to generate understandable information that may be disseminated for use by all levels of stakeholders; and data funders, or those involved in paying for, or providing support for, the collection of data (UNDP, 2016).

Fundamental to the functioning of any data ecosystem is the efficient interaction among stakeholders. For example, data producers need to ensure that they meet the needs of data users and infomediaries. Data producers must also be able to convince data funders to provide appropriate levels of resources to support their organisations. The interactions among Caribbean stakeholders are examined in a subsequent section.

A functional national data ecosystem requires capacity in terms of skilled personnel to effectively support the activities of all stakeholders including access to various data products, analytical services, and technical support. Geospatial data organisations must be adequately resourced with funding, human capacity, and ICT infrastructure for data acquisition, processing, analysis, and visualisation and empowered through legislation and policies to interact and participate in the data ecosystem. Additionally, the general public needs to be data literate to consume the geospatial data products as well as have access to the data ecosystem. Data champions are needed to ensure that financial and other support is available to data organisations. Data champions include politicians, professional organisations, heads of organisations, and other individuals who are able to lobby support for data organisations.

In the Caribbean, there is a need for additional resources to sustain existing capacity of experts in key agencies responsible for supporting the data ecosystem (UNDP, 2016, UNGGIM Americas, 2016). Competitive compensation packages, access to high quality academic programmes, local data professional bodies, service providers, and continuous professional development programmes are needed to ensure that professionals stay in the region (UNDP, 2016).

Clear and well-documented processes are needed for the creation, collection, conversion and dissemination of spatial data. In addition, mechanisms are required to receive and respond to feedback and to ensure accountability and transparency throughout the data ecosystem. Furthermore, mechanisms to allow for sharing and data and information access are limited in the Caribbean (UNGGIM Americas, 2016) and are needed to effectively support decision-making (Taylor 2011, McNaughton 2017).

Processes to clearly identify mechanisms for regional, national and public sharing and access are enabled through appropriate regulations, legislation, and policies (UNDP, 2016) and are crucial to the success of a data ecosystem. These mechanisms determine what actions are allowable, under what conditions, and by whom. In addition, the actions that are prohibited are also included in these mechanisms. Many countries have enacted legislation relevant to the implementation of geospatial data ecosystems. These include the sharing, access, and use of data in diverse ways, laws that address freedom of information, data protection, copyright, privacy, national security, and e-commerce (Taylor, 2011).

Furthermore, many Caribbean countries are signatories to international and regional agreements and resolutions such as the UN Fundamental Principles of Statistics (UNSD, 2018), the 2030 Agenda for Sustainable Development (United Nations, 2018), the UN Resolution on the Global Geodetic Reference Frame (UNGGIM, 2018), and the Treaty of Chaguaramas and subsequent agreements (CARICOM, 2018), with obligations to support the data ecosystem. Policies are often used to provide avenues for more efficient operations. For example, data sharing and pricing policies are needed to facilitate interactions amongst stakeholders (UNDP, 2016).

Robust and reliable Information and Communication Technology (ICT) infrastructure is needed to support a functional data ecosystem. For example, telecommunications networks are essential in all the activities associated with the data ecosystem, including real time collection, exchange, and consumption of digital data. Associated with the advent of these technologies is the generation of large amounts of data that must be stored and analysed for use, as well as access to data centres and supercomputing infrastructure.

Software needed to execute diverse analyses, and visualisations (such as tables, maps, charts, reports, websites) are needed to provide the results in forms that are usable by all levels of stakeholders in order to ensure proper access. The use of data requires the provision and adoption of several data standards including: interoperability standards, metadata, quality, and data definitions standards (UNDP, 2016).

4. Methodology

The readiness assessment of the NGDE among Caribbean countries is based on data obtained via an online survey administered to twenty-four heads of organisations and seventeen other members of staff of national organisations as part of the Caribbean project described above. The online survey contained questions that covered all aspects of the NGDE. For example, respondents were asked about existing legislation, regulations, and geospatial data sharing policies as part of the Legislation component of the NGDE. Respondents were required to rate the level of readiness on a scale of 1 to 5 with respect to each sub-component of the NGDE. The agencies targeted in each country are listed in Table 2.

Individual consultations were conducted to address gaps in the data received from the survey. Data obtained through interviews conducted as part of another study with heads of organisations from countries of the Organisation of Eastern Caribbean States (OECS), were also used to supplement the survey (Mohammed, 2016). A document analysis based on existing legislation, regulations, government reports, completed studies, and assessments from regional and international organisations, published material, and Internet resources was completed and used to triangulate the information obtained from the online survey and interviews. Gaps and challenges were also identified. Where possible, findings were verified through further interactions with stakeholders.

5. Results

The NGDEs of fourteen Caribbean countries were assessed. While several of these countries have introduced and used GIS to some extent over the last three decades, and many have initiated the development and implementation of SDIs, only The Bahamas and Jamaica were successful in achieving functional systems. SDI initiatives in Belize, Antigua and Barbuda, Dominica, Grenada, Guyana, Haiti, Suriname, and Trinidad and Tobago have had limited success, with only some components being achieved (UNGGIM Americas, 2014, 2015; Ramlal et al., 2013).

Over the last three decades years, many organisations have contributed to the development of the NGDEs in Caribbean countries; however, these have had limited success. Consequently, efforts to improve NGDEs throughout the region are on-going. At the international level, the United Nations Committee of Experts on Global Geographic Information Management (UNGGIM) was set up in 2011 to provide a forum for dialogue and coordination among member states, and to promote global frameworks, principles, policies, and standards for geospatial data and services.

The UNGGIM established several regional groups including the UNGGIM Americas, with Caribbean countries being part of this group. However, delegates

Table 2. Stakeholders consulted in each country

Country	Organisation	No of Responses
Antigua and Barbuda	Surveys and Mapping Division Department of Environment	3
The Bahamas	Bahamas National GIS Centre	2
Barbados	Lands and Surveys Department	2
Belize	Lands and Surveys Department	2
Dominica	Lands and Surveys Division Planning Division	4
Grenada	Lands and Surveys Department Planning Division	2
Guyana	Lands and Surveys Commission Ministry of Natural Resources and Environment	3
Haiti	Centre National de l'Information Geo-Spatiale	2
Jamaica	National Spatial Data Management Division National Land Agency	4
St. Kitts & Nevis	Lands and Surveys Division Department of Environment	2
St. Lucia	Ministry of Physical Development Surveying and Mapping	4
St. Vincent and Grenadines	Lands and Surveys Department Ministry of Housing	3
Suriname	Management Institute for Land Information and Registration System	3
Trinidad and Tobago	Surveying and Mapping Division Town and Country Planning Division Land Management Division	5

from Caribbean countries were not able to participate because of a lack of funding and support from governments. Financial support from the governments of Mexico and Chile has now made it possible for Caribbean delegates to attend meetings and workshops (UNGGIM Americas, 2018). In addition, the funding also provides for the development of a platform for strengthening spatial data infrastructures in Association of Caribbean States (ACS) countries, the establishment of the Caribbean Platform for Territorial Information for Disaster Prevention (PITCA) in collaboration with CDEMA (2018), and technical capacity building in collaboration with the UWI (UNGGIM Americas, 2016).

Several other recent initiatives by international organisations include: capacity building and establishing geospatial data portals using Geonode supported by the World Bank Group (The World Bank, 2018a), the CHARIM project funded by the ACP-EU Disaster Risk Reduction Programme (CHARIM, 2018), the Climate Change GIS project funded by the United Nations Population Fund (GORTT, 2018), and land registration systems development projects (USAID, 2018).

Previous initiatives by regional organisations include efforts by CARICOM to establish a regional spatial data infrastructure (Wall, 2009), establishing GIS in member countries by the OECS (Yaw Ching, 2016), and the launch of the GeoSUR project in 2007 to provide a geospatial clearinghouse for data for Latin American and Caribbean countries by the Development Bank of Latin American in conjunction with the Pan American Institute for Geography and History (PAIGH) (GeoSUR, 2018). Other efforts in the region include numerous projects completed by agencies established by the CARICOM (https://www.caricom.org), several units of the UWI including Mona Geoinformatics (http://www2.monagis.com/), the Caribbean Open Data Institute (http://caribbeanopeninstitute.org), the Centre for Resources Management and Environmental Studies (http://www.cavehill.uwi.edu/cermes/home.aspx), the Centre for Geospatial Studies (https://sta.uwi.edu/eng/ei/Services.asp) and the the Geospatial Information Research and Innovation (GIRI) Group (http://uwi.maps.arcgis.com/home/index.html). Several national and regional non-governmental organisations exist in the region. One such organisation that has done significant GIS work is the Caribbean Natural Resource Institute (CANARI) (https://www.canari.org). The only professional organisation at the regional level is the URISA Caribbean Chapter. It has been involved in hosting conferences and workshops since 2001 (http://www.urisa.org/chapters/caribbean-chapter/).

Several national and regional non-governmental organisations exist in the region. One such organisation that has done significant GIS work is the Caribbean Natural Resource Institute (CANARI). The only professional organisation at the regional level is the URISA Caribbean Chapter. It has been involved in hosting conferences and workshops since 2001. Reports focused on geospatial issues for specific countries include Jaggernauth et al. (2000), Ramlal et al. (2013, 2014), Blake, (2009), and Raghoebar (2009).

The results of the NGDE readiness assessment are summarised in Table 3. A simple readiness scoring system, similar to one used by Delgado Fernández and Crompvoets (2008) was used for the online survey and includes: (1) little to no development work done, (2) very limited development achieved to date, (3) limited development achieved, (4) good development achieved, and (5) very good development achieved. A total of twenty variables were used in the assessment.

The geospatial data ecosystems of the Bahamas (66) and Jamaica (66) are the most ready, while those of Dominica, St. Lucia, and St Vincent and the Grenadines (34) are least ready. However, it is noted that overall, with an average score of 45, the data ecosystems in most countries in the Caribbean are not well developed and are unable to adequately support the countries in achieving their objectives, which include, but are not limited to, the SDGs. Countries are better prepared in terms of data production, data funding, and meeting international obligations, but are least prepared in terms of availablitity of informediaries, analytics, and capacity for policy making. Similar conclusions were made in several other studies (UNGGIM Americas, 2014, Ramlal, 2016, The World Bank, 2013, 2014, McNaughton, 2017, Delgado Fernandez and Crompvoets, 2008). Detailed discussions on each assessment component are presented below.

5.1 Data Stakeholder

While some countries such as Jamaica, Haiti, and Trinidad and Tobago show good progress in the production of geospatial data, all of the other countries made limited or very little progress (average score of 2.9 out of 5) in the production of such data sets. Several factors impacted data production including: the lack of a modern regional geodetic referencing framework; a general lack of resources to convert, collect, and acquire data, including financial, human, and technological resources; limited funding available to collect data sets at regular intervals coupled with the high cost of data acquisition; the lack of demand for, and capacity to use, available data; and a general perception that geospatial data is not important.

Overall, except for Jamaica, and to a lesser extent Antigua and Barbuda, there has been very limited development of data used and data users in the region. Several factors account for this include: a lack of knowledge of what geospatial data are available from data producers; a lack of metadata for data discovery; difficulties in accessing data because of long delays from data producers in responding to requests; the absence of online data clearing houses for data access; the absence of open access to data; and a lack of literacy and skills in

Table 3. Results of Geospatial Data Ecosystem Assessment for Caribbean Countries

Country	Total(100)	Stakeholders				Capacities				Processes				Policies				Infrastructure			
		Data Producers	*Data Users*	*Data Funders*	*Infomediaries*	*Geospatial*	*Analytical*	*Data Literacy*	*Leadership*	*Monitoring*	*Development Plan*	*Policy Making*	*Knowledge Sharing*	*Legislation*	*Data Sharing Policy*	*E-Commerce*	*Int'l Obligations*	*Telecom*	*Analytics*	*Data Standards*	*Interoperability std.*
Antigua & Barbuda	44	3	3	3	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2
Bahamas	**66**	3	2	4	2	2	2	3	4	3	3	4	4	4	4	4	4	4	2	4	4
Barbados	38	2	2	2	3	2	2	2	2	2	2	2	1	1	1	2	2	2	2	2	2
Belize	41	3	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	1	2	2
Dominica	28	2	1	2	1	2	1	1	1	1	1	1	1	2	1	1	3	2	1	1	2
Grenada	40	3	2	3	2	2	2	2	2	2	1	2	2	2	1	2	3	2	1	2	2
Guyana	52	3	2	3	2	2	2	3	3	2	2	3	3	3	3	3	3	4	2	2	2
Haiti	46	4	2	3	2	2	2	2	3	2	2	3	2	2	2	2	3	2	2	2	2
Jamaica	**66**	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	4	4	3	4	3
St. Kitts & Nevis	46	3	2	4	2	2	2	3	3	2	2	2	1	2	2	2	3	3	2	2	2
St. Lucia	34	2	2	2	1	2	1	2	2	1	1	2	1	2	2	2	2	2	1	2	2
St. Vincent & Grenadines	34	3	2	2	1	2	1	2	2	2	1	1	1	2	2	2	2	2	1	1	2
Suriname	48	2	2	2	2	2	2	3	2	2	2	3	3	3	3	3	2	3	2	3	2
Trinidad & Tobago	44	4	2	3	2	2	1	2	2	2	2	2	2	2	2	3	2	3	2	2	2
Average	45	2.9	2.1	2.8	1.9	2.1	1.8	2.4	2.4	2	1.9	2.3	2	2.3	2.1	2.4	2.6	2.6	1.7	2.2	2.2
Key		*5–Very Good, 4–Good, –Limited, 2–Very Limited, 1–Little to no work done*																			

using data.

The Bahamas, Jamaica, and St. Kitts and Nevis are sufficiently funded to support data acquisition. However, in many countries, funding for data acquisition is negatively affected by a lack of systematic and coordinated strategies for funding data projects, a lack of oversight and priority-setting organisations, and data-producing organisations having little or no control of budgets and income.

With the exception of Barbados and Jamaica, there is very limited, or no capacity for, the provision of value-added data services in the countries surveyed. The overall number of Infomediaries available through organisations, and trained specialists with such capabilities is extremely small in the region as a whole. In addition, there seems to be a perceived lack of need for such services by data-producers and policy-makers.

5.2 Capacity

The geospatial capacity in the region continues to be very limited (UNGGIM Americas, 2014, Delgado Fernandez and Crompvoets, 2008). There is a general lack of technical and human capacities to collect, conduct analyses, and disseminate geospatial data in all the countries surveyed, with the exception of Jamaica. An important consideration is the lack of approved, public service positions for geospatial specialists. This is compounded by uncompetitive compensation packages and employment conditions that are not conducive to attracting the best candidates to government organisations in most of these countries. Additionally, there is a general absence of analytical capacity in many government organisations in the region. There are very few trained personnel to fill regional needs. The second lowest score (1.8) was recorded in this area of assessment. Data literacy also appears to be a major challenge in most countries.

While leadership is reported as good only in the Bahamas, other countries such as Guyana, Haiti, Jamaica, St. Kitts and Nevis, reported limited leadership, and the other nine reported very limited leadership. Existing institutional arrangements of organisations within the Government bureaucratic structures seem to be a cause of frustration. The public service regulations of many countries seem to work against stable leadership in data-producing organisations. In addition, in many instances, there seem to be very few data champions at the highest levels of government.

5.3 Processes

The processes for monitoring and evaluating NGDEs are, at best, limited (average: 2). Several factors may account for this, including the absence of appropriate systems, standards, policies, regulations, and legislation to effectively monitor processes in government organisations. Additionally, there is limited use of quality management systems and inadequate systems to provide for accountability and transparency. The absence

of single, national organisations in each country, with the authority and mechanisms to coordinate data ecosystem development planning with respect to geospatial data, is also a challenge.

There is a lack of clear and well-articulated data policy formulation and adoption mechanisms that is exacerbated by a lack of capacity, resources, perceived authority, and motivation for policy-making by geospatial agencies in most countries. While some countries have had limited success with knowledge sharing, many countries do not have formal mechanisms to achieve this. In fact, there seems to be a lack of perceived need by some organisations, with limited resources allocated to support such activities. As a result, there is very little documentation and institutional memory, and therefore, greater reliance on gatekeepers.

5.4 Policies

Except for The Bahamas, no legislation exists in any of the other countries requiring government organisations to disseminate and share geospatial data at the national level in order to facilitate collaboration, coordinate efforts, and develop policies and standards. In countries where multiple data-producers exist, some duplication of efforts, resources, and authority may exist. Similarly, except for The Bahamas, most countries do not have national geospatial data-sharing policies (Taylor, 2011). Another challenge for many countries is that existing policies are inconsistent across government organisations and may be inconsistent with international obligations such as open government partnership and open data initiatives. Most countries have limited or very limited e-commerce policies. Some countries have enacted legislation to support these activities, while others have not done so to date. The level of success in meeting international obligations in the provision of geospatial data and information varies widely amongst the countries surveyed.

5.5 Infrastructure

Telecommunications services to support NDGEs are not equally available and affordable to all stakeholders across the region. While the services were considered good in The Bahamas, Guyana and Jamaica, all the other countries reported limited or very limited levels of service in this component. In addition, except for The Bahamas and Jamaica, other countries have not developed national data centres. In some instances, countries such as Trinidad and Tobago, where data centres exist, have found that national data centres are very expensive to support and are often underutilised by most government organisations (Ramlal, 2016).

