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Editorial

This Volume 38 Number 2 includes eleven (11) research articles. The relevance and usefulness of respective articles are summarised below.

I.O. Oladele, M.S. Omokafe and J.S. Olusegun, "Influence of Chemical Treatment on the Constituents and Tensile Properties of Selected Agro-Fibres", investigate the effect of chemical treatment on the tensile properties of Banana (Musa acuminata), Plantain (Musa parasidica), Coconut (Cocos nucifera) and Sisal (Agave sisilana) fibers. These fibres were treated with four different chemical solutions at 60 °C for 4 hours. The percentages of the fibre constituents were characterised and the tensile properties were determined. The results showed that the cellulose, hemicelluloses and lignin contents were all affected. The chemical treatment procedures had great influence on the constituents of the fibres and their eventual tensile properties. Alkaline treatment with sodium hydroxide (NaOH) gave the best result for improved tensile strength in sisal fibre.

M. Nathai-Balkissoon and K.F. Pun, "Factor Analysis of Elements Influencing Occupational Safety and Health Management System (OSHMS) Development in Trinidad and Tobago", report on factor analysis conducted upon a recent survey of OSHMS implementation in the manufacturing sector. With a targeted group of 40 small and medium-sized manufacturing enterprises (SMEs), the study explored the factors influencing OSHMS development from among 22 elements. It was found that two overarching factors correlate significantly to OSHMS implementation in SMEs were "Safety Structure and Practices" and "Improvement Drivers". The paper puts forward that government- and industry-supported systems could be critical aids to promote collaboration among SMEs and help them to set up their own formal OSHMS.

D. Sooknanan, S. Bahadoorsingh, A. Joshi and D.P. Sharma, "Smart Grid Analysis for the Caribbean Region", present a gap analysis of smart grid technology for the Caribbean region, and explore the opportunities for the potential widespread roll-out of this technology, the challenges posed and the exercises employed to assist legacy power systems transition to the smart grid. It was found that, the most important factor is the adoption of renewable energy sources and a distributed generation paradigm that is characteristic of the smart grid, as well as the widespread use of relevant communications and information technologies in the region. Other recommendations include rigorous planning with cost versus benefits analyses being performed with respect to the applicable technologies and a strategic business plan. The paper concludes by describing the transition to the smart grid using micro-grids.

E.J. Peters and L. Goberdhan, "Potential Consumers' Perception of Treated Wastewater Reuse in Trinidad", report the main findings of a recent consumer survey on the re-use of treated wastewater, using unstructured interviews and questionnaires. It was found that the idea of non-potable use of treated wastewater for such purposes as firefighting and watering of public lawns was generally acceptable to the public. However, there was more apprehension about direct uses, particularly those involving human contact. The current perception is significantly influenced by the public's mistrust of the local water authorities to deliver safe and quality water; a general lack of knowledge of the treatment process; and perceived health risks associated with using treated wastewater.

I.J. Dookie, A. Singh, A. Pooransingh and S. Rocke, "A Review of Critical Infrastructure Interdependency Simulation and Modelling for the Caribbean", investigate the importance of critical infrastructure interdependencies (CII) in disaster risk reduction. This paper contextualises the role of CII simulation as part of a complete disaster and emergency management programme, and reviews the state-of-the-art as pertains to utilisation of such tools among Caribbean emergency management agencies (EMAs). It finds that Caribbean EMAs do not currently utilise CII tools. The paper then reviews some of the most popular simulation tools under development such as CIPDSS, HAZUS, I2Sim/DR-NEP and ESRI Sim Disaster. Their applicability and ease of adoption to the Caribbean context is considered.

In their article, "Soil-Metal Sliding Resistance Forces of Some Trinidadian Soils at High Water Contents", **R.A. Birch, E.I. Ekwue, and C.J. Phillips**, experiment the soil-metal sliding resistance and acquire data on the normal stress against shear stress at the soil-tool interface for some common soils in Trinidad. Using a soil-metal adapter tool (SMAT) to a Hounsfield tensometer, the measured shear stress at the soil-tool interface was separated into the components of adhesion constant and external friction angle. Analysis of variance showed that the experimental factors such as soil type, water content and compaction effort had significant effect on adhesion constant and the external friction angle. Regression models were developed to predict the behaviour of the soil and the tool at the boundary surfaces. This information could be used in performing simulations at the soil-tool interface and thereby aid in improving designs of earth-working tools.

G. Shrivastava, "A Road Collapse at Pont Cassé, Dominica: Hydrologic and Hydraulic Aspects", provides a technical note, based on a site visit during 5th to 7th May 2013, to discuss the hydrologic and hydraulic setting of the road collapse, as well as the unavailability of event specific hydrologic data. It concludes that the probable causes of the road failure were twofold - firstly, a flash flood, arguably, with a return period in excess of 100 years, and secondly, an inadequate maintenance of a concrete culvert in a terrain prone to slope instability. It

ends with the several recommendations for the Dominica government and other stakeholders to consider.

J.K. Odusote, D.O. Owalude, S.J. Olusegun, and R.A. Yahya, "Inhibition Efficiency of *Moringa Oleifera* Leaf Extract on the Corrosion of Reinforced Steel Bar in HCl Solution", report that as the concentration of the extract increases, the inhibition efficiency increases in three investigation scenarios. The volume of the hydrogen gas evolved reduces with an increase in the exposure time during the gasometric test. The formation of an adsorption layer on the surface of the metal reduces the rate at which hydrogen gas is evolved, which is a function of the concentration of the extract. Potentiodynamic polarization results revealed that the Moringa Oleifera leaf extract modifies the mechanism of anodic dissolution and cathodic hydrogen evolution. The results showed that the leaf extract could be used as a green inhibitor to slow corrosion of metals in aggressive media.

In their article, "Design of a Special-Effects Wrist-Mounted Flamethrower", **K. Maharaj, C. Maharaj, and U. Persad.** present the design of a device that facilitates the illusion of the user holding a flame in the palm. It is intended as a cost-effective special effects device to be used in the local entertainment industry. This paper covers the main issues that were considered during the development of the flamethrower from inception to the development of the final design concept. With initial tests of the prototype, the potential utility and usability of the device are demonstrated. The potential of the flamethrower as an enabling tool in the Special Effects sector will also be discussed.

N. Hyatali and K.F. Pun, "Aligning Project Quality and Risks into Business Processes: A Review of Challenges and Strategies", explore the literature on managing project risks and quality as they relate to business processes. A literature search of project management (PM) processes was conducted using articles abstracted from two databases, Ebscohost and Emerald Insight, spanning the period from 2000 to 2014. The conceptual links between the PM and business processes are discussed, and the attributes of project risks and quality are identified. The paper concludes by advocating a process paradigm for managing project risks and quality in organisations.

C. Mohammed, "Communicating in the Workplace: Self-Reports by New UWI Electrical and Computer Engineering Graduates", discusses the findings from a recent study on mapping the broad terrain of communicating in local industry. Based on quantitative data gathered from 58 new hires in the field of Electrical and Computer, the study revealed that in an 8-10 hour workday, new hires spend upward of two hours per day writing and three hours in formal oral communication scenarios. New hires can also expect that with and without substantial support they will be required to produce an array of communication artefacts. Respondents rated proficiency in writing, speaking and teaming as critical to career advancement.

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.

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Influence of Chemical Treatment on the Constituents and Tensile Properties of Selected Agro-Fibres

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Abstract: *The effect of chemical treatment on the tensile properties of Banana (Musa acuminata), Plantain (Musa parasidica), Coconut (Cocos nucifera) and Sisal (Agave sisilana) fibers was investigated. These fibres were obtained from plants in Akure, Ondo State, South-West, Nigeria and were treated with four different chemical solutions at 60 °C for 4 hours. The percentages of the fibre constituents were characterised and the tensile properties were determined using the Instron digital universal tensile testing machine. The results showed that the chemical treatment procedures had different effects on the fibers: the cellulose, hemicelluloses and lignin contents were all affected. All the chemical treatment procedures had great influence on the constituents of the fibres and their eventual tensile properties. Alkaline treatment with sodium hydroxide (NaOH) gave the best result for improved tensile strength in sisal fibre with a value of 0.81 MPa, followed by coconut fibre treated with the mixture of hydrochloric acid (HCl) and NaOH with a value of 0.69 MPa. These treatments were best for the constituents and surface modification of these selected fibres. The optimum advantage from these treatments was that, these fibers will perform better as reinforcement in composite development due to increased strength and roughed surfaces which aid binding between fibre and matrix.*

Keywords: *Chemical treatment, constituents, tensile properties, Agro fibres*

1. Introduction

Composite materials are materials that are comprised of two or more different materials and which have properties that transcend those of the individual component materials from which the composite was developed. Although the use of composite materials has somewhat waned since man discovered metals and the art of alloying, using composite materials has continued till modern times and is not likely to become obsolete anytime soon, as they continue to be useful in many engineering applications such as aerospace, civil, machine parts, automotive and household goods.

The need and use of composite materials in modern times was borne out of man's realisation that hardly does a single material possess all of the properties that are desirable. Natural fibres have been used to reinforce materials for over 3000 years. Dwindling energy resources, the emergence of new operating conditions and environmental concerns have resulted in renewed interests in bio-based materials.

Plant fibres are perceived as environmentally friendly substitutes to glass and other synthetic fibres for reinforcement in composites, particularly in automotive engineering due to their wide availability, low cost, low density, high-specific mechanical properties, and they are extracted from renewable sources-plants. They are increasingly being employed as reinforcements in polymer matrix composites (Oladele and Adewuyi, 2008). Anselm and Afiukwa (2007) investigated the mechanical properties of fibre reinforced polypropylene composite and concluded that the flexural strength, flexural modulus and Izod Impact strengths were significantly increased by a 60% fibre filling ratio. Li et al. (2009) investigated the mechanical properties of pulp fibre reinforced thermoplastic composite and the stiffness was found to increase by a factor of 5.2 and strength increased by a factor of 2.3 relative to the virgin polymer.

Natural fibres are obtained from natural sources and this includes plant/cellulosic fibres, animal/protein fibres and mineral fibres. Of the natural fibres, agro-fibres are increasingly being studied as they offer greater potential as reinforcement. Natural fibres are renewable, in so far as there is a continuous supply which will not negatively impact food security. Finding alternative, lucrative industrial uses for natural fibers will encourage unemployed youths in the developing countries to go into agriculture. Plants from which useful fibres can be obtained include banana, plantain, sisal, and coconut.

Despite the numerous potential benefits offered by natural fibres, their rapid adoption and widespread usage in the development of engineering materials has been set

back by various factors. Chief amongst these are: moisture sensitivity and absorption; thermal and dimensional instability of the developed natural fibre reinforced composite; and poor adhesion and wetting action at the fibre-matrix interface. The subsequent effects are poor load transfer between fibre and matrix; wide-spread variation in composition and properties making their characterisation difficult; entanglement of fibres, leading to uneven load distribution; and weakening of the structure (Govardan and Rao, 2011; Mohd et al., 2012; Oladele et al., 2014). All these factors lead to early failure of the developed fibre reinforced composites. The first two shortcomings are due to the hydrophilic nature of cellulose (the most abundant and load bearing constituent of the fibers). Cellulose contains numerous hydroxide (OH^-) ions which cause it to greatly absorb moisture and swell, disrupting the composite structure and resulting in poor mechanical properties and dimensional instability of the natural fibre reinforced composites (John et al., 2008; Tungjitpornkull et al., 2009).

There are two approaches to improve the interfacial adhesion between the lignocellulosic fibres and matrices. One involves the use of a separate interphase or coupling agents. The second approach to overcoming the fibre-matrix adhesion and fibre-moisture sensitivity challenge is through pretreatment of the fibres prior to their incorporation in the matrix (Dhakal et al., 2007). This is known as fibre treatment and it is done to modify the fibre surface and topology. It can be achieved by a number of process routes all of which can be categorised into physical, chemical and mechanical techniques (Mohd et al., 2012; Oladele et al., 2010).

Chemical treatment has been the most promoted fibre pretreatment technique (Fidelis et al., 2013). This is probably because of its lower energy and manpower requirements. Natural fibres have been found to have good potential for chemical treatment due to the numerous hydroxyl groups present in lignin and cellulose. Chemical treatment directly influences the fibre structures and changes their compositions, resulting in reduced moisture absorption tendencies and facilitating better bonding with the matrix materials. Chemical treatment of natural fibres prior to incorporation is done in many ways depending on the intended end properties, purpose of treatment and available reagents amongst others.

Typical chemical treatment procedures include; alkali treatment / mercerization (Chang et al., 2009), Acidic treatment/ Hydrolysis (Oladele et al., 2010) silane treatment (Bouza et al., 2008; Xue et al., 2007), acetylation (Larson-Brelid et al., 2008), benzoylation (Mohanty et al., 2001), acrylation (Huda et al., 2008), isocyanate treatment, peroxide treatment (Oladele et al., 2014, Brigida et al., 2010), permanganate treatment (Dhanalakshmi et al., 2012) and others.

The present research investigated the effect of such chemical treatments on the tensile properties of agro or (plant) fibres using readily available reagents and hybridized or combinatorial treatments. The properties and compositions of the chemically treated fibres were also compared with those from the untreated ones.

2. Materials and Methods

2.1 Materials

The major materials for this research included: Litmus papers (blue and red), solutions of potassium hydroxide (KOH), sodium hydroxide (NaOH), hydrochloric acid (HCl), sulphuric acid (H_2SO_4) distilled water and; fibres from banana (*Musa Parasidica*), plantain (*Musa Acuminata*), coconut (*Cocos nucifera*) and sisal fibres (*Agave Sisalana*).

2.2 Preparation of Fibres

Banana and plantain fibres were obtained from dew retted banana and plantain pseudo stems which were left on the farmland for 3 months after the fruits were harvested. While sisal fibre was extracted by soil retting (Oladele et al., 2014). Coconut fibres were obtained by mechanical decortications after the seeds were removed from the coconut husks. All these agro-fibers were obtained from farmland in Akure, Ondo State, South-West, Nigeria.

2.3 Chemical Treatments

The selected fibers were divided into five portions of 30 g each and subjected to the treatments outlined below. Four treatments were carried out on the fibers while the fifth part was left as the control sample.

2.3.1 Mercerisation with NaOH

A portion of each fibre type was immersed in beakers containing 500 ml of 1M NaOH solution. This was then placed in the shaker water bath maintained at 50 °C for 4 hours. The treated fibres were then removed from the beakers and washed with tap water followed by distilled water until test from litmus paper indicated pH of 7.0 which signify neutral status. The treated samples were made to dry at room temperature in the laboratory for 7 days before carrying out tests on them.

2.3.2 Mercerisation with KOH

Mercerisation was done by immersing another portion of the fibres from each plant in beakers containing 500 ml of 1M KOH solution and the same procedure as stated above under mercerisation treatment with NaOH treatment was followed.

2.3.3 Treatment with HCl + NaOH

Regarding treatment with HCl + NaOH, 500 ml solutions comprising of 375 ml of 0.75M HCl and 125 ml of 0.25M NaOH solution were prepared. The same procedure as stated above under mercerisation treatment with NaOH treatment was followed.

2.3.4 Treatment with HCl + KOH

The fourth portion of each the fibres was immersed in a beaker containing 500 ml of a reagent prepared by mixing 375 ml of 0.75M HCl and 125 ml of 0.25M KOH solution. The same procedure as stated above under mercerisation treatment with NaOH treatment was followed.

2.4 Determination of Fibre Fractions/ Proximate Analysis

The cellulose, hemicellulose and lignin contents of the fibres were determined using Goering and Van Soest's method of investigating the Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) (Goering and Van Soest, 1991; Oladele *et al*., 2010). The masses of the Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) were obtained and used to determine the hemicelluloses and cellulose contents. Lignin content was determined using the gravimetric method.

2.5 Determination of Neutral Detergent Fibre (NDF)

The fibre samples were dried and ground into about 1mm diameter using (porcelain) laboratory mortar. 1 g of air dried ground sample was taken and placed into a beaker of refluxing apparatus. 100 ml of neutral detergent solution and about 0.5 g of Sodium Sulphite solution was then added. It was then heated to boiling and refluxed for 60 mins after the onset of boiling. The samples were then filtered into a pre-weighed crucible and washed thrice with boiling water and then twice with acetone, dried for 8 hours at 105 °C and cooled in a desiccator. The crucible was then finally reweighed and the Neutral detergent fibre was computed using:

$$\%NDF = \frac{W_2 - W_1}{W_3} X\ 100 \quad (1)$$

Where;

W_1 = weight of empty crucible,
W_2 = weight of crucible + weight of residue,
W_3 = weight of dry sample.

2.6 Determination of Acid Detergent Fibre (ADF)

The procedure is similar to that followed in determining NDF. That is, the residue after NDF determination was taken and placed into a beaker of the refluxing apparatus. 100ml of acid detergent solution (detergent+dil.H_2SO_4) was then added. The mixture was also heated to boiling and refluxed for 60mins after the onset of boiling, filtered into pre-weighed crucibles and washed thrice with boiling water and then twice with cold acetone. It was next dried for 8 hours at 105 °C, left to cool in a dessicator and finally reweighed. The ADF was then determined using the relation;

$$\%ADF = \frac{W_2 - W_1}{W_s} X\ 100 \quad (2)$$

Where;

W_1 = weight of empty crucible,
W_2 =weight of crucible + residue,
W_s = weight of sample

2.7 Determination of Lignin Content (Gravimetric method)

The procedure followed was similar to that used by Oladele et al. (2010). 1.5 g of the sample was weighed and 72 % H_2SO_4 was added and soaked for 2 hours. 8 % H_2SO_4 solution was later added and the solution was refluxed for four (4) hours. The residue was filtered with purpling cloth and washed several times with hot water. A crucible was weighed and the sample was scraped into it. The hydrolyzed sample was then oven dried at 105 ºC for two (2) hours and cooled inside desiccators after which the weight was taken. The dried sample was next ashed in the muffle furnace at 550 ºC for three (3) hours after which it was cooled inside the desiccators and finally reweighed. The % Lignin computed using the relation:

$$\%Lignin = \frac{W_2 - W_1}{W_s} X\ 100 \quad (3)$$

Where;

W_1 = weight of the ash sample + crucible,
W_2 = weight of the oven dried sample +crucible
Ws = weight of dried extractive free sample i.e. NDF residue.

The percentage Lignin content is also known as the Acid Detergent Lignin (ADL).

2.8 Determination of Cellulose content

The cellulose content of each fibre was determined using the relation:

$$\%Cellulose = ADF\text{-}ADL \quad (4)$$

2.9 Determination of Hemicelluloses Content

Hemicelluloses content was determined by using the equation:

$$\%Hemicelluloses = NDF\text{-}ADF \quad (5)$$

2.10 Tensile Testing

Tensile tests were performed on the plant fibres according to ASTM D-638**.** An Instron Universal tensile testing machine model 3369 made from Instron Incorporated USA was used. The machine applied 50 KN at a crosshead speed of 20 mm/min. Two specimens were tested from each sample after which the average was taken as the representative values.

3. Results and Discussion

3.1 Effects of Chemical Treatment on Composition of Treated and Untreated Fibres

The results of the proximate analysis of the treated fibres are presented in Tables 1, 2 and 3. As shown in Table 1 and Figure 1, alkali treatment with both KOH and NaOH

significantly improved the cellulose content of the resulting banana fibres from about 25.51 to 34.24 and 46.46 %, respectively. Treatment with NaOH performed best in this respect. This effect has been reported by Oladele et al., (2010) and can be attributed to the removal of the pectins, waxes and lignin from the fibre surface as reported by Xue et al. (2007), Jayabal, et al. (2012) and Sgriccia (2008). The hydrolysis effect of acids like HCl and H_2SO_4 on cellulose has been widely reported. Both the blend of HCl + KOH and HCl + NaOH solutions actually contain the respective chloride salts of the alkalis; KCl and NaCl in an excess of the respective acids. These excess acids are responsible for the significant reduction in cellulose content of the banana fibres.

Table 1: Proximate analysis results for the treated and untreated banana fibres

Constituent (%)	Untreated	KOH Treated	NaOH treated	HCl+KOH treated	HCl+NaOH Treated
Cellulose	25.51	34.24	46.46	9.12	24.56
Hemicellulose	2.13	5.82	7.43	2.60	11.9
Lignin	42.50	2.72	5.82	59.38	44.12

Table 2: Proximate analysis results for the treated and untreated plantain fibres

Constituent (%)	Untreated	KOH Treated	NaOH treated	HCl+KOH treated	HCl+NaOH Treated
Cellulose	24.82	2.61	36.87	3.69	10.82
Hemicellulose	12.88	1.21	22.19	2.01	3.94
Lignin	15.56	55.52	17.68	46.42	36.60

Table 3: Proximate analysis results for the treated and untreated coconut fibres

Constituent (%)	Untreated	KOH Treated	NaOH treated	HCl+KOH treated	HCl+NaOH Treated
Cellulose	15.8	22.58	4.37	35.77	10.86
Hemicellulose	0.44	5.5	38.93	9.53	6.46
Lignin	56.94	33.84	51.04	40.88	74.96

Table 4: Proximate analysis results for the treated and untreated sisal fibres

Constituent (%)	Untreated	KOH Treated	NaOH treated	HCl+KOH treated	HCl+NaOH Treated
Cellulose	4.68	30.16	1.83	0.57	1.74
Hemicellulose	43.88	48.97	45.97	62.91	50.34
Lignin	30.92	1.05	31.16	19.82	29.72

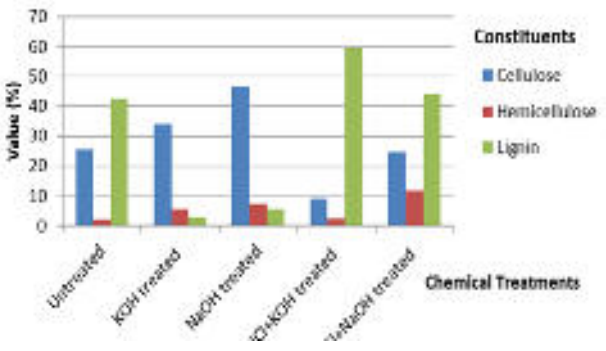

Figure 1: The proximate constituents of treated and untreated Banana fibres

3.*1.1 Effect of chemical treatments on the constituents of banana fibres*

The delignification effect of the alkalis (NaOH and KOH) may be responsible for the apparent increase in hemicelluloses content from 2.13 % for the untreated fibres to 5.82 % and 7.43 % for the KOH and NaOH treated banana fibres respectively. Rather than the reduction reported by (Lacerda et al., (2012) and ; Safinas et al. (2013), the use of HCl + KOH and HCl + NaOH treatments seemed to increase the hemicelluloses content of the banana fibres to 2.6 % and 11.9 % respectively. Although, this may be due to factors like acid concentration or possible inhibition by the dissolved salt ions. It may also be attributed to the concurrent hydrolysis of the cellulose by the excess acid, which also

takes place during the process as confirmed by the reduction in cellulose content.

Recent studies by Oladele et al. (2014) which indicate that alkali treatment reduces the lignin content of natural fibres holds good for banana fibres as shown by the reduction in lignin content from 56.94% to 51.04% and 33.84% for the 1 M NaOH and 1 M KOH treated fibres respectively (see Figure 1). As reported by Oladele et al. (2010), KOH performed better in this respect. The expected delignification effects of KOH and NaOH are non-evident in the HCl + KOH and HCl + NaOH treatments. This is because on mixing both solutions, the alkalis are completely neutralised into the normal salts (KCl and NaCl) which are dissolved in an excess of the acid.

Natural fibres are composites in which the lignin serves as matrix while the cellulose serves as reinforcement. Chemical treatments are usually carried out to modify the surface conditions of the fibers so as to be able to ensure proper adhesion between fibre and matrix. This is achieved by the removal of the deleterious constituents like lignin and hemicelluloses while retaining cellulose. The cellulose was the main constituent that enhances the strength of the fibre for engineering application (Oladele et al, 2010). Besides, the treatments will prevent the fibers from being susceptible to fungi attack.

3.1.2 Effects of chemical treatments on constituents of plantain fibres

As can be deduced from Table 2 and Figure 2, plantain fibres reacted quite differently from banana fibres when subjected to similar chemical treatments. Only NaOH treatment significantly increased the cellulose content from 24.82 % to 36.87 % (a lesser extent than was obtained in the case of banana fibres) whereas KOH treatment led to a reduction.

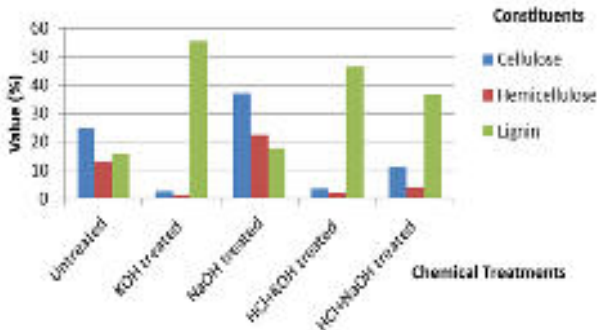

Figure 2: Tthe constituents of the treated and untreated plantain fibres

A similar situation to the cellulose response played out in the response of the hemicelluloses in plantain fibres to similar chemical treatments as those from banana. Treatment with KOH also reduced the hemicelluloses content significant to 1.21 %. In addition, the hemicelluloses in plantain fibres showed similar response but less stability to attack by the acidified salt solutions (HCl + KCl and HCl + NaCl from HCl + KOH and HCl + NaOH treatments respectively) or alkali-acid mixtures. Hemicelluloses content was reduced from 12.88 % for the untreated plantain fibres down to 2.01 % and 3.94 % for the HCl + KOH and HCl + NaOH treated fibres, respectively.

All the treatments led to an increase in lignin content. Only NaOH treatment gave marginal increase which causes it to appear to be the best treatment.