Overall, the analytical capacity of the region is very limited. In fact, the lowest score was recorded for this component of assessment. However, many stakeholders suggested that there is a perception within many government organisations that there is no need for such specialised expertise. In addition, there is a lack of documented standards in many countries. A challenge in implementing such standards is the lack of analytical infrastructure and resources. There is also limited use of data standards including metadata standards, accuracy specifications, and interoperability standards in most countries in the region.

6. Discussion

There are major gaps and challenges in all components of the NGDEs in the Caribbean. However, these gaps are wider in some components: limited data availability, use and users, Infomediaries, and a lack of analytical capacity and infrastructure, very limited monitoring and development planning processes, limited knowledge sharing, and only a few existing data sharing policies and standards.

As part of an effort to support NGDE readiness in the Caribbean, we argue that an academic institution such as the UWI is an appropriate organisation to leverage resources for capacity development, research and other technical services (Iaaly et al., 2016). The UWI has physical presence in most of the Caribbean countries assessed here (www.uwi.edu), and has worked with many international, regional, national and governmental organisations, and many community-based and non-government organisations. It is therefore possible to build appropriate networks and support systems with diverse institutions to address many of the issues identified above. However, it is noted that there are inherent limitations with academic institutions with respect to the extent to which interventions are possible, even in conjunction with other stakeholders.

7. Geospatial Research and Innovation Centre

Given the lack of capacity in the region, many of the challenges and gaps reported in the assessment cannot be easily addressed without intervention and the provision of support to stakeholders, especially in the short term. It is therefore proposed that a regional Geospatial Research and Innovation Centre (GRIC) be established to work with stakeholders in closing gaps and mitigating existing challenges. It is envisaged that the GRIC will be composed of members from academic institutions, the geospatial industry, professional bodies, and organisations from across the region. The UWI, in collaboration with the ACS and CARICOM will provide leadership to the Centre. Initially, academics from different institutions can serve as researchers and innovators on a part-time basis. This can evolve to full-time engagement as the Centre matures.

As a formal organisation supported by major stakeholders, the GRIC would be able to coordinate efforts to secure funding from various national, regional, and international agencies to support research and development works for the Caribbean. This would allow the completion of preparatory work to establish

functional NGDEs and to sustain these systems with high-level support. The Centre could be responsible for coordinating the conduct of appropriate research and developing innovative solutions based on the specific needs of stakeholders. This would include working to develop new policies and legislation, processes, and standards and specifications. In addition, where capacity is lacking, it may be possible to deploy personnel to provide temporary high-level technical support when needed. This may be especially important in times of natural and other disasters. The Centre can work with other institutions on on-going research and development efforts from researchers across the region. These may include but are not limited to the following:

1) Development of Regional Geodetic Infrastructure to Support Geospatial Activities

As part of the Caribbean SDI project supported by the ACS and GOM, fourteen GPS CORS stations have been installed to ensure that all geospatial activities in the region are tied to an international reference framework. The data from these stations will be sent to a dedicated server housed at the UWI, St. Augustine Campus for processing and open online dissemination. Training and technical support will be provided to ensure that regional stakeholders are able to use the results. This particular initiative will ensure that all geospatial data are standardised to a single global referencing system. A regional standard needs to be developed to guide users.

2) Develop Affordable Rapid Geospatial Data Collection Methodologies

Further research needs to be conducted to develop affordable rapid geospatial data collection methodologies to support stakeholders in the region. Previous research includes the use of Unmanned Aerial Vehicles (UAV) (Hunte et al., 2016, Al-Tahir et al., 2011, Baldwin, 2017), satellite imagery (Gilbert, 2015, Helmer et al., 2008, Sonnemann et al., 2016), participatory mapping (De Graff and Ramlal, 2015, CANARI, 2018), PGIS (Baldwin, 2012; DeGraff and Baldwin, 2013; Baldwin et al., 2013, Baldwin and Oxenford, 2014), and crowd sourcing strategies (Haklay et al., 2014, GIRI, 2018). Other voluntary mapping approaches need to be evaluated to support low-cost and rapid mapping of Caribbean countries. These solutions are expected to support more-affordable and frequent data acquisition and maintenance exercises.

3) Creation of a Clearinghouse for Regional Geospatial Data

Open access to digital geospatial data sets is not common in the Caribbean. While some countries (St. Lucia, Dominica, Grenada, and St. Vincent and the Grenadines) have used Geonode and other countries (Jamaica, Trinidad and Tobago, and Suriname) have used other solutions such as ArcGIS (ESRI) online to share data, most of these sites provide access static data. Only a few countries have set up national geospatial data clearinghouses that allow easy data access, avenues for contributing to the creation and maintenance of data sets, and therefore allow stakeholders to benefit from available data sets.

In order to address this challenge, technical support and access to computer resources are made available to data-producers in the region to allow the hosting of clearinghouses, data sets, and other relevant information. Strategies to facilitate the regular upload and maintenance of data sets in the clearinghouse need to be developed. In addition, further research needs to be conducted to identify the most appropriate strategies to develop and sustain national data clearinghouses in the Caribbean.

4) Programme Development for Capacity Building

Most Caribbean countries have limited numbers of well-trained geospatial personnel to support the many activities of NGDEs. A major challenge with training additional personnel is that many migrate or move into the private sector once further training is provided. At present, with the introduction of appropriate education technology solutions at most academic institutions, and the availability of appropriate ICT services to the region (CTU, 2017), it is now possible to develop and make available training modules for online delivery and access. See for example: Spatial Query Lab (2018), ESRI (2018), Geo-for-All (www.geoforall.org), UNIGIS (2018), and the Centre for Geographic Analysis (2018). Several Massive Open Online Courses (MOOC, 2018) and YouTube videos are also accessible as resources to support such efforts.

The availability of several open access software packages and digital data (GeoSur, 2018, GEO, 2018, www.data4sdg.com) for training purposes also contributes to greater affordability by stakeholders. However, online offerings of specialised and regionally-relevant modules to train technicians, specialists, analysts, and managers, need to be developed to meet the particular requirements of Caribbean countries. Agreements may be negotiated with local institutions in the respective countries to support efforts to facilitate the development and delivery of training to stakeholders. This initiative is expected to address several challenges, especially in capacity requirements, which in turn will lead to improvements amongst data stakeholders, change processes, inform policies, and support infrastructural development and maintenance.

5) Building Leadership Awareness and Capacity

The value and benefits of developing robust geospatial data ecosystems are quite significant (Oxera Consulting, 2013, Vershulst and Young, 2017, AlphaBeta, 2017) and are important for supporting efforts towards implementing and monitoring strategies for the

sustainable development of countries (UNGGIM, 2017). Specialised training modules, seminars, and high-level meetings and forums targeted to leaders of geospatial organisations and high-level government officials, need to be developed and delivered at national and regional levels, where possible. It may be argued that national political leaders are more likely to become data champions if they appreciate the benefits and value of NGDEs.

The GRIC can serve as a vehicle to secure assistance from organisations such as The World Bank (2018b), the UNGGIM Academic Network (http://unggim.academicnetwork.org), the Group for Earth Observation (GEO, 2018), the Open Source Geospatial Foundation, (OSGEO, 2018), and the Global Spatial Data Infrastructure Association (GSDI, 2018) to provide, where appropriate, financial or technical support for these initiatives.

While several of these organisations and programmes have existed for many years, there has limited effort to secure such support. This may be due to several factors, including a lack of awareness by stakeholders, a lack of adequate numbers of geospatial personnel to benefit from such support, and a perceived lack of importance by political leaders and managers. In addition, much of the funding received in the region is for short-term projects. Most interventions are therefore, not sustainable. Mechanisms to provide sustained and indigenous support through the GRIC may prove to be more successful (Heeks, 2002).

6) Geospatial Best Practices Clearinghouse

Knowledge sharing by geospatial practitioners and academics within and among Caribbean countries is very limited; therefore, the GRIC should develop a Clearinghouse to provide access to appropriate material and publications to all stakeholders. This material should include the latest developments in technology, standards, specifications, hardware, software, mobile applications, legislation, policies, and processes. Blogs, webinars, newsletters, and technical publications should be made available to Caribbean practitioners online. Support from other academic networks and professional organisations such as the UNGGIM Academic Network (http://unggim.academicnetwork.org), the Academic Network of the Americas (http://redacademica.org), URISA (http://www.urisa.org), and other organisations, would be sought in this regard.

8. Conclusions

Most Caribbean countries require assistance to improve the functional readiness of their NGDE to support the development, implementation and monitoring of strategies to achieve the SDGs and other national priorities. Several major challenges and gaps exist and require intervention from various internal and external stakeholders. The UWI, in collaboration with other organisations, can play a significant role in influencing change by providing indigenous input to mount a coordinated effort to develop and deliver much-needed support and services to address many of these issues.

While such initiatives would reap real benefits, convincing organisations in the region to work together will require much effort. Academic institutions will benefit in diverse ways from the implementation of the initiatives discussed above. Improved functionality and awareness in the region would likely lead to cost-savings, increased employment of geospatial personnel, and greater demand for further training and professional development. It is necessary and feasible to address many of the issues plaguing NGDEs in the Caribbean using available indigenous talent and resources.

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Automated Identification of Vehicular Accidents from Acoustic Signals Using Artificial Neural Networks

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Abstract: *As a consequence of its critical impact upon societies, the occurrence of vehicular traffic accidents is a globally studied phenomenon. Much effort has been directed towards the understanding and identification of causal factors, with the intention of minimising the occurrence. In a related area, the development of methods for the identification and classification of vehicles has also received necessary attention. However, little work has been done on the development of methods for the identification of motor vehicle accident occurrences. Thus, this work sought to develop an automated system for the identification of motor vehicular accidents. It utilises an artificial neural network approach to estimate the probability of occurrence, based on recorded acoustic signals. More specifically, it first characterises accident acoustic signals by 9 selected signal features, in both the time and frequency domains. It then develops a dual layer artificial neural network, which accepts as its input the 9 characterising signal features and as its output calculates the probability of occurrence. The system was built and tested in the MATLAB environment, utilising 22 sample signals in the design phase and a further 53 for testing. An evaluation of the system found it have an accuracy of 86% and a precision of 76%, with a 100% identification of actual accidents. Additionally, it was found that the system prioritises the time domain signal features over those of the frequency domain, in the identification process. These results validate the structure of the system used and demonstrate its potential for real-world applications.*

Keywords: *Vehicular accident detection; artificial neural network; signal processing; time domain; frequency domain; acoustic signals*

1. Introduction

Road safety is a global concern. The World Health Organisation reports that there were 1.25 million road traffic deaths in 2013 alone (WHO, 2017). The impact of this phenomenon is far reaching and many countries have been aggressively seeking to counteract it. Accordingly, much effort has been directed into the research of various aspects of accident occurrences. Many researchers have investigated the causal factors in the occurrence of accidents (de Ona et al., 2013; Dadashova et al., 2016; Mujalli and de Ona, 2011). The primary goal in most of these instances has been to understand what causes accidents, with the intention of minimising their occurrence. Similarly, other researchers have sought to develop methods for identifying road conflicts (Cafiso et al., 2017) or for assessing the likelihood of an accident occurrence in a particular location (Li et al., 2017). Further, some investigators have developed methods for reconstructing accidents, based on data gathered from the scene of an accident (Li et al., 2017; Evtiukov et al., 2017). Yet further, some researchers have developed methods for the determination of the level of injury of a vehicle's occupants, upon the occurrence of an accident (Kononen et al., 2011; Delen et al., 2006).

A related field of study of particular interest, is the detection and identification of motor vehicles. Several researchers have used vibration and/or acoustic data, coupled with signal processing techniques, to develop effective vehicle recognition and detection methods. Wu et al. conducted significant work in this area and were among the first to utilise a frequency spectrum principal component analysis approach for vehicle sound recognition (Wu et al., 1999). George et al. (2013 a) also used vehicle sound signals to detect and classify vehicle types in an Indian context. They developed an algorithm that processed the acoustic data and allowed for vehicle detection, then used a neural network for classification. George et al. (2013 b) have advocated for the use of wavelet analyses in their detection and classification techniques. Yet in another case, Ozgunduz and Turkmen (2010) designed a vehicular classification system using a Mel frequency Cepstral coefficient algorithm and extracted features of the acoustic data which was then reduced by using a vector quantisation algorithm.

Despite these efforts, little work has been done on the development of methods for identifying the actual occurrence of accidents. Currently, accident identification primarily relies on visual recognition. In many cases, this is based on reports by person(s)

involved in the accident or by bystanders. In others, the analysis of real time traffic camera data allows for accident identification. However, this is limited by several environmental factors such as the state of the vehicle's occupants, the presence of bystanders and their willingness to assist, lighting conditions and the level of monitoring of traffic camera data. In-vehicle collision systems provide an effective alternative. However, this too is limited by the make and model of the vehicles involved and the level of support system architecture in a particular location.

In light of this, this work presents an automated approach for the identification of vehicular accidents. It utilises a combination of an artificial neural network and some selected signal processing techniques, to identify the occurrence of an accident based on acoustic signal data. Such an approach can be incorporated into existing traffic management systems or form the basis for a standalone system. In so doing, it can facilitate faster response times to critical accidents and increase the chances of saving an injured occupant's life.

2. System Design

2.1 General Approach

By virtue of the phenomenon's nature, there are a number of attributes that can be considered and examined in seeking to detect the occurrence of an accident. Some of these include visual imagery, vibration data, scents/odors and sounds. However, not all of these features are as easily quantified and recorded, and the level and type of information provided by each feature varies significantly. Notwithstanding this, the work done on vehicle detection methods suggests that acoustic data samples provide a wealth of information that can be used for accident identification, if processed correctly. In keeping with this, this work sought to use acoustic sample data as the primary data source for a proposed identification system.

Figure 1 shows a typical acoustic sample recorded for an accident. It can be seen that the accident is defined by a distinct rise in the amplitude of the acoustic signal and for a short period of time. This pattern repeats itself for most of the acoustic samples examined. Given the repetitive nature of the pattern, the use of an artificial neural network was considered to be a feasible approach for identifying its occurrence within a recorded signal.

2.2 Identification of Signal Features for Characterisation

The efficacy of neural networks in pattern matching and identification, has been steadily increasing over the past few years. Two key contributing factors have been the increasing computational power of computing systems and the growing access to more detailed data sets. However, despite this increase in computational power, there are still some evident limitations, i.e., the processing of large data sets by a neural network does present a challenge for most standard computers. For instance, the car accident acoustic sample of Figure 1, which is 2.5 seconds long and sampled at 44.1 kHz, contains 110,250 data points. Attempts to directly utilise this sample in an artificial neural network, have proven to be memory-intensive for a current, standard desktop computer. Accordingly, an alternative approach to utilising the acoustic data in an artificial neural network had to be developed.

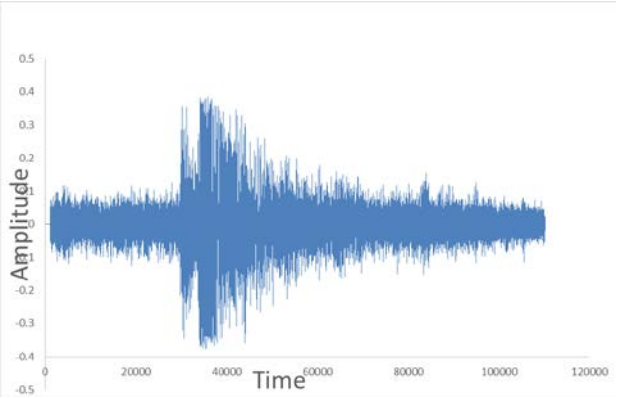

Figure 1: Sample of accident acoustic data signal – Amplitude versus Time

As an alternative, it was considered that a signal can be represented in both the time and frequency domains. In keeping with this, either presentation of the signal presents unique aspects of the data. Accordingly, the signal can be characterised by the features of either representation, or a combination of both. Thus, the authors posit that if a unique subset of the signal's features in both the time domain and the frequency domain are identified, such that these features are influenced by the occurrence of an accident. Then, this subset can be used to identify the presence of an accident. Key to this proposition is that the features must vary specifically with the occurrence of an accident.

In so doing, they provide both a basis set for representing the accident signal and for assessing the presence of an accident within a wider signal. However, it is unclear which of the many signal characteristics in the time or frequency domain would be critical in assessing the occurrence of an accident. In light of this, a number of well-known signal features and characteristics were examined, to determine their level of influence in accident identification from acoustic sample data. Table 1 gives the list of the features assessed in this work.

3. Data Sets and Data Acquisition

For the purposes of training and evaluation of the system, acoustic samples of various accidents were required. However, due to limited funding availability, the recreation and/or simulation of real time vehicular accidents were not feasible in this work. Alternatively,

existing accident data sets were used. These comprised of data obtained from various crash intuitions namely Insurance Institute for Highway Safety (IIHS) and European New Car Assessment Programme (Euro Ncap). Both institutions conduct crash testing on a wide range of vehicles and various types of collisions (e.g., head-on, and small overlap). The sampling frequency for audio capture used in these data sets, was given as 44100 Hz for both institutions. The distance from the microphone to the point of impact was not given; however, it was known to vary for both. The acoustic data was converted to a wav format from these mp3's for greater accuracy of representation. The vehicle type and accident details for the various samples examined, are presented in Table 2.

Table 1: Acoustic signal features examined to determine effectiveness in accident identification

Signal feature	Domain
zero crossing rate	Time
short time energy	Time
Fundamental frequency	Frequency
Bandwidth	Frequency
Signal amplitude mean	Time
Signal power	Time
Frequency envelope	Frequency
Variance	Time
Spectral crest	Frequency
Spectral flux	Frequency

Table 2: Types of vehicles for which data was acquired

	Micro-car	Small	Midsize	Large
small overlap		√		√
moderate overlap	√		√	
front			√	
side crash	√		√	
trailer underride		√		√
head on			√	

As opposed to one type, various types of collisions were used to ensure variability in the accident features examined. The aim of this approach was to increase the system's likelihood of identifying a random accident. A total of 45 vehicular accident samples was used in the development of the system.

Additionally, simulated accident data was obtained from a test rig that was setup for the purposes of the work. The test rig consisted of a weighted automobile front bumper, suspended in mid-air by a pulley system. The bumper was lifted to a height of 12 feet and then allowed to fall and strike a metal sheet, which was fitted with an accelerometer. A microphone was positioned 10 feet away from the drop site, to record the acoustic data. The data was recorded at a sampling rate of 44,100 Hz. A picture of the setup is shown in Figure 2. Some of the amples recorded here were used in the identification of the set of key signal features. Additionally, acoustic samples taken of a jackhammer in operation and of random noises were also recorded for use in assessing key signal features.

Figure 2: Image of simulated accident testing setup

4. Results and Discussion

4.1 Identification of Key Signal Parameters

The signal features presented in Table 1 were assessed for all of the test signals previously mentioned. Various plots were made to examine the performance of each characteristic. The results obtained here were used to determine which characteristics were most suitable for classification of an accident. Figure 3 shows the plot of normalised mean signal amplitude against signal variance.

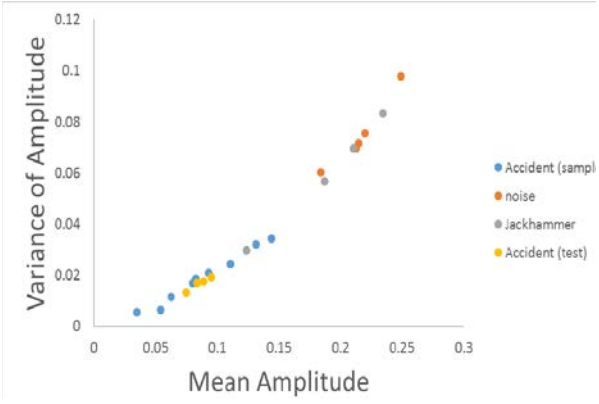

Figure 3: Pot of mean amplitude vs. variance

It can be observed from the figure that an accident is easily characterised by the variance of the amplitude time plot. The variance of the accident signals is found to be lower and exhibits less variability than the other signals examined. An examination of the normalised, mean amplitude shows that for an accident signal, the values are much lower than the other signals considered. This is due to the fact that accident signals contain localised points of very high amplitude, with the remaining portion of the signal having significantly lower values. On the contrary, noise signals generally do not have notable localised peaks and consequently their normalised means are higher. Accordingly, both features are suitable for characterisation.

Figure 4 illustrates the changes in the fundamental frequency and the zero-crossing rate of the signal. From the figure, it is evident that the values of the zero-crossing rate are much higher for both sets of accident signals, as compared to other signals considered. Accordingly, this is a suitable signal feature for characterisation. Conversely, the fundamental frequency demonstrates a high degree of variation and does not show any specific relationship for the signals considered. In keeping with this, the fundamental frequency serves as a poor characteristic and its use would lower the efficacy of the system.

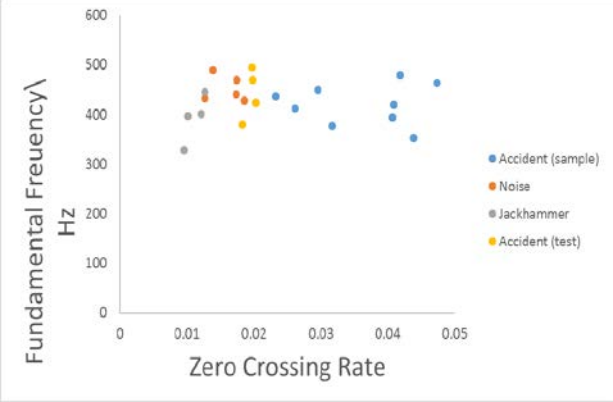

Figure 4: Plot of zero crossing rate vs. Fundamental frequency

An examination of the bandwidth values in Figure 5, shows that it is difficult to differentiate an accident signal from those of the other signals considered. Accident signals have wider bandwidth ranges than the other signals, making characterisation difficult. Conversely, accident signals can clearly be distinguished by the spectral crest values. The spectral crest values for both sets of accident signals are visibly lower than the other signals considered. Accordingly, the spectral crest was selected as a feature for characterisation, while bandwidth was not.

An examination of Figure 6 shows no clear relationship or correlation between the occurrence of an accident and the maximum energy or the energy flux. These two signal features are dispersed through a large area, and hence attempts to use them for accident characterisation may introduce some error into the system. Consequently, both parameters were not included in the final subset used to develop the system.

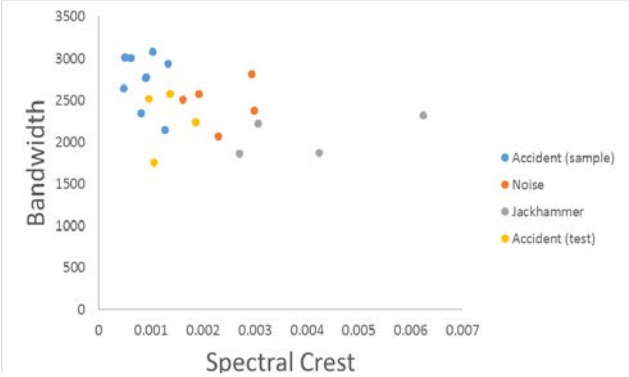

Figure 5: Plot of bandwidth vs spectral crest

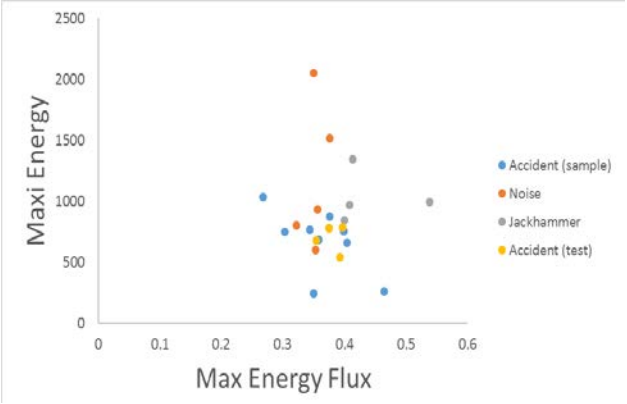

Figure 6: Plot of energy flux vs. Maximum energy

Figure 7 displays the frequency envelopes of the accident and noise signals tested. The signals have been converted into the frequency domain using a fast Fourier transform. An analysis of the graph shows a distinct difference between the noise signal (blue) and the accident data (black). It can be seen that the frequencies present within the accident signals are more stochastic as compared to the noise signals. Additionally, the amplitudes of the frequencies that are present in the accident signals are larger than those of the noise. Accordingly, the frequency envelope was chosen as a feature for accident characterisation.

4.2 Network Development and Architecture

Based on the previous analysis, 9 signal features were identified for the characterisation of accident signals. The features include both time domain and frequency

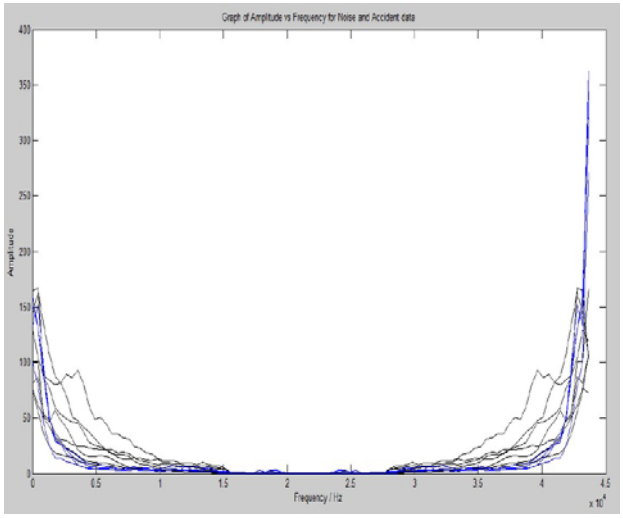

Figure 7: Frequency envelope of various acoustic events

domain identifiers. The time domain features selected were the energy flux, mean amplitude, power, zero crossing rate and variance; whereas the frequency domain features include frequency envelope, bandwidth, spectral crest and variance. In so doing, this allows for the reduction of an accident signal having 110,250 points to 9 characteristics. Figure 8 shows the sequence of computational steps within the final system.

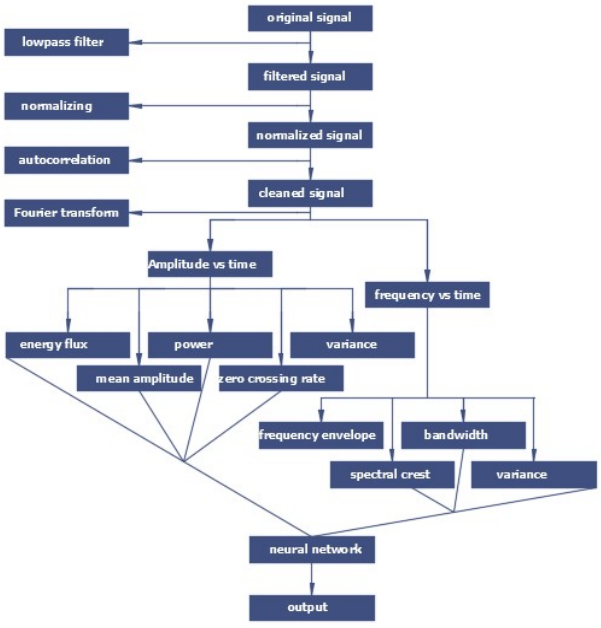

Figure 8: Final system architecture

The development and subsequent analysis of the network's performance was done using MATLAB 2015. This process entailed two primary decisions: a determination of the number of layers in the network and a determination of the number of neurons required for accurate functionality. The previous analysis indicated that the characteristics of an accident signal are not linearly separable. In keeping with this, a multilayer approach was considered to be more suitable. More specifically, a dual layer configuration was implemented, with a hidden layer containing a linear function and an output layer.

Figure 9 shows the final architecture of the neural network. The batch training method was selected as the basis for training the network, using a sample set of 22 signals. This was implemented with randomly determined batches, using a gradient descent algorithm via the MATLAB interface. This approach minimises the loss function as a means of adjusting function weights and improving the network performance. MATLAB subsequently validates the network with a subset of samples.

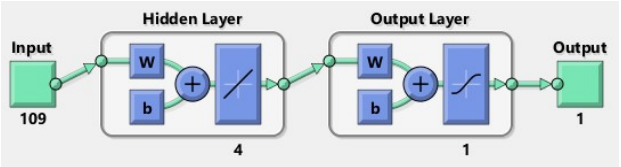

Figure 9: Final architecture of the neural network

The determination of the most suitable number of neurons was effected via the pruning approach. The proposed sequence of computational steps in Figure 8 was implemented using a test network having 11 neurons in the hidden layer. This test network was trained and validated as previously discussed. Subsequently, its performance was assessed via the examination of key network characteristics. More specifically, the root mean squared error (R^2 value) relative to a set target value was calculated for the test network, which was indicative of its ability to observe trends.

Nine other test networks were subsequently developed, using a different number of neurons in the hidden layer, ranging from 10 to 2 neurons. Each test network was trained, validated and assessed in a manner that was identical to that of the 11-neuron network. Three of the test networks were found to have R^2 values of 0.999, indicating the ability to accurately differentiate between a car accident signal and the other test samples. Using Ockham's razor principle, four neurons were selected as the most suitable number of neurons to be used in the network. Accordingly, the final system architecture consisted of 2 layers with four neurons in the hidden layer. This system is such that 109 points are inputted based on the 9 characterisation features and a probability value is outputted.

4.3 System Performance

The system was tested using a number of new data sets, i.e., signals that had not previously been used in the

development and training of the system. These data sets consisted of 16 car accidents signals obtained from the Insurance Institute of Highway Safety (IIHS), 7 simulated accident signals, 12 noise signals, 9 sample signals of impact strikes on different materials, and 9 other sample signals of noises likely to be recorded on the roadway (e.g., emergency sirens and jackhammering). Of the 53 tests on the system conducted, Figure 10 presents the results of 36 outputs of the network. Table 3 presents a confusion matrix for the predictions made by the system.

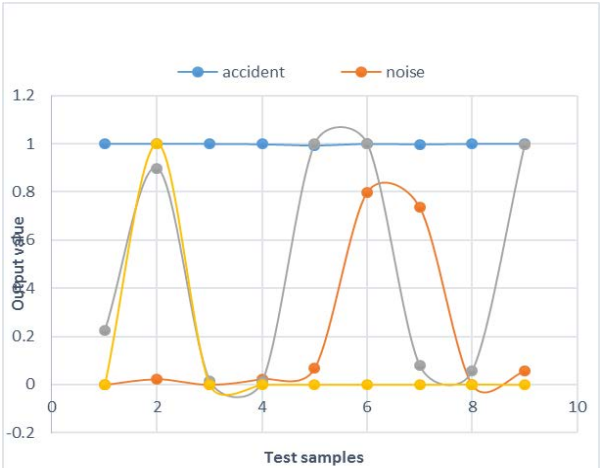

Figure 10: Results of Classifications– System Output for Acoustic Data

Table 3: Confusion matrix for predictions made by system

	Predicted: No accident	*Predicted: Accident*	
Actual: No accident	*23*	*7*	*30*
Actual: Accident	*0*	*23*	*23*
	23	*30*	

In keeping with Table 3, the following performance criteria can be evaluated:

Accuracy = (true positive + true negative)/total = 86%
True positive rate = True positive/ Actual positive = 100%
False positive rate = False positive/ Actual no = 30.4%
Precision = True positive/ predicted yes (when it predicts yes, how often is it correct) = 76%

4.4 System Behaviour

In examining the system, some key relationships and behavioural trends were identified. One of these concerns the issue of the incorrect classification of the impact strike signals. It was noticed that impact strike signals where a high force was used, had a higher chance of being classified as an accident. This false positive classification occurred both with strikes to steel and polyethylene materials. Although the natural frequencies of both steel and polyethylene of similar masses contrast greatly, both were still classified as a car accident. This suggests that the neural network gives precedence to characteristics in the time domain, as opposed to those in the frequency domain. This is likely a consequence of the fact that the features in the time domain display a greater correlation with the occurrence of a car accident, than those in the frequency domain.

A second key behavioural trend concerns the nature of the probability values obtained. The outputs for the tests conducted showed a range of values between 0.7 - 1.0, to predict the occurrence of an accident. Conversely, probabilities of 0 - 0.21 were found in cases where the system suggested that an accident did not occur. These ranges of probability values allowed for clear interpretations to be made on whether or not an accident did occur. This result was a consequence of the sigmoid function in the hidden layer. Its insertion reduces the probability of having instances where the neural network predicts a 50% chance of the occurrence of a car accident. These results serve to validate the structure of the system used.

5. Conclusion

This paper presented the work done on the design of an automated system for identifying vehicular accidents, using acoustic signal data and utilising an artificial neural network approach. The system was based upon the identification of key signal features that were used to characterise an accident acoustic signal. A total of nine signal features was identified with five being time domain features and four of the frequency domain. These features allowed for large data signals to be represented by a much smaller data set; in so doing significantly decreasing the computing requirements of the system.

The system was designed and tested using MATLAB. In designing and training the system, 22 signals were used. These signals consisted of actual accident recordings, simulated accident data and other recorded acoustic data. The system was subsequently tested using 53 additional signals that were not used in the design phase. An evaluation of the system's performance found that it had an accuracy of 86% and a precision of 76%, with a 100% identification of actual accidents. Testing also served to identify that the system prioritises the time domain signal features, due to a greater correlation between changes in these values and the occurrence of an accident.

With correct incorporation into a wider traffic management and/or emergency system, the approach presented here has the potential to significantly increase the likelihood of identifying vehicular accidents. In so doing, it can increase the response time of emergency personnel and increase the potential for saving lives.