3.1.3 Effects of chemical treatments on constituents of coconut fibres

Considering the alkaline treatments, Table 3 and Figure 3, KOH treatment led to the expected increase in cellulose content from 15.8% to 22.58%, whereas NaOH treatment caused it to reduce. However, treatment with HCl + KOH causes an increase that is up to 35.77 % and was observed to be the best treatment for the enhancement of the cellulose content of the fibres.

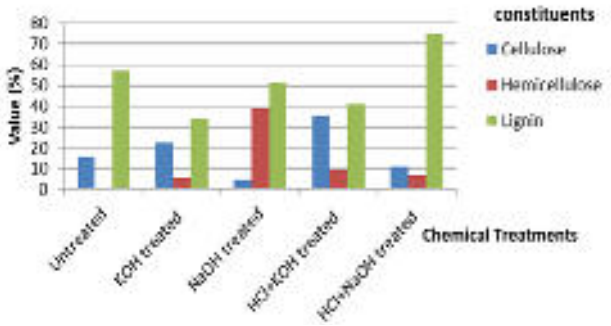

Figure 3: The constituents of treated and untreated coconut fibres

Just as with plantain fibres, coconut fibres showed different responses to alkali or mercerization treatment. All the treatments increased the hemicelluloses content of the coconut fibres, with NaOH treatment having a significantly greater effect as shown in Figure 3. This can result from the reduction in cellulose content as well as the delignification influence of the alkalis. All the treatments except HCl + NaOH led to the delignification effect. The best reduction was achieved from alkali treatment as evident in Figure 3 in which the lignin content reduced from 56.94 % to 33.84 % for the KOH treatment.

3.1.4 Effects of chemical treatments on constituents of sisal fibres

Table 4 and Figure 4 give the results of the analysis for the sisal fibre constituents. For cellulose, only KOH treatment gave improvement compared to the untreated fibre from 4.68 to 30.16 % respectively. Based on the reasons stated above, the hemicellulose content was

increased by the chemical treatments. The lignin was drastically reduced by KOH and HCl+KOH treatments from 30.92 to 1.05 and 19.82 % respectively. This shows that KOH treatment is responsible for the reduction since the best results are coming from the treatment with this chemical compared to NaOH.

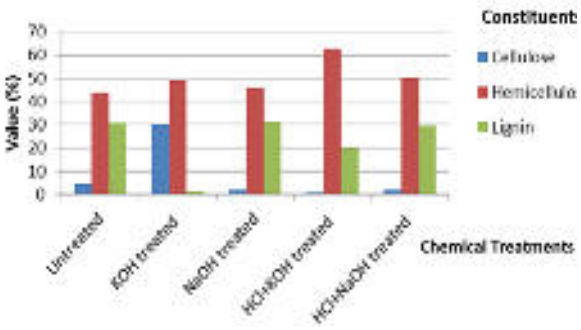

Figure 4: The constituent of treated and untreated sisal fibres

3.2 Effect of Chemical Treatment on the Tensile Properties of Agro-fibers

3.2.1 Effects on tensile strengths of banana fibres

As shown in Table 5 and Figure 5, all the chemical treatments improved the tensile properties strengths of the banana fibers. This is because these treatments in one way or the other, contributed to the removal of the unwanted constituents such as pectin, waxes, lignin and hemicelluloses. Delignification frees up the cellulose fibres to be able to stretch with less inhibition and hydrolysis of the hemicellulose further aids this effect. The hydrolyzing effect of HCl treatment on amorphous cellulose can also be responsible for the increased strengths in the HCl + KOH and HCl + NaOH treated banana fibers, as this crystalline cellulose, are able to align and stretch along the stressing axis. KOH treatment gave the best performance in this respect. The sample treated with 1 M KOH provided the best result with a value of 0.27 MPa compared to the untreated fibre with a value of 0.04 MPa.

Table 5: Ultimate tensile stresses withstood by the treated and untreated fibres

Fiber	Ultimate tensile stress after treatments (MPa)				
	Untreated	KOH treated	NaOH treated	HCl+KOH treated	HCl+NaOH treated
Banana	0.03672	0.27102	0.20071	0.19096	0.09039
Plantain	0.10896	0.17769	0.107955	0.06245	0.03719
Coconut	0.49927	0.5472	0.535	0.60184	0.68646
Sisal	0.65467	0.5843	0.81268	0.34807	0.38353

Table 6: Strain at maximum tensile stress for the treated and untreated fibres

Fiber	Tensile strain at maximum tensile stress (%)				
	Untreated	KOH treated	NaOH treated	HCl+KOH treated	HCl+NaOH treated
Banana	0.8333	9.25	4.5	4.583	3.332
Plantain	1.583	2.667	2.417	1.333	2.417
Coconut	58.084	36.75	53.667	56.417	52.417
Sisal	5.083	8.833	9.333	3.917	5.500

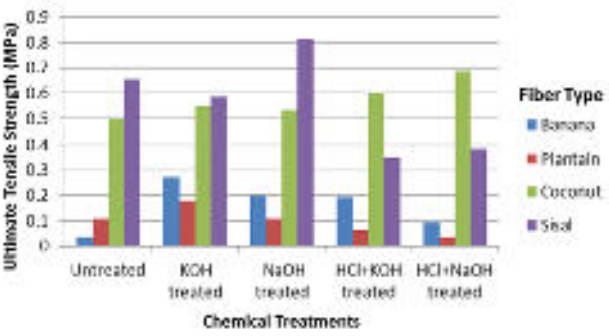

Figure 5: Variation of Ultimate Tensile Strength of the selected agro fibres in both Treated and Untreated Conditions

The other interesting thing about the performance of these chemical treatments was that the fibre surfaces will be roughened thereby making the surface readily available for proper bonding between the fibre and the matrix when use as reinforcement material for composite development.

3.2.2 Effects on tensile strength of Plantain fibres

Considering the effects of the treatment on the tensile strength of plantain fibers, only KOH treatment marginally enhanced the tensile strength of the plantain fibres from 0.11 for the untreated to 0.18 MPa for KOH treated fibre. This may be because the lignin content was increased while the cellulose content greatly reduced by this treatment. Increase in lignin content might infer better stress transfer due to proper binding effect of the residual lignin matrix that prevents excessive defibrillation of the cellulose fibrils. This aided their stretching and load distribution and thereby contributed to tensile strength improvement.

However, the removed cellulose fraction might be the crystalline form which would definitely reduce the tensile strength since the untreated fibres contain more of these. The presence of lignin makes it an unsuitable reinforcement material due to the smoothness of the surface. A smooth surface will not allow proper bonding between fibre and matrix. One of the reasons chemical treatment is being carried out was to achieve a rough surface for the fibre which will aid proper bonding between the fibre and the matrix in composite development

3.2.3 Effect on tensile strength of Coconut fibres

The results showed that all the chemical treatments improved the tensile strengths of the coconut fibres as shown in Figure 5. Treatment with the blend of 1 M HCl + NaOH gave the best performance with a value of 0.69 MPa compared to the untreated fibre with a value of 0.50 MPa. This might be due to the increased hydrolysis of amorphous cellulose fibrils (Onyeagoro, 2012) and the presence of more crystalline cellulose which has better tensile strengths than amorphous cellulose.

3.2.4 Effect on tensile strength of Sisal fibres

The results of the tensile strength property for sisal fibre shows that only mercerization with 1 M NaOH solution significantly improved the tensile strength of the sisal fibres from 0.66 to 0.81 MPa for the untreated and NaOH treated sisal fibres respectively. All the other treatment procedures investigated reduced the tensile strength of the sisal fibres. This can be attributed to the effective cleaning and delignification property of NaOH solution on the sisal fibres.

Except for the coconut fibre which showed the best enhancement in tensile strengths with synergistic treatments, the response of other fibres to the chemical treatment showed that alkali treatments with KOH and NaOH respectively were acceptable. However, by correlating the tensile strengths performance with the chemical treatments, it was noticed that the chemical treatments have influenced the fibers in different ways. These might be in connection with the interaction between the fibre constituents and the chemicals. Banana and plantain that are of the same family were observed to be highly enhanced by KOH treatment while sisal fibre was highly enhanced by NaOH treatment.

3.3 Effect of Chemical Treatment on Strain at Maximum Tensile Stress of Agro-fibers

3.3.1 Effects on the strain at ultimate tensile strength of banana fibres

The strains experienced up till maximum tensile stresses were reached for each fibre. As can be deduced from Table 6 and Figure 6, all the chemical treatment procedures had similar effect on tensile strains of the banana fibres and in this case, KOH treated fibres also experienced the highest strains of 9.25 % which can be deduced as the main reason why this sample possess the best tensile strength property. The reasons for this is as explained concerning the effects of chemical treatment on the tensile strengths of banana fibers.

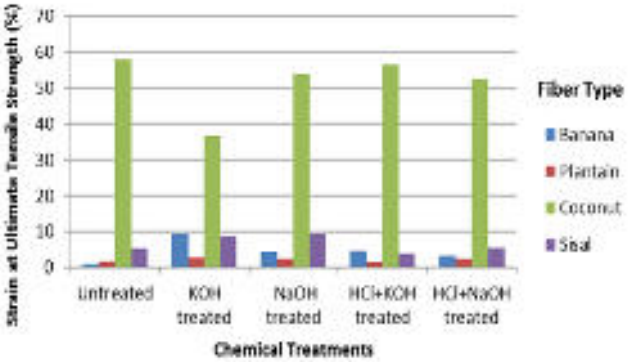

Figure 6: The strains experienced by the treated and untreated fibres at the ultimate tensile strengths

3.*3.2 Effects on strains at ultimate tensile stress of plantain fibres*

Figure 6 showed that plantain fibres had lower tensile strains than banana fibres. Almost all the treatments also showed improved tensile strains from 1.58 to 2.67 % for the untreated and KOH treated fibres respectively. This result is also in agreement with results from tensile stress and strain above for banana and plantain.

3.*3.3 Effect on strains at ultimate tensile stress of coconut fibres*

All the treatment procedures reduced the strains experienced by the coconut fibres before their tensile strengths were reached during testing. This can of course be attributed to the various effects these treatments had on the constituents of the coconut fibres. Potassium hydroxide treatment increased the cellulose and hemicellulose contents but reduced the lignin content, thus causing significant defibrillation of the fibres.

3.3.4 Effects on the strain at ultimate tensile strengths of Sisal fibres

The results in Figure 6 show that the treatments increased the strains and extension ability of the sisal fibres. The highest strain enhancement of more than 9 % was obtained with treatment using 1M NaOH solution. This was also in agreement with the result from tensile strength, where the same chemical treatment aids the best performance.

Natural fibers with good tensile properties are potential material for reinforcement in composites development with short or long strand. A very good knowledge about these will aid in the selection of the appropriate materials and production process.

5. Conclusion

This work has been successfully carried out to investigate the best treatment for the selected agro-fibers as potential reinforcement materials for the development of environmental friendly materials. From the research, it was established that:

1) All the chemical treatment procedures had great influence on the constituents of the fibres and the ensuing tensile properties. Alkaline treatments were best for the constituents and surface modification of these selected fibers: treatment of banana and plantain with 1 molar solution of KOH gave the best output while treatment with 1 molar solution of NaOH gave the best result for sisal fibre. Coconut fibre shows the most positive response to synergistic treatment in which the blend of HCl and NaOH as well as HCl and KOH gave the best results. Sisal fibre possesses the overall best tensile strength followed by coconut fibre. All except coconut fibre had their tensile strain at maximum tensile strength increased by some of the chemical treatments.
2) One objective was to compare the tensile strength properties of banana and plantain, being plants from the same family. It was discovered that banana fibre possesses higher strength than plantain fibre. It was found that at both treated and untreated conditions, banana maintains higher strength than plantain despite the fact that the plants look alike. This shows that their constituents differ.
3) The work has further substantiated the fact that chemical treatments can enhance the tensile properties of agro fibres targeted for use as reinforcement in polymer composites development for automobile applications. It was observed that all the selected agro fibres had their tensile strength enhanced relative to their individual untreated counterparts in the following order: sisal, coconut, banana and plantain.

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Factor Analysis of Elements Influencing Occupational Safety and Health Management System Development in Trinidad and Tobago

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Abstract: *It is increasingly important that organisations focus on occupational safety and health (OSH) to enhance their competitive edge. In Trinidad and Tobago (T&T) the OSH Act aims to reduce risk levels through development of safe systems of work. This paper reports on factor analysis conducted upon a recent survey of Occupational Safety and Health Management System (OSHMS) implementation in the manufacturing sector of T&T. The survey targeted a group of 40 small and medium-sized manufacturing enterprises (SMEs). It explored the factors influencing OSHMS development from among 22 elements. It was found that two overarching factors correlate significantly to OSHMS implementation in SMEs. Factor 1, "Safety Structure and Practices", consisted of 11 OSHMS elements in two groups ("OSH Oversight" and "OSH Arrangements") with factor loadings ranging between 0.599 and 0.876. Factor 2 "Improvement Drivers" consisted of 4 OSHMS elements with factor loadings ranging between 0.805 and 0.846. The remaining 7 elements were eliminated during the course of the analysis due to low correlation or low communality of elements, or double-loading on factors. The paper puts forward that government- and industry-supported systems could be critical aids to promote collaboration among SMEs and help them to set up their own formal OSHMS.*

Keywords: *OSH Act, Factor Analysis, Occupational Safety and Health Management System, OSHMS*

1. Introduction

Recent studies advocate the importance of safety and health practices that promote economic wellbeing and productivity for both businesses and nations (Abdul Raouf, 2004; Hawkins and Booth, 1998; ILO, 2001; Law et al., 2006). In Trinidad and Tobago (T&T), more focus is being placed on developing and growing the manufacturing sector so as to diversify its economy. This sector consists mainly of small and medium enterprises (SMEs). The Occupational, Safety and Health (OSH) Act encourages micro-enterprises to have OSH systems in place, but they are not mandated to maintain much documentation or even have OSH Committees or policies. However, in the case of larger organisations, the OSH Act does require more formal, documented systems (GORTT, 2004). At present, it is not known to what extent T&T manufacturing companies which have installed OSH Management Systems (OSHMS) are in compliance with the OSH Act, as data and statistics have not been publicly published. There is therefore a need to evaluate the extent to which OSHMS implementation has been effected in compliance with the OSH Act. This paper reports findings of a recent survey of OSHMS implementation, and identifies the main factors that contribute to the OSHMS development in the manufacturing sector with a focus on SMEs in T&T.

This paper has five (5) sections. Following the introduction, a Literature Review is presented in Section 2. An outline of the study approach is provided in Section 3. In Section 4, the various stages of analysis are described, ideal values of constants are compared to the empirically determined values, and further actions are rationalised. The paper concludes in Section 5 with recommendations based on the findings of the research.

2. Literature Review

There is, to a large extent, concurrence on good safety management practices around the world. For many years, the UK's Health and Safety Executive (HSE) using the POPMAR approach, recommends that OSHMS development and implementation include setting *policy* for OSH, *organising* staff, *planning* for health and safety, *measuring* OSH performance, and devising a system *audit* and *review* activities (HSE, n.d.). Since 2013, the HSE (2013) has aligned its recommendations with the 'Plan, Do, Check, Act' (PDCA) approach, pointing out that OSH management systems should be integrated within companies' overall management systems and rolled out in accordance with

each individual company's risk profile. In addition to this overarching recommendation, the HSE makes several guidelines and templates freely available to its stakeholders via its website. The ANSI/AIHA (2005) OSHMS standard seems strongly aligned with this approach as well.

Commonly recommended OSH elements include developing an OSH policy, providing OSH training, setting OSH rules and regulations, performing inspections for hazardous conditions, performing job hazard analysis, conducting investigations of accidents and incidents, establishing programmes promoting OSH, establishing programmes to protect employee health and well-being, managing subcontractors, and establishing programmes to plan for emergencies (Nathai-Balkissoon, Pun, and Koonj Beharry, 2012). Teo and Ling (2006) also called for the use of team meetings, proper equipment maintenance, control of hazardous materials, and safe work practices. Chan, Kwok, and Duffy (2004) support the development of OSH organisation elements, including a safety committee, as well as OSH arrangements including programmes for process control and personal protection.

T&T's OSH Act (GORTT, 2004; 2006) requires the following to be included with an OSHMS: OSH policy, safety information, instruction, training, and supervision, risk assessments, accident investigation, health surveillance, measures to protect the safety, health and welfare of employees and non-employees, emergency preparedness, employee consultation and functioning of a safety committee in larger organisations, hazardous material management, personal protective equipment and devices, safe work systems and practices, including safeguarding of machinery. The challenge with the T&T OSH Act is that implementation of some elements is left to the discretion of the company. The likelihood that manufacturing organisations will place a high priority on OSHMS development is lowered because there is little enforcement by T&T's OSH Authority and Agency, OSHA (Nathai-Balkissoon, 2011). It is difficult to assess the state of OSHMS implementation across the industry sectors within T&T, since there is a paucity of published and publicly available data on the subject.

3. Methodology

3.1 Survey Instrument and Administration

A survey questionnaire was developed, with reference to the OSH Act content. Data, presented in this paper, were sourced from the section of the survey that evaluated the extent to which OSHMS elements had been implemented. Table 1 shows the survey question and the 22 items that were the focus of this factor analysis, along with the 5-point Likert scale and rating values used in coding the data.

For the convenience of respondents, an electronic version of the survey was developed within the Survey Monkey online survey programme, and disseminated using a web-link. The web-link was sent to the sample population via email, along with a message explaining the survey purpose, giving assurance of confidentiality, describing the approach to data treatment and requesting completion of the survey online.

The survey was distributed to 100 SMEs within the manufacturing industry. Attempts were made to increase the response rates of potential respondents by targeting persons who were safety or engineering practitioners. The representatives all had technical backgrounds and held some responsibility for safety performance in their companies. If they did not consider themselves suitable to complete the survey, they were asked to forward the survey to the appropriate person for completion. Efforts were also made to contact respondents through professional networks such as LinkedIn, obtain direct email addresses rather than those of administrative assistants, and send reminder messages a few weeks later in the survey process. Valid completed questionnaires were obtained from a total of 40 respondents.

3.2 Analysis Method

Quantitative analysis of multivariate data may be done using a range of techniques, including factor analysis and principal components analysis, multiple regression, multiple discriminant analysis, canonical correlation, variance and covariance multivariate analysis, conjoint analysis, cluster analysis, perceptual mapping, correspondence analysis, and structural equation modelling (Hair et al., 2010). If there are many independent variables which may help a phenomenon to be more easily understood by grouping them into dimensions of similarity, then factor analysis is likely to be useful (Hair et al., 2010). Factor analysis can help with both the identification of variables that correlate with one another, and with the identification of variables that are fairly independent of one another.

This paper presents the findings at the various stages of the factor analysis performed on the 22 survey items that evaluated the extent of the company's implementation of OSHMS. A total of 40 complete responses were received. While it is usually recommended that sample size exceed 50 for a factor analysis to be performed, given the difficulty experienced in obtaining further survey responses from the field, the choice was made to conduct an initial exploratory factor analysis. According to de Winter, Dodou, and Wieringa (2009), sample sizes of less than 50 are capable of yielding acceptable factor loadings as long as high communality values, a high number of observed variables, and a low number of factors characterise the undertaking.

Table 1. Survey Questionnaire Items

To what extent do you agree that the following elements are properly addressed at your company?			
No.	**Item**	**Rating**	
1	There is a safety and health committee	SD D N A SA	
2	There is a documented safety policy	SD D N A SA	
3	There is a dedicated safety officer, safety practitioner, or other person hired or contracted with specific responsibility to fulfil this function	SD D N A SA	
4	Top managers know the requirements of the OSH Act, and are committed to complying with them through planning, resource allocation, and provision of support	SD D N A SA	
5	Employees know the requirements of the OSH Act and play an active role in developing and improving elements of the safety management system	SD D N A SA	
6	The company identifies hazards, assesses risk levels, and implements action plans to prevent and control these hazards	SD D N A SA	
7	The safety of at-risk persons have been considered, including pregnant or nursing females, young persons, and non-employees	SD D N A SA	
8	There are checks in place to ensure contractor safety performance, when contractors perform duties at, or for, your company	SD D N A SA	
9	Hazardous chemicals (materials) are properly identified and safely used, handled, stored, transported, and disposed of	SD D N A SA	
10	Confined spaces have been identified and precautions have been taken to protect worker safety when accessing confined spaces	SD D N A SA	
11	Emergency plans, fire safety arrangements, and safe access and egress points have been established	SD D N A SA	
12	Proper safeguards (e.g. guards, fencing on equipment) are in place	SD D N A SA	
13	Training, information, instruction, and supervision are provided to ensure employee safety and health	SD D N A SA	
14	Reporting and investigation of accidents, injuries, and death is consistently done	SD D N A SA	
15	The company is environmentally responsible	SD D N A SA	
16	Conditions required to satisfy the OSH Act's Health requirements have been met	SD D N A SA	
17	Conditions required to satisfy the OSH Act's Welfare requirements have been met	SD D N A SA	
18	The company conducts medical examinations of employees	SD D N A SA	
19	The company practices health surveillance of employees	SD D N A SA	
20	The OSH Act is posted in the organisation as required	SD D N A SA	
21	All information, notifications and records are submitted as required by the OSH Act	SD D N A SA	
22	Protective clothes and devices are supplied to employees in accordance with the OSH Act	SD D N A SA	

Rating scale (coding value) key: SD – strongly disagree (1), D – disagree (2), N – neither agree nor disagree (3), A – agree (4), SA – strongly agree (5)

For this analysis, three assumptions were made, namely:

- suitable data used in the analysis, with the intention of using appropriate statistical tests to evaluate the sampling adequacy.
- linearity among variables, with the intention of correcting for any non-linearity with transformations as appropriate.
- errors that were uncorrelated with each other.

The Statistical Package for the Social Sciences (SPSS-21) computer programme was used to perform the statistical analysis, with principal component analysis selected from within the factor analysis menu setting in that programme.

3.2.1 Principal Components Analysis

A total of 22 OSHMS variables were measured. This is to determine whether summative scales existed that could contribute to understanding the extent to which OSHMS implementation was achieved within the surveyed companies. The analysis method selected was factor analysis, which would help to derive an understanding of relationships among a large number of OSHMS variables by identifying a smaller number of variable clusters (Fang et. al, 2004). There are several approaches to factor analysis which may be used. principal components analysis (PCA) was performed so that the high number of variables could be grouped into summated scales, i.e. factors (Hair et al., 2010). Using PCA, the 22 OSHMS elements were structured into factor groupings in such a way that there would be high correlations between variables and their respective factor, as well as high between-variable correlations within individual factors (Jolliffe, 2002).

3.2.2 Correlation Matrix

One outcome of PCA was a correlation matrix (see Table 2) showing the extent to which the variables were correlated to each other. Since identification of factors depends on being able to group variables into areas of commonality (Fields, 2000), variables were expected to correlate highly with at least one other variable under consideration. A correlation lower than 0.3 was considered undesirable as this suggested that factorability of the variable is unlikely (Tabachnick and Fidell, 2007). Any variable having correlation <0.3 with

other variables (underlined in Table 2) was discarded from further consideration.

3.2.3 Measures of Sampling Adequacy

Measures of sampling adequacy (MSA) were used to determine whether the data being analysed were sufficient to allow valid conclusions to be drawn. In SPSS, MSA values were computed for each individual variable under consideration. There was also an overall MSA evaluation done per iteration generated within the software. This overall MSA evaluation was located in the Anti-Image Correlation table, and included Kaiser-Meyer-Olkin (KMO) and statistical significance values. The KMO value is a measure of sampling adequacy for which Othman and Owen (2001) recommend a minimum value of 0.5. The Bartlett's test of sphericity looks at the distribution of the data and helps to judge whether it is adequate and suitable to apply factor analysis to the data as a test of its multidimensionality (Othman and Owen, 2001). It also includes a measure of the significance of the data, which should not exceed 0.05 (Fields, 2000).

3.2.4 Factor Extraction and Factor Rotation

The variance table was carefully scrutinised to ensure that an appropriate number of factors were selected for extraction. Eigenvalues inform the determination of the number of factors selected in PCA by successively extracting factors in descending order of total variance across all variables accounted for by each factor (Moonsamy and Singh, 2014). One may either look at a scree plot to see where the scree curve flattens off, thus indicating the point from which additional factors have reduced influence on the dependent variable, or as Kaiser (1960) recommends, one may choose the number of factors for which eigenvalues are greater than 1.000. For this study, SPSS was instructed to extract factors corresponding to eigenvalues greater than 1.000. Hair et al. (2010) suggest that when factors are extracted, their combined variances should not be less than 60% in order to derive a meaningful factor relationship.

When factors were extracted, item communality (extraction) values were also determined. High communality of a variable is desirable because it indicates that the proposed factors of the model explain a high portion of the variance of the variable. According to Moonsamy and Singh (2014), if communality exceeds 1.000, the solution is invalid and there is likely to be either too small a sample or an unacceptable number of factors. For the purpose of this study, an extracted communality of $\geq 0.5$was sought per variable.

Additionally, when two or more factors are extracted, the component matrix is unsuited to evaluating relationships among variables, since it is likely to find considerable occurrence of cross-loading onto more than one factor. By rotating the component matrix, variable loadings are maximised onto single factors and cross-loading of variables onto multiple factors is minimised. The rotated component matrix could then be used to discern the loadings of individual variables on single factors, and to recognise which variables may not fit well into summated factor scales. In SPSS, a varimax rotation was selected to minimise the number of variables loading onto factors and to reduce the likelihood of small loadings (Yong and Pearce, 2013).

3.2.5 Factor Analysis Iterations

Where measures are out of acceptable bounds for measures such as correlation, significance, factor loading, and communality, then further decisions were taken to treat with the data. A common approach to out-of-limit measures would be to discard the variable in question and to do another iteration within the software. In the course of the analysis, a total of 7 variables were discarded for various reasons (correlation <0.3, significance <0.05, communality <0.5, and cross-loading of variables onto more than one factor), and a total of 5 iterations were done before all conditions were met.