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Employee Perception of the Impact of Occupational Health and Safety Management on Organisational Commitment: A Case Study of an Energy Sector Organisation in Trinidad and Tobago

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Abstract: *Occupational Health and Safety (OHS) is one dimension of the work environment which can impact employee commitment to organisations. A poor work environment can lead to high attrition rates, employee unrest and disruption in production. A cross-sectional case study was conducted using 31 non-managerial employees identified in the Petroleum Sector in Trinidad and Tobago. Data was collected using a virtual snowball sampling technique, utilising an online questionnaire which combined the Survey of Perceived Organisational Support (SPOS) and the Organisational Commitment Questionnaire (OCQ). The data was then analysed using Spearman's Correlation. Findings revealed that employee perception of managerial OHS support practices had a significant and positive correlation with affective commitment ($r_s(22) = 0.4$, $p = 0.03$). This indicates that managerial OHS support would have an impact on employees wanting to remain employed in the organisation. It was concluded that the prioritisation of occupational health and safety in the workplace facilitates employees' organisational commitment. It is therefore critical to recognise that the workers, who perceive that their health and safety are given sufficient consideration by management, will demonstrate strong emotional attachment and therefore commit to the organisation.*

Keywords: *Employee Perception, Occupational Health and Safety Management, Organisational Commitment*

1. Introduction

There is a growing trend in Trinidad and Tobago where managers continue to neglect local occupational, health and safety standards resulting in their employees engaging in various protest actions. The Prisons Officers' Association filed a complaint in the Industrial Court citing Occupational Health and Safety (OHS) infractions including a lack of emergency/evacuation plans being put in place for prison officers as it relates to dealing with fires and riots, poor ventilation and toilet facilities along with the lack of firefighting equipment and inadequate lighting. Another breach was the increasing overcrowding of prison cells at the remand yard of the Golden Grove Prison Arouca and these were cited as issues that were being overlooked by the relevant government authorities (POA versus State, 2015) Similarly, Trinidad Offshore Fabricators (TOFCO) workers launched a protest outside the main gate of the TOFCO compound at the Labidco Industrial Estate, citing serious health and safety issues that were being ignored by the company (Dowlat, 2016).

After three years of complaints from employees about health and safety concerns, the offices of three (3) departments of government were shown, by the court, to be unfit for office use and were shut down. Among the hazards listed were no proper fire escape, air pollutants, unsafe and badly functioning escalators. The workers of the Water and Sewage Authority (WASA) together with the Public Services Association President (PSA), shut down the authority's water treatment plants causing a temporary disruption to the water supply in North and East Trinidad as part of a protest action as a result of management's failure to comply with OHS standards as it related to worker safety (Asson, 2016).

Furthermore, it is important to note that the Water and Sewage authority had previously come under criticism for ignoring similar OHS standards in 2010, when workers complained that they were not given adequate accommodations, personal protective equipment and sufficient security when assigned to high crime areas, in which they were subject to attacks by residents of said areas. Such events prompt further investigation into how management's performance in maintaining OHS standards may affect employees' commitment to their companies.

The preceding paragraphs provide an indication of the impact of OHS practices on organisations. This paper reports a study that investigated the relationships between employee perception of OHS support practices of a local oil company and their levels of *Affective*, *Continuance* and *Normative* to the organisation. The specific objectives of the study were to identify the

perception of the employees on the managerial OHS support practices and to determine the type of commitment which is to be expected by the organisation based on the level of OHS support that the management gives to the employees.

This paper explores the literature to identify the variables which affect employee commitment to their employers. The methodology utilised in conducting the research is then described, followed by a summary and discussion of the data collected via a survey of the Energy Company. The paper is then concluded by the cataloging of inferences gleaned from the literature based on the findings of the survey.

2. Literature Review

Renowned lawyer in the field of labour and employment law, Bill Phelps, posits that it is irresponsible for employers to disregard the importance of worker health and safety complaints. This can be a precursor for incidents of serious destruction and avoidable calamity. Within the employment setting, such indifference can lead to lost productivity from aggrieved workers or peaceful or even violent strikes. He further suggests that employers who have access to feedback on the matter from their employees, but fail to implement corrective procedures, have missed a tremendous opportunity to avoid catastrophe and to show to his/her employees that he/she cares about their wellbeing (Van Eeden, 2016).

If employees' concerns for safety are ignored, eventually the employees will stop reporting safety issues which will eventually lead to a catastrophic incident. The social exchange theory kicks in, as employees who feel cared for and respected, will continue to care for their place of employment.

2.1 Social Exchange Theory

Historically, the motivation behind the attitudes and behaviours exchanged between human beings has been explained, in detail, by the Social Exchange Theory. Eisenberger et al. (1986, 1990) expounded on this theory by providing evidence which revealed that the perspective of social exchange and what is described as "the norm of reciprocity" that also assisted in explaining aspects of the relationship between the organisation and its employees. Based on their research, it was concluded that employees formed ubiquitous perceptions about the intentions and attitudes of the organisation in which they worked toward them. And these perceptions were based on the various policies and procedures enacted by agents of the organisation e.g. managers and supervisors.

The tendency for employees to personify the organisation led to the theory of social exchange being applied to the relationship between the personified organisation and its employees. With continued investigation into this situation, researchers were then able to precisely predict that positive actions aimed at employees, by the company, significantly contributed to the emergence of high quality exchange relationships that created opportunities for employees to reciprocate in positive and beneficial work behaviour.

Moreover, the social exchange theory revealed that employees' level of commitment and their performance as it relates to the execution of their work which was hinged on the degree to which they perceived that they were reaping the rewards of the company's activities. This condition has been highlighted as perceived organisational support and is the condition where employees' perception of the extent to which the company shows appreciation for worker contributions, shows genuine care about their well-being, and employees' feeling that the positive initiatives being performed by the company, have been voluntarily performed by the organisation.

This means that organisational support represents a situation where the company's core values and care for the overall well-being of employees are evidenced by such qualities that significantly reduce worker unhappiness. Hence, it was ultimately determined that "perceived" rather than "provided" organisational support altered the attitudes of employees towards the work and also, the company itself.

2.2 Managerial OHS Support Practices

Investments that catered for health practices based on the social exchange theory and the principle of reciprocity lead to an increase in employee health and well-being, which then lead to an increase in employees' attraction and commitment to the organisation. Perception, as defined by Turunc and Celik (2010) is the process of reception, interpretation and organisation of information emerging from the surrounding environment towards the individual. They further highlighted that perception should be created in a positive way, to make certain employees perform their duties in a way that benefits and/or favors the organisation.

Amponsah-Tawiah and Dartey-Baah (2011) posited that OHS characterised not only the physical well-being of the employee but also the emotional and mental prosperity of the worker as well as pertaining to the performance of his/her work. Therefore, occupational health and safety highlights an essential topic of interest, as it has the potential to impact positively on the achievement of organisational goals. Brown (1996) and Pagell et al. (2013) made a critical point that occupational health and safety should be given more emphasis in the workplace, by management, in conjunction with cost, flexibility, innovation, quality and delivery. Many governments of contemporary society have made it mandatory (usually in the form of an OHS Act) that employers implement some sort of OHS management system in their organisation. Also globally, the majority of workers demand the latter as a basic human right.

OHS has been recognised as an area of significant importance, and it has been given increased attention at both the national and international levels. At the organisational level, occupational health and safety cannot be taken for granted. The entire organisation, not just the safety units, must actively take part in ensuring the health and safety of every worker employed at the establishment. In order to achieve operational success, operational literature suggested that instead of managers giving OHS more attention over production, they should use OHS as a precursor. Hayes et al. (1998) suggested that site and job safety, co-worker safety practices, managerial safety commitment, supervisor safety practices, and safety programs/policies, are examples of important issues in the workplace. Safety can be a very complex and dynamic problem not just for management, but for society at large. Steenkamp and Van Schoor (2002) emphasise that OHS must be given ample attention especially by top management.

When it comes to critical aspects of safety interventions, management commitment has an imperative role. When managers show that they have both positive and supportive attitudes towards the safety of their employees this demonstrates that they are committed to the health and safety initiatives set forth by the company's health and safety policy. Yule et al., (2007) revealed that when employees believed that management took diligent action in ensuring their overall health and safety, the amount of accidents occurring in the workplace decreased significantly. Ali et al., (2009) added further to this point and stated that when managers exhibited positive safety practices, it plays an effective role in reducing workplace accidents and injuries.

Supervisors are considered to be one of the most important elements when it comes to health and safety management; usually because it is their responsibility to ensure compliance with safety measures and encourage safety participation among employees. Yule et al. (2007) observed that workers abided by the safety regulations and procedures when they believed that their supervisors' actions were not only fair, but in accordance with the company's OHS policy. Supervisors' safety practices were outlined as the following activities:

- Supervisors keeping track of unsafe practices
- Supervisors acknowledging employees who adopted safe work practices.

In management studies, organisational commitment has been intensively researched. Organisational commitment has been linked to organisational citizenship behaviour as well as work aversion behaviours such as absenteeism and employee turnover Banai et al. (2004). For many years this particular field of study has preoccupied the interest of many researchers. Organisational commitment has been significantly correlated with increased worker endeavor, decreased absenteeism and turnover, higher job satisfaction and increased employment in various organisations. As such, many scholars have shown increased interest in this topic over the years (Morrow, 2011).

Organisational commitment has been defined in a multitude of ways, but the underlying principle remains the same with each definition. Values (2003) defined organisational commitment as "the condition that occurs when a worker identifies with his/her place of employment and its goals, and desires to preserve membership in that organisation, strictly based on genuine interest and association with the company's values and goals". Cohen (2003) defined commitment as a strong force that binds a person to a plan of action that is relevant and pertinent to one or more targets.

2.3 The Three-Component Framework of Organisational Commitment

Since the term organisational commitment was coined, it has been primarily measured as a universal construct. Meyer and Allen (1991) in their three-component model, identified three forms of organisational commitment namely affective, continuance and normative commitment.

Affective commitment was defined as the psychological state characterised by the employee's identification with, attachment to, and involvement in the organisation, as well as enjoyment of being a part of the organisation. When employees experience strong affective commitment they continue employment in the organisation because they *want* to do so. Continuance commitment refers to the condition where the worker is aware of the costs associated with leaving the company. What this means is that employees whose main link to the company is based on continuance commitment, continue employment in said company because they feel as though they *need* to do so. Finally, normative commitment has been defined as the psychological state where the employee feels obligated to continue employment in a company i.e. employees experiencing high levels of normative commitment feel as though they *ought* to remain with the company. One interesting commonality among these three approaches is that commitment is considered to be a psychological condition that defines the worker's relationship with the organisation, and has the potential to influence the employee's decision to either stay with or leave the company. However, it is important to understand that beyond this commonality the nature of each psychological state is unique.

Meyer and Allen (1991) argued however, that it is more appropriate to study affective, continuance and normative commitment as components, rather than as types of commitment. To them, the latter implied that the psychological states representing these three commitment states are mutually exclusive, when in reality, it is not that straightforward. Meyer and Allen (1991) also proposed that it is more acceptable to expect

that employees have the tendency to experience all three forms of commitment to varying degrees, at the same time. They provided the following examples: one employee might feel both a strong desire and a strong need to remain, but feel little obligation to do so; while another might feel little desire, a moderate need, and a strong obligation, and so forth. They also outlined that a critical implication for analysing commitment in this way, is that the various components of commitment might be expected to work together in influencing employee behaviours.

3. Methodology

3.1 Delimitations of this Study

In this study, data was not collected directly from upper, middle or lower level management representatives. Instead, data was collected from temporary and permanent non-management staff. The study did not examine managerial performance overall, but rather it relates specifically to health and safety. This study did not focus on managerial performance and its effects on overall employee job satisfaction.

3.2 Data Collection

Data was collected in one specific company, as a case study. A quantitative approach, in the form of an experiment to collect data, was not utilised. Rather, a quantitative approach via a cross-sectional survey, with questionnaires containing rating scale questions was used.

Data was collected via an online questionnaire adapted from the Survey of Perceived Organisational Support (SPOS) and the Organisational Commitment Questionnaire (OCQ). Some questions were modified slightly (in terms of the language) in the SPOS scale only, in an effort to capture the variables needed. In no way were the questions modified to elicit a specific or biased response from the participant.

3.2.1 The Survey of Perceived Organisational Support

The Survey of Perceived Organisational Support (SPOS) was designed with 32 items. However, after extensive redesigns more recent versions have demonstrated adequate psychometric properties using 8 or as few as 3 items. Respondents are asked to indicate the extent to which they agree with the following statements on a seven-point Likert scale (1= *Strongly Disagree*, 7= *Strongly Agree*). By using specific facets in the survey for example "Health and Safety", respondents are able to provide specific answers about problems that may be unknown to employers.

3.2.2 The Organisational Commitment Questionnaire

The Organisational Commitment Questionnaire (OCW) was used to measure the three components of organisational commitment, which are affective, continuance and normative commitment. In total the OCQ had 24 items, and it was answered on a seven-point Likert scale ranging from 1 ("Strongly disagree") to 7 ("Strongly agree").

3.3 Sample Size

The sample units consisted of non-managerial staff members, specifically working in that particular petroleum marketing company only. Using Survey System's Sample Size Calculator it was determined that with the sample size using a confidence level of 95%, a confidence interval of 20 and an unknown population size, this resulted in the sample size being at least 24 participants. However, we were able to successfully obtain 31 non-managerial staff responses from the period 13th March to 24th March 2017, thus improving the level of confidence to 98%.

3.4 Quality Control Procedures

Online questionnaires were administered. The responses that were subjected to pre-analysis in MS excel to correct for any possible errors. This was done to ensure good dataset quality before transference into SPSS. Item #5 in the survey was used as a tool to specify whether the respondents were managerial or non-managerial staff. This was included in the survey to ensure that the target sample was being captured. Items 11, 12 and 13 in the survey were reversely coded in the original scale and therefore were also reversely coded in the modified scale.

3.5 Instrumentation and Reliability Analysis

A Cronbach's alpha "α" analysis was conducted to measure the internal consistency (reliability) of each research scale since each scale was slightly modified to capture the relevant variables. Due to the ordinal and Likert type nature of the data one could not use parametric techniques in the analysis. Therefore, the Spearman's Rank-Order Correlation was utilised.

Worley et al. (2009) reported a Cronbach's alpha for the eight item version as $\alpha = 0.93$, with item-total correlations ranging from 0.70 to 0.84. Meyer and Allen (1991) reported Cronbach α reliabilities of 0.74 for the affective commitment dimension, 0.84 for the continuance commitment dimension, and 0.74 for the normative commitment dimension.

Employees' perception of managerial OHS performance was measured using the 8-item (answered on a 7-point Likert scale) Survey of Perceived Organisational Support (SPOS). After accounting for the reversely-worded items, this scale had a high level of internal consistency as determined by a Cronbach's alpha (α) coefficient of 0.80.

Meyer and Allen's questionnaire on Organisational Commitment was used to measure employee commitment. This measured the three dimensions of organisational commitment: Affective commitment,

normative commitment, and continuance commitment. The OCQ has a total of 24 items, and is answered on a seven-point Likert scale ranging from 1 ("Strongly disagree") to 7 ("Strongly agree"). The affective commitment dimension reported a Cronbach's alpha of 0.91. The continuance commitment dimension reported a Cronbach's alpha of 0.91. The normative commitment dimension reported a Cronbach's alpha of 0.88. Each organisational commitment subscale demonstrated very high levels of internal consistency.

It is critical to have the demographic characteristics of respondents. Table 1 provides the background statistical information of the respondents.

Table 1. Distribution of respondents' demographic characteristics

Variable	Characteristics	Frequency	Percentage
Sex	Male	18	58
	Female	13	42
Age Group (y)	15-24	1	3
	25-34	13	42
	35-44	9	29
	45-54	8	26
Tenure (y)	1-6	9	29
	7-12	14	45
	13-18	4	13
	19-24	4	13
Job Status	Temporary/Contract	7	23
	Permanent	24	77

3.6 Assumptions of Spearman's Rank-Order Correlation

The use of Spearman's Rank Order Correlation requires that before using this test, the study design and data met three specific assumptions. These assumptions were as follows:

Assumptions about the study design:

(a) There are two continuous or ordinal variables; and
(b) These two variables represented paired observations.

Assumption about the data:

The third assumption involved using SPSS Statistics to determine whether there was a monotonic relationship between these variables; in this case, a monotonic relationship between "perception" and "affective commitment, "perception" and "continuance commitment" and finally "perception" and "normative commitment".

Before testing for a monotonic relationship, it was necessary to compute the total score for each participant in each of the measurement scales i.e. the SPOS, Affective, Continuance and Normative Commitment scales. This was done by transforming the data in SPSS using the following formulas: PQ1 + PQ2 + PQ3 + PQ4 + PQ5 + PQ6R + PQ7R+ PQ8R (*R = reversed coded item*), ACQ1 + ACQ2 + ACQ3 + ACQ4 + ACQ5 + ACQ6 + ACQ7 + ACQ8, CCQ1 + CCQ2 + CCQ3 + CCQ4 + CCQ5 + CCQ6 + CCQ7 + CCQ8, and finally, NCQ1 + NCQ2 + NCQ3 + NCQ4 + NCQ5 + NCQ6 + NCQ7 + NCQ8.

Table 2. Variables included in analysis

Independent Variables		**Dependent Variables**
Perception of managers conducting building inspections.		Affective Commitment
Perception of managers providing Health and Safety training.		Continuance Commitment
Perception of managers providing PPE and ensuring its usage.		Normative Commitment
Perception of managers investigating workplace accidents and injuries.		
Perception of managers providing feedback on OHS complaints		
Sex	Male	
	Female	
Age (y)	15-24; 25-34	
	35-44; 45-54	
Tenure (y)	1-6; 7-12	
	13-18; 19-24	

3.7 Test for Normality

As a precautionary measure, the normality of the transformed dependent variables was assessed by conducting the Shapiro-Wilk test. The results of the test proved that the data were normally distributed $p>0.05$ and therefore, no further transformations were necessary.

4. Results

A scatterplot was done in SPSS and inspected to determine whether there was sufficient evidence to suggest a monotonic relationship existed between the variables. Upon a visual inspection of the following scatterplots it can be concluded that there is a monotonic (but non-linear) relationship between employee perception and affective commitment, employee perception and continuance commitment and finally employee perception and normative commitment, as the scatterplots illustrate that the relationship between employee perception and affective commitment is positive (see Figure 1), the relationship between employee perception and continuance commitment is negative (see Figure 2), and the relationship between employee perception and normative commitment is positive (see Figure 3).

The Spearman's correlation confirmed that there was a moderately positive correlation between employee perception of managerial OHS support practices and affective commitment. Therefore, we can infer that as employees have positive perceptions/beliefs as it relates to their managers' Health and Safety performance on the job, their emotional attachment and identification with their organisation became stronger. Even though the sample populations differed, the results of this study can still be compared to the work done by Amponsah-

Tawiah and Mensah (2016), who also found a positive relationship between occupational health and safety management and affective commitment. It can therefore be concluded that there is a significant relationship between employees' perception of managerial OHS support practices and affective commitment.

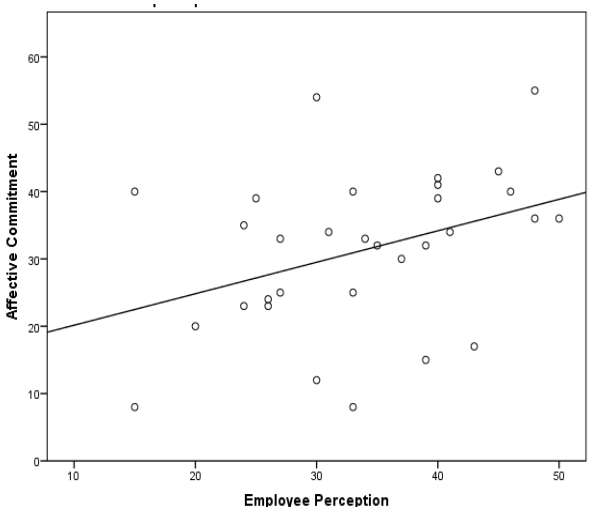

Figure 1: Monotonic Relation between Employee Perception and Affective Commitment

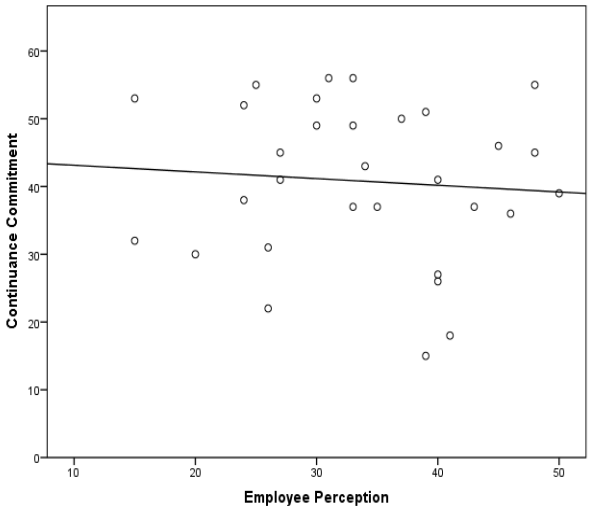

Figure 2: Relationship between Employee Perception and Continuance Commitment

The finding indicates that employee perception of the managerial OHS support is a determinant in the employee wanting to remain with the organisation. Employee perception of managerial OHS support does not influence their belief that they have to stay with the organisation. This result is not consistent with the study by Amponsah-Tawiah and Mensah (2016) in which a positive relationship was also found between occupational health and safety management and continuance commitment. They interpreted their findings as; where employees perceived the health and safety management in the organisation to be appropriate and adequate, they were more likely to have a continuing relationship with the organisation knowing that their health and safety was secured in the company.

However, the interpretation of the results of the current study was different based on how continuance commitment was operationally defined in this study. Therefore, as employees believed that their managers performed favorably as it related to OHS support practices, their need to continue employment in said organisation based on the perceived costs associated with leaving decreased. This indicates that employee perception of managerial OHS support has an influence on employee belief that they ought to remain in the employ of the organisation.

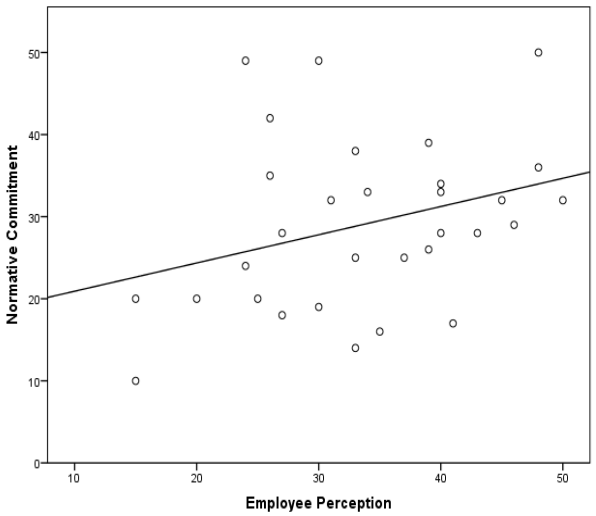

Figure 3: Monotonic Relationship between Employee Perception and Normative Commitment

The results further illustrated that there was a weak positive correlation between employee perception of managerial OHS support practices and normative commitment. Hence, as employees have positive perceptions/beliefs as it relates to their managers' Health and Safety performance in their workplace, the more they felt obligated and loyal to their company.

This finding corroborates the results of the study conducted by Eisenberger et al. (1990) to some degree, in which they concluded that when employees felt that the organisation was in support of their best interests e.g. improving their health and safety at work, employees developed a sense of loyalty towards the organisation.

In the study by Amponsah-Tawiah and Mensah (2016) the positive relationship between occupational health and safety management and affective commitment was moderate. In this study, the positive relationship was considered weak. This finding was not statistically significant which indicates that there is no significant

relationship between employees' perception of managerial OHS support practices and normative commitment. It is speculated that the current weak economy with increasing unemployment may have a more statistically significant impact on the continuance and normative commitment constructs. In stronger economies employees may not perceive that they ought to remain on a job if their health and safety are at risk.

These findings from this study gave credence to the various theories on reciprocity, specifically the social exchange theory, which proposed that social behaviour is the result of an exchange process, the purpose of which is to maximise benefits and minimise costs.

5. Conclusion

The impact of OHS issues on the effective operations of state organisations has been significant as reported in the press. The literature provides a '*moral impetus'* for employers and management of organisations to ensure that there is no loss of productivity or cessation of work due to union action. This is predicated on a basis of social exchange where employees commit to their places of employment based on their levels perception towards the management and by extension the organisation.

This study identified that at a 98% level of significance, in a local oil company that there is a weak negative correlation between employee perception of managerial OHS support practices and continuance commitment. This indicates that managerial OHS support practices do not make employees feel that they *have* to remain in the organisation. The study also confirms a positive correlation between employee perception of managerial OHS support practices and affective commitment. This implies that managerial OHS support would make the employees *want* to remain in the employ of the organisation. Also revealed was a weak positive correlation between employee perception of managerial OHS support practices and normative perception. This is an indication that employees *ought* to remain in the employ of the organisation.

It can therefore be concluded that for organisations wishing to retain their employees then their implementation, and commitment to OHS support imperative should be given some priority. In the present economy where jobs are difficult to come by and there is an increasing rate of unemployment, the continuance commitment of employees may have been more motivated by this factor, than by their perception of managerial OHS support. However, this study focused on the employee perception of managerial OHS support. The factor may need further investigation to confirm.

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Modelling the Rehydration Characteristics of White Yam

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Abstract: *Presented in this paper is a proposed model describing the variation in the rehydration ratio with rehydration time for yam slices. The 'new' model describes the relationship between the moisture content of yam slices with time when rehydrated. The changes in mass and moisture content data with rehydration time, during the rehydration process, were recorded. Rehydration was carried out at 27 ^oC, 40 ^oC, 60 ^oC, and 80^oC for 3.0 mm thick dehydrated yam slices. Regression analysis established that the variation in rehydration ratio vs rehydration time data, better fitted a two-term exponential equation rather than a quadratic equation. Also, regression analysis done on variation in rehydration ratio vs rehydration time data of cube sweet potatoes found it literature, further validated that the rehydration ratio vs rehydration time data better fitted a two-term exponential equation rather than a quadratic equation. For the recorded moisture content versus rehydration time data, a better fit was obtained for the new model rather than the Weibull, Peleg, and Exponential models. This study is essential for a better understanding of the rehydration characteristics of yam slices during the rehydration process. Information about rehydration characteristics of the yam slices presented in this work will also be valuable to optimise and characterise the soaking conditions, design yam-processing equipment and predict water absorption as a function of time and temperature. The rehydration process clearly indicates that rehydration occurs very rapidly in the first few minutes of the rehydration process, and this process is faster as the rehydration temperature increases.*

Keywords: *Rehydration Ratio Models; Rehydration kinetic models; Yam; Weibull, Peleg, and Exponential models*

1. Introduction

White yams *(Dioscorea rotundata)* are very nutritious and are an excellent source of energy and dietary fiber (USDA, 2017a; USDA, 2017b; Hackett *et al.*, 1986; Subar *et al*., 1998a; Subar *et al.*, 1998a; Reedy and Krebs-Smith, 2010). Yams are eaten routinely in the tropical region of the world, and they constitute a dominant portion of the standard diet for many people. They are used, worldwide, in many different recipes. For this reason, yam tubers are moved to the many locations where they are consumed. However, they are heavy, constituting of at least 70% water. Dehydrating yams like most foods and agricultural products is becoming an essential method of processing before being shipped to where they are consumed.

Dehydration which is the process of removing moisture from a food product to decrease bulk has been studied extensively. Akinola *et al.* (2017, 2018) and Akinola and Ezeorah (2016, 2018) investigated the use of the Refractance Window^{TM} drying technique to dehydrate carrots, yam, cassava and potato slices in the temperature range of 60 -95^{o}C. The root tubers were sliced to a size range of 1.5 - 6.0 mm; they established that the tuber slices could be dehydrated to a moisture content of 0.01 g-water/g-solid within 45 - 200 minutes depending on the temperature. Lin *et al*. (2007), studied dehydration of yams studied using freeze drying with far-infrared radiation. The study was done using a 3 factor design of temperature, thickness and distance for heater, to find the optimum drying conditions. The yam slices were 1.5-6.0 mm thick. Also, dehydration of yams is performed for preservation purposes.

The dependence of many dehydrated food and agricultural commodities in the present marketplace is increasing as this is a means of extending the length of time that the products may be stored without becoming unfit for future use. Rehydration operations, therefore, are gaining importance as these dried products will need to be rehydrated before use. There is, therefore, need to understand the issues relating to rehydration processes concerning the design and the operations of these processes.

Mathematical modeling has been useful in the study, design, optimisation, and operations of these rehydration processes (Marinos-Kouris *et al.*, 1991; Vagenas and Marinos-Kouris, 1996). This study involves investigating the variations in the rehydration ratio and moisture content of the samples with rehydration time, and estimating other rehydration characteristics of the dehydrated products.

The models that have been used to study the rehydration characteristics of foods are the Peleg model (Gowen *et al.*, 2007), the Weibull distribution model (García-Pascual, *et al.*, 2006; Machado *et al.*, 1999; Marabi *et al.*, 2003), and the exponential model (Gowen *et al.*, 2007; Kashaninejad, 2007). However, for accurate use of these models, the rehydration data and knowledge of some physical parameter(s) of the product studied, is required. For the Peleg, Weibull distribution and Exponential models knowledge of the initial moisture content before rehydration is needed (Misra and Brooker, 1980). For the Exponential model, the equilibrium moisture content also needs to be known; and for the Weibull model, knowledge of scale and shape parameters of the samples are required (Saguy *et al.*, 2007). Presented in this study is a new rehydration model for yam that requires only the moisture content rehydration data. Also, performed is a comparison of all the four (4) rehydration models.

2. Materials and Methods

2.1 Sample Preparation and the Dryer

White yam tubers acquired from the local market were washed, peeled, cut into 3 mm thick slices. As indicated in literature, (Adelaja, *et al*, 2010; Akinola *et al.*, 2017, 2018; Akinola and Ezeorah, 2016, 2018; Lin *et al.*, 2007), tubers are cut into slices 1.5 – 6.0 mm thick before dehydrating. On this basis, yam slices 3.0 mm thick were chosen for the work done in the study. The Refractance Window™ dryer used in this study was fabricated in the laboratory. The equipment is similar to the used by Akinola *et al.* (2018).

The dryer was 2.0 m in length, 1.0 m wide and had a depth of 10 cm and it was covered with a 0.15 mm thick colourless polyethylene terephthalate (PET) Mylar plastic film. The water in the dryer was heated using a 2.5kW electric immersion heater. The temperature of the water was maintained using a BAYITE BTC211 Digital Temperature Controller which was manufactured by Shenzhen Bayite Technology Co., Ltd, Shenzhen City, China, (Shenzhen Bayite Technology Co., Ltd., 2018). The yam slices were dried until the moisture content was about 0.03g-water/g-solid. The dehydrated samples were kept in air-tight polyethylene bags and stored in a refrigerator until further use in the rehydration experiments.

2.2 Rehydration experiments and Rehydration Equipment

The dried samples of yam slices were brought to room temperature before starting the rehydration experiments. Rehydration of the yam slices was done in 250-mL beakers filled with distilled water. The beakers were immersed in a 19.5L Thermo Scientific™ Precision™ General-Purpose Water Bath, Model 184/284, manufactured by Fisher Scientific Suwanee, GA 30024 USA (Fisher Scientific, 2014). Each set of experiments was performed at 27°C, 40°C, 60°C, and 80°C (±0.5°C). Approximately 3.75 ± 0.25g of yam slices was immersed in 100 ml of distilled water for periods of 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 180, 210 and 240 minutes. The temperature of the water inside the beakers was determined with the use of the Digi-Sense® Type K thermocouple thermometer, manufactured by Oakton Instruments, Vernon Hills, IL 60061, USA (Oakton Instruments, 2014). Cups made from perforated plexiglass were used to cover the samples to ensure they were entirely immersed in the water in the beakers during rehydration.

After rehydration, the water was drained from the flask, and excess water on the samples was removed using tissue paper. The samples were then weighed. The moisture content of the samples was determined using an OHAUS MB45 moisture analyser manufactured by OHAUS Corporation, Pine Brook, NJ, USA, (OHAUS Corporation, 2011). The analyser measured moisture content to an accuracy of 0.01% on a wet basis. To eliminate anomalies, in the data recorded, every experiment was done in triplicate.

2.3 Modelling the Rehydration Ratio

The rehydration ratio (RR) was calculated according to equation 1.

$$RR = W_t/W_o \quad (1)$$

where W_t is the mass of the rehydrated sample at time t, and W_o is the initial mass of the sample to be rehydrated.

The rehydration ratios and rehydration times were correlated first according the quadratic equation of the form given in equation 2.

$$RR = p_5 * t^2 + p_6 * t + p_7 \quad (2)$$

where p_5, p_6, and p_7, are constants and t is the rehydration time in minutes.

Singh and Pandey (2011) used equation 2 to correlate the rehydration ratios and rehydration times of cubed potatoes; they claimed to have satisfactory results. However, a quadratic equation model suggests that the rehydration ratio will rise to a maximum value and then fall. However, the laws of mass transfer do not suggest that moisture or water will be lost by a substance when the substance is immersed in water. Rather, the moisture content will rise to a steady value. A two-term exponential equation in the form presented in equation 3, relating the rehydration ratio and rehydration times suggests a peak rehydration ratio value will be attained.

$$RR = p_1 * \exp(p_2 * t) + p_3 * \exp(p_4 * t) \quad (3)$$

where p_1, p_2, p_3, and p_4, are constants and t is the rehydration time in minutes. The constants p_1, p_2, p_3, p_4, p_5, p_6, and p_7 are obtained by regression analysis

2.4 Modelling the Rehydration Data

The experimental moisture content/time variation data was fitted to the equations 4, 5, 6 and 7 to determine the model that best describes the variation data of the yam

slices.

$$M_t = M_o + (t/(a+bt)) \text{ Peleg model} \quad (4)$$

$$M_t = M_o [1 - exp(-(t/\alpha)^{\beta})] \text{ Weibull model} \quad (5)$$

$$M_t = (M_o - M_{e)} exp(ct^d) + M_e \text{ Exponential model} \quad (6)$$

$$M_t = g\ exp(h\ t) + j\ exp(q\ t) \text{ New Model} \quad (7)$$

where M_t is the moisture content at time t, M_o is the initial moisture content, M_e is the equilibrium moisture content, and α, β, a, b, c, d, g ,h, j, and q are constants observed from regression analysis

For quality fit, the coefficient of determination (R^2) should be closest to unity while the sum of square-error (SSE), and the root-mean-square-error (RMSE) should closest to zero. The methods of estimating R^2, SSE and RMSE are discussed extensively in the literature (Ogunnaike, 2011; Johnson, 2017). In this work, the software package from Matrix Laboratory (MATLAB) was used to perform the statistical analysis (MathWorks, 2017).