4. Survey Findings and Discussion

According to Nunnally and Bernstein (1994), the reliability of a survey questionnaire would be considered as acceptable if the Cronbach-α value exceeds 0.70. The Cronbach-α value for the 22-item scale being analysed was found to be 0.965. Also, every item correlated well with the rest of the scale (the minimum corrected item – total correlation value was 0.546) and it was observed that there was no benefit to deleting any item from the scale, as such alteration of the instrument would only cause the α value to rise by a maximum of 0.001 (negligible). Therefore, results showed that all items correlated well within the scale, and the survey scale had very strong inter-item consistency.

4.1 Data Factorability and Sampling Adequacy

Tabachnick and Fidell (2007) advise that, before performing a factor analysis, the data must be evaluated for suitability in terms of its factorability and the sampling adequacy using Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy. Factor analysis is considered an appropriate method once Bartlett's test is significant to the level of $p<0.05$, while the KMO value should be a minimum of 0.6 to support a good factor analysis. SPSS evaluation of the data yielded a KMO value of 0.811, and a significance of 0.000. From this, the data were considered adequate for use, and able to be used to perform factor analysis.

4.2 Factor Analysis: Initial Iteration

The initial factor analysis was performed on all 22 elements. As shown in Table 2, 20 of the 22 variables

Table 2. Correlation Matrix for the Initial 22 Elements

	OSH Cmttee exists	Doc'd SPol exists	Dedic'd SLead exists	Top mgmt committment	Employee participation	Risk Assessments done	At-risk grps considered	Contractor safety checks	HazMat practices	Confined space practices	Emergency planning	Proper safeguards	T.I.I.S.	AINM report & investig'n	Envir. responsibility	Health requirements met	Welfare requriements met	Med. exam of employees	Hlth surveill. of employees	OSh Act posted up	OSH submissions made	PPED for employees
OSH Cmttee exists	1.000	.825	.800	.464	.456	.541	.573	.644	.581	.624	.548	.507	.476	.486	.435	.424	.501	.521	.372	.327	.611	.607
Doc'd SPol exists		1.000	.863	.553	.455	.738	.667	.680	.727	.709	.786	.713	.602	.625	.481	.620	.699	.543	.465	.510	.662	.774
Dedic'd SLead exists			1.000	.479	.410	.684	.603	.716	.570	.629	.669	.464	.512	.527	.305	.605	.644	.413	.321	.493	.638	.663
Top mgmt committment				1.000	.712	.496	.532	.646	.663	.524	.560	.507	.713	.702	.510	.680	.663	.289	.268	.424	.397	.550
Employee participation					1.000	.486	.505	.654	.496	.463	.522	.372	.695	.665	.479	.610	.563	.298	.319	.387	.323	.470
Risk Assessments done						1.000	.682	.812	.631	.767	.818	.611	.667	.718	.347	.654	.666	.365	.385	.506	.538	.770
At-risk grps considered							1.000	.648	.693	.598	.700	.578	.508	.510	.417	.578	.666	.417	.202	.386	.540	.689
Contractor safety checks								1.000	.639	.768	.774	.561	.681	.695	.430	.804	.718	.441	.419	.564	.556	.767
HazMat practices									1.000	.717	.664	.786	.523	.526	.603	.688	.710	.532	.439	.426	.571	.645
Confined space practices										1.000	.726	.629	.572	.654	.355	.629	.608	.557	.461	.354	.565	.755
Emergency planning											1.000	.641	.704	.700	.521	.725	.776	.631	.541	.581	.700	.924
Proper safeguards												1.000	.619	.587	.609	.523	.641	.518	.456	.411	.419	.666
T.I.I.S.													1.000	.898	.528	.619	.688	.426	.414	.513	.483	.731
AINM report & investig'n														1.000	.343	.627	.669	.295	.316	.484	.449	.727
Envir. responsibility															1.000	.571	.682	.643	.613	.317	.496	.542
Health requirements met																1.000	.899	.399	.456	.658	.545	.709
Welfare requriements met																	1.000	.538	.495	.708	.564	.767
Med. exam of employees																		1.000	.787	.296	.494	.619
Hlth surveill. of employees																			1.000	.343	.378	.496
OSh Act posted up																				1.000	.497	.507
OSH submissions made																					1.000	.727
PPED for employees																						1.000

revealed correlation scores above 0.30 with at least one other variable, suggesting reasonable factorability. However the correlation scores were under 0.30 within elements 18 and 19, which addressed the conduct of medical examinations, and health surveillance checks on employees respectively. Principal components analysis yielded composite scores for the factors contributing to the OSHMS. The eigenvalues from the first iteration attributed 59.940% of the variance to a first factor, 7.355% of the variance to a second factor, and 6.300% of the variance to a third factor. Factors four, five, and six had eigenvalues of 0.954, 0.831, and 0.768, respectively, each factor explaining just about 4% of the variance. The three factor solution (which explained a high 73.595% of the variance) was selected because they matched the condition of the eigenvalue being greater than 1 (see Table 3).

4.3 Factor Analysis: Second Iteration

With elements 18 and 19 excluded, the factor analysis was repeated on the remaining 20 elements. For the second iteration, all correlations were greater than the required 0.3 and statistically significant at the 0.05 level. Looking at the anti-image correlation table, it was found that the MSA for each individual element was greater than 0.5, ranging from 0.594 to 0.911. The 0.803 KMO value also indicated that there was good sampling adequacy.

In iteration 2, three factors were again extracted, with variances of 62.586%, 6.977%, and 5.226%, totalling 74.789% of the full variance. The communality extraction values all exceeded the required 0.5 value (0.617 to 0.870) except for element 20 (*OSH Act posted up*) which had a value of 0.428. This element needed to be discarded.

Table 3. Total Variance Explained for the Initial 3-Factor Solution

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.187	59.940	59.940	13.187	59.940	59.940	6.648	30.216	30.216
2	1.618	7.355	67.295	1.618	7.355	67.295	5.973	27.149	57.365
3	1.386	6.300	73.595	1.386	6.300	73.595	3.571	16.230	73.595
4	.954	4.335	77.929						
5	.831	3.778	81.708						
6	.768	3.492	85.200						
7	.582	2.647	87.847						
8	.557	2.532	90.379						
9	.410	1.865	92.244						
10	.328	1.492	93.736						
11	.295	1.342	95.078						
12	.234	1.065	96.143						
13	.184	.838	96.981						
14	.164	.746	97.727						
15	.127	.579	98.306						
16	.124	.565	98.871						
17	.085	.385	99.256						
18	.054	.244	99.501						
19	.046	.208	99.709						
20	.031	.141	99.850						
21	.020	.091	99.941						
22	.013	.059	100.000						

Remarks; Extraction Method: Principal Component Analysis.

4.4 Factor Analysis: Third Iteration

Factor analysis on the remaining 19 elements returned all correlations greater than 0.3 and statistically significant at $p<0.05$. Each individual element's MSA had improved, now ranging from 0.724 to 0.954. Communality values were acceptable, ranging from 0.618 to 0.868. Again, 3 factors emerged; they accounted for 76.659% of the total variance. Because more factors were identified from the PCA, the component matrix could not be used to obtain further understanding of the variable relationships, and a rotated component matrix was called for instead. A varimax rotation was performed and the resulting rotated component matrix is shown in Table 4.

The component transformation matrix revealed that the three factors were highly correlated before and after the rotation, with the correlations being 0.688, 0.679, and 0.875 for Factors 1, 2, and 3, respectively. Because variables were reflecting high loadings on more than one component (i.e. factor), the structure of the PCA was considered complex. Examining the loadings of each variable revealed that items 8, 16, and 17 (*Contractor safety checks*, *Health requirements met*, and *Welfare requirements met* respectively) were cross-loading (i.e. showing loadings of similarly high magnitude) on multiple components, so these 3 variables were excluded.

4.5 Factor Analysis: Fourth Iteration

While the fourth iteration performed on the remaining 16 elements resulted in all correlations being statistically significant and greater than 0.3, only 2 factors were

Table 4. Rotated Component Matrix[a] generated using a varimax rotation in SPSS

Element/ Item	Component		
	1	2	3
OSH Committee exists	.776	.166	.230
Documented Safety Policy exists	.824	.272	.339
Dedicated Safety Lead exists	.851	.254	.113
Top management commitment	.212	.730	.403
Employee participation	.150	.798	.251
Risk assessments done	.714	.520	.113
At-risk groups considered	.616	.332	.359
Contractor safety checks	.630	.622	.187
Hazardous materials practices	.524	.307	.643
Confined space practices	.712	.421	.190
Emergency planning	.684	.479	.336
Proper safeguards	.459	.297	.611
Training, Information, Instruction, and Supervision	.330	.799	.267
Accident/Incident/Near Miss report and investigation	.408	.824	.102
Environmental responsibility	.148	.241	.882
Health requirements met	.410	.593	.465
Welfare requirements met	.451	.527	.578
OSH submissions made	.698	.121	.369
Personal Protective Equipment and Devices for employees	.699	.453	.348

Remarks: Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalisation[a]
[a] - Rotation converged in 6 iterations.

yielded, instead of 3 as in all prior iterations. Of the cumulative variance loading of 70.978%, Factor 1 accounted for 62.622%, while Factor 2 accounted for 8.356% of the variance. All communality values were acceptable (ranging from 0.595 to 0.876) except for the element *Environmental responsibility*, which reflected an extracted value of 0.426 and was excluded in yet another iteration.

4.6 Factor Analysis: Final Iteration

The final iteration was performed on the remaining 15 elements and all correlations were statistically significant and acceptably high (ranging from 0.323 to 0.924, as seen in Table 5 and Figure 1).

All individual item MSA values ranged from 0.822 to 0.941 and the overall KMO-MSA value was 0.886, high enough to be categorised as "meritorious" (Hair et al., 2010). Principal components analysis again yielded just 2 factors with the eigenvalue >1, as seen in Table 3 and Table 6. Of the cumulative variance loading of 73.208%, Factor 1 accounted for 64.419% of the variance, while Factor 2 accounted for 8.789%. Communalities were all acceptable, ranging between 0.578 and 0.876.

Because more than one factor were identified from the PCA, a varimax rotation of the data space was performed in order to maximise the variance of the factors, strengthen the distinction between factors, and clarify the relationships of variables loading onto factors (Jabnoun and Sedraani, 2005; Kakkar and Narag, 2007). The emerging result from the completed principal component analysis of the pilot data is summarised in Table 7. The factor loadings showed that 11 of the factor loadings were excellent (>0.7), while the remaining 4 factor loadings were very good (>0.63). Therefore, it was postulated that these 15 items could be structured into just 2 factor groups that correlate with the existence of a safety management system.

Table 5. Correlation Values for the Final 15 Extracted Elements

	1.OSH Cmttee exists	2.Doc'd SPol exists	3.Dedic'd SLead exists	4.Top mgmt committment	5. Employee participation	6. Risk Assessment is done	7.At-risk grps considered	8. HazMat practices	9. Confined space practices	10.Emergency planning	11. Proper safeguards	12. T.I.I.S.	13. AINM report & investig'n	14. OSH submissions made	15. PPED for employees
OSH Cmttee exists	1.000	.825	.800	.464	.456	.541	.573	.581	.624	.548	.507	.476	.486	.611	.607
Doc'd SPol exists		1.000	.863	.553	.455	.738	.667	.727	.709	.786	.713	.602	.625	.662	.774
Dedic'd SLead exists			1.000	.479	.410	.684	.603	.570	.629	.669	.464	.512	.527	.638	.663
Top mgmt commitment				1.000	.712	.496	.532	.663	.524	.560	.507	.713	.702	.397	.550
Employee participation					1.000	.486	.505	.496	.463	.522	.372	.695	.665	.323	.470
Risk Assessments done						1.000	.682	.631	.767	.818	.611	.667	.718	.538	.770
At-risk grps considered							1.000	.693	.598	.700	.578	.508	.510	.540	.689
HazMat practices								1.000	.717	.664	.786	.523	.526	.571	.645
Confined space practices									1.000	.726	.629	.572	.654	.565	.755
Emergency planning										1.000	.641	.704	.700	.700	.924
Proper safeguards											1.000	.619	.587	.419	.666
T.I.I.S.												1.000	.898	.483	.731
AINM report & investig'n													1.000	.449	.727
OSH submissions made														1.000	.727
PPED for employees															1.000

Table 6. Total Variance Explained for the Final 2-Factor Solution

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.663	64.419	64.419	9.663	64.419	64.419	6.528	43.519	43.519
2	1.318	8.789	73.208	1.318	8.789	73.208	4.453	29.688	73.208
3	.789	5.261	78.469						
4	.749	4.990	83.459						
5	.536	3.576	87.035						
6	.480	3.200	90.235						
7	.371	2.475	92.710						
8	.287	1.915	94.625						
9	.224	1.493	96.118						
10	.197	1.310	97.428						
11	.115	.764	98.192						
12	.095	.632	98.824						
13	.077	.511	99.335						
14	.058	.386	99.722						
15	.042	.278	100.000						

Table 7. Rotated Component Matrix Showing Final Factor Loadings

Element/ Item	Component/ Factor	
	Factor 1, Safety Structure and Practices	Factor 2, Improvement Drivers
Documented Safety Policy exists	.876	.330
Dedicated Safety Leader exists	.838	.215
OSH Committee exists	.795	.209
OSH submissions made	.780	.168
Personal Protective Equipment and Devices for employees	.758	.486
Emergency planning	.741	.503
Confined space practices in place	.718	.430
Risk Assessments done	.695	.492
At-risk groups considered	.682	.394
Hazardous Material practices in place	.680	.451
Proper safeguards in place	.599	.467
Training, Information, Instruction, and Supervision	.364	.846
Accident/Incident/Near Miss reporting and investigation done	.387	.829
Employee participation	.192	.826
Top management commitment evident	.298	.805

Remarks: Extraction Method: Principal Component Analysis; Rotated Component Matrix[a] · Rotation Method: Varimax with Kaiser Normalisation.

[a]. Rotation converged in 3 iterations.

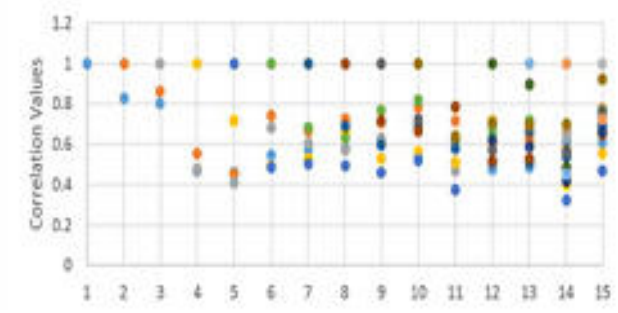

Figure 1. Scatterplot of Correlation Spread for Final 15 Extracted Elements

Figure 2. Factor Loadings plot illustrating relationships between the elements and factors

Besides, a plot was constructed of the factor component weightings for each element, and this revealed that the points fell into three clusters. The plot added to an understanding of the relationships between elements and factors, as annotated in Figure 2.

Based on the elements loaded onto factors, titles were assigned to the factors. With 11 elements, Factor 1 "Safety Structure and Practices", consisted of two clusters near to the base of the plot. The first 4 of those 11 elements were influenced predominantly by factor 1,

with very little influence from factor 2. The remaining 7 elements were influenced somewhat more heavily by factor 2. Considering the plot's dual cluster pattern, the 11 elements within Factor 1, "Safety Structure and Practices" were arranged into two sub-groupings, namely (1) "OSH Oversight" with the following 4 elements: *Documented safety policy exists*, *Dedicated safety leader exists*, *OSH committee exists*, and *OSH submissions made* and (2) "OSH Arrangements" with the following 7 elements: *Personal protective equipment and devices for employees*, *Emergency planning*, *Confined space practices in place*, *Risk assessments done*, *At-risk groups considered*, *Hazardous material practices in place*, and *Proper safeguards in place*.

Factor 1, "Safety Structure and Practices", highlights the critical impact that formal structure and routine practices have on the existence of an OSHMS. *OSH Oversight* is borne through policy and leadership elements. A safety policy must focus the OSHMS effort, leadership must control the reins and operate through a functional OSH Committee, and there must be continual monitoring of statutory submissions to meet the mandates of the OSH Act.

OSH Arrangements must be put in place to keep core aspects of the OSH System operating well. Perhaps most critical is the documentation of risk assessments that consider at-risk groups. Also, systems must be in place to promote safety with regard to emergency planning, confined spaces, hazardous materials control, safeguarding, and personal protective equipment and devices.

On the plot, all elements of the "Improvement Drivers" factor fit into one cluster. For all of these elements, there is the predominant influence of Factor 2 ($\geq$0.805) and much smaller influence of factor 1 ($\leq$0.387). Hence, Factor 2 (Improvement Drivers) consists of 4 elements, including: *Top management commitment*, *Employee participation*, *Training, information, instruction, and supervision*, and *Accident/incident/near miss reporting and investigation*.

Factor 2, "Improvement Drivers", would promote buy-in and continual improvement of the OSHMS by ensuring that managers and employees are involved in the day-to-day functioning of the OSHMS, leading by example, providing and benefitting from training, instruction, information, and supervision, and using proper accident, incident, and near miss reporting and investigation to identify root causes of challenges and bring about improved systems. Based on the above rationale, a model was derived showing how the elements influence the existence of an OSHMS (see Figure 3).

One might try at this point to make sense of why 7 of the initial 22 elements were discarded in the course of the analysis. These 7 elements were *Medical examination*, *Health surveillance*, *OSH Act posted up*, *Contractor safety checks*, *Health requirements met*, *Welfare requirements met*, and *Environmental responsibility*. These variables are important considerations in any OSHMS but it appears that they were not sufficiently prioritised by the SMEs being studied.

It is possible that many SMEs would perceive these elements as "nice to have" but would not yet recognise them as critical to the OSHMS. Companies might consider these elements as areas in which time, effort, and financial investment could be saved. The lack of focus on these areas could be compounded by the relatively low level of enforcement existing in the manufacturing industry. Employers are currently implementing elements of an OSHMS on a voluntary basis, because there are few resources available to enable the OSH Authority to perform inspection activities. Rather than carrying out safety checks on their contractors, for example, SMEs might hold the view that the onus is on contractors to adhere to the OSH Act.

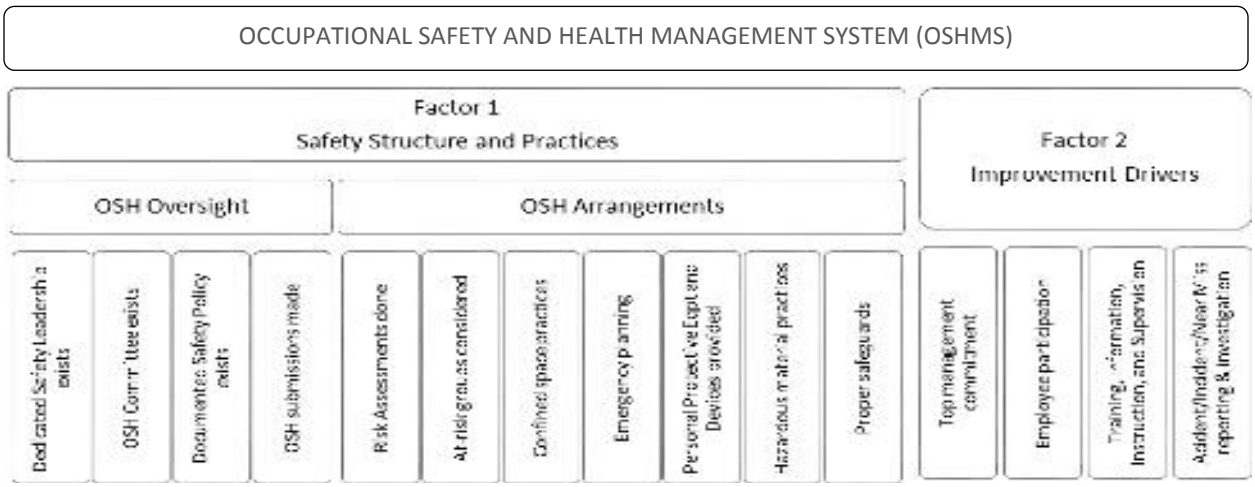

Figure 3. How SMS elements influence the existence of an OSHMS

Moreover, since the OSH Act advises that medical checks and surveillance are voluntary unless an inspector mandates such practices, few SMEs are motivated to incur such "unnecessary expenses". Finally, where health, welfare, and environmental requirements are stipulated in the OSH Act and other legislation, the near-absence of enforcement would still be enabling lax practices in SMEs in T&T.

5. Conclusion and Recommendations

Out of the 22 elements that were considered in this factor analysis, 15 elements significantly correlate with the establishment of an OSHMS in the companies sampled. Based on the principal components analysis performed on the sampled manufacturing SMEs, this study concludes that two main factors are linked to a large extent to the establishment of an OSHMS.

Factor 1, "Safety Structure and Practices", is a summated scale consisting of 11 variables addressing OSH oversight and OSH arrangements, and accounts for over 64% of the variance contributing to the establishment of an OSHMS. Factor 2, "Improvement Drivers", is a summated scale consisting of 4 variables, and accounts for almost 9% of the variance contributing to the establishment of an OSHM

Several recommendations are put forward based on the study. These are:

1. The findings of this paper are based on a survey of 40 SMEs from Trinidad's manufacturing sector. The study therefore is not generalisable to the whole manufacturing sector, and there is a need to carry out a wider, more representative survey of SMEs from the entire manufacturing sector. Given the relatively low response rate obtained in this study, the conduct of a more representative, wide-ranging study would require buy-in and active support from T&T's manufacturers' associations and chambers of commerce to incentivise or otherwise encourage participation by their members.
2. While the posited model cannot be considered as final because of the relatively small sample size of respondents, it can nevertheless provide some insight into variables that likely impact on OSHMS as they currently exist in T&T. There is a need for T&T's OSH Authority and Agency to support implementation of the model's factors and elements by documenting a full range of standards, codes of practice, guidelines, checklists, and other tools to aid companies in establishing or enhancing their OSHMS.
3. Perhaps the 7 elements not included in the model were excluded because survey respondents perceived them as unimportant as they appear in the OSH Act as non-mandatory or are perceived as being non-mandatory. The documented materials mentioned in Recommendation 2 will also raise implemented OSHMS standards by communicating how even elements perceived as voluntary could reduce risk and expense to businesses.
4. Many a local SME may hold the view that several OSH Act requirements require large budgets, and that their companies will be unable to discern sufficient return on this investment. It is up to OSHA to convince employers that investing in safety will bear them rich dividends. OSHA should more consistently track and disseminate data about the cost of lax safety, and the savings to be gained by investing in an effective OSHMS.
5. Data can also provide insight into the needs of companies in certain subsectors. There is a need to empower SMEs to develop themselves, rather than expecting them to hire experts to build their systems. This latter expectation might be impractical as costs may be too high for some companies. Certainly, there will always be aspects of OSHMS development that can only be adequately addressed through the involvement of specialist-experts, but there are also many aspects that can be addressed by making appropriate guidance, information, and stories/cases freely available to companies, as has been done in the case of the UK's Health and Safety Executive website and social media outreach efforts. Similar outreach should be done via the T&T OSHA website.
6. OSHA is not the only entity from whom insights and data dissemination should be generated. There is a need for more active sharing of best practices within the field. Research is needed to share updates on approaches that have worked and those that have failed in industry sectors. Studies should put forward recommendations on OSHMS establishment and improvement, with a special focus on sectors (such as manufacturing) that may not be current priority areas for OSHA.
7. With a little support and structure from an umbrella organisation (such as the Ministry of Labour or the Trinidad and Tobago Manufacturing Association), SMEs should be encouraged to collaborate on setting up their own formal OSHMS and auditing each other's systems, in a thrust for continual improvement and competitiveness. Research geared toward structuring user-friendly OSHMS development, implementation, and/or evaluation tools would assist in this regard.

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Smart Grid Analysis for the Caribbean Region

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Abstract: *This paper presents a gap analysis of smart grid technology for the Caribbean region, and outlines the opportunities for the potential widespread roll-out of this technology, the challenges posed and the exercises employed to assist legacy power systems transition to the smart grid. By exploring the evolution of the smart grid and smart grid statistics, this paper applies smart grid technology to regional and local contexts. The available technologies involved are also discussed, as well as economic and business strategies for the smart grid in a Caribbean context. For the region, the most important factor is the adoption of renewable energy sources and a distributed generation paradigm that is characteristic of the smart grid, as well as the widespread use of relevant communications and information technologies. Other recommendations include rigorous planning with cost versus benefits analyses being performed with respect to the applicable technologies and a strategic business plan. The paper concludes by describing the transition to the smart grid using micro-grids.*

Keywords: *Smart grid, Electricity, Power system, Caribbean, Renewable*

1. Introduction

In the Caribbean, the electrical network is considered to be antiquated as the current electrical infrastructure in most, if not all, Caribbean nations has remained unchanged for decades and is aging while electricity consumption is increasing. One means of enhancing the existing grid is the adoption of smart grid (SG) technology. The smart grid is a next generation electrical power system, typified by increased use of communications and information technology (ICT) in the generation, delivery and consumption of electrical energy (IEEE Smart Grid 2014). While the traditional grid has always been "smart" to some extent, there is a need for grids to get smarter. Utilities are developing and deploying standards and technologies to transform the traditional grid into a smart grid, leading to higher levels of resilience and reliability. The smart grid is, therefore, a modern electrical power grid infrastructure, boasting improved efficiency and sustainability, with smooth integration of renewable and alternative energy sources.