3. Results and Discussions

3.1 Evaluation of the Rehydration Ratio Models

Four sets of rehydration experiments were performed at rehydration water temperatures of 27°C, 40°C, 60°C, and 80°C. The rehydration ratio at each rehydration time was calculated according to equation 1 using the weight data obtained during the rehydration experiments. Table 1 presents the statistical parameters when the rehydration ratios were correlated with rehydration time according to equations of the form given in equations 2 and 3. Table 1 clearly indicates that the two-term exponential model fits the rehydration ratio versus time data better than the quadratic equation model. For the two-term exponential equation form, the R^2 values were closer to unity and the SSE and RMSE values were closer to zero than the quadratic equation form. Table 2 shows the constants obtained with a 95% confidence bound, by fitting the rehydration ratio data to the exponential equation form presented in equation 2.

Figure 1 shows a plot of the variation in the experimental and the predicted (Exponential) rehydration ratio with drying time at different temperatures for white yam. The initial rehydration ratio is 1.0. The plots of the experimental and predicted rehydration ratios versus time are observed as expected to be a good fit and the results of the regression analysis are shown in Table 1. In the first few minutes of experimentation, the rehydration ratio increases rapidly from a value of 1 and less rapidly thereafter. Besides, the rate of increase of the rehydration ratio increases with increasing rehydration temperature.

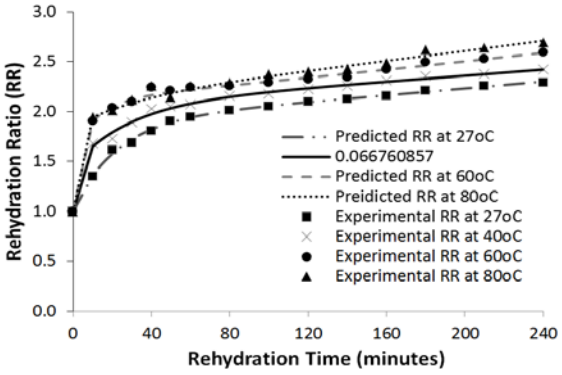

Figure 1. Variation in Rehydration Ratio with Drying Time at Different Temperatures for white yam

Table 1. Statistical Parameters for Yam when correlating Rehydration Ratios with Rehydration Time at different temperature

	Exponential Equation Form			Quadratic Equation Form		
Water Temperature	R^2	RMSE	SSE	R^2	RMSE	SSE
27 °C	0.9966	0.0180	0.0032	0.9245	0.0808	0.0719
40 °C	0.9860	0.0311	0.0097	0.9447	0.0591	0.0384
60 °C	0.9030	0.0214	0.0046	0.9420	0.0501	0.0276
80 °C	0.9864	0.0317	0.0100	0.9803	0.0364	0.0146

Table 2. Constants For The Models Obtained By Fitting Rehydration Data The Exponential and Quadratic Models For Yam Slices

Temperature	Exponential Model Constants	Quadratic Model Constants
27 °C	p_1 = 1.92E+00 ±5.20E-02 p_2 = 7.52E-04 ±1.53E-04 p_3 = -8.88E-01 ±9.01E-02 p_4 = -4.32E-02 ± 8.88E-03	p_5 = -2.04E-05 ± 1.07E-05 p_6 = 8.13E-03± 2.63E-03 p_7 = 1.45E+00 ± 1.26E-01
40 °C	p_1 = 2.08E+00 ±1.14E-01 p_2 = 6.46E-04 ± 2.97E-04 p_3 = -6.22E-02 ±1.34E-01 p_4 = -3.47E-02 ±1.77E-02	p_5 = -1.54E-05 ± 7.80E-06 p_6 = 6.55E-03± 1.92E-03 p_7 = 1.69E00 ± 9.20E-02
60 °C	p_1 = 2.11E+00 ± 4.00E-02 p_2 = 8.50E-04 ± 1.18 E-04 p_3 = -4.871E-01 ± 2.30E-01 p_4 = -7.61 E-02 ± 4.43E-02	p_5 = -5.90E-06 ± 5.90E-06 p_6 = 3.88E-03± 1.63E-03 p_7 = 1.98E+00 ± 7.80E-02
80 °C	p_1 = 2.15E+00 ± 1.40E-01 p_2 = 9.70E-04 ± 3.31E-04 p_3 = -3.08E-01 ± 1.33E-01 p_4 = -2.85E-02 ± 2.85E-02	p_5 = -7.18E-06 ± 4.82E-06 p_6 = 4.87E-03± 1.18E-03 p_7 =1.93E+00 ± 1.99E+00

3.2 Validation of Rehydration Ratio Models

To establish whether the two-term exponential model fits better the rehydration ratio/time data than the quadratic equation model, experimental data in literature was used. Singh and Pandey (2011) studied the rehydration characteristics of sweet potato cubes at 50°C, 60°C, 80°C, and 90°C after dehydration in a cabinet hot air dryer. Singh and Pandey (2011)'s work concluded that rehydration ratio relationship with rehydration time followed a quadratic equation. In this study, the data from Singh and Pandey (2011)'s work was obtained by graphical extrapolation from the graph. The same set of data was applied to the two-term exponential model and the quadratic equation model. Table 3 presents the results of the regression analysis.

3.3 Evaluation of the Rehydration Moisture Content/ Time Variation Models

Yam slices with moisture content of 0.03g-water/g-solid were rehydrated at 27°C, 40°C, 60°C, and 80°C. The moisture content data obtained from the rehydration experiments was fitted to the New Model, the Weibull model, the Peleg model, and the Exponential model presented in equations 4, 5, 6 and 7. Table 4 presents the statistical results of correlating the moisture content rehydration data using the Peleg, Weibull, and Exponential and New models. For quality fit, the model chosen to best fit the rehydration moisture content/time variation data of the yam slices is the one that meets the following three criteria: R^2 is closest to unity, and SSE and RMSE are closest to zero. While most of the models fitted the moisture content experimental data with a coefficient of variance values exceeding 0.9600, the R^2 for the New model was the one closest to unity for all the temperatures. For the experiments performed at 27°C, 40°C, 60°C, and 80°C, R^2 exceeded 0.995 for the model.

Moreover, for the temperatures considered, the SSE, and RMSE, values were the least for the New model. The implications are that the model best fits the rehydration data among the models examined. However, the SSE, and RMSE values are large. This implies that the model would be used in the range of process conditions studied, but it would not be used for predictions outside that range. The coefficients obtained by fitting rehydration moisture content data to the new model for the yam slices are presented in Table 5.

To validate whether the new rehydration model best fits the moisture content rehydration data, a simple linear regression analysis was performed between the experimental and predicted rehydration values. Table 6 depicts the relationship between the experimental and predicted rehydration moisture content values.

Figure 2 shows the variation in moisture content of the yam samples with time rehydrated at different temperatures. The initial moisture content of the yam slices was 0.03 g-solid/g-water. The plots show that for any given time, the moisture content of the yam sample is higher as temperature increases. The plots show that as the rehydration temperature increases the extent of rehydration increases.

Table 3. Statistical Parameters for Sweet Potatoes When Correlating Rehydration Ratios with Rehydration Time at Different Temperature

	Exponential Equation Form			**Quadratic Equation Form**		
Temperature	R^2	SSE	RSME	R^2	SSE	RSME
50 °C	0.9966	0.0007	0.0132	0.9739	0.0053	0.0325
60 °C	0.9967	0.0008	0.0139	0.9718	0.0065	0.0362
80 °C	0.9976	0.0007	0.0130	0.9647	0.0101	0.0450
90 °C	0.9975	0.0008	0.0141	0.9599	0.0126	0.0503

Table 4. Regression Constants Correlating the Moisture Content Rehydration Data Using Different Models

Temperature	**Models**	**R^2**	**RMSE**	**SSE**
27 °C	New	0.997	1.511	15.00
	Peleg	0.995	2.772	92.19
	Weibull	0.977	6.089	444.92
	Exponential	0.976	6.234	466.40
40 °C	New	0.996	1.842	33.91
	Peleg	0.988	3.050	111.59
	Weibull	0.966	5.174	321.28
	Exponential	0.965	5.224	327.42
60 °C	New	0.996	1.596	25.46
	Peleg	0.952	4.866	284.15
	Weibull	0.976	3.454	143.19
	Exponential	0.976	3.473	144.73
80 °C	New	0.993	2.248	50.53
	Peleg	0.881	8.195	805.82
	Weibull	0.982	3.171	120.63
	Exponential	0.982	3.152	119.22

Table 5. Coefficients Obtained by Fitting Rehydration Moisture Content Data to the New Model for Yam Slices

	Temperature			
Constants	27°C	40°C	60°C	80°C
α	99.76000	46.11000	24.63000	17.30000
β	0.50350	0.33500	0.27290	0.30650
a	0.15880	0.06158	0.03210	0.03559
b	0.00513	0.00528	0.00522	0.00490
c	-0.09350	-0.26920	-0.40800	-0.40840
d	0.51180	0.33900	0.27570	0.30960
g	136.10000	154.60000	164.20000	176.10000
h	0.00118	0.00089	0.00080	0.00081
J	-128.40000	-116.80000	-85.58000	-59.72000
q	-0.03772	-0.06141	-0.06353	-0.03705

Table 6. Relationship between the Experimental and Predicted Rehydration Moisture Content

Temperature	Equation	R^2
27 °C	$PMC = 0.9991EMC$	0.9945
40 °C	$PMC = 0.9997EMC$	0.9962
60 °C	$PMC = 1.0018EMC$	0.9977
80 °C	$PMC = 0.9998EMC$	0.9925

In the first ten minutes, the moisture content of the yam slices for rehydration temperatures of 27°C, 40°C, 60°C and 80°C are 46.69, 91.53, 120.41, and 137.87 g-water/g-solid respectively. There is a 3-fold magnitude in the moisture content of the samples rehydrated with a water temperature of 80°C over the moisture content of sample rehydrated at 27°C. However, after about 240 minutes, the difference in the magnitude of the moisture contents decreases; the moisture content ranged from 179.02 - 212.60 g-water/g-solid for rehydration done in the temperature range of 27-80 °C.

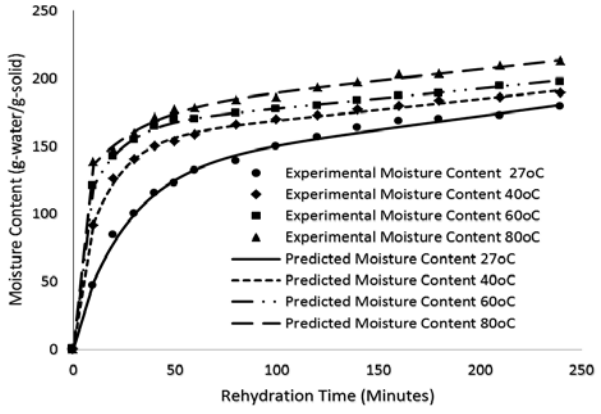

Figure 2. Variation in Moisture contents of yam with rehydration time at 27 °C, 40 °C, 60 °C and 80°C

4. Conclusions

White yam *(Dioscorea rotundata)* slices, 3.0 mm thick, dehydrated to a moisture content of about 0.03g-water/g-solid in a Refractance Window™ dryer were rehydrated at 27°C, 40°C, 60°C and 80°C. The variation in mass and moisture content of the samples with rehydration time was recorded. By fitting the variation in rehydration ratio with time data, to the two-term exponential and the quadratic rehydration ratio models, and by fitting the variation in moisture content with rehydration time data to the Weibull, Peleg, and Exponential models, the following are the conclusions:

1. The two-term exponential equation fits the rehydration ratio variation data better than the quadratic equation proposed by Singh and Pandey, (2011). For the rehydration temperatures considered, the R^2 values for the two-term exponential equation were higher and also closest to unity in all cases. For the samples rehydrated at 27°C, 40°C, 60°C and 80°C, R^2, for the two-term exponential equations were 0.9966, 0.9860, 0.9903, and 0.9864, respectively as opposed to 0.9245, 0.9447, 0.9420 and 0.9803 for the quadratic equation. Also, for the samples rehydrated at 27°C, 40°C, 60°C and 80°C, the root-mean-square-error (RMSE) were 0.0180, 0.0311, 0.0214 and 0.0317 respectively, and the sum-of-squared-error (SSE) were 0.0032, 0.0097, 0.0046 and 0.0100, respectively. All the RMSE and SSE values are close to zero.
2. When applying the models to Singh and Pandey (2011) data for rehydrating cubes of sweet potato, the two-term exponential equation was a better fit than the quadratic equation. The coefficient of variation, R^2, for the two-term exponential equations, was closer to unity than for the quadratic equations at all temperatures (see Table 4).
3. When rehydrating the slices, the mass (see Figure 1) and moisture content (see Figure 2) values reached higher values for the same rehydration time as the temperature increased. The rehydration ratio and moisture content for the slices rehydrated at 80°C were about 50% higher for samples rehydrated at 27°C after ten minutes.
4. For the yam slices, the new model better fits the rehydration moisture content/time variation data than the Peleg, Weibull and Exponential rehydration models for the process temperatures studied. Among the models investigated, the R^2 value for the new models was closest to unity for all the process temperatures studied.

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Redesign of a Furniture Industry Component: A Sustainable Design Approach

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Abstract: *Sustainability has been a recent trend in the manufacturing industry, owing to environmental concerns. Product designers are now looking at effective approaches for sustainable product design. Design for X (DFX) tools and techniques have widely been used over the years to streamline the design and manufacture processes. Design for environment (DFE) is becoming of critical use in the preliminary phases of the product design process in order to render cost-effective and environmentally friendly products. This can be enhanced by deploying computer-aided design and engineering (CAD/CAE) tools which have the ability to manipulate the product concepts in a virtual environment. The efficacy of this approach is demonstrated through a case study involving the redesign of a component selected from the local Caribbean market. The SolidWorks package was used to generate CAD models which were further analysed by using the Simulation and Sustainability modules. The guidelines of Design for Manufacture and Assembly (DFMA) and DFE were also utilised in the redesign. The research shows that DFX tools and techniques, namely CAD/CAE and DFE, can be combined in a single platform to effectively redesign products to meet functional and environmental requirements.*

Keywords: *DFX tools, product redesign, product sustainability, case study*

1. Introduction

Manufacturing organizations are showing increased interest in sustainability due to the environmental concerns, namely global warming and resource depletion, which arose in the last few decades. Sustainable design is a comprehensive, holistic approach for creating products and systems that are gentle on the environment, socially equitable and economically viable (Vinodh 2010). It is defined as a design approach which strives to increase quality while reducing or eliminating negative environmental impact (McLennan 2004). Sustainable product design considers both functional characteristics and environmental impact at the product design stage (Hosseinpour et al. 2015). Several external pressures, including environmental interest groups and environmental laws and regulations, demand that companies provide more sustainable products with minimal material usage, minimal energy consumption, and without producing hazardous wastes. Becoming environment-friendly also provides several internal incentives to companies, including improvement of product quality, reduction in costs, management of risks and the acquisition of an eco-friendly social image (Alblas et al. 2014).

Product designers are in need of methods and tools that accelerate and streamline sustainable design. Design for X (DFX) is a generic term describing product design approaches where X denotes manufacture, assembly, environment, disassembly, recyclability, life-cycle, and maintainability (Kuo et al., 2001). DFX tools range from broad guidelines to specific software tools. Many case studies have reported the benefits achieved by utilizing DFX approaches (Huang and Mak, 1998). In this context, the paper presents a product redesign case study to ensure the sustainable design of a component currently used in the assembly of a computer keyboard shelf by a Caribbean computer furniture fabricator.

The main focus of the paper is to demonstrate a case study in which product sustainability is realised using integrated DFX tools, specifically computer-aided design and engineering (CAD/CAE) tools and DFE principles. The product redesign exercise starts with CAD modelling of the selected component followed by a sustainability analysis in the four prominent spheres of environmental impact namely, carbon footprint, water eutrophication, air/water acidification and total consumed energy in the selected component's material sourcing, manufacturing, use and end of life. The environmental impact of the selected component is assessed using the Sustainability module of the SolidWorks package. Moreover, engineering analysis using the Simulation module of the SolidWorks package

enabled the assessment of the structural integrity of the design. The results facilitated the redesign of the component in an iterative manner. Furthermore, the component modelling and computer-aided engineering (CAE) analysis were conducted on the same CAD platform, which further facilitated an improvement in assembly efficiency.

2. Literature Review

The literature has been reviewed from the perspective of sustainable design and integration of DFX tools and approaches. Checklists, quality function deployment (QFD) and life cycle assessment (LCA) methods have widely been used to limit the environmental impact of products during the design stage (Hosseinpour et al., 2015). Checklists are easy to implement at the early stages of the product design process but are impractical in providing design details (Hosseinpour et al. 2015). The effectiveness of QFD based tools relies greatly on the experience and knowledge of designers (Masui et al., 2003). Moreover, LCA tools are difficult to use in the early design stages if details of the final product are unknown (Yang et al., 2012).

Current efforts at sustainable product design focus on integrating eco-design tools. Hosseinpour et al. (2015) proposed a benchmark based method for sustainable product design. The method integrates QFD, benchmarking, and LCA to conduct the evaluation of the environmental impact of the product. A CAD/CAE simulation methodology was also used to determine the parameters of the benchmark products and finite element analysis (FEA) was performed to validate the design parameters. Vinodh and Rathod (2014) presented an integrated technical and economic model to evaluate the reusability of products or components using LCA methodology and Monte Carlo simulation technique. The authors showed that the developed model was capable of assessing the reusability of products and the use of simulation reduced uncertainties in input data and parameters and increased the effectiveness of the model. Soft computing and artificial intelligence approaches are also being explored for sustainable product design. Mutingi et al. (2017) proposed a fuzzy grouping genetic algorithm (FGGA) approach to evaluate modular designs in terms of sustainability parameters, namely design fitness, cost fitness, and green fitness.

It has been noted by several researchers that engineering analysis in a CAD environment facilitated eco-friendly product redesign (Wu et al., 2007; Vinodh, 2010). In addition, sustainable product design using CAD facilitated the organisation to achieve business benefits such as reduced cost and time which would, in turn, improve profitability (Vinodh, 2010). Russo (2011) stated that CAD platforms are ideal for sustainable design because product assemblies are already organised and the information on materials, manufacturing processes, and mass-properties is easy to integrate. Further, the study proposed an integrated approach for sustainable product design linking CAD, FEA, and LCA tools. Vinodh and Rajanayagam (2010) proposed an integrated approach using a CAD-based sustainability analysis and Design for Manufacture (DFM) guidelines to implement a sustainability concept at the early stages of product design with minimal environmental impact.

The theory of DFE has proven successful in the development of eco-friendly products as well as reducing environmental impact. DFE aids in sustainable product development which states that resources must be used in such a manner so as to ensure their availability for future generations (Giudice et al., 2006). Moreover, application of DFE guidelines in product design process can improve product life cycle by reducing the overall cost as well as the impact of manufacturing and disposal on the environment (Chowdary and Gittens, 2008). Noteworthy DFE guidelines to enhance the product sustainability include having multifunctional parts, use of the same material for neighbouring parts, and easily located high-value parts ensuring the ability of the product to be recyclable at the end of its life cycle (Fiksel, 1996).

A large number of case studies and research articles on DFX applications have been published over the years. Huang and Mak (1998) reported that multiple DFX tools should be used to attain overall optimum solutions. In this regard, the author developed a DFX shell to serve as a generic platform for the integration of DFX tools. Holt and Barnes (2010) suggested the integration of DFX tools as an enabler of concurrent engineering. The authors also revealed that although DFX techniques are popular, they are used discretely in the product design phases as opposed to concurrently. Chowdary and Harris (2009) deployed DFMA and DFE principles in conjunction with market research, product research and QFD to drive reductions in overall product costs by decreasing part numbers and assembly time. Chowdary and Kanchan (2013) suggested the use of DFE guidelines and CAD/CAE tools as enablers for integration in product design and development. The efficacy of the proposed methodology was validated through a case study using a desktop organizer selected from the Caribbean market. Computer-aided design (CAD) and DFE integration was also used by Chowdary and Phillips (2014) in the development of a tennis ball retriever concept to demonstrate the agility in the design of new products.

Moreover, Chowdary (2014) proposed an approach where computer aided design and engineering (CAD/CAE) and design for environment (DFE) integration were combined with a fuzzy QFD tool to prioritise product sustainability. Suresh et al. (2015) integrated DFE and DFMA for the sustainable development of a component from the automotive industry. Vinodh (2010) used CAD and CAE analysis to determine the sustainability and environmental impact of an existing product as measured in terms of parameters such as carbon footprint, energy consumption, water

eutrophication and air acidification. Moreover, the study concluded that the conduct of the sustainability analysis in a CAD environment enabled the re-design of the existing product making it more eco-friendly. Both Vinodh (2010) and Suresh et al. (2015) suggested that for future research, the sustainability methodologies be performed for different organisations across different sectors in several countries to augment and strengthen the practical applications. Product sustainability is currently not a widespread practice in the Caribbean region, but the recent onset of environmental troubles and exhaustion of natural resources has uncovered the need for sustainable product design. This can be accomplished through implementation of DFX tools at the early stages of the product design process.

From the literature review, it can be seen that although many researchers integrated eco-friendly product design approaches and DFX tools, the concurrent application of DFX tools to optimise the redesign of products in CAD environment has not been thoroughly investigated. The use of DFX tools has also not been implemented in the Caribbean industry so this present case study will supplement the past and future research in this direction.

3. Research Methodology

Figure 1 depicts the logic flow methodology of the study. It starts with the literature review on DFX tools and sustainable product design. Step 2 starts with the selection of the local firm and identification of a product for investigation. In step 3, the generation of the CAD/CAE model of the bracket is performed using the SolidWorks package. Then in step 4, within the SolidWorks environment, the sustainability analysis of the bracket is conducted to assess the environmental impact. Based on the sustainability results, the redesign of the bracket is accomplished in step 5. Moreover, in order to support the bracket redesign process, CAE model results are taken into consideration. Furthermore, to prove the merits of the selected bracket redesign, the sustainability analysis is again conducted to assess the environmental impact in step 6. Lastly, the study inferences are reported in step 7.

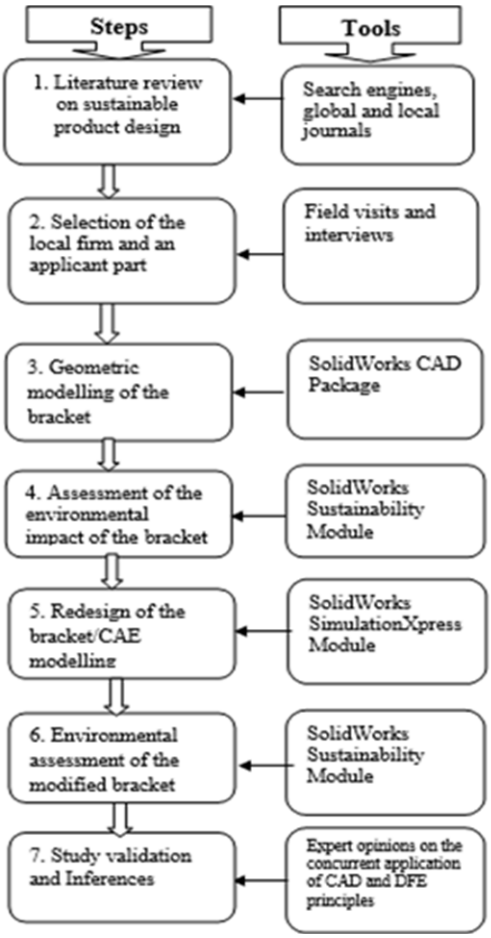

Figure 1. Research Methodology

4. Case Study

4.1 Case Component and Background

A bracket from a keyboard shelf assembly supplied by a local manufacturing company is selected as the case component. The location of the bracket is shown in Figure 2.

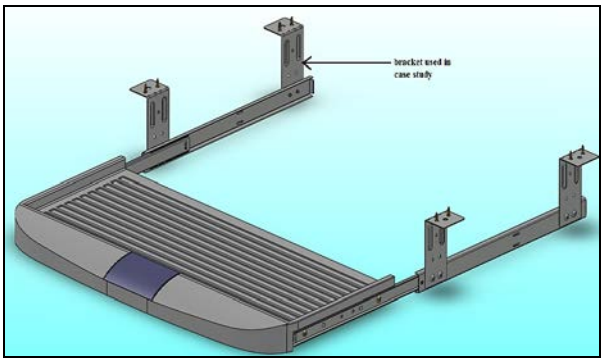

Figure 2. Keyboard shelf assembly showing the brackets to be redesigned in the case study

4.2 CAD/CAE Modelling of Existing Bracket

The bracket of the computer shelf was modelled using the SolidWorks package and is shown in Figure 3. Then, the CAE model was created using the SolidWorks Simulation module to simulate the performance of key product components under practical loading conditions and constraints, permitting the assessment of the stress, displacement and factor of safety distributions for such parts. Basic design criteria used for the redesign of the bracket are as follows:

- No stress developed under the loading conditions must exceed the yield point for the material. Surpassing the yield point of the material will result in unwanted plastic deformation of the part.

- Displacement should be kept to a minimum under loading conditions. The lower the displacement of the part, the sturdier the design and the less flexing the assembly will experience under load.
- A factor of safety (FOS) of 1.0 indicates that the material has just begun to exhibit plastic deformation. As a result, the minimum factor of safety should have a value that is greater than 1.0. Higher FOS is always favourable.

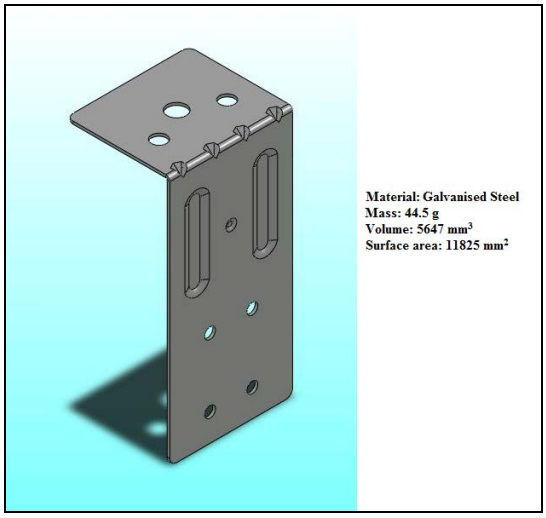

Figure 3. 3D CAD model of the bracket

A review of available desktop computer keyboards indicated that a typical keyboard has a mass less than 1 kilogram (kg). The keyboard shelf selected for this case study was however rated at a maximum capacity of 6.80 kgs. In light of this, the CAE analysis was conducted to simulate the worst-case loading conditions on the brackets with the slides of the shelf assembly fully extended and supporting a uniformly distributed load of 6.80 kgs at the location of the keyboard tray. The simulation also accounted for the masses of the various components of the assembly that were directly supported by the four (4) brackets. Though time-consuming, the finest mesh settings were applied when analysing the virtual model of the assembly to provide the most accurate CAE results.

The results of the initial CAE analysis are shown in Figure 4. It was revealed that the forward brackets are placed under more stress than the aft brackets during the applied worst-case loading scenario. Taking this into consideration, the stress, displacement and minimum FOS results obtained for a single forward bracket would be used to provide comparisons between the alternative bracket designs.

4.3 Sustainability Analysis of Existing Bracket Design

The SolidWorks Sustainability module was used to assess the environmental impact of the selected bracket. The material has been selected as galvanised steel. The surface area, volume and mass are computed. The manufacturing process has been specified as progressive die stamping. Figure 5 shows the results of the sustainability analysis. The four examined parameters include carbon footprint, water eutrophication, air acidification and total energy consumed, as defined by Vinodh (2010).

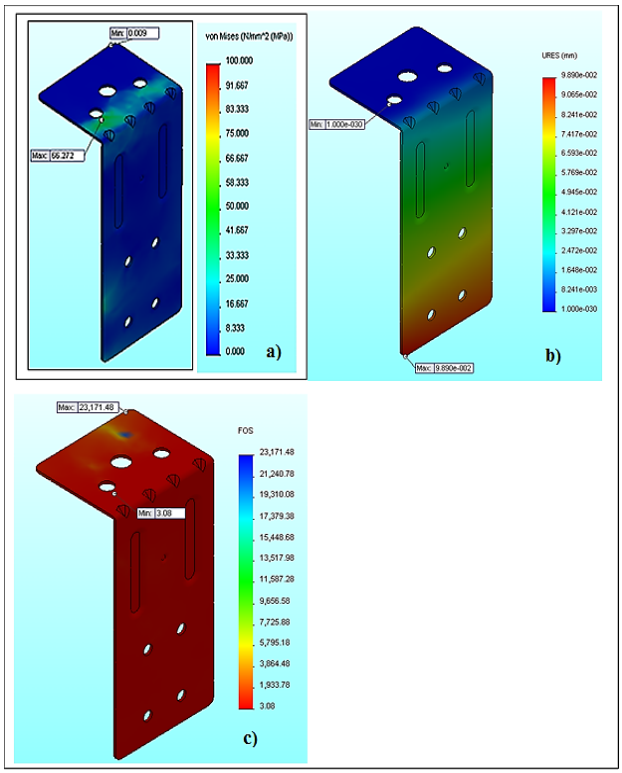

Figure 4. FEA analysis of the existing bracket a) Stress b) Displacement c) Factor of Safety

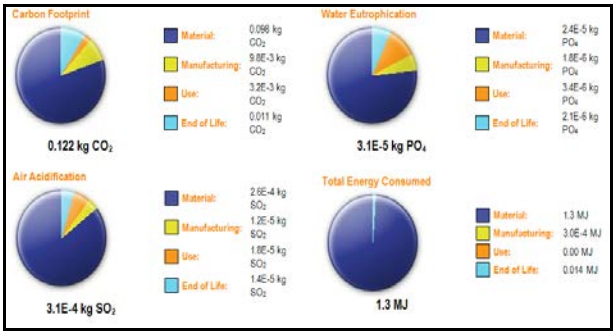

Figure 5. Sustainability analysis results for existing keyboard shelf bracket

4.4 Bracket redesign

In order to improve the design sustainability and assembly efficiency of the bracket in the keyboard assembly, an alternative component design was proposed

based on the simulation results. An alternative design was developed with the intent to strike a balance between part performance and environmental impact. The material selected for the redesign was galvanised steel of 2 mm thickness. The bracket width was reduced to 15 mm to lower component volume and mass and reduce the environmental impact of the design. The final dimensions of the bracket are 92mm x 38mm x 15mm. Moreover, after discussing with the managers of the case study unit, the product structure guidelines (Giudice et al., 2006) and ease of assembly and disassembly guidelines (Boothroyd et al.,2002; Giudice et al., 2006) were also followed while designing the alternative bracket. The 3D CAD model of the alternative bracket design can be seen in Figure 6. The results of the CAE and sustainability analysis conducted on this alternative design are shown in Figures 7 and 8.

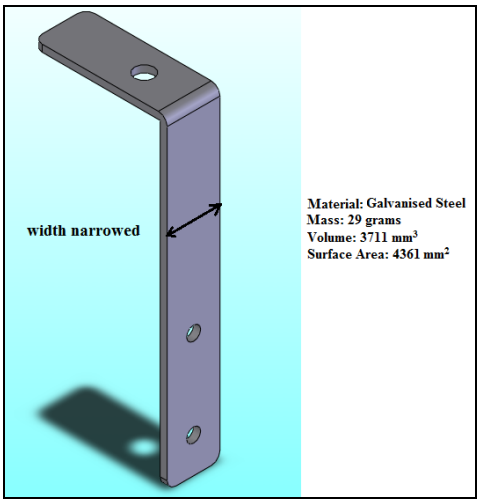

Figure 6. 3D CAD model of the redesigned bracket

5. Results and Implications

5.1 Development/Deployment of Guidelines

In the present case study, DFX tools were integrated to achieve the sustainable redesign of a furniture component. CAD/CAE tools enabled the testing of the design in a virtual environment which facilitated the redesign of the component making it more sustainable. This involved CAE analysis in the SolidWorks Simulation module to ensure design integrity and sustainability analysis in the SolidWorks Sustainability module to ensure the design exhibits minimum environmental impact.

Several guidelines were applied to the deployment of the research methodology. These are as follows:

a) DFE Guidelines

- Waste source reduction: The mass of the bracket was reduced in the alternative design which may limit the waste generated per unit of production.