While most developed countries, European countries and the US for example, have embarked on enhancing their 20th century grids with SG technology, the Caribbean region is focusing on renewable energy (RE) research and deployment. According to the Caribbean Electric Utility Services Corporation (CARILEC), 85% of all electric power in the Caribbean is generated with fuel oil and most Caribbean countries are either fully or more than 90% dependent on oil, thus emphasising the need for energy diversification in the region (CARILEC 2008). On March 1, 2013, the Caribbean Community (CARICOM) countries embarked on the development of a Regional Energy Policy focused on the widespread deployment and integration of renewable energy sources, in an attempt to reduce dependence on fossil fuels and contribute to the fight against climate change (CARICOM 2013).

Smart grid technology is therefore promising for the Caribbean region: The emergence of the SG will lead to enhanced environmental sustainability, with more reliable power supply services. There is, then, the need to investigate the suitability of SG technology to the region and to determine the measures needed for full-scale roll-out. The University of the West Indies (UWI) is currently undertaking a research and capacity building initiative on how this technology will enhance the efficiency of present electrical power networks in the region.

This paper outlines the requirements to enable the evolution of the existing grid in the Caribbean to SG status. This gap analysis will also focus on the opportunities and challenges for the smart grid in the region. Some insights on regionally relevant technologies are shared. As an outcome, the UWI intends to construct and deploy a microgrid within a laboratory environment, which will be used to simulate the technology on a small scale.

2. Grid Evolution

The smart grid can be thought of as the outcome of the evolutionary development of existing networks towards an optimised and sustainable energy system (Hashmi, Hanninen, and Maki 2011). The International Energy Agency (IEA) defines a smart grid as an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids coordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability (International Energy Agency 2011).

This evolutionary development is centred on the mass infusion of Information and Communication Technology (ICT) and Computational Intelligence (CI) into the existing grid. The smart grid is emerging as a convergence of computing and communication technologies with power system engineering (Farhangi 2010). At the core of this transformation is the need to make use of current assets, incorporating new technologies gradually, thus following an evolutionary trajectory, rather than performing a complete overhaul. The evolution of the grid is illustrated in Figure 1.

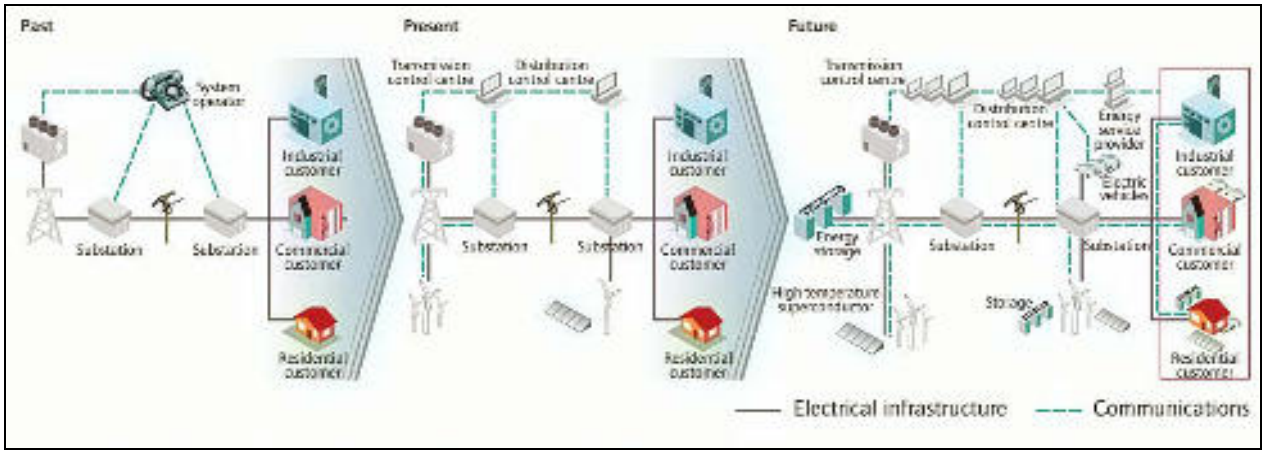

Figure 1. Grid Evolution
Source: International Energy Agency (2011)

Referring to the traditional grid as having always been "smart", implies that traditional grids make use of ICTs. However, in a truly smart grid, there is heavy use of modern communication and high performance computing technologies. SG evolution can be segmented into distinct versions. For the sake of clear nomenclature, the terminology presented by Trilliant Inc. (2015) will be utilised. Smart Grid v0.0 is the base case – this cannot be classified as a "smart" network since each network used proprietary protocols to read meters on isolated networks. This phase is typically associated with automated metre reading (AMR). Smart Grid v1.0 saw the advent of advanced metering infrastructure (AMI), a smarter version of AMR. In AMI, metres are automatically read and standards-based solutions provide applications like demand response and time-of-use (TOU) billing. The next phase of the SG, Smart Grid v2.0, involves the consumer becoming directly involved with energy utilisation. It highlights the necessity for two-way communication and the advent of a consumer-oriented grid. Finally, Smart Grid v3.0 is the future of SG technology, where plug-in hybrid electric vehicles (PHEVs) and micro-grids of distributed generation interact with the grid to balance energy supply and demand (Trilliant Inc. 2015).

Communication and data management play an important role, placing a layer of intelligence over the existing and future infrastructure. It is worthy to note that in the future grid, communications and electrical infrastructure work in tandem from generation to consumption, which results in improved control, monitoring and automation, as well as stronger consumer involvement (Farhangi 2010).

The smart grid can therefore be realised through strategic implants of distributed control and monitoring systems within and alongside the existing electricity grid. This will facilitate the distributed generation and co-generation of energy and allow for the integration of alternative energy sources and the management of a system's carbon footprint. It will also enable utilities to make more efficient use of their existing assets through demand response, peak shaving and service quality control (Farhangi 2010).

According to Farhangi (2010), 90% of all power outages and disturbances originate in the distribution network. Therefore, the move towards the smart grid should start in the distribution system. A proposed method to modernise the distribution network is the introduction of technologies that help with demand-side management and revenue protection. Utilities across the world are moving towards deploying advanced metering infrastructure (AMI), which provide utilities with two-way communication to the metre (Farhangi 2010).

The IEA lists some general characteristics of the smart grid which are applicable in any regional context. The SG enables informed dynamic participation by customers (usage data and pricing); integrates all generation and storage options; provides the power quality for the range of needs driven by market conditions; optimises asset utilisation and operating efficiency (automation and remote control); and provides resiliency to disturbances, attacks and natural disasters. The smart grid cannot and should not be a replacement for the existing electricity grid, but is a complement to it. It should coexist with the existing grid, adding to its capabilities, functionalities and capacities by means of an evolutionary path (Farhangi 2010).

Farhangi (2010) describes the smart grid as an ad hoc integration of complementary components, subsystems and functions. The evolution of the smart grid is facilitated by the integration and interconnection of smart microgrids. Smart microgrids are defined as distributed energy systems that can function either connected to or be independent of the electricity grid. These interconnected microgrids have dedicated paths for command, data and power exchange. The system of integrated smart microgrids operates in parallel with the existing grid, with functionality and load gradually being migrated from the existing grid to the smart grid. The topology of the emerging grid will therefore resemble a hybrid solution (Farhangi 2010).

3. Smart Grid at the Global Level

Worldwide statistics ought to be considered when performing a gap analysis to determine the direction towards the full scale roll-out of a smart grid for the Caribbean. These statistics are drawn from projections as well as results from pilot implementations. The integration of (intermittent) renewable energy sources (RES) is a major benefit of the smart grid, because it reduces a country's carbon footprint. Electricity distribution within the smart grid paradigm would reduce carbon dioxide emissions by up to 25%. A 25% reduction in CO_2 emissions equates to 7.6 billion tons by 2030 (U.S. Department of Energy 2014). The reduction of Green House Gas (GHG) emissions via smart grid deployment would be as a result of removing 140 million cars from the road (by encouraging the use of PHEVs), lowering coal use by 18% and natural gas use by 50%, and avoiding the construction of 80,000 MW coal-fired generation plants (U.S. Department of Energy 2014).

Some of the requirements of smart grids include improved utilisation through the use of improved control and monitoring of networks, and reduced consumption via Demand Side Management (DSM) (Hashmi, Hanninen, and Maki 2011). From pilot implementations in the US, it has been found that smart grid enabled energy management systems have been able to reduce electricity usage by 10-15% and up to 43% of critical peak loads. A state of the art high capacity transmission line can conduct as much electricity as six standard lines, at one-third the cost, using 25% less land, and with one-tenth the line losses. Smart grid enabled distribution could reduce electrical energy consumption by 5-10%, carbon dioxide emissions by 13-25% and the cost of power related disturbances to business by 87% (Energy Future Coalition 2015.).

The global market for smart grid IT and management services will grow from $1.7 billion in 2014 to more than $11.1 billion in 2023. Services include home energy management, advanced metering infrastructure, distribution and substation automation communications, asset management and condition monitoring, demand response, software solutions, and analytics (Energy Future Coalition 2015).

4. Smart Grid: Regional and Local Context

This section of the paper will examine where the Caribbean stands currently in terms of its progress towards achieving smart grid status, and covers the goals in bridging the gap.

4.1 Renewable Energy

There is a disproportionate dependence on fossil fuels in the Caribbean region, particularly oil and natural gas, (CARILEC 2008, CARICOM 2013). This dependence on fossil resources is primarily for electricity generation and vehicular transport. According to GIZ and CARICOM (2014), over 95% of the commercial energy consumption is based on mineral oil products. This leads to high levels of national debt and high costs for electricity generation (GIZ and CARICOM 2014). As such, the Caribbean region is faced with several critical challenges with respect to the generation, distribution and use of energy (Auth et al. 2013). With the CARICOM countries focusing on the deployment of renewable and alternative energy, in an attempt to diversify energy sources and combat climate change as a regional body, it is important to examine the renewable energy plans of each country.

As an outcome of the CARICOM Regional Energy Policy, the first phase of the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS) was commissioned. C-SERMS Phase 1 is aimed at coordinating a regional approach to expedite the increased use of renewable energy and energy

efficiency, while promoting climate-compatible development, minimising environmental damage and fostering economic growth and innovation (Auth et al. 2013). Another such outcome is the Renewable Energy and Energy Efficiency Technical Assistance (REETA) Project. The REETA project builds on the results and successful approaches of the Caribbean Renewable Energy Development Programme (CREDP) and other projects in the region (such as C-SERMS) (GIS and CARICOM 2014). The REETA project focuses on the development of a regional energy strategy, the establishment of regional know-how and the support of the regional networking of stakeholders. The overarching project goal is for regional and national players in the areas of RE and energy efficiency to increasingly comply with the political, organisational and technical demands of a growing market in the Caribbean (GIZ and CARICOM 2014).

One of the main characteristics of the smart grid is the deployment of renewable and distributed resources, thus leading to a reduction in GHG emissions. In particular, smart grids are characterised by distributed generation (DG), which refers to the introduction of small rating electricity sources, typically decentralised and located close to end-user locations on the distribution side of the grid. This gives rise to an on-demand power quality of supply, enhanced grid security (reduced susceptibility of a centralised power source) and reliability, and deferrals in the transmission investment (Simoes et al. 2012).

As such, the first step towards the regional deployment of a smart grid in each Caribbean nation, from a technological standpoint, is the adoption of the DG paradigm, which involves the deployment of distributed, renewable energy sources. For power generation there are no viable alternatives that could compete on price with oil, coal or natural gas. The Caribbean region therefore needs to explore the best possible and most economically feasible options in the field of renewables. The most obvious options in the Caribbean are wind power, biomass, geothermal, ocean thermal, hydropower and solar power (CARILEC 2008). Tremendous potential exists in many countries to meet most or all of current demand with renewables. Table 1 illustrates the technology potential measured with respect to its measured share of peak demand in each member state.

Table 2 compares the renewable energy target of each Caribbean nation, and also indicates whether or not these countries have already deployed RES in their grid supplies. Some countries already have provisions for widespread deployment of renewable energy sources. This underscores the need for larger countries such as Trinidad and Tobago and Belize to introduce renewable sources into their local energy mix and/or enforce time of use tariffs on non-renewable sources. The development and deployment of alternative and RE sources is therefore one of the major gaps between the region's SG roll-out when compared to already existing SG implementations. Apart from this, economic and business factors must be considered.

The use of renewable energy sources and energy efficiency (EE) technologies in each country would lead to reduced dependency on mineral oil imports. According to GIZ and CARICOM (2014), "increased investments in EE and RE will mitigate some of the uncertainties in the future costs of energy".

Table 1. Technology potential measured with respect to measured share of peak demand in CARICOM member states

	Hydro	Wind	Geo-thermal	Solar	Biomass/ Other
Antigua and Barbuda					
The Bahamas					
Barbados					
Belize					
Dominica					
Grenada					
Guyana					
Haiti					
Jamaica					
Montserrat					
St. Kitts and Nevis					
St. Lucia					
St. Vincent and the Grenadines					
Suriname					
Trinidad and Tobago					

Extremely High (>100%)	Very High (50-100%)	High (20 – 50%)	Medium (0 – 20%)	None/Low	Unknown

Source: adopted from Auth et al. (2013)

Table 2. Renewable energy targets of each Caribbean country and whether or not RE exists in the grid supply

Country	Renewable Energy Target	Renewable Energy in Grid Supply
The Bahamas	NYA	No
Barbados	40% by 2010	Yes
Belize	NYA	Yes (HEP)
Dominica	25% by 2010	Yes (22% HEP in 2007)
Grenada	10% by 2013; 20% by 2017	No
Guyana	70-80% by 2012 (HEP)	No
Jamaica	15% by 2020	Yes (Wind, HEP)
St. Kitts	100% by 2012	No
St. Lucia	30% by 2012	No
*Trinidad and Tobago	NYA	No
St. Vincent	NYA	Yes (20% HEP)

Remarks: *5% target of 60 MW in 2022; NYA = Not Yet Available; HEP = Hydro Electric Power
Source: Ministry of Energy and Energy Affairs (2011)

Reducing electricity tariffs in countries that do not have their own energy sources would effectively lower the bills of domestic consumers. Figure 2 illustrates the typical bills of domestic consumers at 100 kWh/month for September 2012. Countries, like Trinidad and Tobago, which produce its own fossil fuels and hydrocarbons from abundant sources within the nation's territory, have lower bills: the commodity is more expensive for those countries which import resources.

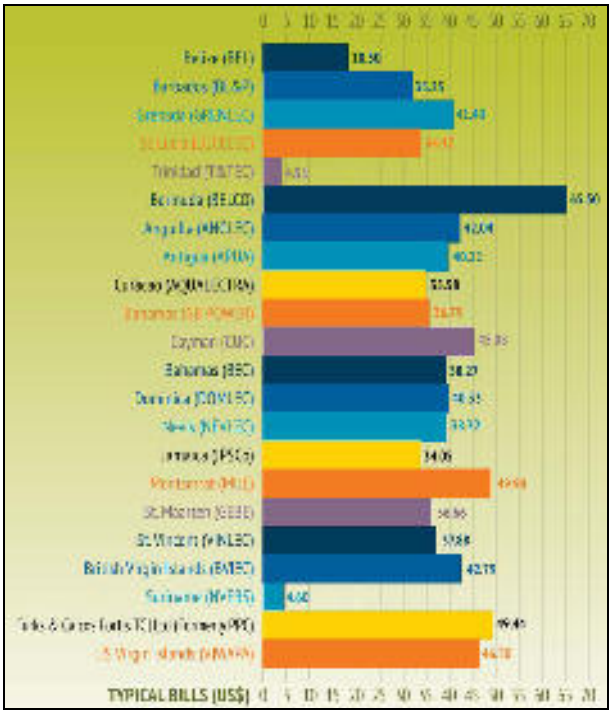

Figure 2. Typical Bills for 100kWh/month Domestic Consumers for 2012
Source: CARILEC (2012)

4.2 Smart Grid Business Plan for the Caribbean

Before the deployment of SG technologies can occur, utilities and researchers alike must examine how implementation of the smart grid can be done in a cost effective and efficient manner. A number of economic factors affect the roll-out of new technologies. Any utility which wishes to implement a smart grid on a macroscopic level must first determine and select various business objectives to suit their needs, i.e. implementation needs and the needs of consumers. This is especially important in the Caribbean region since most countries are developing nations and each has a different economy, budget, developmental priorities, and supply and demand factors. Due to the diversity of operational challenges that each utility will face, SG implementation will differ from one utility to the next. However, one thing remains common: the driving objective of every smart grid is ultimately a business objective (Barbosa 2012).

As a result, utilities must undertake strategic planning, selecting business objectives according to their priorities. Typical SG business objectives are similar, however priority will differ from one utility to the next (Barbosa 2012). According to Barbosa (2012), typical business objectives for the planning of the smart grid include:

- Enabling informed participation by consumers
- Reducing operational costs through better voltage control
- Improving power quality delivered to customer
- Enabling DG and storage options throughout the network and better management of those assets which are owned by both utility and customer
- Strengthening the network's resiliency in the face of cybersecurity attacks and natural disasters
- Introducing new products and services to the consumer
- Optimising existing and new asset utilisation

Barbados Light & Power (BL&P) suggests a phased approach, i.e. implementing the SG in several phases, driven by various business objectives (Barbosa 2012). BL&P's phased approach allows control of: budget, technology deployment, application of key technologies in the highest priority areas, technology evaluation, change management, maintenance and implementation

phases within a realistic plan (Barbosa 2012). This shows that Barbados is one of the few Caribbean countries which has made progress to bridge the economic/business gap of SG deployment. Their business model as mentioned above, is sound, and avoids common pitfalls to which some utilities succumb. This approach and model is useful to other Caribbean nations as they move towards SG implementation.

After determining and selecting the most suitable business objectives, the utility must then select the SG technology that meets these business goals. There should be a thorough evaluation of potential technologies before selection; utilities must conduct cost-benefit analyses and investigate integration issues when selecting technologies (Ockwell 2012). According to Ockwell (2012), the evaluation of a well-designed and integrated pilot program may reveal the need to invest in primary infrastructure before proceeding with technology deployment. The rationale behind this is that the smart grid is not a single technology proposition. A true smart grid involves integrated architecture that can adopt new technologies as new business objectives emerge and change (Barbosa 2012; Ockwell 2012).

5. Smart Grid Opportunities in the Caribbean

This section highlights the range of opportunities available for smart grid implementation and deployment in the region. With a focus on the development of Trinidad and Tobago's smart grid, an attempt will be made to present opportunities which may be applicable to other Caribbean countries, mainly from a technological standpoint, while also performing a gap analysis on SG technologies.

The instrumental role of ICT based applications in the SG revolves around real-time control and monitoring. There is the need for automated control, modern communications infrastructure and sensing technologies. Smart grids generally feature increased digital information, in particular the bi-directional flow of information, which requires sophisticated control, sensing and computer-oriented monitoring devices. This is achieved through the use of Advanced Metering Infrastructure (AMI), which facilitates two-way communication and the transmission of delivered and generated energy data, along with actionable commands to customers, thus affording consumers better control over energy usage (Simoes et al. 2012). Data from sources (metres, sensors) must be relayed to appropriate controllers in the grid to make smart decisions. In 2006, the Trinidad and Tobago Electricity Commission (T&TEC) developed a plan to install over 40, 000 metres across its customer base. As of 2008, sixteen thousand metres were installed (CARICOM 2013).

Smart grid advancements have the potential to manage demand by shifting loads to off-peak hours and better utilising domestic renewable energy resources (Auth et al. 2013). This is referred to as the peak shaving of load demand and in the case of Trinidad and Tobago, can result in a 13-24% peak reduction. At the household level, the deployment of smart meters (AMI), combined with appropriate policy provisions, would allow customers to generate their own power and sell excess electricity back to grid (Auth et al. 2013). This gives rise to another highly desired feature of the smart grid, the bi-directional flow of power. This is facilitated by the DG paradigm mentioned previously, as well as efficient electricity storage. The use of smart meters also facilitates real time pricing, which can potentially result in energy consumption behaviour modification.

As stated, the SG is also characterised by the embedding of Computation Intelligence (CI) in the grid. This implies that computing technologies play a major role in the implementation and deployment of smart grids, making it a truly cyber-physical system. This can potentially translate to a technological revolution for the region, with the infusion of high performance computing technologies to facilitate processing of data in ensuring efficient control, monitoring and automation processes. In particular, it ensures that these processes can be carried out in real-time, and allows for data mining/storage, intelligent coordination, security, simulation, visualisation and control (Green II, Wang, and Alam 2013). This therefore opens opportunities in the Caribbean for high performance computing solutions. Such technologies include cluster, multi-core, many-core (GPU), grid and cloud computing.

Cloud computing opportunities are vast due to the one to many relationships between data and devices over the Internet. This translates to extensible and secure computing data centres and enables cost effective incremental development. It leverages Software as a Service (SaaS), effectively minimising capital and implementation time. This also gives rise to the opportunity for creating a thriving smart grid IT market within the region, providing jobs for professionals, and reducing the need for outsourced labour.

System security in a smart grid context may refer to many things, which include, but are not limited to resilience, stability and reliability of the power supply. The smart grid solution provides the opportunity to improve system security in the region. Existing grid infrastructure is outdated and often insufficient to meet the population's current and growing energy needs; this is evidenced by the region's high technical losses and, in select member states, an unreliable electricity supply (Auth et al. 2013). System security manifests itself in the SG in real-time monitoring, fault anticipation, corrective action, expeditious (self) restoration and the reduction of outage frequency and spread.

Another sustainable opportunity of SG deployment in the Caribbean is electrification of the transport sector. This is linked to the reduction of GHG emissions since it includes eco-friendly and financially feasible transport. This may even be extended to include mass transportation systems, but will focus mainly on

Plugin Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). This will lessen the dependence on fossil fuels and could eventually lead to the gas station becoming obsolete.

6. Smart Grid Challenges in the Caribbean Region

Just as there are numerous opportunities within the region for Smart Grid deployment, there are also numerous challenges which arise due to several, usually unavoidable, factors, as well as poor planning in the initial stages. These challenges manifest themselves in economic and business setbacks, poor technology deployment, vulnerabilities in the grid and shortfalls in the technologies used.

Often, within the utility, the corporate business objective is not well known; engineering, operations and IT may not agree on the direction in which they are taking the utility (Barbosa 2012). Utility executives often do not clearly identify the strategic business objective of the utility (Ockwell 2012). According to Barbosa (2012), the utility executive must provide clarity in leading the organisation in their strategic business objectives and the organisation must cooperatively create a multi-department tactical plan that is able to meet those objectives.

The unclear business objectives result in another challenge in the SG setting, i.e. the selection of SG technology. It is common for a utility to invest early in a single technology under a system wide roll-out without performing some critical analysis on cost vs benefit. Often, the technology is selected first without a sound business objective. This can be seen in the case of AMI. AMI has the potential to consume multi-year budgets using time and resources that may be spent on the deployment of other integrated SG solutions (Barbosa 2012). The business objectives drive the technologies and the technologies will specify the deployment plan. To overcome this, BL&P suggests the phased roll-out in a minimal area of the network (Barbosa 2012). This reflects the microgrid approach, discussed further on. A phased roll-out affords the utility the opportunity to evaluate the technology from many aspects, in terms of meeting technical requirements and deployment costs (Barbosa 2012).

Existing grid infrastructure poses a major challenge. The smart grid is susceptible to all threats which the existing grid faces, such as natural disasters and intentional attack. As the existing grid evolves, there is the increased interdependence among the fields of energy, telecommunications, transportation and financial infrastructures, which poses increased risk (Amin and Giacomoni 2012). This interconnectivity makes the grid vulnerable to a spectrum of threats – cascading outages brought on by material failure, natural disasters, sabotage or human error, and failure in one part of an infrastructure network can have adverse effects in other areas (Amin and Giacomoni 2012).

The energy aspect of the smart grid also faces numerous challenges. Generation sources, particularly RES, are intermittent; this affects the output characteristic of generator and convertor sets (Simoes et al. 2012), as well as the transient stability of supply. Interconnection standards must be developed and adhered to when considering diverse generation sources. There are also potential problems in the transmission and distribution systems due to new power flow patterns and quality concerns. Protection, automation and control upgrades may also prove challenging. The introduction of the electric vehicle also poses some challenges in terms of distribution system loading and quality of supply concerns.

A common hidden challenge which obstructs deployment is the lack of data or data quality (Barbosa 2012). Before specific SG technologies are deployed, primary infrastructure should be developed to ensure data quality. On a similar note, there may be integration issues with data infrastructure. The framework of communications, data, computing platforms, sensors, switching devices, active devices and software may not support integration of other solutions (Barbosa 2012).

The infusion of ICTs and upgrade of control systems in the smart grid can introduce vulnerability in terms of cyber-security. Digitisation increases the threat of remote attacks by hackers, who capitalise on known vulnerabilities and misconfigured operating systems, servers and network devices (Amin and Giacomoni 2012). Existing control systems which were initially intended for use with proprietary, stand-alone communication networks are now being connected to the Internet without adding the technology necessary for security. Furthermore, in the communication and control of power systems, various forms of communication media and protocols are used. This diversity and lack of interoperability causes problems when attempting to establish secure communication to and from a substation (Amin and Giacomoni 2012). Increased automation which entails a complex system of sensors and automated controls, tied together through communication systems, also presents a threat. Activities that compromise the operation of sensors, communications and control systems could disrupt the system, cause blackouts and even result in physical damage to key system components (Amin and Giacomoni 2012). To counteract these challenges, Amin and Giacomoni (2012) suggest a layered security approach to minimise disruptions. Multiple security technologies should be combined and deployed at each layer of a computing system (personnel, networks, operating systems, applications, databases) to reduce the risk of unauthorised access (Amin and Giacomoni 2012). Security features include examination, detection, prevention and encryption (Amin and Giacomoni 2012).

The implementation and deployment of AMI, which is typically one of the first steps in the digitisation of the grid, also introduces potential security breaches.

According to Amin and Giacomoni (2012), possible threats include: fabricating generated energy metre readings; manipulating energy costs; disrupting the load balance of local systems by increasing or decreasing the demand for power; gaining control of millions of metres and simultaneously shutting them down; sending false control signals; disabling grid control centre computer systems and monitors; and disabling protective relays. AMI also introduces privacy concerns, as customer energy usage information will be stored at the meter. Unauthorised access and malicious use of this data could expose customer habits and behaviours, opening up avenues for personal profiling, identity theft and home invasions (Amin and Giacomoni 2012). AMI systems also need to be defended against traditional cyber-threats, like malicious code, denial-of-service attacks, accidental faults due to human error and problems associated with aging hardware and software (Amin and Giacomoni 2012).

These threats and challenges bring to the fore further economic setbacks. There are price distortions in the region, for example where there is a fuel subsidy favouring fossil fuel and a lower tax burden compared to renewable energy. With intermittent sources being used for generation, there is the need for advanced storage technology. The energy storage market is estimated to reach $50 billion by the year 2020 (Jacques 2014), leading to increased expenditures on the part of the region. Other challenges posed are legislative in nature. Financial, technical and administrative legislation must be put in place and be on par with the rest of the world. Legislation must also be developed for the use of electric vehicles treating with issues related to charging, billing and dynamic tariffs.

Finally, there are the socio-cultural and human capital challenges of SG deployment. The Caribbean region generally does not have an energy conservative culture. This must be fostered throughout the region to ensure sustainability of energy resources. Additionally, on the utility side, there must be certain training requirements for operational and maintenance personnel (Barbosa 2012). The utility must possess the core competencies necessary to achieve full deployment.

7. Discussion

Smart grid growth is now a necessity; factors such as aging infrastructure, retiring personnel and abundant DG resources are creating a situation where traditional generation technology will be incapable of ensuring grid safety and stability (Elberg 2014; Gipling 2014).

In order to facilitate the full-scale roll-out of a smart grid, The University of the West Indies, St. Augustine Campus has embarked on a project/initiative entitled “Capacity Building and Research on Smart Grid Technology in the Caribbean Region”, with the intent of pioneering the enhancement of electrical power networks in the Caribbean Region by adopting smart grid technology. Research is being conducted on each of the technological aspects of the SG (Power, Communications and High Performance Computing), and implementation will be done on the microgrid level. A microgrid is a small-scale, localised version of the smart grid, achieving specific local goals (The Galvin Project Inc. 2014). It is envisioned that The UWI microgrid will foster the modernisation of the campus power grid.

Until there exists policy to support the integration of smart grid technology into the nationwide power system, yielding financial benefit to the consumer as a net producer, increased savings and efficiencies must occur at the micro level. This will result in localised facilities employing suitable technologies to address the specific concerns while hopefully improving some aspect of their power system.

8. Conclusion

The smart grid is essential to improved energy efficiency, economic development and climate change mitigation. Participation by government, the private sector, consumers and environmental advocacy groups is imperative to successful deployment. Caribbean member states must ensure that the necessary regulations are in place and market models are developed accordingly. System investment, prices and customer participation must evolve in the same manner as SG technologies for incremental smart grid deployment/implementation.

The gaps which exist in the Caribbean must be closed before full-scale deployment can occur within the region. These gaps would generally be similar across nation states. However, there would be minor variations among countries. In summary, utilities must determine and select relevant business objectives; select the appropriate SG technologies to match these objectives, while avoiding total investment in any one technology without proper evaluation; invest in and deploy renewable and alternative energy sources; find and promote local and regional smart grid markets; implement legislation and regulation frameworks, while adhering to worldwide standards; and foster and promote an energy conservative, eco-friendly culture.

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Potential Consumers' Perception of Treated Wastewater Reuse in Trinidad

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Abstract: *In many countries around the world, the reuse of treated wastewater has been adopted as a means of supplementing dwindling water resources and promoting water conservation. During the dry season of 2010, the Water and Sewerage Authority of Trinidad and Tobago provided treated wastewater from its Beetham Plant for industrial and agricultural purposes. The public's acceptance of reusing treated wastewater is a key element in its successful implementation as a water source. A survey of targeted sections of the population was carried out using unstructured interviews and questionnaires. It was found that the idea of non-potable use of treated wastewater for such purposes as firefighting and watering of public lawns was generally acceptable to the public. However, there was more apprehension about direct uses, particularly those involving human contact. The current perception is significantly influenced by the public's mistrust of the local water authorities to deliver safe and quality water; a general lack of knowledge of the treatment process; and perceived health risks associated with using treated wastewater. The ability to widely use treated wastewater in Trinidad in the future would depend on the relevant authorities mounting appropriate public awareness and education programmes.*

Keywords: *Wastewater reuse, public perception, Trinidad*

1. Introduction

In response to growing freshwater shortages, many water utilities around the world have implemented plans to augment their traditional water supplies (e.g. dams and groundwater) with new or alternative sources (e.g. recycled wastewater and desalinated sea water). An assessment of the status of wastewater management shows that in Caribbean region, particularly the Eastern Caribbean, municipal wastewater collection and treatment are underdeveloped and there is potential for its use to meet the demands of the tourism sector primarily in the form of irrigation water (Groves and Saldinger 2011; Peters, 2014). The use of treated wastewater to overcome water shortages has had success in many parts of the world (Miller and Buys, 2008). In the Caribbean, the four year GEF CReW Project with the overall goal of reducing negative environmental and human health impacts of untreated wastewater (Spencer 2013) is likely to lead to an increase in water reuse in the Caribbean, including Trinidad and Tobago. Notwithstanding the potential for wastewater reuse as possible means of achieving water security, gaining public acceptance is proving to be difficult (Longsworth, 2014).

For water augmentation projects to be successfully implemented, the support of the general public is required. Social acceptance is a key element to any reuse project, and can become the main barrier for a water reuse project (Jiménez 2012). Favourable Public perception of a project and so its feasibility can be facilitated by better communication between the sectors involved (Baggett et al., 2006).

It is critical, therefore, to understand public perception on the use of an alternative water source such as wastewater. Public perception can change through improve knowledge and awareness of issues related to wastewater treatment processes, particularly by promoting the high quality and safety of such treated wastewater. The media can play a major role in shaping perception. Yet, it was found that while media practitioners in Caribbean and Central America who participated in a sensitisation workshops on wastewater for journalists were prepared to improve their understanding of environmental and wastewater issues and felt they have a role in shaping or changing people's perception of wastewater, more than 50% of those surveyed could be classified as having low levels of knowledge on issues related to wastewater and the environment in general (Spencer 2014). In 2010, the water demand in Trinidad and Tobago was estimated at 224 million gallons per day (MGD) with a deficit of 38MGD (WASA 2013). The deficit can be satisfied by the 80 ML/d of wastewater collected and treated at Beetham Wastewater Treatment Plant (BWTP). Bahadoorsingh et al (2010) proposed a number of reuse options for the BWTP, ranging from urban to industrial

uses as well as options for indirect potable reuse and a multi-user option. During the drought of 2010, island-wide water shortages led to the experimentation with wastewater reuse. The Water and Sewerage Authority (WASA) provided treated wastewater from the BWTP for irrigation and industrial uses (Newsday, 2010).

In 2013, WASA signed a loan agreement for local wastewater management which included water recycling for industrial use (Boodram, 2013). The success potential for wider wastewater reuse in Trinidad, as in many other jurisdictions, can be limited by the level of public perception of recycled wastewater. In developing the potential reuse options for the BWTP, Bahadoorsingh et al. (2010) and Marx et al. (2011) highlighted that one of the main challenges in making use of the treated wastewater at the Beetham Plant is obtaining end user commitment. Consequently, during project design and implementation, appropriate consideration must be given to public attitudes towards wastewater reuse.

This paper explores the public's perception of reusing treated wastewater to better understand public acceptability of reused water. It is hoped that the results of this study can better inform decision makers in implementing future wastewater reuse projects and so increase water resource availability in Trinidad

2. Background

Worldwide, there is a growing shortage of fresh water, due to dwindling resources and increasing demands as a result of population and economic growth (Postel, 2000; Higgins et al, 2002; Hartley 2006). These shortages have motivated policy makers and water utilities to look for alternative fresh water sources like desalination and wastewater reuse. While treated wastewater is often superior to current potable water standards (Bixio et al., 2005; Wintgens, 2005), the notion of drinking wastewater is not a concept that gains full public support. In fact, Dolnicar and Schafer (2006) reported that the public often vehemently rejected wastewater reuse.

The benefits of wastewater reuse include reducing water pollution from wastewater disposal, reducing energy costs (Robinson, Robinson and Hawkins, 2005), and the provision of a reliable and constant water source (Toze, 2006). Moreover, it protects dwindling fresh water resources, prevents coastal pollution, expands river flow, provides savings in wastewater treatment and aids in replenishing groundwater resources (Angelakis and Bontoux 2001). Notwithstanding the benefits, there are many challenges in implementing wastewater reuse projects. In many cases, where wastewater reuse is being considered, municipalities are finding it difficult to gain public acceptance for the prospect. Robinson, Robinson and Hawkins (2005), Hartley (2006) and Po, Kaercher and Nancarrow (2003) all agree that public acceptance of wastewater reuse is integral to successful reuse projects and must be comprehensively addressed as it is the public who is served by and pays for this new technology.

There have been various studies on the public perception of wastewater reuse. Jeffrey (2002), Hurlimann and McKay (2003) and Robinson, Robinson and Hawkins (2005) assessed the relationship between socio-demographic factors and public perception of wastewater and concluded that regardless of the factors, respondents were generally willing to accept the reuse of water for non-potable uses but were strongly against its use with direct contact to humans. Hartley (2006) also reported that people generally supported the concept of using reclaimed water, with stronger support for using it for non-potable purposes. However, support waned as the possibility of human contact increased. In Australia, Dolnicar and Hurlimann (2010) reported that 92% of respondents would use recycled water for non-potable use like garden watering, but only 36% of drinking. Po, Kaercher and Nancarrow (2003) stated that the disgust emotion and risk perception may explain the research results that show that public perceptions and acceptance are affected by the specific use of the recycled water.

Hartley (2006) highlighted a case study from the mid-1990's, in which a wastewater reuse project was shut down due to the perception that the poorer neighbourhoods would be drinking the treated wastewater which was sourced from rich neighbourhoods. Po, Kaercher and Nancarrow (2003) stated that these perceived social justice issues would influence people's tendency to accept or not accept wastewater reuse projects. For example, Kaercher et al (2003) reported that there was a perception amongst communities that wastewater reuse projects should begin with larger consumers of water (e.g. industrial users) before domestic householders, as they believed that the amount of water that could be saved would be greater by targeting industrial users. Determining public perception by demographics is not straight forward. Savage (1993) found that the relationship between demographic factors and the dread of a hazard is the perceived personal exposure to the hazard. Later, Miller and Buys (2008) studied the difference in knowledge and acceptance of water recycling between genders and found that overall men and women's attitudes and perceptions of recycled water did not differ significantly. However, Hurlimann (2007) found that concerns increased as use became more personal, with women expressing greater concerns than men about the use of recycled water for clothes washing, vegetable growing and showering. Accept change above

The 'yuck' or disgust factor has been documented to influence a wide range of decisions including evaluative or intuitive judgments (Kelly and Morar, 2014).There is consensus among participants in wastewater reuse studies that there were psychological barriers to using treated wastewater. The yuck-factor is almost magical in nature, essentially the same type of thinking that

underlines voodoo practices (Monks, 2014). The barrier stems from the thought of using water that originated from unclean sources. Po, Kaercher and Nancarrow (2003) citing Rozin and Fallon (1987) explained this phenomenon through the "law of contagion" which suggests that a neutral object may become perceived as disgusting through association with another object. Schmidt (2008) explained that some concepts or objects like faeces are universally repugnant and are 'core disgust elicitors'. Miller and Buys (2008) noted that the 'yuck' factor has spurred heavy public opposition to several water recycling projects, resulting in their cancellation or delay. Public concerns about real or perceived risks hamper the use of reclaimed water (Robinson, Robinson and Hawkins, 2005). Risk perceptions are almost always related to public health issues from using the recycled water. Dolnicar and Hurlimann (2010) stated that perceived health risk is the dominant factor preventing people from accepting the use of recycled water. Participants in a study by Jeffrey (2002) claimed that they had no problem with using recycled water so long as it did not compromise public health. Po, Kaercher and Nancarrow (2003) proposed that based on the outrage factors adapted from general literature on risk by Frewer, Howard and Shephard (1998), people may perceive treated wastewater as unsafe and harmful to public health with unknown long term implications, leading to irreversible decisions on its use. In places where water shortages are experienced there is greater acceptance of wastewater reuse (Dishman, Sherrard and Rebhun, 1989). In Israel, with its water shortage problems, wastewater reuse is readily acceptable, and in the USA wastewater reuse for non-potable or indirect potable is widely accepted in drought-ridden communities (Hartley, 2005). In Singapore, Po, Kaercher and Nancarrow (2003) reported that the implementation of the NEWater project materialised after Singapore's water supply was threatened due to potential shortages associated with disputes with Malaysia over imported water. In Greece, Anastasiadis et al. (2014) reported that the public had a positive attitude towards wastewater reuse in agriculture.

Public attitudes on the environment may influence the willingness to accept treated wastewater reuse (Po, Kaercher and Nancarrow (2003). Jeffrey (2002) found that people who practiced water conservation in their homes were more tolerant of reusing greywater for non-potable purposes. Moreover, there is greater awareness of the need for the conservation of natural water resources through treated wastewater where dual systems exist (Hurlimann and McKay 2003; Marks et al, 2002).

Public acceptance of wastewater reuse can also be determined by the degree of public trust in the treatment processes and in the competencies of water utilities (Po, Kaercher and Nancarrow, 2003). Ormerod and Scott (2012) found that the public's acceptance of potable reuse was heavily dependent on the trust in the water and wastewater authorities, regulators, consultants, academics and elected local officials. Hartley (2006) reported that many scientific and engineering professionals agree that non-potable reuse is acceptable and necessary. However, there is non-uniform acceptance with respect to potable use. Such lack of consensus can introduce public doubt and lead to greater opposition to the use of treated wastewater. Consequently, mistrust in public agencies and officials creates challenges for wastewater reuse professionals (Hartley, 2006). There is greater trust, where organisations have a long history of good safety records and the objectives are not monetarily or politically driven (Nancarrow et al., 2003).

Marks et al. (2002) found that the majority of participants in his study expected to pay less for recycled water since they considered it to be of lower quality. Further, lower prices were seen as a necessary incentive to improve the willingness to use treated wastewater. For example, customers' expected lower prices for vegetables grown with treated wastewater (Nancarrow et al., 2003).

It was found, from numerous studies, that the public is more accepting of treated wastewater reuse for non-potable uses but becomes increasingly concerned and less accepting of wastewater reuse that involves direct human contact. The main factors shaping the public's perception of treated wastewater reuse were found to be, but not limited to, the 'yuck' factor; real or perceived risks; the awareness of water shortage problems; trust in the authorities; the costs; attitudes towards the general environment; and social justice issues (Po et al. 2014). While there is increasing support and acceptance of wastewater reuse for non-potable purposes, the support is progressively decreased for intended uses of the water as the degree and likelihood of close personal contact is increased. Lower levels of support were consistently reported for consumptive uses such as drinking and cooking. Moreover, widespread "in principle" acceptance does not automatically translate into the acceptance of real projects (ACTSE 2013).

In the Caribbean, for example in Jamaica, wastewater reuse is practiced in industries, some hotels and institutions (Caribbean Regional Fund for Wastewater Management 2015). However, given the high scarcity of water for irrigation in the Caribbean, wastewater reuse for farmers is getting support at the policy levels. A planned demonstration project to influence public perception to be undertaken by the United Nations Environmental Programme (UNEP) will be implemented in collaboration with the Food and Agriculture Organisation (FAO) and the Pan American Health Organisation (PAHO), to demonstrate how wastewater can be treated and reused to become a feasible option in combating the region's water scarcity (Longsworth, 2014).

In brief, public acceptance of reuse projects is vital to the overall future of wastewater reuse and the

consequences of poor public perception could jeopardise future wastewater reuse projects (Asano and Levine, 1996). The implementation of domestic wastewater reuse projects requires the consideration of all relevant factors and risks including public health, environmental, economic, scientific, energy and public perception (Peters 2014). Negative public perception can be modified by explaining to people the process of producing recycled water (Dolnicar, Hurlimann and Nghiem, 2010). In the Caribbean, the CRew GEF project can improve the situation by establishing innovative mechanisms for cost-effective and sustainable financing of wastewater management in the region; facilitating policy discussions and strengthening legislative frameworks; and facilitating regional dialogue and knowledge exchange on wastewater (The Gleaner, 2014). In conclusion, therefore, the willingness to reuse treated wastewater is based on subjective perception or expectations rather than on objective truth (Pannell et al. 2005), a cultural shift in relation to water management and social learning processes are key requirements to achieve a successful transition to wastewater reuse.

3. Methodology

The fieldwork for this study was carried out during February and March in 2014 using questionnaires and conducting personal interviews. A co-author and four assistants administered the interviews and questionnaire at the participant's residence or workplace. The questionnaire and interviews explored the relationship between the participants' perception of using and willingness to use treated wastewater. In November, 2013, a pilot study was carried out to test and finalise the questions to be used in the study.

For the study, a total of 195 questionnaire were administered to four (4) categories - general public (from North, South, East, West and Central Trinidad); farmers (from Central Trinidad), and professionals. For the general public, the areas were selected to give a more diverse sample and to highlight varying socio-economic backgrounds and water shortage issues. In the case of the professionals (that is technical and managerial persons who were likely to make decisions on the use of treated water in their organisations), twenty questionnaires were distributed to each group. Accept changes

Professionals were selected from 3 organisations—the Petroleum Company of Trinidad and Tobago Limited (Petrotrin), an industrial user; the Environmental Management Authority (EMA),a regulator; and the National Agricultural Marketing and Development Corporation (NAMDEVCO),a distributor of agricultural products.

The questionnaires were supported by personal interviews with 30 householders and 10 farmers who did not complete any of the 195 questionnaires. Farmers were accessed for the questionnaires and interviews over a two-day period at the Ministry of Food Production Central Division

The questionnaire included items related to socio-demographic indicators such as gender, age, education and income, and explored factors related to costs and incentives, environmental consciousness, knowledge and awareness of wastewater treatment processes, trust in local authorities and water utility, the yuck factor, perceived risk and water availability. To determine participants' perception of water reuse for different purposes, participants were asked to say whether they agreed, disagreed or were unsure. To determine participants' trust in the ability of water providers to deliver a safe supply, participants used a five point Likert scale (1= full trust; and 5= No trust). To determine participants' attitudes to the use of treated wastewater, , environmental and water conservation practices, costs and potential incentives questions were posed requiring a response of 'Never', 'Rarely', 'Sometimes' or 'Often'. Additional questions were asked to rate the participants' trust in the local water authorities. In the case of farmers, the questionnaire sought information on crop types, water availability, willingness to use treated wastewater for irrigation and used a four point scale ('Often', 'Sometimes', 'Rarely' and 'Never').

The interviews were designed to identify the interviewee's perception of wastewater reuse and understand the psychological and/or technical reasoning behind this perception, if any. Additional questions were used to rank the acceptance of wastewater reuse for various purposes. In all cases, participants were assured of the confidentiality of their responses before commencement of the interview and the completion of the questionnaire. Participants were given the option to have their responses excluded in the study even after providing their responses. IBM SPSS V.16 Student version was utilised to analyse the results of questionnaires. Descriptive statistics and frequency analyses were used to assess perceptions.

4. Results and discussions

4.1. Preferred use of treated wastewater

In terms of the specific use of treated wastewater, it was found that for both the general public (n = 111) and the professional group (n = 84), there was a greater willingness to accept non-potable uses of treated wastewater for purposes such as firefighting, watering of public lawns, agricultural irrigation and groundwater recharge. As the proposed uses involved more direct contact with humans, the acceptance declined as shown in Figure 1. Almost total average acceptance ninety-seven percent (97%) was for firefighting which was perceived as providing least contact with people. In the case where wastewater reuse was considered acceptable for household purposes, the greatest preference (sixty-nine percent) was for laundry use while the smallest

preference (sixteen percent) was for consumption uses. Further, there was a slightly higher willingness to accept the use of wastewater, among the professional groups at Petrotrin, the EMA and the NAMDEVCO than the general public, particularly for firefighting and the irrigation of public parks. This may be explained by greater understanding of the treatment processes amongst these groups.

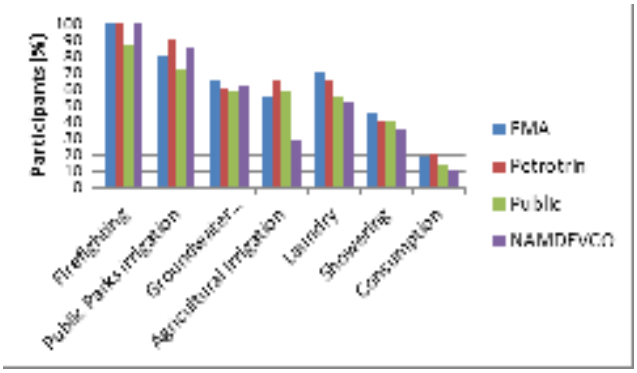

Figure 1. Willingness to use treated wastewater for different purposes

Amongst the 10 farmers, ninety percent (90%) were willing to use treated wastewater for irrigation of their crops in times of water shortage. However, five farmers (i.e., 50%) were willing to use treated wastewater for irrigation all the time. Seven farmers stated that if they were to use treated wastewater for irrigation of crops, they would select the types of crops that would be at low risk to be contaminated by treated wastewater. It was found that these farmers were enthusiastic about the reuse of treated water for irrigation. These farmers credit this high willingness to accept treated wastewater to good knowledge and understanding of the treatment processes allowing them to have greater confidence in the safety of the treated wastewater.

4.2. Socio-demographic Factors

Although women (n = 125, see Table 1) were less inclined than men (n = 70) to use treated wastewater for non-potable household use, the Chi-square test on the responses (significance level, $\alpha = 0.05$; p-values = 0.125 to 0.806 (see Table 2) found that there was no significant difference between the genders and acceptance of various uses of treated wastewater. Similarly, there were no significant statistical differences (significance level, $\alpha = 0.05$; p-values = 0.08 to 0.84 see Table 2) between the different age groups and their willingness to use treated wastewater for firefighting, irrigation, groundwater recharge, laundry and bathing. However, this was not the case for potable use (significance level, $\alpha = 0.05$; p-values = 0.03). The age of participants influenced the willingness to consider treated wastewater for potable use with the greatest willingness among the older (50 year plus) group. The 18 to 25 years group showed least willingness to consider the potable use of treated wastewater.

Table 1: Socio-demographic makeup of respondent

Socio-demographic Factor		Frequency
Gender	Male	70
	Female	125
Age Group	18-24	29
	25-34	76
	35-49	55
	50-64	24
	65+	11
Education	Did not complete high school	13
	Graduated from high school	52
	Did not complete university	19
	Graduated from university	84
	Completed Masters' Degree or higher	27

Table 2: Pearson chi-square tests for gender and educational influence on willingness to reuse treated wastewater

	Gender			Education		
Uses	**Value**	**df**	**p-value**	**Value**	**df**	**p-value**
Firefighting	2.351	1	.125	2.898	4	0.575
Public Lawns	0.155	1	0.694	1.404	4	0.844
Agri. Irrigation	1.401	1	.237	2.169	4	0.703
Groundwater Recharge	3.097	2	0.213	5.493	8	0.704
Laundry	0.60	1	0.806	3.678	4	0.451
Showering	0.579	1	0.447	8.269	4	0.082
Consumption	1.825	1	0.177	10.324	4	0.035

Four educational categories were used in the survey-did not complete high school, graduated from high school, and university graduate. It was found that among the participants of the four educational categories, the university graduates appeared to be more willing to use treated wastewater for non-potable uses (see Figure 2).

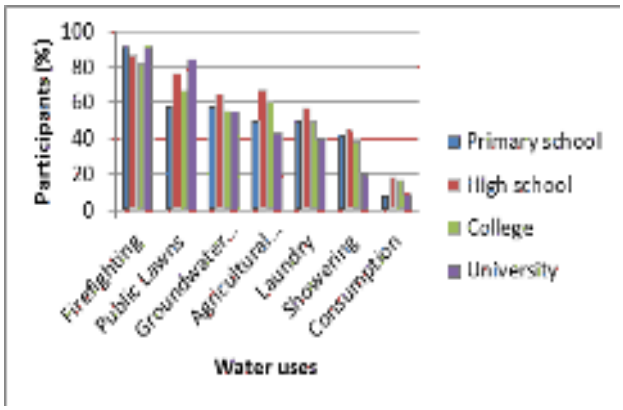

Figure 2. Education influence on acceptable uses of treated wastewater

However, there was a major drop in acceptance as the use of treated wastewater was focused on indirect or direct potable use and domestic purpose. Those participants who indicated that they had completed high school were more willing to use treated wastewater for potable use and other domestic purposes. Overall, there were no statistical differences among the educational categories in their willingness to accept treated wastewater since the p-values for the Chi square test (at $\alpha = 0.05$) ranged between 0.101 and 0.955.

Like age, income affected the willingness to accept treated wastewater for potable uses in the same ranking of uses (see Figure 3). Based on the Chi-square test results, it was found that there was a significant statistical association between income and the acceptance of treated wastewater for irrigation of public parks and for potable uses and at the 5% level, the p-values were 0.047 and 0.026, respectively (see Table 3). Participants in the low income (less than $5000 monthly) and high income (more than $20,000 monthly) categories were twice as willing, when compared with the middle income earners, to consider treated wastewater for domestic purposes.