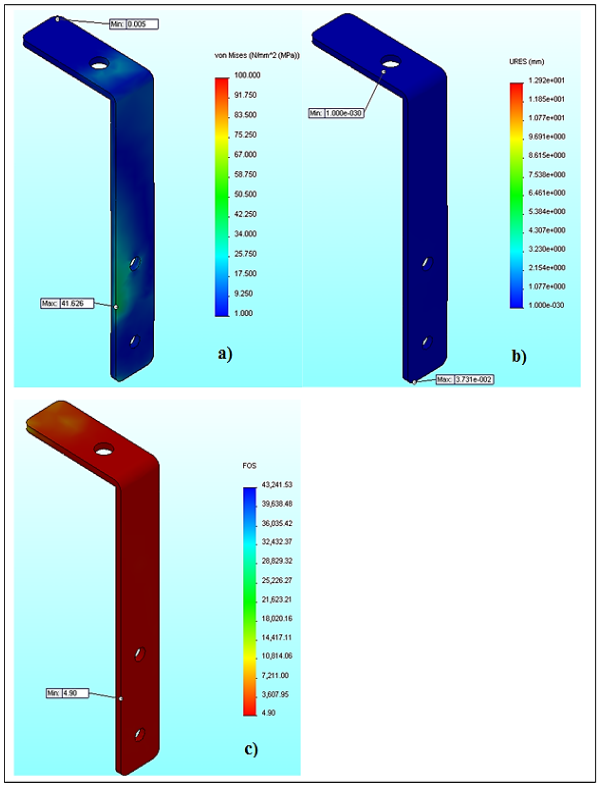

Figure 7. FEA analysis of the redesigned bracket a) Stress b) Displacement c) Factor of Safety

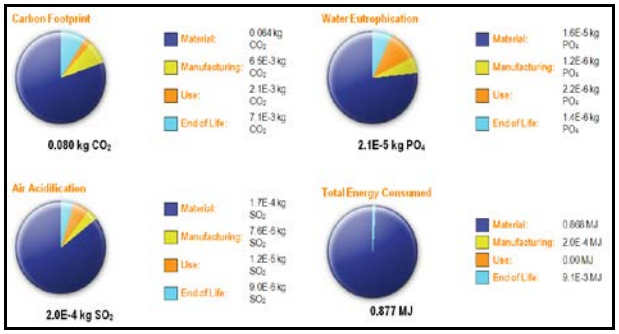

Figure 8. Sustainability analysis results for redesigned bracket

- Toxic substance reduction: No toxic substances used in the alternative design.
- Energy use reduction: The total energy consumed to produce, transport, store, maintain, use, recycle and dispose of the bracket was reduced by 33%.
- Design for disassembly: Number of fasteners reduced by 50% which may facilitate material recovery at product end-of-life.
- Design for recyclability: The material used is recyclable.
- Design for remanufacture: Less stamped features are present in the alternative design to minimise manufacturing costs.

b) Product Structure Guidelines

- Minimise the number of parts: The alternative bracket design uses a single self-threading screw for attachment to the desktop and a single fine thread screw for attachment to the outer slides.
- Design for parts orientation and handling: Alternative bracket design is symmetrical, has no hidden features, no sharp edges and can be easily oriented for assembly.
- Design for ease of fabrication: Less stamped features are present in the alternative design to minimise manufacturing costs.

c) Fastener Guidelines

- Minimise the number of fasteners: Number of fasteners reduced in the alternative bracket design by the adoption of single attachment points.
- Eliminate adhesives unless compatible with both parts joined: No adhesive used.

d) Ease of Assembly and Disassembly Guidelines

- Simplify the design and reduce the number of parts: Number of fasteners reduced from 4 to 2 and the design is simplified by reducing the number of stamped features.
- Design for disassembly: The slightly decreased material thickness ensures that the self-threading and fine thread screws will have to be manually driven through fewer rotations in order to secure this bracket to the rest of the assembly.

5.2 Analysis of results

Design improvements were revealed through comparison of the alternative design results to the original model as highlighted in Table 1. From these results, it is clear that ample improvements were made to the redesigned product. Moreover, parametric refinement of the virtual prototypes through CAD/CAE and DFE served to strengthen the design and boost its sustainability.

Substantial improvement in environmental impact was displayed by the alternative design. Approximate reductions of 51%, 50%, 51% and 52% were observed for the metrics of carbon footprint, water eutrophication, air acidification and total energy consumed respectively. Moreover, the performance metrics of maximum stress, maximum displacement and a minimum factor of safety were significantly superior to those obtained for the original benchmark investigation. An approximate increase of 45% was observed for maximum developed stress. Maximum displacement increased by 37% with a minimum factor of safety declining by approximately 29% to a value of 4.9. These results highlight an improvement in the part performance at the reduced environmental impact.

Based on the case study, it can be deduced that the integration of DFX tools (specifically CAD, CAE and DFE) enables the sustainable development of keyboard shelf bracket.

Table 1. Comparison of results of the baseline and the proposed alternative design model

	Parameter	Benchmark	Final Design Iteration	Improvement (%)
General	Material	Galv. Steel	Galv. Steel	n/a
	Surface Area (mm^2)	11825	4361	63%
	Volume (mm^3)	5647	3711	34%
	Mass (g)	44.5	29	35%
Environmental	Carbon Footprint (kg CO_2)	1.22×10^{-1}	0.80×10^{-1}	34%
	Water Eutrophication (kg PO_4)	3.13×10^{-5}	2.08×10^{-5}	34%
	Air Acidification (kg SO_2)	3.04×10^{-4}	1.99×10^{-4}	35%
	Total Energy Consumed (MJ)	131.43×10^{-2}	87.73×10^{-2}	33%
Performance	Maximum Stress (MPa)	66	42	36%
	Maximum Displacement (mm)	9.9×10^{-2}	3.7×10^{-2}	63%
	Minimum Factor of Safety	3.1	4.9	58%

5.3 Industrial Implications

The presented method enables the assessment of the environmental impact of a product at the design stage. The case study was conducted to ensure sustainable product design by the concurrent application of DFX tools using CAD/CAE and DFE. The study has also addressed the three sustainability requirements of environmental, social and economic feasibility. In comparison with other integrated methods presently available, this integrated sustainable approach can aid product designers in finding effective solutions to create environmentally friendly products quickly, using widely available tools and without spending much time in accessing product lifecycle data.

6. Conclusions

A case study involving a systematic procedure to enable the re-design of an existing product assembly was documented. The approach endorses the joint application of DFX tools, namely CAD/CAE and DFE, to optimise assembly efficiency, lower manufacturing costs, improve component performance and reduce environmental impact on several levels. The method was successfully applied to the redesign of a bracket selected from a typical keyboard shelf assembly. The results of the case study indicate that the redesigned bracket possess minimal environmental impact and superior structural performance. To bolster the findings, the method should be applied to redesign a greater sample of product assemblies. Assemblies with higher degrees of

complexity, either having larger part numbers and/or components with more intricate features, should be studied thus creating the opportunity for more widespread deployment of the proposed procedure.

Overall, it can be stated that CAD/CAE and DFE are powerful DFX tools when applied on their own. The concurrent use of these philosophies and techniques, however, makes it possible for manufacturers to comprehensively optimise their designs for the complex demands of the present market.

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Eur Ing Aldwyn Lambert Lequay (1927-2018): A Memorial

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Eur Ing Aldwyn Lambert Lequay was one of the most distinguished engineers in Trinidad and Tobago and the Caribbean who will be remembered by the people he touched and many others. He was the loving husband of Dora, deceased, and is survived by his son Bernard.

Aldwyn was born in Blanchisseuse, Trinidad in 1927 and came to the city of Port of Spain to go to secondary school. He attended Queen's Royal College and left in 1948 to study in England, at Bournemouth Technical College. Later he graduated with a BSc in Mechanical Engineering from London University in 1955 and spent two years as an Engineering Graduate, training with the Central Electricity Generating Board, UK.

In Britain, he trained in manufacturing at the Falcon Works of Brush Engineering (Hawker Siddley), Loughborough, England, consisting of exposure to steam turbine manufacture and testing, motor design and construction, transformer erection and testing, oil circuit breaker assembly and testing and assembly of alternators. He was also trained in power station operations and maintenance at Poole, Marchwood, Earley, Portsmouth and the 132,000-volt national grid.

On his return from his studies and engineering training in Britain he started in 1958 in the Trinidad and Tobago Electricity Commission (T&TEC) as a Shift Charge Engineer, Port-of-Spain Power Station, was Resident Engineer and Superintendent in the Penal Power Station and was Assistant Resident Engineer with Preece, Cardew & Rider (Consulting Engineers of the UK) on the construction of the Port-of-Spain "B" Power Station, responsible for the supervision of suppliers, contractors and erectors of electrical and mechanical plant and equipment. He was also responsible for the training of operating staff for the new power station. He was the Superintendent of the Port-of-Spain Power Station, responsible for all aspects of operations, maintenance and training, in 1970 when he left to form his own company, Inspection Services Company Limited, which he led up to his death.

He had the designation of European Engineer (Eur Ing) and was a Chartered Engineer and Fellow of the Institution of Mechanical Engineers (IMechE), Fellow of the Institution of Electrical Engineers (now the Institution of Engineering and Technology (IET) and the American Society of Mechanical Engineers (ASME), the largest such international learned societies in the world. He was one of few engineers in the world who had attained the grade of Fellow in both the IMechE and the IEE (as it was then).

Aldwyn was a Registered Engineer in Trinidad and Tobago, Founding Member, Past President and a Fellow of the Association of Professional Engineers of Trinidad and Tobago (APETT). He served the Association of Professional Engineers of Trinidad and Tobago (APETT) and the Board of Engineering of Trinidad and Tobago on several committees and panels over the years and always gave of his time and advice when called upon.

He was the most qualified and experienced quality inspector/failure analyst in mechanical and electrical systems in Trinidad and Tobago and the region. He

qualified as a Non-Destructive Testing (NDT) Inspector at the School of Non-Destructive Testing in Cambridge, UK, in Dye Penetrant, Magnetic Particle, Ultrasonic and Radiographic (Gamma Ray) Flaw Detection and was a pioneer in NDT in Trinidad and Tobago and other parts of the Caribbean. He had also done specialised courses and was qualified in Fracture Mechanics, Pressure Vessels, Piping, Rotating Machinery, Electrical Cable Technology and Power Supply.

He was a Government appointed "Competent Person" for the testing of Flammable Gases, testing for H2S and oxygen levels, issuing of "Gas-Free" Certificates for Hot Work and other relevant certificates, and certifying relevant personnel. He was an advisor on issuance of Permits to Work in electrical systems and other systems with respect to isolation and safety. He was also a Government appointed "Competent Person" for the inspection of: Boilers, Unfired Pressure Vessels, Cryogenic Storage Tanks, Hoists, Cranes, Elevators and Escalators.

Aldwyn's experience and skill in inspection was typified by an encounter that took place around 1990, as recalled by his good friend, Dr. Julian "Jules" Ferdinand. At the time Jules was Manager of East Caribbean Feeds Limited, a subsidiary of East Caribbean Group of Companies, owned by the Government of St. Vincent and the Grenadines (20%), Maple Leaf Mills of Canada (40%), and private investors (40%). A Canadian engineer had visited the feed mill to assess the physical assets. While investigating the equipment in the mill he recommended that provision be made for replacing the boiler in the next year's budget. This was a very expensive piece of equipment costing upwards of one million East Caribbean dollars, at that time. Jules invited Aldwyn to visit the mill in order to get a second opinion. After inspecting the boiler Aldwyn recommended that it merely needed to have the good tubes cleaned, some worn tubes replaced and the fire eye replaced also. He then commented to Jules, "This boiler will outlive you and me, my friend. There is no need to replace it." Almost three decades have passed and the boiler is still operational. It has outlived Aldwyn and Jules has no reason to believe that it will not outlive him as well.

Aldwyn took his job very seriously and never shirked what he considered his responsibility to point out any shoddy, unsafe or lackadaisical practice he encountered. He did so with such sincerity, encouragement and sound recommendations that he was never rebuffed. He was well known for this and even after he left the Trinidad and Tobago Electricity Commission, where he worked for twelve years, workers there had to be on their Ps and Qs whenever he came by. He valued industriousness in people no matter their circumstances. This was exemplified by his admiration (in a missive he sent to his friend Jules) for a blind man in Blanchisseuse, whom he knew when he (Aldwyn) was a young boy. The man owned and ran a "Sweetie Shop" by himself. Sandy's Shop, as it was called, was perched above the sea's rocky coast. Blind Sandy was able to climb down the precipice to the rock where he would cast his fishing line - all by himself. He did his own washing, laundry, and cooking and attended to his shop. In the same communication Aldwyn also recorded his admiration for the blind person who constructed a 14-inch model sailing ship, fitted with all the rigs, which he saw in the office of his good friend and colleague Donald Baldeosingh, whom, in 1993, Aldwyn joined to found the ENMAN Group where he motivated and mentored the staff for 25 years and was a strong proponent for the energy integration of Trinidad and Tobago gas generated power with hydroelectric power in Guyana, a project under development for 17 years.

He was always involved in training technicians and engineers and conducted short courses at various levels throughout the Caribbean on High Voltage Cable Splicing and Termination, Power Plant Operations, Operation and Maintenance of Switchgear, Transformers and Motors, Oil/Gas Platform Operations, Boiler Operations, Steam Injection Boilers in the Petroleum Industry, Diesel Engine Maintenance and Lubrication Technology, among others. He lectured in the course "Occupational Health and Safety" for MSc. Engineering students at The University of the West Indies. As the local ASME representative for many years he facilitated many ASME courses locally by leading experts in the world. He personally trained and mentored several engineers. He was very passionate about the training of craftsmen and technicians as the very important support structure upon which the engineering profession and industry are built, operated and maintained.

He gave yeoman service to the formation and functioning of technical institutions including technicians' associations where he found great support from his friends and colleagues Clyde Phillip and Allister Bowen.

Eur Ing Aldwyn Lequay served in several positions, most in the area of training, his passion. Among his many appointments were:

1) Chairman of the Cabinet appointed Committee on Craft and Technician Training.
2) Chairman of the Education and Training Committee of APETT.
3) Chairman of the National Training Board of Trinidad and Tobago.
4) Chairman of the Education and Training Committee of the Council of Caribbean Engineering Organisations.
5) Chairman of the National Internship Training Committee for Engineering Graduates.
6) Chairman of the Trinidad and Tobago Chapter of the Caribbean Association of Technical Vocational Education and Training (CATVET).
7) Chairman – Trinidad and Tobago Group of the American Society of Mechanical Engineers (ASME).

8) Chairman (the first) of Youth Training and Employment Partnership Programme Limited (YTEPP).
9) Deputy Chairman of the Board of the Port Authority of Trinidad and Tobago.
10) Deputy Chairman of the Board of the Trinidad and Tobago Electricity Commission.
11) Member of the Board of Directors of Meat Processors Limited - a Government owned company.
12) Member of the Government Appointed Committee for the Expansion of the Faculty of Engineering at The University of the West Indies.
13) Member of the National Committee on Non-Destructive Testing (NDT).
14) Member of the Standards Committee for Cranes.
15) Member of the Standards Committee for the Colour Coding Identification of Pipelines.

Allister Bowen has spoken glowingly of his relationship with him as his mentee for four decades and the validation and support of Aldwyn for his (Allister's) TVET innovations. He also had the good fortune to have served on four Boards under Lequay's chairmanship.

Aldwyn played a very significant role in my development as an engineer and later on throughout my career. As a young Materials Engineer at CARIRI. I was trained by him in NDT, inspection of hoists and lifts (particularly elevators) and failure analysis. This started in 1974 and later on we collaborated on failure analyses, particularly using my expertise in microscopy, including the Scanning Electron Microscope (SEM).

I had always assisted him with organising local ASME courses and at his request, I succeeded him as the ASME regional representative, but, much to his chagrin, I gave it up due to what I considered a conflict of interest because as the ASME rep I was expected to organise ASME training courses independent of any other training institution but I was in charge of the UWI Continuing Engineering Education Centre.

As a Fellow of the ASME he urged me to apply to be a Fellow at a special dinner he arranged when I was appointed a Professor, as he wanted me to be the next person in the region to be so appointed. He was a bit annoyed with me when I delayed for a few years and he literally forced me to apply and was absolutely elated when I was appointed a Fellow, which meant another special dinner.

I remember, several years ago, he was an external examiner for a PhD thesis from Cuba and asked me for my comments which formed the basis of his report. That and other times when he asked for my advice have been the greatest compliments I have ever received in my career - to be consulted by such a great engineer, a Guru to so many.

He loved gardening. As soon as he got home he would spend the majority of time in the garden either with soil preparation, planting or cleaning out the weeds and watering. If he was not at work, he was at work, in the garden. He would enjoy planting tomatoes and ochros. He also planted flowers. He had a large collection of orchids at one time. He used to own land in Arima, up in the hills, and when his son Bernard was very young they would spend either the Saturday or the Sunday there collecting fruits.

He loved animals and always had either dogs or cats or both. No dogs ever bit his dad, Bernard recalled. There is the story of Aldwyn being warned to keep his distance from a bad dog he agreed to feed in the absence of the owners, his friends, who were away. To their amazement, on their return, Aldwyn and the dog were the best of friends.

Aldwyn often went for sea-baths at Maracas Bay with the family, including the dogs of course. He would swim out to sea and one of his dogs always tried to rescue him. The dog would swim past Dora and Bernard, and grab onto Aldwyn's arm gently and pull him back to shore.

He used to race pigeons back in the late 1970s and early 1980s. He was a member of the Trinidad Pigeon Club and held some administrative positions in the club. Knowing him I am sure he would have been asked to be president or some other senior position. He had two pigeon lofts with about a hundred birds and won several trophies in races from several places in Trinidad, Tobago, Guyana and further afield. He visited Belgium with the family to see how professional pigeon racing was done on a large scale. He gave away most of the pigeons when Bernard left to study in England as it was too much to do without the help of his loving son.

Bernard recalled that when he was younger the family would frequently visit the zoo and Aldwyn would always stick his finger in the Toucan cage and the Toucans would come and try to sit on his finger and play with him. Clearly he was very careful where he stuck his finger as he had all his fingers intact.

He was awarded the Humming Bird Medal Gold (HBM) for service to Engineering Education in1991 and was conferred with an Honourary Doctorate in 2017 by The University of Trinidad and Tobago.

He was still active as an engineer at the advanced age of 91 before he fell ill. One only has to look at the certificate in elevators all over the country, even up to today, to see his name as the inspector. He was an outstanding engineer and even more outstanding as a human being. He will be missed by many.

Acknowledgements:

The author wishes to thank Bernard Lequay for sharing fond memories of his father and Allister Bowen, Clyde Phillip, Donald Baldeosingh and Julian "Jules" Ferdinand for sharing their remembrances of their friend and mentor Aldwyn Lequay.

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Editorial Aim and Policy:

The WIJE is an international journal which has a focus on the Caribbean region. Since its inception in 1967, it is published twice yearly by the Faculty of Engineering at The University of the West Indies and the Council of Caribbean Engineering Organisations in Trinidad and Tobago.

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