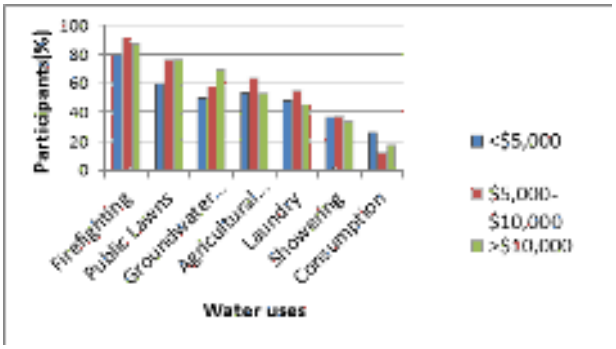

Figure 3. Influence of income on the acceptable use of treated wastewater

Table 3: Pearson chi-square tests for the influence of water shortage experiences on willingness to reuse treated wastewater

Uses	Value	df	p-value
Firefighting	6.683	3	0.083
Public Lawns	7.876	3	0.049
Agri. Irrigation	0.859	3	0.835
Groundwater Recharge	4.956	6	0.592
Laundry	0.352	3	0.950
Showering	1.643	3	0.65
Consumption	9.285	3	0.026

The order of acceptance of water reuse for the different purposes did not change for different socio-demographic groupings. The order of acceptance for non-household purposes was firefighting, irrigation of public lawns, groundwater recharge and agricultural irrigation. For household purposes, the order of preference for use was laundry then showering and finally consumption.

4.3. Impact of Water Shortage on Acceptability of Wastewater Reuse

For the general public in this study, eight percent (8%) and forty-one percent (41%) experienced water shortages never or rarely, respectively. Sixteen percent (16%) of participants frequently experienced water shortage and thirty-five percent (35%) sometimes experienced water shortage. Where participants experienced water shortages, all were prepared to use treated wastewater for firefighting, industrial purposes or for irrigating public lawns but expressed concerns for use in agricultural irrigation, domestic uses and for potable use. The correlation of water shortages to participants disposition for the acceptance of wastewater reuse to the different non-potable uses of treated wastewater is generally the same for all groups of participants (see Figure 4) with no statistical significance as shown by the Chi-square test (at significance level, $\alpha = 0.05$; $p = 0.35$ to 0.95, see Table 4).

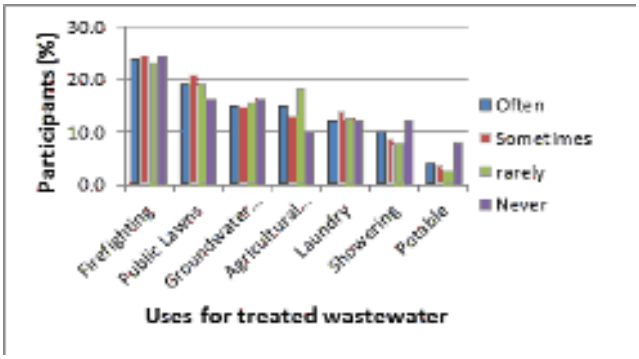

Figure 4. Willingness to reuse treated wastewater and frequency of water shortage

Table 4: Pearson chi-square tests for the influence of the trust in the authorities and willingness to reuse treated wastewater

Uses	Value	df	p-value
Firefighting	1.632	3	0.652
Public Lawns	3.284	3	0.350
Agri. Irrigation	12.182	3	0.007
Groundwater Recharge	1.559	6	0.955
Laundry	1.766	3	0.622
Showering	0.663	3	0.882
Irrigation of fruits and vegetables for direct consumption uses	3.242	3	0.356

Those participants who never experienced water shortages were more open to using treated wastewater for personal uses such as showering and potable purposes. Participants who rarely experienced water shortages showed the highest willingness to use treated wastewater for agricultural purposes where the product is not consumed directly, for example, ground provision

production, than for where it may be consumed directly without washing, such as lettuce or cucumbers. In the case of the farmers, sixty-five percent (65%) experienced some water shortage during the year with sixty percent (60%) of these experiences taking place during the dry season. Sixty percent (60%) of the farmers who experienced water shortages were willing to use treated wastewater for irrigation with greater willingness among those who were affected by dry season shortages (see Figure 5). The availability and use of treated wastewater in these circumstances was seen as providing opportunity for greater production and profits. However, farmers were generally unwilling to consider the use of treated wastewater as a replacement for their current water supplies. Where farmers did not experience water shortages, it was found that this was due to the availability of supplies from self-owned rainwater harvesting systems and nearby rivers. Only twenty-eight percent (28%) of these farmers were willing to consider the use of treated wastewater.

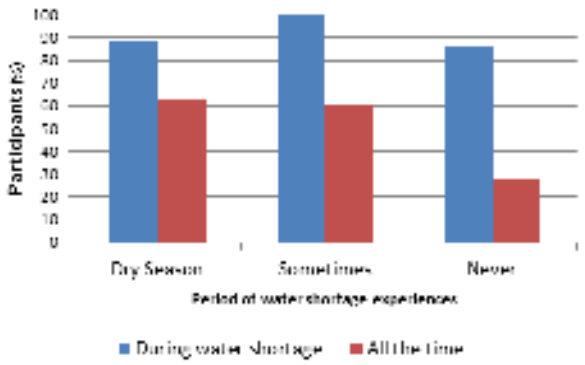

Figure 5. Time of irrigation application by farmers

4.4. Perceived Risks

As shown earlier, there is low level of support for treated wastewater to be used for potable purposes. Both farmers and the general public expressed serious concerns of possible risks that may be associated with using treated wastewater on farms within close proximity to human contact. Amongst the general public, seven percent (7%) believed that there were serious health risks associated with using treated wastewater for agricultural irrigation, showering and consumption. However, there was general willingness to use the treated wastewater for irrigation and non-potable domestic purposes if there was a guarantee given by some international agency that the water is safe. Participants' health concerns include skin diseases caused by inadequate treatment of wastewater, and the presence of chemicals and heavy metals like lead and other unnatural substances that may aggravate skin conditions. Some participants believed that there were long term health risks associated with using treated wastewater that could manifest itself into cancers in humans. Although over sixty percent (68%) of participants were aware of the possible negative impacts of indiscriminate disposal of toxic chemicals and other harmful substances in drains and ultimately into wastewater, only 8% were aware of the adequacy of current technologies in the treatment for such substances and as such there was a general concern about the possible existence of toxic chemicals in treated wastewater. Further, an associated concern is that initial mistakes that can be made with the introduction of wastewater reuse technology may adversely affect the population.

Perceived health risks impacts farmers' willingness to use treated wastewater for irrigation and which type of crops farmers would irrigate with this water. Thirty percent (30%) of farmers believed that there were serious health risks associated with using treated wastewater for agriculture. Twenty percent (20%) were unsure and fifty percent (50%) did not believe there were any health risks. Farmers were generally willing to use treated wastewater on crops where the water would not be in contact with any edible parts of the plant. Livestock farmers on the other hand, would only use treated wastewater for cleaning purposes and would not allow livestock to consume it for fear of the introduction of unknown diseases to the animals that can subsequently be transmitted to humans. The perceived risks induced unwillingness to use wastewater for financial reasons, as 45% of farmers believed that wastewater reuse would decrease customer confidence in their produce.

4.5. Trust in Water Authority

One of the factors considered by participants in their willingness to use treated wastewater was the lack of trust in the water authority to deliver safe and high quality treated wastewater. Ninety percent (90%) of participants were dissatisfied with the current water service, considering it substandard resulting in low levels of trust in WASA. Further, thirty-three percent (33%) of participants had little confidence in new state sponsored projects which are perceived as driven by political motives and lead to poor quality products.

Participants were asked to rate their trust in WASA to deliver treated wastewater for irrigation that was safe on a scale of 1 to 5, where 1 was full and complete trust and 5 was no trust. Figure 6 shows that participants had a low level of trust with about fifty percent (50%) having very little or no trust (represented by 4 and 5 as seen in Figure 6). Less than ten percent (10%) of the participants had full confidence in the ability of WASA to provide treated wastewater for reuse that was safe. The mistrust among participants is reduced when participants considered the scenario where the implementation of treated wastewater reuse is undertaken by WASA in partnership with an international organisation.

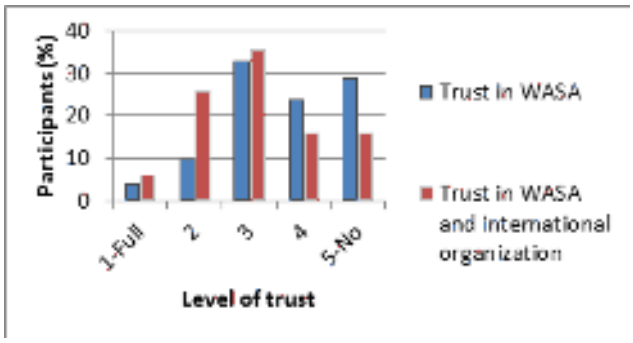

Figure 6. General public trust in water authority

On the other hand, farmers had a higher level of confidence in the local water authorities with forty percent (40%) having full and complete trust (see Figure 7). As in the case of the general public, farmers' level of trust would increase if WASA partnered with an international organisation to implement treated wastewater reuse. The farmers' greater trust appeared to be due to their lesser concern about water quality for their operation which is different from that of the general public's.

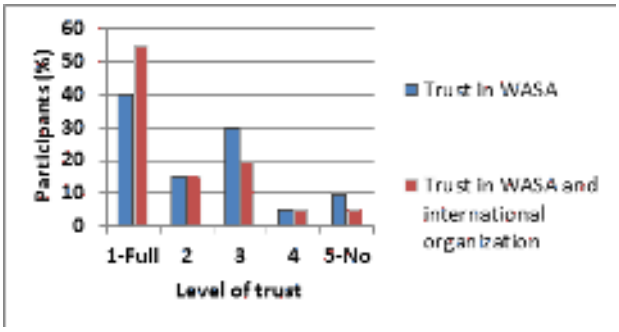

Figure 7. Farmers' level of trust in water authority

It was found that participants who were unwilling to use treated wastewater generally had low levels of trust in WASA, suggesting that trust may be an important factor in assessing willingness to use treated wastewater. This is supported by the Chi-square test (significance level, $\alpha = 0.05$; p-value < 0.001; see Table 5) which showed that there was a significant correlation between the public's trust in the water authorities and their acceptance of various uses of treated wastewater.

Generally, trust in the water authority was high for the farmers, with forty percent (40%) having full trust should WASA introduce a plan to distribute treated wastewater to farmers; and fifty-five percent (55%) having full trust if WASA, in conjunction with an international water authority, were to introduce a wastewater reuse plan for farmers. The farmers' challenges with the use of the treated wastewater had less to do with trust in the quality of the water to be provided but more to do with the inaccessibility of the potential points of delivery to some farms.

Table 5: Pearson chi-square tests for the influence of the trust in the authorities and willingness to reuse treated wastewater

Uses	Value	df	p-value
Firefighting	3.184	4	0.527
Public Lawns	18.827	4	0.001
Agri. Irrigation	31.554	4	0.000
Groundwater Recharge	18.141	8	0.20
Laundry	44.712	4	0.000
Showering	54.168	4	0.000
Consumption	34.685	4	0.000

4.6. Costs of Water

The willingness to accept treated wastewater was unaffected by the potential of lower water rates for eighty-two percent (82%) of the participants as there is general satisfaction with current water rates. In the particular case of farmers, however, the cost of the water was a concern and the indication is that water must be provided freely, as sources such as rainwater harvesting ponds and rivers are considered free. Moreover, forty-five (45%) of farmers were motivated to use treated wastewater due to the lower potential cost of irrigation water (see Figure 8). Lower costs of water and an improved availability could impact their financial operations.

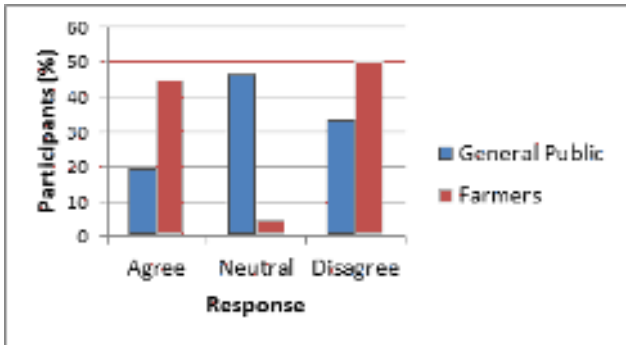

Figure 8. Costs as an incentive for accepting treated wastewater

4.7. Water Conservation and Environmentally Friendly Practices

Fifty three percent (53%) of participants practiced water conservation techniques and sixty-seven (67%) practiced other environmentally friendly activities or considered environmental issues in everyday decisions. However, sixty-eight (68%) of participants were unaware of the current water pollution rules. Previous studies (Po, Kaercher and Nancarrow, 2003; Jeffrey 2002) found that participants who practiced water conservation and participated in environmentally friendly activities were more open to using recycled water for various purposes.

While in this study, among the participants who did not practice water conservation and other environmentally friendly activities it appears that there is a greater willingness to use treated wastewater for laundry, showering and non-direct consumption (see Figure 9). The p-values which were greater than 0.35 for the Chi-square test (at α =0.05; see Table 6) showed that there was no significant correlation between respondents' environmental practices and their acceptance of various uses of treated wastewater. In the case where participants were dependent on rainwater harvesting as their main water supply, there was a high interest shown in treated wastewater reuse but they also shared the same health and quality concerns as the rest of the population.

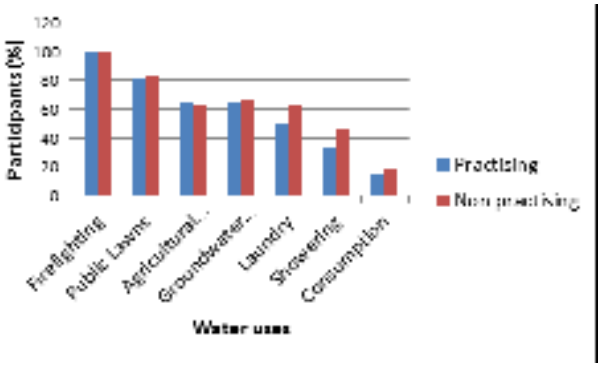

Figure 9. Willingness to reuse treated wastewater and environmental practices

Table 6. Pearson chi-square tests for the influence of the involvement in good environmental practices and the willingness to reuse treated wastewater

	Practice water conservation			Involved in good environmental practices		
Uses	**Value**	**df**	**p-value**	**Value**	**df**	**p-value**
Firefighting	0.804	2	0.669	0.455	2	0.797
Public Lawns	0.622	2	0.733	0.983	2	0.612
Agri. Irrigation	1.592	2	0.451	1.478	2	0.478
Groundwater Recharge	6.053	4	0.195	1.873	4	0.759
Laundry	1.532	2	0.465	1.899	2	0.387
Showering	2.110	2	0.348	0.802	2	0.670
Consumption	0.435	2	0.804	4.548	2	0.103

Faeces are a universal disgust substance and that disgust is deeply seated within our psychological make-up. The common "yuck-factor" reported elsewhere was not as evident in this study. Respondents were asked to select on a scale of 1 to 5 how they would feel if drinking purified wastewater where 1 and 5 represent disgusting and appealing respectively. Eighty percent (80%) of the general public showed no or little disgust to the idea of drinking treated wastewater. In this study, there was a general agreement that once the water was treated properly and was aesthetically equivalent to regular water there would be little concern.

The remainder consider treated wastewater as dirty water because of their perception of the current poor quality of water supply. Many of these participants use bottled water in preference to tap water. Twenty-one percent (21%) of participants agreed that their negative reaction to the use of treated wastewater would diminish if the water was provided in a developed country, particularly where the practice is already in use. This shows that there is greater trust in foreign water providers. The importance of the yuck-factor cannot be underestimated, as in many cases, wastewater projects have been abandoned due to public disgust of the concept. This was most vividly shown in the Australian city of Toowoomba in 2006 when local activists, represented by the group "Citizens against drinking sewage", defeated plans to introduce reclaimed sources, citing health risks and emotive factors (Monks, 2014).

5. Conclusion and Recommendations

People have a natural revulsion to water that is perceived to be contaminated, and sometimes that feeling can translate into opposition to reusing treated wastewater. In Trinidad, the public is generally uneasy with direct reuse of wastewater and this will likely pose a substantial barrier to promoting wider use of treated wastewater. However, while the majority of the participants in this study indicated a willingness to accept the non-potable use under some circumstances and for purposes such as firefighting and watering of public lawns, but there appears to be no support for the reuse of wastewater for drinking water.

Socio-demographic factors, water shortage issues, participation in environmentally friendly activities and cost of treated wastewater did not appear to be shaping the public's perception of using or willingness to use treated wastewater in Trinidad. For example, although there is a slightly greater portion of the technical and professional persons are more inclined to accept wastewater reuse, there were no significant differences among groups surveyed.

This study revealed that the current perception of the use of treated wastewater in Trinidad is mainly shaped by the public's mistrust of the local water authorities to deliver safe and high quality water; a general lack of knowledge of the treatment process; and perceived health risks associated with using treated wastewater.

While farmers have similar concerns about the use of treated wastewater for irrigation, they are willing to use treated wastewater for irrigation particularly during the dry season, but are concerned about the possible negative impact on the marketing of their products. As Trinidad and Tobago prepares to develop a viable treated wastewater reuse subsector, it is recommended that efforts to improve the public's trust and acceptance be strengthened through improvement of the current services and by public awareness programmes. Moreover, implementation programmes should be informed by the level of willingness to accept treated wastewater for different uses.

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A Review of Critical Infrastructure Interdependency Simulation and Modelling for the Caribbean

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Abstract: *Caribbean Small Island Developing States (SIDS) are particularly disaster prone and, as such, disaster risk reduction and effective emergency management are crucial to sustainable development. Studying critical infrastructure interdependencies (CII) is a relatively new facet of disaster risk reduction. Computer simulation software is the most effective and economical method of studying these relationships. This paper contextualises the role of CII simulation as part of a complete disaster and emergency management programme, and reviews the state-of-the-art as pertains to utilisation of such tools among Caribbean emergency management agencies (EMAs). It finds that Caribbean EMAs do not currently utilise CII tools. The paper then reviews some of the most popular simulation tools under development such as CIPDSS, HAZUS, I2Sim/DR-NEP and ESRI Sim Disaster. Their applicability and ease of adoption to the Caribbean context is considered. I2Sim was viewed as being the best suited for Caribbean EMAs.*

Keywords: *Emergency Management, Critical Infrastructure Interdependencies, Simulation, SIDS, Caribbean, I2Sim*

1. Introduction

In the Americas alone, every year, on average, disasters kill more than five thousand people; affect more than five million lives and cause economic damage in excess of twenty billion US dollars (PreventionWeb, 2014a). Caribbean countries are among the most natural disaster prone in the world (Carby, 2011, Rasmussen, 2004); Acevedo (2013) discusses the high incidence of disasters in the region, noting that the region has been struck by 187 disasters in the last 60 years, with 26 storm impacts in the last 4 years alone (Fraser, 2013, EM-DAT, 2014). When using the number of natural disasters to land area, the six (6) Eastern Caribbean Currency Union (ECCU) countries rank among the ten (10) most disaster prone, and the rest of the Caribbean countries fall amongst the top fifty (Rasmussen, 2004).

Developing countries face much larger shock to their macro-economies following a disaster of similar relative magnitude than do developed countries (Noy, 2009). An extreme example is Hurricane David that hit Dominica in 1979 causing damage exceeding 100% of the country's Gross Domestic Product (Benson et al., 2001). Besides the immediate fallout of a disaster, the effects can spark economic crisis and increase poverty leading to social unrest (Rasmussen, 2004). When a disaster strikes, losses are inevitable. However, lives can be saved and losses mitigated through coordinated emergency management (ISDR, 2005).

2. Phases of Emergency Management

Emergency management is typically analysed by dividing the process into four (4) phases: mitigation, preparedness, response and recovery (NGA, 1979, Waugh and Hy, 1990, Baird, 2010), although other models consisting of more or different phases have been proposed (Neal, 1997). The problem of critical infrastructure interdependency (CII) comes to the fore in both the response and recovery stages.

Response includes the execution of emergency plans and procedures, and seeks to reduce the probability of secondary damage (Baird, 2010). These actions necessitate an understanding of critical infrastructure interdependency such that complex vulnerabilities can be recognised and an informed response can be coordinated.

The issue is also apparent in the recovery stage. This stage is complex and requires coordination of a number of stakeholders as noted by Haddow, Bullock and Coppola (2007) and Phillips (2009). A critical requirement of effective disaster preparedness is that agencies and actors operate in a coordinated manner to avoid time loss and duplication of work (UN/ISDR and UN/OCHA 2008, 11). Likewise, the World

Meteorological Organisation noted that good early warning systems require coordination across many agencies to be successful (WMO, 2013).

3. Importance of Simulation Tools

The Hyogo Framework is a global blueprint for disaster risk reduction efforts during the next decade (UNISDR, 2005; PreventionWeb, 2014b). Studying Critical Infrastructure Interdependency is encapsulated in the recommendations of this framework which include using knowledge and innovation via research methods and tools for multi-risk assessment. Additionally, the United Nations Office for Disaster Risk Reduction's (UNISDR) 2015 Global Assessment Report for Disaster Risk Reduction identifies the dynamics of risk in urban settings while recognising the interconnectedness of risk as a thematic area that requires research and closer examination. An example of damage to power utilities triggering a failure in water management systems was given (UNISDR, 2013).

As such, understanding CII should be an integral facet of any emergency management programme. Since the relationship between critical infrastructures cannot be tested in the real-world without disruption of those infrastructures, and because CIIs can become quite complex, software simulation is the preferred method of analysis.

The U.S. established the National Infrastructure Simulation and Analysis Center (NISAC), within the U.S. Department of Homeland Security, to provide strategic, multidisciplinary analyses of interdependencies and the consequences of infrastructure disruptions (NISAC, 2015). Additionally, increased attention to this field has increased governmental and private funding to universities, laboratories, and private companies involved in modelling and simulation of critical interdependencies, thus even though this field is relatively new, a great deal of valuable work has been done (Pederson et al., 2006). Using the example of the Critical Infrastructure Protection Decision Support System (CIPDSS, 2015) produced at NISAC, Figure 1 outlines the role such simulation software plays in formulating a disaster response plan.

This paper examines both the existing use of CII simulation tools in the Caribbean, and identifies tools that can be most beneficial to the Caribbean given the current operational constraints of their emergency management agencies.

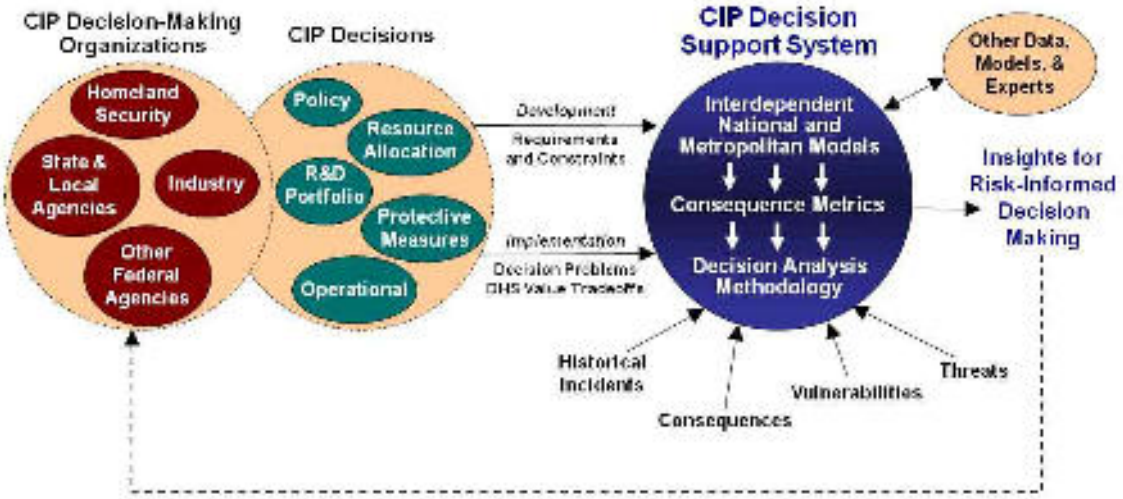

Figure 1: Role of Simulation Software - Case of CIPDSS
Source: NISAC (2006)

4. Usage of CII Tools in the Caribbean

In the Caribbean, little seems to be done in the field of CII Simulation by emergency management bodies. By contrast, in the United States the need for research in the field CII and its importance in preparing for disasters and emergencies has long been recognised and pursued. In the year 2000, the National Infrastructure Simulation and Analysis Center (NISAC) – now under the US Department of Homeland Security – was established, engaging technical staff from the Los Alamos National Laboratory (LANL, 2015) and Sandia National Laboratories (SNL). The Caribbean, however, does not enjoy the financial resources to establish such centres and Emergency Management Agencies are often pressed with more immediate concerns, leaving them little time for extending themselves into less established fields such as CII simulation.

To gauge the penetration of CII simulation usage in the region, attempts were made to reach all of the member agencies of the CDEMA via contact information provided by the CDEMA website (CDEMA, 2014). A survey (by emails) was conducted with each

agency asking about their use of CII simulation software and plans for using such software. Numerous phone calls were made to agencies who did not reply to the initial emails. Table 1 summarises the information gleaned via this exercise.

As evident from Table 1, CII simulation tools are not currently being used by any responding state as part of their Disaster Risk Reduction programme. To underscore this problem, it is important to note that responding agencies often were not aware of the CII simulation as a field of study or its importance to their activities, and would associate the words "software tools" with platforms such as WebEOC (WebEOC, 2015) for emergency reporting and ArcGIS (ESRI, 2015) for geo-spatial data management and analysis and decision support or the DEWTERA Platform (CIMA, 2015) for weather related risk forecasting and monitoring. The word "simulation" was also often associated with first responder exercises and not computer simulation.

Furthermore, most responding agencies – with the exception of the Office for Disaster Preparedness and Management (ODPM) of Trinidad – had no short term plans to introduce this facet of risk assessment into their DRR (Disaster Risk Reduction) Schemes. Some agencies did not respond to attempts made at contact, which seems to further highlight the problem of limited resources from which many of the organisations suffer.

Table 1: Use of CII simulation tools by CDEMA member states

Country	Agency Name	**Does your organisation use Critical Infrastructure Interdependency simulation software?**	
		Yes? Which software and why?	*No? Are there plans?*
Anguilla	Department of Disaster Management	Unknown	Unsure
Antigua and Barbuda	National Office of Disaster Services	Unknown	Unsure
Bahamas	National Emergency Management Agency	No	No Plans
Barbados	Department of Emergency Management	No	No Plans
Virgin Islands (UK)	Department of Disaster Management	No	Interest shown.
Dominica	Office of Disaster Management	Unknown	Unsure
Grenada	National Disaster Management Agency	No	No Plans
Guyana	Civil Defence Commission	Unknown	Unsure
Haiti	Directorate of Civil Protection	Unknown	Unknown
Jamaica	Office of Disaster Preparedness and Emergency Management	No response	Unknown
Montserrat	Disaster Management Coordination Agency	No response	Unknown
St. Kitts and Nevis	National Disaster Management Agency	No response	Unknown
St. Lucia	National Emergency Management Organisation	No	No Plans
St. Vincent and the Grenadines	National Emergency Management Organisation	No response	Unknown
Trinidad and Tobago	Office of Disaster Preparedness and Management	No	In the process
Turks and Caicos Islands	Department of Disaster Management and Emergencies	Unknown	Unsure
Suriname	National Coordination Center for Disaster Relief (NCCR)	No response	Unknown

Two of the Caribbean stakeholders (Trinidad and Tobago and the British Virgin Islands) have shown marked interest in including CII Simulation in the Disaster Risk Reduction schemes. Trinidad and Tobago has already initiated steps towards this via coordination with The University of the West Indies (UWI) while the Department of Disaster Management of the British Virgin Islands has also indicated interest in doing the same. These findings corroborate the observation made by Carby (2011) that no Caribbean disaster management office reported a budget for research.

5. Survey of Critical Infrastructure Interdependency Simulation Tools

Since the emergence of CII modelling and simulation, a number of tools have been produced. Many of these tools were reviewed in Pederson et al. (2006). Further investigation revealed that a significant number of these tools were either proprietary software, not available for procurement, or are now defunct. This section highlights some of the software tools which include aspects of CII simulation and modelling for which information was

available and which are actively maintained by their companies.

5.1 HAZUS

HAZUS is a geographic information system-based natural hazard developed and freely distributed by the Federal Emergency Management Agency (FEMA). It is an auxiliary tool for estimating physical, economic and social impacts of disasters which are critical data for generating scenarios for CII simulations (FEMA, 2014). It graphically highlights locations at high risk of earthquake, hurricane and floods. Users can then view how population densities relate to assets and resources thus providing data that can inform decisions on resource management and risk mitigation. After the analysis is run, the details of the extent of damage expected to specific structures, infrastructures and loss of resources are shown along with the overall economic impact of an event.

HAZUS operates on ESRI's ArcGIS software, a tool that some Caribbean agencies are already equipped with. It also has the advantage of already being compatible with the SUMMIT Platform for visualisation (SUMMIT, 2015). The technical support and training for HAZUS is available through FEMA.

5.2 Critical Infrastructure Protection Decision Support System

Critical Infrastructure Protection Decision Support System (CIPDSS) is a decision support tool that aids the user in assessing candidate decisions (CIPDSS, 2015). The tool combines simulating the event and assessing risk while considering threats and vulnerabilities associated with the emergency scenario whether manmade or natural (see Figure 2). CIPDSS models the interdependencies of up to 17 types of Critical Infrastructures and Key Resources (DHS, 2015) and the mutual impacts upon each other. The model includes critical infrastructure sectors - energy, communications, transport, agriculture and economy.

CIPDSS Simulations model the use of resources such as hospital beds, and the operation of emergency personnel. Results of the simulation can include hospital bed usage, average time waiting for care, a count of fatalities and the cost of damage. CIPDSS has been reviewed by academia and industry analysts. However the software is the property of Los Alamos Laboratories and requires procurement and licensing.

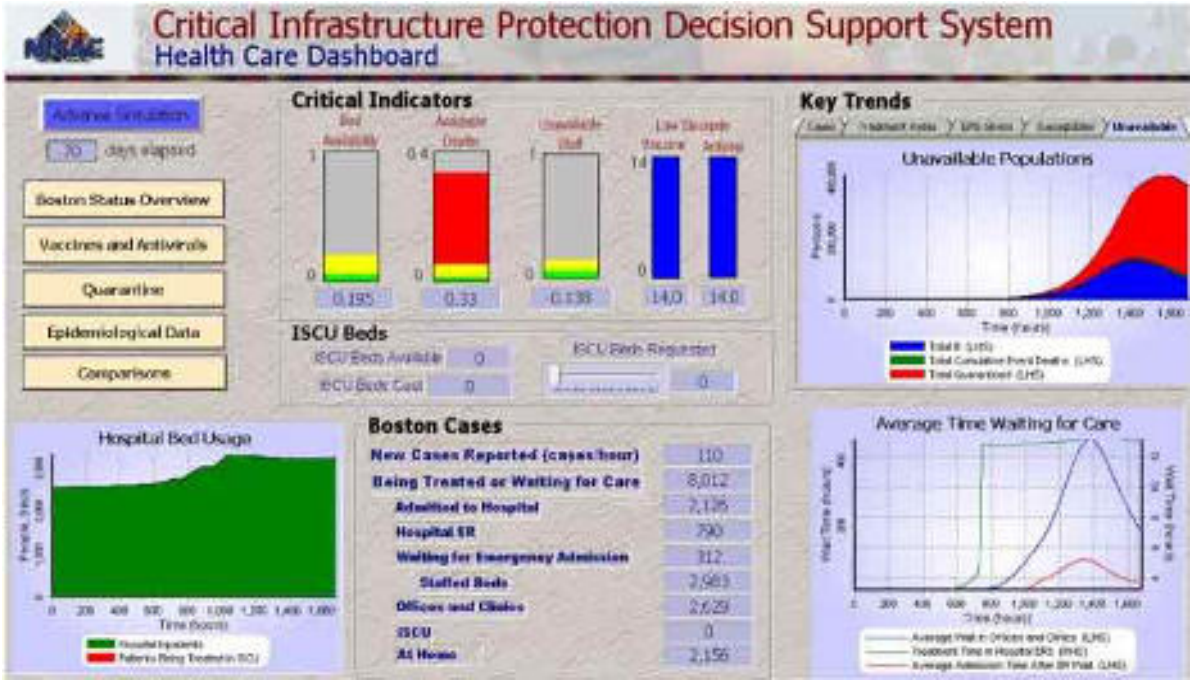

Figure 2: CIPDSS Screenshot

5.3 Disaster Response Network Enabled Platform

Disaster Response Network Enabled Platform (DR-NEP/I2Sim) was developed by the I2Sim/DR-NEP group of The University of British Columbia (UBC, 2015; Martí et al., 2008) to model the interdependencies among critical infrastructure (CI). It allows coordinated decision making to inform allocation of resources and helps to identify the parts of the system which carry the highest priority for restoration after a disaster (see Figure 3)

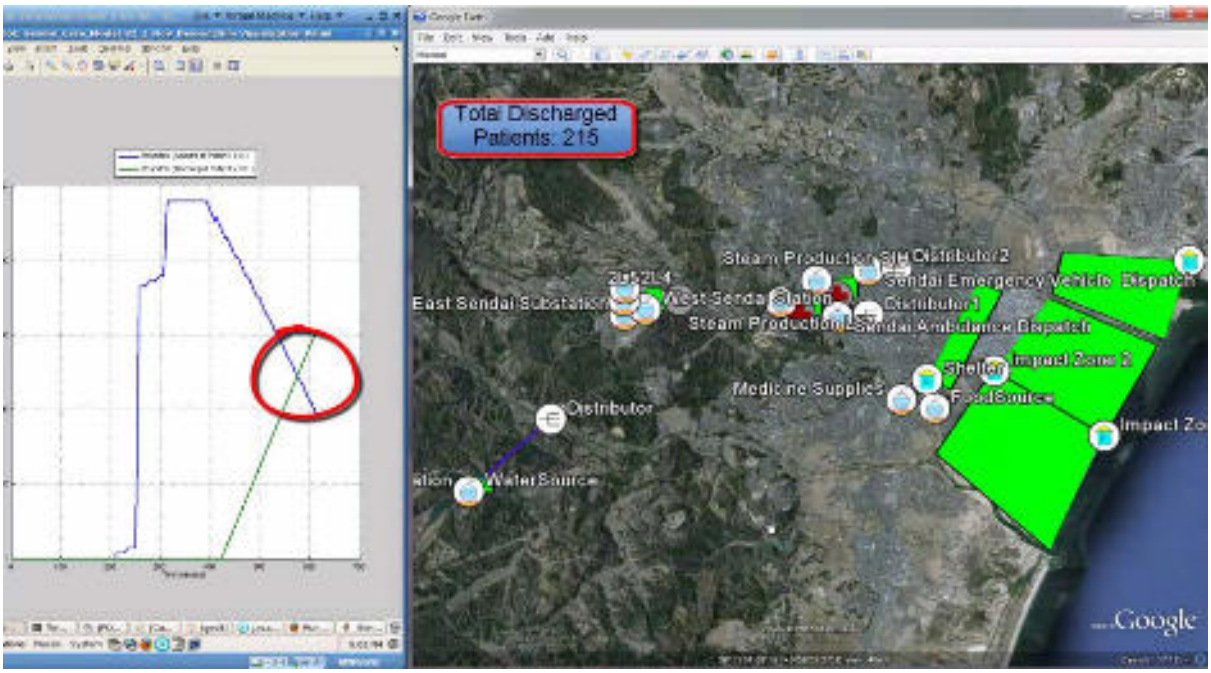

Figure 3: I2Sim/DR-NEP screenshot

A variety of case studies have been performed using I2Sim. These include an earthquake in Guadeloupe, and various scenarios for the Vancouver 2010 Winter Olympics. I2Sim has also been successfully utilised for modelling the failure of a municipal water system (Shypanski et al., 2011). The tool is continually under development and the power of I2Sim lies in its abstraction of critical infrastructure problems such that a wide variety of infrastructures can be modelled using a common framework. The results are viewed via monitoring the output of any combination of particular infrastructures in the network, such as the number of treated patients discharged by a hospital.

Since I2Sim simulates the interaction between different infrastructures and resources, it can easily be used to assess policies and disaster response procedures concerning coordination of these entities. I2Sim's developers have indicated that steps are being taken towards enhancing the tool with the capability to automate this type of assessment and find best-fit solutions for policy makers. I2Sim is not distributed commercially but is available via collaboration with participating academic and research institutions. Of the region's institutions, The University of the West Indies has an on-going collaboration with The University of British Columbia on this project and has commenced research and software development in the field of CII.

5.4 SIM Disaster - Modelling and Simulation Consequence Management System

This is a FEMA-funded tool inspired by the popular videogame Sim City (MATRIC, 2011). It was developed to assist in planning for preparation, recovery and response to a crisis that requires mass evacuation. The simulations depict how mass evacuation will impact critical infrastructure and resource consumption such as fuel, water, first aid, and shelter. The simulator is built on ArcGIS and simulates congestion considering time and geographical information. Results take the form of resource consumption figures and charts showing the number of affected people receiving treatment and finding shelter.

Even though this software is closely related to the field of CII and covers some of the same metrics as a CII simulator does (such as hospital beds available), the emphasis of Sim Disaster is on evacuation and egress. Infrastructure such as electricity lines, water pipelines and gas pipelines are not considered in the model (see Figure 4). This software must also be paid for.

6. Comparative Analysis

A comparison of simulation software was made to determine which would be suitable for CII simulation in the Caribbean (see Table 2). Non-proprietary software is preferred, since Caribbean agencies do not have the budgets of larger, more developed nations. The flexibility offered through open source solutions is preferable given the diverse operational contexts; additionally, they allow for regional innovation through customisation to meet local needs. The software should be able to simulate CII in the strictest sense. Furthermore, since data collection infrastructure in the Caribbean is weak the software should not require very detailed data input. Finally, the availability of local or regional support is paramount to the longevity of any technology based disaster risk reduction programme.

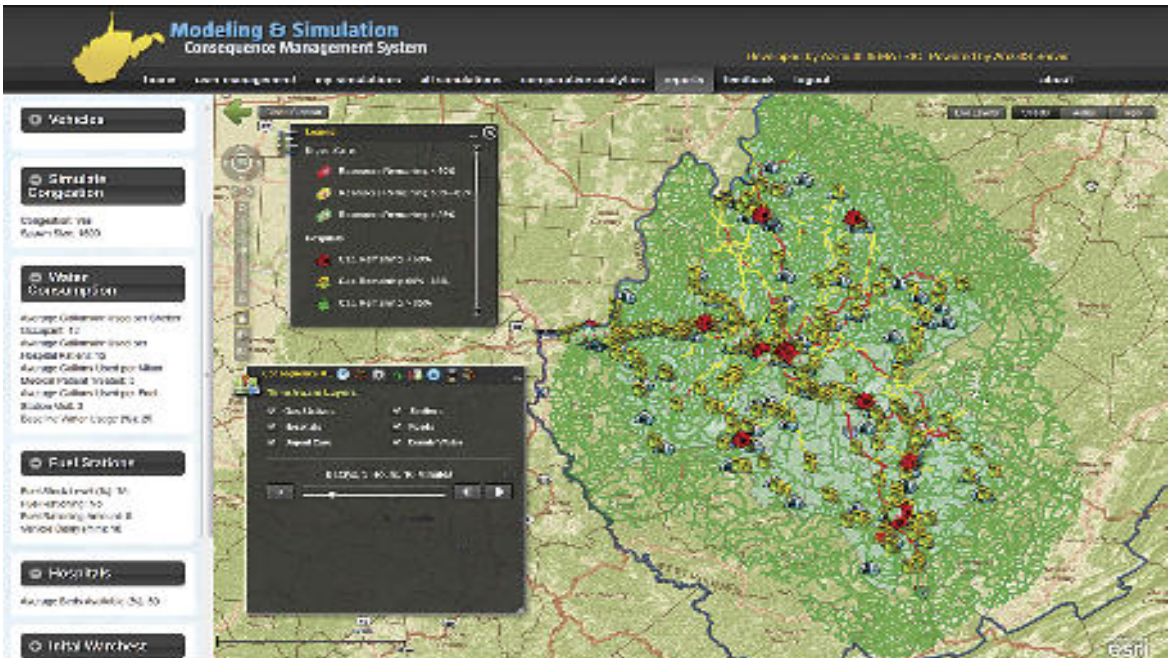

Figure 4: Sim Disaster Screenshot

6.1 Critical Infrastructure Sectors modelled

Additionally, a key metric for comparing CII simulation tools is the number of critical infrastructure sectors which are facilitated. The tool should ideally facilitate modelling the sixteen critical infrastructure sectors as envisaged by The White House's Presidential Policy Directive on Critical Infrastructure Security and Resilience (DHS, 2015, PPD, 2013) listed in Table 3. It is noted that this acknowledges a tool's modelling of damage sustained in a particular sector even if the information does not translate into modelling the dependency of other critical infrastructures on that sector.

Table 2: Basic Comparison of Simulation Tools

Simulation Tool	Proprietary	Open Source	CII Modelling (in the strict sense) enabled	Local/Regional Support
HAZUS	Freely available	No	No	No
CIPDSS	Yes	No	Yes	No
I2Sim	No	Yes	Yes	Yes
Sim Disaster	Yes	No	No	No

Table 3: Comparison of CI Sectors facilitated by each tool

Simulation Tool	Chemical and Hazardous Materials	Commercial Facilities	Communications	Critical Manufacturing	Dams	Defence
HAZUS	Yes	-	-	-	-	-
CIPDSS	Yes	-	-	Yes	-	Yes
I2Sim	Yes	-	Yes	Yes	Yes	Yes
Sim Disaster	-	-	-	-	-	-

Simulation Tool	Emergency Services	Energy	Financial Services	Food and Agriculture	Government Services	Healthcare
HAZUS	Yes	Yes	-	Yes	-	Yes
CIPDSS	Yes	Yes	Yes	Yes	-	Yes
I2Sim	Yes	Yes	-	Yes	-	Yes
Sim Disaster	Yes	-	-	-	-	-

Simulation Tool	Information Technology	Nuclear	Transport	Water and Wastewater	Postal and Shipping
HAZUS	-	-	Yes	Yes	-
CIPDSS	Yes	-	Yes	Yes	Yes
I2Sim	Yes	Yes	Yes	Yes	Yes
Sim Disaster	-	-	Yes	Yes	-

6.2 CII Software Features

Another way of comparing these simulation tools is by comparing the features afforded by each (see Table 4). A comprehensive CII tool would include features such as:

- Physical Disaster Models, so that the effect of a particular disaster type can be automated and randomised when running simulations.
- Empirical Data Models, where the simulator facilitates automated incorporation of collected infrastructure data and third party data into the model.
- Egress modelling, to simulate the movement of people and its effect on infrastructures and resources.
- Spatial data-source integration, where GIS information can be incorporated into the model and there is compatibility with widely used software such as ArcGIS or even Google Earth.

It is worth noting that although two tools may include the same feature, they may vary in the level of sophistication with which the feature is implemented. For example, I2Sim's egress modelling is rudimentary compared to that of Sim Disaster.

6.3 Summary of the Analysis

The two tools that provide CII modelling functionality in the stricter sense, such that the cascading effect of infrastructure failures upon other infrastructures is specifically modelled, are I2Sim and CIPDSS. When considering the number of CI sectors facilitated by each tool I2Sim surpasses CIPDSS, whereas when the special features of tools are compared CIPDSS offers the advantage. As the comparison is aimed at assessing suitability for the Caribbean context, accessibility and support are of significance. I2Sim carries an advantage in this regard since it is non-proprietary, open source and is regionally supported through academia.

Table 4: Comparison of CII Software Features

CII Simulation Tool	Physical Disaster Models	Empirical Data Models	Egress modelling	Spatial Data-source integration
HAZUS	Yes	Yes	No	Yes
CIPDSS	No	Yes	No	Yes
I2Sim	No	No	Yes	Yes
Sim Disaster	No	No	Yes (Detailed)	Yes

7. Conclusion

Critical Infrastructure Interdependency has been identified as an important field in assessing a nation's or community's vulnerability to disaster in the Hyogo Framework for Action as well as by the UNISDR and the WMO. Caribbean disaster management agencies, however, have not yet initiated research in this field or incorporated this facet of DRR in their programs. Some agencies have indicated their interest or intention in pursuing this, while others have not. The Caribbean is behind on research on CII and such efforts need to be initiated.

Towards this objective, examples of available tools which offer aspects of CII simulation were presented. At this stage of development, use of open source, highly customisable tools such as I2Sim are the best options for Caribbean countries since they rely on reduced order data sets that do not demand detailed knowledge of infrastructure operations and are supported by academic institutions in the region.

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Soil-Metal Sliding Resistance Forces of Some Trinidadian Soils at High Water Contents

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Abstract: *Soil-metal sliding resistance forces are influenced by factors such as soil physical properties, the geometrical characteristics of the tool and the speed between the two interacting surfaces. Soil-metal sliding resistance has a negative effect on the operation of earth-working machines. It results in increased downtime for cleaning tool surfaces, increased draft forces, and increased fuel consumption during the operation of the machinery thus leading to reduced operation efficiencies. This results in increased operational cost to the end user. Previous research exists on the subject area. However, there are few equipment that have been designed to adequately measure the dynamic forces that exist during this phenomenon. In this paper, soil-metal sliding resistance tests were performed by incorporating a soil-metal adapter tool (SMAT) to a Hounsfield tensometer. This permitted measurements of the dynamic forces on the SMAT as it moved on the soil surface. Data on the normal stress against shear stress at the soil-tool interface for some common soils in Trinidad were obtained. The measured shear stress at the soil-tool interface was separated into the components of adhesion constant and external friction angle. Soil penetration resistance measurements were also taken. Analysis of variance showed that the experimental factors such as soil type, water content and compaction effort had significant ($P < 0.001$) effect on adhesion constant and the external friction angle. Regression models were developed to predict the behaviour of the soil and the tool at the boundary surfaces. This information could be used in performing simulations at the soil-tool interface and thereby aid in improving designs of earth-working tools. Also the information could be used in improving soil management practices during tillage operations.*

Keywords: *Adhesion, Friction, Soil, Metal, Sliding, Resistance*

1. Introduction

Soil-metal sliding resistance can be described as the binding force that exists between the soil and solid (metal) area of contact (Ren et al., 2006). This phenomenon occurs when frictional forces and adhesive binding forces between the soil and the surfaces in contact are greater than the cohesive forces of the soil aggregate (Ren et al., 2001). Adhesion of soil on earth-working equipment and machinery results in downtime for cleaning, increased fuel consumption, draft of the machinery, loss of power of the machinery, and reduced efficiency and quality of work (Wang et al., 1998). Earth-working tools and machinery are constantly subjected to adhesion between soil particles and the surface of the tool during operations such as tilling, drilling, and excavating (Ramsahai et al., 2011).

Soil-metal sliding resistance is a factor which is normally considered when designing earth-working machinery and equipment (Shen and Kushwaha, 1998). It is a function variable in the fundamental earth moving equation (FEE) for draught requirements for earth-working equipment (Sahu and Raheman, 2006; Patel and Prajapati, 2011). Both physical properties of the soil and the tool influence adhesion (Sharifat and Kushwaha, 2000). Some of these soil properties include water content, void ratio, organic matter content, grain size distribution and clay content of the soil (Onwualu, 2010). Tool properties include the tool material characteristics, the geometry of the tool, surface roughness of the tool and the speed of operation (Ren et al., 2001). Fountaine (1954) when investigating the effects of normal loads on soil found that the soil-metal sliding resistance can be attributed entirely to the water film between the jointed surfaces of the soil-metal interface.

Adhesive forces are at maximum levels when the water content is between the plastic and liquid limits of the particular soil (Ramsahai et al., 2011). Khan et al., (2010) highlighted the effects of varying water content on soil adhesive property and showed that a particular soil would have its highest value of adhesion at water contents between 22% and 32%. This range also

corresponds to the plastic limit of most soils in Trinidad (Roopnarine et al., 2012).

Satomi et al. (2012) identified that adhesive stress decreased as void ratio increased. Hence the bulk density and thus soil compaction will also influence adhesion. Sakharov et al. (1973) and Ramsahai et al. (2011) indicated that the value of adhesion is highest in clay soils. This is due to the fineness of the particles and the greater surface area developed at the soil-metal interface.

Soil-metal sliding resistance is a complex process and very difficult to measure. The process is a combination of adhesion and frictional forces (Soni and Salokhe, 2006). Authors such as Shrivastava et al. (1993) have proposed a simplified equation (Equation 1) to relate the phenomenon.

$$\tau = C\_\alpha + \sigma \tan(\delta) \quad (1)$$

where τ is the sliding resistance stress and C_α is the stress due to adhesion, σ is the normal stress acting on the surface and δ is the external friction angle.

This equation can be further rewritten as equation (2) developed by Chancellor (1994).

$$\tau = \mu (A\_N + \sigma) \quad (2)$$

In this format the coefficient of friction is represented as μ and is equal to tan (δ). The term, A_N is the adhesion stress constant divided by friction. The equation argues that the combined effect of the adhesion (A_N) and normal stresses (σ) results in a total normal stress (Chancellor, 1994). This total normal stress when multiplied by the coefficient of friction gives the sliding resistance stress. Further the factors that affect the coefficient of friction ultimately affect the sliding resistance stress.

Limited tests on soil adhesion properties have been performed on local and regional soils of the Caribbean. Perusal of the literature revealed no information on the combined effects of water and compaction on soil-metal sliding resistance forces. One of the main reasons for this deficit could be the lack of specialised laboratory test equipment. Results from soil-metal sliding resistance experiments would be beneficial to the agricultural, mining and construction industries as such data would assist engineers and scientists to model the behaviour of soil under varying conditions. Such models would be useful in simulations and can be applied in the design analysis at the soil-tool interface, hence, improving the design of earth-working equipment and thereby optimising efficiencies during operations. This paper investigates the effect of varying water contents and compaction efforts on sliding resistance forces at the soil-metal interface of three local soils. A soil-metal adapter tool (SMAT) device was designed and fabricated. This device allowed the determination of coefficients of adhesion and friction of specific soil types with varying water contents of the soil.

2. Materials and Methods

Three local soils, Piarco sandy loam, Maracas clay loam and Talparo clay (Table 1) were used to represent some of the major soils in Trinidad. These soils are a representative of the three common soil textures common in Trinidad. Dehumidified soil samples were ground to pass through a 4.75 mm sieve. Particle size analysis (see Table 1) was carried out using the hydrometer method (Lambe, 1951). The organic matter content in the samples was measured using the method advocated by Walkley and Black (1934). The measurement of organic matter was done for completeness in determining the soil's physical properties. However, organic matter was not considered as a factor in these tests. The plastic limit test was carried out using the method described by Das (2012). The initial water contents of the soil were determined by the gravimetric method (Das, 2012). Water contents in the samples were then increased by adding the amount of water required for soil testing.

To determine the sliding resistance between the soil and a tool, a special device called the soil-metal adapter tool (SMAT) was designed, fabricated and used as a special attachment to the horizontal Hounsfield tensometer (see Figure 1(a) and (b)). The SMAT device is comprised two parts: one part is a moving blade whose surface roughness was 1.19 μm and the other is a fixed modified compaction mould (see Figure 2). The combined apparatus measured the sliding resistance forces between the metal blade and the soil surfaces. To measure soil penetration resistance on the soil surface, a hand pushed spring-type Proctor Penetrometer (ASTM, 1985) was used.

Before placing the soil samples in the Hounsfield tensometer, each sample was compacted in the compaction mould using the standard Proctor compaction method (Lambe, 1951). Three levels of compaction efforts (5, 15 and 25 Proctor blows) were applied each at four levels of water content (15%, 20%,

Table 1. Classification, organic matter, the particle size distribution (%) and plastic limit for the soils

Soil Series	Classification [a]	Organic Matter Content (%)	Sand (0.06-.002 mm)	Silt (.06 - .002 mm)	Clay (<0.002 mm)	Plastic Limit (%)
Piarco	Aquoxic Tropudults[1]	1.7[b]	64.9	17.0	18.1	20.29
Maracas	Orthoxic Tropudults[2]	4.7	44.7	24.7	30.6	23.37
Talparo	Aquentic Chromuderts[3]	2.7	25.4	28.3	46.3	27.13

[a] Classification according to Soil Taxonomy System (Soil Survey Staff,1999). Numbers in superscript are soil mineralogy given by Smith (1983) and represent (1) kaolinitic clay (2) clayey oxidic and (3) mixed clay mineralogy

[b] All values are means of three replicates

25% and 30%). The range of water content was chosen to represent those close to the plastic limit of all three soils. For each sample of soil tested, four normal loads of zero (0) kg, 1.0 kg, 2.0 kg and 3.0 kg mass were added incrementally. Two replicates were done for each test.

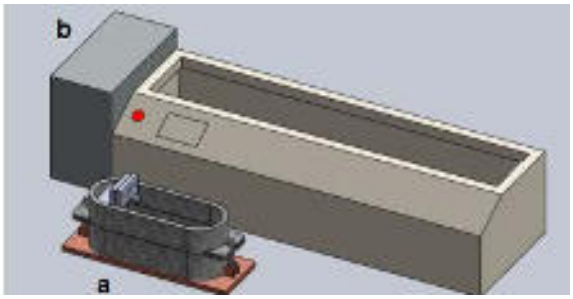

Figure 1: (a) Soil-Metal Adapter Tool (SMAT) and **(b)** Horizontal Hounsfield Tensometer

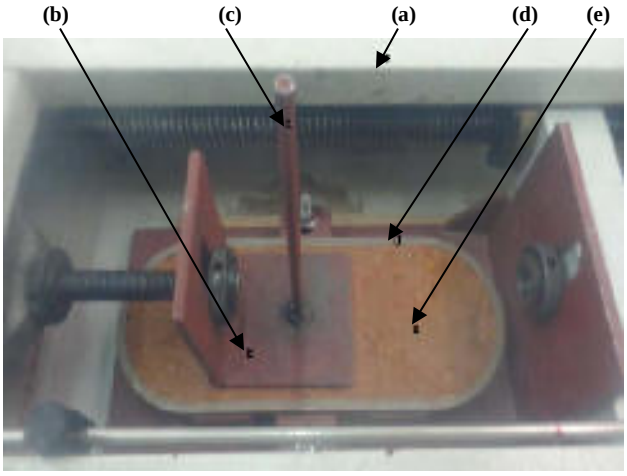

Figure 2. SMAT Tool Assembled in Tensometer and under Operation

(a) Horizintal Hounsfield Tensometer Cavity
(b) Moving Tool Place (Dimensions 70 mm (L) x 70 mm (W) x 90 mm (H))
(c) Extended Rod for Placement of Weights (Dimensions Φ 6 mm x 180 mm (H))
(d) Fixed compaction mould (Dimensions 350 mm (L) and Φ 100 mm for semi-circle)
(e) Compacted Soil

Before testing, the surfaces of the compacted samples were rolled forward and reversed twice with a miniature roller. Then the Proctor Penetrometer was placed on the surface of the soil. Two readings of penetration resistance were obtained. The surfaces of the soil samples were again rolled forward and reversed twice. The compaction mould was then placed and fixed on one end of the tensometer while the blade was attached to the opposite end and its bottom surface moved over the soil surface (see Figure 2). A constant speed of 20 mm/min was maintained for half hour on each test. 20 mm/ min was chosen as it is a sufficiently slow speed for easily obtaining measurements. For the first run, no normal load was added. Thereafter, loads were added in increments. Each time a new load was added the surfaces of the soil samples were rolled. This formed part of the preparation method.

The measured resistive forces occurred mainly at the interface of the soil and tool and were a combination of frictional forces and adhesion forces. In our investigations, we applied varying normal forces per unit area (σ) at the soil-tool interface and measured the corresponding resistive shear force (τ) per unit area. The approach as discussed by Koolen and Kuipers (1983) requires that plots of τ against σ be done. Hence, values of adhesion constant(C_α) and external frictional angle (δ) were graphically extrapolated.

This experimental investigation uses disturbed samples for measuring soil-metal sliding resistance forces. Though disturbed soils cannot fully replicate natural soil conditions they are suitable when seeking to simulate the tilled layer of soil (Moldenhauer, 1965) which is highly compactable. Woodburn and Kozachyn (1965) and Rose (1962) worked with disturbed and undisturbed samples and observed that the relative readings of the strength parameters of the soil they measured remained the same. Diaz-Zorita et al. (2002) showed that laboratory procedures using disturbed soils can be used to characterise soil conditions as found in the field, as long as only small stresses are applied to the soil during handling. In the present research, soil samples were not compressed after collection, but were gently fragmented and quickly air dried before sieving through 5 mm openings in order to minimise the disruption of the aggregates in the laboratory. It was therefore expected that results in this research will not be significantly affected by soil structure condition.

3. Results and Discussion

Table 2 shows the values of the maximum sliding resistance stress (τ_{max}), the adhesion (C_α) constant, external frictional angle (δ) and penetration resistance (P) for three soil types at varying water contents and compaction levels. The highest τ_{max} value for any soil occurred at 20% water content and this was similar to values of δ. The highest values for τ_{max} were observed for Maracas clay loam soil. The values for δ ranged between 15.7 ^{o} to 71.9^o. Maracas clay loam also had the highest value of δ. The lowest δ value occurred at 30% water content for each soil, with Talparo clay having the lowest value. For Talparo clay, after 20% water content there was a greater decrease in the value of the external friction angle. Seemingly, this can be attributed to the higher % clay content of the soil and the onset of the plastic limit. This supports the work done by Sakharov et al., (1973) who showed that after the 20% water content as soils approached the liquid limit, soils decreased in frictional resistance and acted more as a lubricator to implements.

Table 2. Values of the measured parameters for the three soils

Soil type	Water content (%)	Soil compaction Levels											
		5 Proctor blows				15 Proctor blows				25 Proctor blows			
		*τ_{max} (kPa)	**C_α (kPa)	$^{+}\delta$ (^{o})	$^{++}$P MPa	τ_{max} (kPa)	C_α (kPa)	δ (^{o})	P MPa	τ_{max} (kPa)	C_α (kPa)	δ (^{o})	P (MPa)
Piarco Sandy loam	15	7.90	1.99	60.7	5.33	4.03	0.91	43.4	8.50	3.41	0.43	42.2	9.00
	20	9.31	2.18	65.2	0.98	4.60	1.30	45.0	0.95	4.40	0.59	48.9	1.70
	25	6.20	2.40	49.1	0.23	4.60	1.80	39.8	0.30	4.10	1.70	35.3	0.33
	30	6.00	2.80	43.9	0.25	5.20	2.50	39.2	0.10	3.60	2.20	22.0	0.10
Maracas clay loam	15	7.60	1.66	60.9	10.2	6.50	1.40	57.2	11.6	6.24	0.84	58.5	14.2
	20	12.1	2.00	71.9	4.70	7.51	1.69	60.5	4.80	6.80	1.10	59.9	8.60
	25	8.62	2.90	60.2	1.60	6.13	1.80	52.8	3.00	6.35	1.60	55.1	3.30
	30	10.6	5.70	56.6	1.02	8.74	4.50	52.3	1.20	7.08	3.10	50.4	1.41
Talparo Clay	15	3.83	0.22	47.6	19.3	3.50	0.22	44.8	22.6	6.24	4.70	25.6	23.3
	20	5.43	0.97	53.3	6.10	5.32	1.80	47.1	9.00	7.22	3.50	48.6	12.5
	25	4.22	1.98	34.1	3.45	5.17	3.14	31.7	6.60	7.80	6.25	25.0	5.88
	30	5.91	4.16	27.7	1.20	7.47	5.70	28.1	3.10	8.55	7.62	15.7	3.40

* τ_{max} is maximum sliding resistance; **C_α is Adhesion constant; $^{+}\delta$ is the external friction angle, and $^{++}$ P is the Penetrometer Resistance.

Values of C_α increased exponentially with increasing water contents for all soils ranging from 0.22 kPa at 15% water content to 7.62 kPa for 30% water content, with Talparo clay having the highest value at 30% water content followed by Maracas soil and Piarco sandy loam in that order. Soils with substantial clay content tend to bond closer together. Hence there is greater attraction by clay soil particles to metal, resulting in the increase in the adhesion constant. This infers that higher clay content in soils increases the adhesion of the soil. This supports the work by Sakharov et al. (1973). Generally, penetration resistance decreased with increasing water contents varying from 0.1 MPa to 23.25 MPa with the highest value again for Talparo clay soil at 15% water content. It was observed that soils with high C_α values had corresponding low P values and vice versa.

For Maracas clay loam and Piarco sandy loam soils, the penetration resistance increased while sliding resistance, external friction and adhesion decreased with increasing compaction levels. This can be attributed to the increase in cohesive bonding between particles when compaction was increased. This showed that the more compact the soil is, the less likely it offers frictional resistance at the soil-metal interface when a tool moves over the surface. This concurs with the work of Satomi et al. (2012) who mentioned that an increase in void ratio resulted in a decrease in adhesive stresses. However, the more compact the soil, the higher the penetration resistance. Hence earth-working tools spend more energy in penetrating these highly compacted soils than on overcoming the frictional resistance offered by the soil on the tool as it moves through the soil. For Talparo clay soils, the penetration resistance, sliding resistance and adhesion increased with increasing compaction while external friction decreased.

Table 3 summarises the mean values of τ_{max}, C_α, δ and P for different experimental factors. Generally the mean values for the adhesion constant (C_α) showed an increase with increasing clay, water contents and compaction efforts. The mean values for Penetration resistance (P) generally increased with increasing clay and compaction efforts, and decreased with increasing water contents. Hence there was similarity between C_α and P with respect to clay content and compaction effort while the reverse was the case for water content. Mean external friction also increased with water content from 15% to 20% and thereafter decreased as water content increased to 30%. Its values generally decreased with increasing compaction effort. The mean values for maximum sliding resistance (τ_{max}) and the external friction angle varied in a similar manner to the experimental factors. Hence the external friction angle may be the dominant component in the sliding resistance equation (i.e., Equation (1)).

The analysis of variance shows that the main effects of soil type, water content and compaction effort as well as the interaction effects were all significant for the measured parameters. The water content was the most important factor followed by soil type and compaction effort. As shown in Table 4, soil type had a greater influence on external friction angle than water content. In addition, the most significant interaction between the three experimental factors was that between soil type and compaction effort. The main and interaction effects of these experimental factors are discussed below.

3.1 Soil Type and Water Content

The interaction between soil type and water content (see Figure 3(a)) showed that at low water contents, the values of adhesion for the soils were similar but varied immensely on increasing water content to 30%. At low water contents there were small variations in external friction angle among soil types (see Figure 3(b)). However, as soil types approached 20% water content, the values of the external friction angle converged. As

Table 3. Mean[a] values of adhesion, external friction angle, sliding resistance and penetration resistance for the three soils

Factor level	Adhesion Constant, C_α (kPa)	External Friction Angle, δ (°)	Max. Sliding Resistance, τ_{max} (kPa)	Penetration Resistance, P (MPa)
Soil type				
Piarco Sandy Loam	1.74a	44.56a	5.26a	2.29a
Maracas Clay Loam	2.35b	58.01b	7.86b	5.47b
Talparo Clay	3.35c	35.78c	5.88c	9.69c
LSD (p = 0.001)	0.10	1.65	0.27	0.50
Water Content (%)				
15	1.37a	49.0a	5.46a	13.77a
20	1.68b	55.6b	6.96b	5.48b
25	2.62c	42.56c	5.9c	2.74c
30	4.24d	37.3d	7.01d	1.28d
LSD (p = 0.001)	0.12	2.02	0.33	0.62
Compaction effort				
5 Proctor blows	2.41a	52.6c	7.30a	4.51a
15 Proctor blows	2.22b	45.1b	5.72b	5.98b
25 Proctor blows	2.80c	40.6a	5.97bc	6.97c
LSD (p = 0.001)	0.10	1.65	0.27	0.50

[a] Mean values for each factor were obtained by averaging the measured values over the levels of the other two experimental factors. Number of experimental factors was 72 representing a factorial experiment with three soil types, four water contents, three compaction levels and two replications. Values followed by different letters in each column were significantly different at the 0.1% level

Table 4. 'F' values in the analysis of variance for the measured parameters.

Sources of variation	Degrees of freedom	Adhesion constant	External friction angle	Penetration resistance
Soil type	2	845.9	524.6	625.2
Water content	3	1605.1	197.3	1059.6
Compaction effort	2	113.1	153.6	69.9
Soil type x water content	6	149.7	12.3	79.4
Soil type x compaction effort eff	4	895.6	18.6	9.0
Water content x compaction effort	6	25.5	8.3	9.0

* Not significant at 1% level

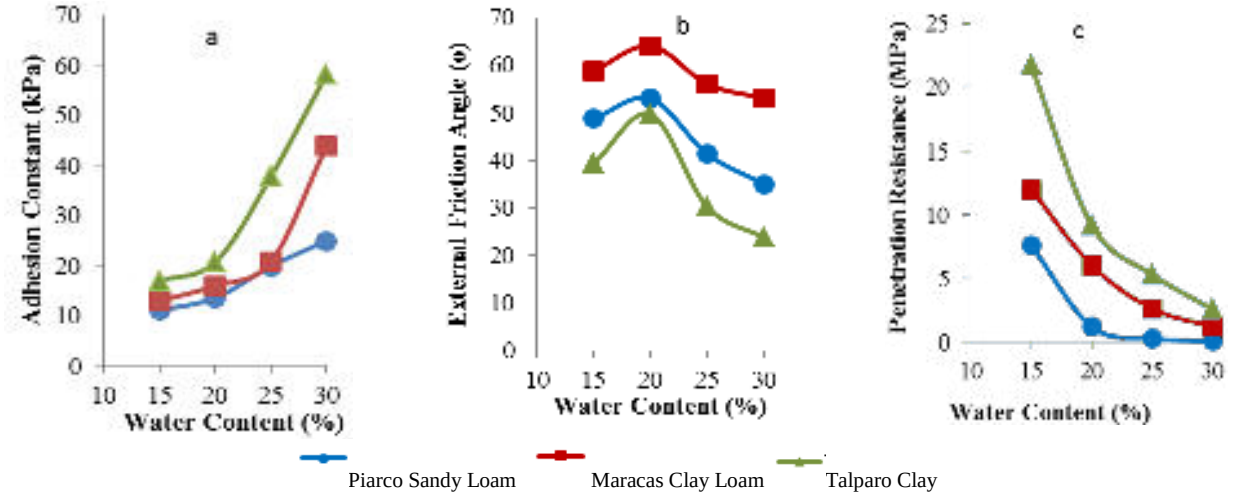

Figure 3. Effect of Interaction between water content and soil type on (a) adhesion (b) external friction angle (c) penetration resistance

the water content increased beyond the 20 % water content, there were large variations in the external frictional angle value among the soil types. Hence high water contents especially greater than 20% decreased the external friction angle for all soils.

In Figure 3(c), at low water contents, there was considerable variation in penetration resistance among soils, but with an increase in water content, the penetration resistance for all soil types converged. Hence at high water contents, penetration resistance among

soils did not vary considerably when compared to soils at low water contents. This agrees with the work by Ekwue et al. (2014) that at water contents of soils below their optimum water contents (OMC), penetration resistance varied widely but at water levels greater that the OMC, there were little variation among the penetration resistance of soils. The penetration resistance thus had the opposite effect to that of adhesion constant.

3.2 Soil Type and Compaction Effort

The interaction of soil type and compaction effort on adhesion constant is depicted in Figure 4. It shows that at the low compaction effort of 5 Proctor blows, the values of adhesion for the three soils were close to each other while at the 25 Proctor blows, the difference in the values for the three soils widened. Hence soils that are loose or not heavily compacted will have little variation in their adhesion constant. However, as the compaction effort increases, the variation in adhesion constant increases among soils; and soils with high clay content having the greatest values. Compacted clay particles have a higher attraction than sand or silt particles. Hence they bind better to metals and therefore stick to metal surfaces easier than other soil particles thus offering a higher adhesion constant than other soils. This agrees with the work reported by Khan et al. (2010).

3.3 Derivation of Regression Equations relating measured soil parameters to experimental factors

For each measured soil parameter, the experimental factors were used to generate linear multiple regression equations that could be used for prediction. The multiple regression equations are of the form:

$$Y = a + b\,(M) + c\,(Ct) + d\,(Pc) \quad (3)$$

Where: Y is the measured parameters of adhesion constant, external friction angle and penetration resistance; M is the water content (%); Ct is clay content (%); Pc is compaction effort and a, b, c, and d are empirically derived coefficients (see Table 5). The signs of the experimental factors obtained confirm how the factors affected the measured parameters.

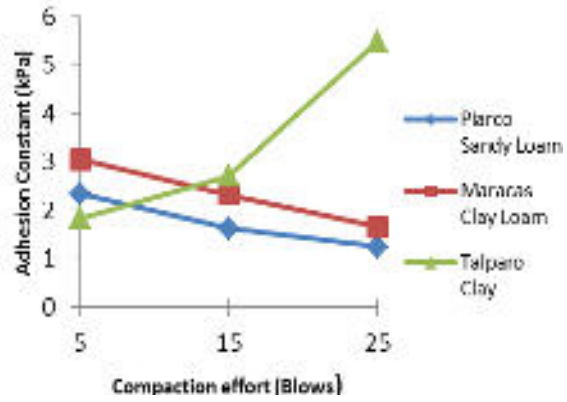

Figure 4. Effect of Interaction between compaction effort and soil type on adhesion

Table 5. Values of coefficients in multiple regression Equation (3) relating the measured parameters to experimental factors

Experimental Factors:	Adhesion Constant (kPa)	External Friction Angle (°)	Penetration Resistance (MPa)
Total Intercept	-3644.00	85.20	14.2
Clay content, %	57.34	-0.36	0.26
Water content, %	191.40	-0.96	-0.80
Compaction effort, kPa	-	-0.02	0.003*
Number of observations	72	72	72
Multiple correlation coefficient	0.714	0.520	0.877

*Not significant at 1% level

4. Conclusion

Water content and soil type had the greatest influence on the soil-metal sliding resistance forces while compaction effort had the least influence. At 20% water content, all soil types showed a substantial increase in frictional resistance. This, however, decreased thereafter as the soil behaved more as a lubricant. Water content affects the adhesion constant with appreciable increase after 20% water content. These findings therefore suggest that an effective soil management practice would be to till soils below 20% water content. This ensures that the sliding resistance forces for soil-metal during these operations are kept to a minimum. The study also show that the effect of soil type on soil-metal sliding resistance will be highest at the highest water contents. At low water contents, soils of diverse texture exhibit similar sliding resistance.

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A Road Collapse at Pont Cassé, Dominica: Hydrologic and Hydraulic Aspects

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Abstract: *In the early morning (about 5:30 AM) of Friday 19th April 2013 a motor vehicle fell in a 13m deep and 25m wide ravine, which had rapidly formed across a major road, at a culvert crossing at Pont Cassé in the island of Dominica (15^0N, 16^0W) in the Lesser Antilles. There were intermittent heavy rains in the preceding three days, and particularly during the preceding twenty-four hours. About 400 mm of rain is believed to have fallen on the catchment upstream of the culvert crossing. This accident unfortunately led to the death of two persons. This technical note, based on a site visit during 5th to 7th May 2013, first outlines the hydrologic and hydraulic setting of the road collapse, as well as the unavailability of event specific hydrologic data. It concludes – essentially using heuristics, judgment and transposition - that the probable causes of the road failure were twofold - firstly, a flash flood, arguably, with a return period in excess of 100 years, and secondly, an inadequate maintenance of a concrete culvert in a terrain prone to slope instability. It ends with the following recommendations (a) there is a need to expand the network of recording rain-gauges and stream-gauges in Dominica for preparing Rainfall Intensity-Duration-Frequency and Flood Frequency Curves respectively, for an optimal design of hydraulic structures; (b) the Caribbean Council of Engineering Organisation should undertake the preparation of a code of practice for engendering the same in the islands of the Commonwealth Caribbean; and (c) in the aforementioned islands, there is a need for preventive maintenance and/or retrofitting of culvert and bridge crossings.*

Keywords: *Culvert, Dominica, Flood, Rain, Road, Scour*

1. Introduction

This technical note refers to the scour of a road during a flash flood in Dominica (15^0N, 16^0W), which is an island in the Lesser Antilles (see Figure 1). Some specific aspects of this event are as follows: at about 5:30 AM on Friday 19th April 2013, a motor vehicle fell in a 13m deep and 25m wide ravine, which had rapidly formed across a major road, at a culvert crossing at Pont Cassé. There were intermittent heavy rains in the preceding three days. A non-recording rain-gauge, located about two kilometers away, indicated that during the preceding twenty four hours, about 400 mm of rain might have fallen on the small catchment upstream of the said culvert crossing. This accident at Pont Cassé unfortunately led to the death of two persons. This technical note presents a brief outline of observations made during a site visit two weeks after the incident and attempts to highlight the underlying causes. Its objective is to reinforce the need for hazard resistant design of Civil Engineering infrastructure in the Commonwealth Caribbean Region.

2. Hydrologic Setting

Dominica is a mountainous island where precipitation is dominated by its orography (see Figure 1). Indeed, it is considered a natural laboratory to study tropical meteorology (Smith et al. 2012).

Figure 1. Dominica: An island in the Lesser Antilles
Source: Macmillan (2006)

Specifically, its orographic enhancement factor, defined as the ratio of precipitation between high and low terrains, can range between 2 to 12 during a storm. Not surprisingly, its average annual rainfall shows a marked spatial variation ranging from a high of more than 7,600 mm at its highest elevation to about 1,500 mm at sea level. In such a hydrologic setting, a carefully planned network (WMO, 2008) of recording and non-recording rain-gauges and stream-gauging stations is essential for hydraulic engineering design of highway drainage structures (FHWA, 2002). In particular, there is a need for Rainfall Intensity Duration Frequency (IDF) Curves and streamflow frequency curves. However, the current data base of hydrologic information in Dominica is limited to a record of daily rainfall at only a few locations and sporadic stream flow measurements across the island.

Unavailability of hydrologic data in Dominica, as mentioned earlier, provides a well-known paradox to Engineering Hydrologists (Prakash, 1999). On the one hand there is the scale and complexity of hydrologic processes. On the other hand there is often an insufficiency of hydrologic data in terms of temporal length, spatial extent, continuity and accuracy. Moreover, engineering projects cannot wait for sufficient hydrologic data to be collected. Under such circumstances use of heuristics, transposition and judgment is therefore inevitable.

Figure 2 shows that the catchment upstream of the road breach is approximately 0.5 km^2 and is almost entirely forested (Google Earth). It seems to have an average slope of 9% and a time of concentration, t_c, of about 17 minutes. There is a 3:1 ratio between the Annual Rainfall at Pont Cassé and Melville Hall (US Army Corps of Engineers, 2004).

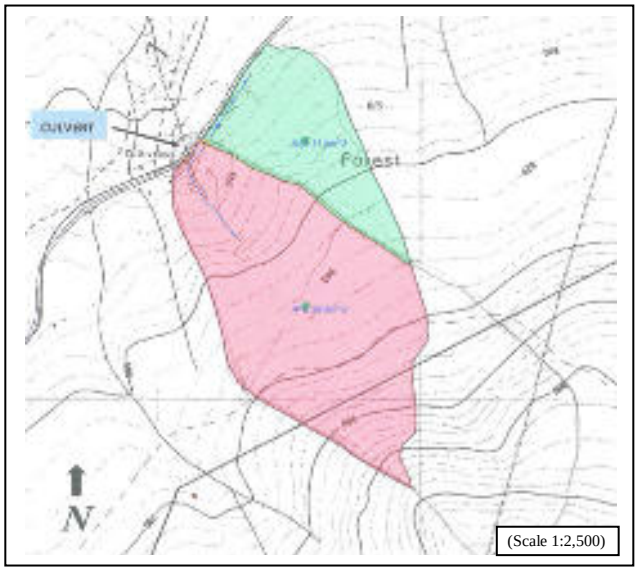

Figure 2. Estimated catchment area upstream of the road collapse
Source: Cooper (2013)

Thus, if we scale the Melville Hall Daily Rainfall of 129 mm on 18th April 2013 to Pont Cassé, we arrive at figures which are close to a 100 year 24 hour rainfall at an orographically similar location in Puerto Rico (US Department of Agriculture 1961). Further, although a temporal distribution of the rainstorm is not known, a cloudburst and flash flood cannot be ruled out. Indeed, there is a record of a cloudburst rain of 198.12 mm in 15 minutes at Plumb Point in Jamaica in 1916 (WMO, 2009). However, a cloudburst (defined as rainfall intensity greater than 100 mm/h over a short duration) is almost an unknown meso-scale weather system throughout the world; since rain-gauge networks generally are unable to capture it due to its highly localised occurrence (Thayyen, 2013). Figure 3 shows a photo taken on a collapse of a road at Pont Cassé on 19th April 2013.

Figure 3. A photo showing a collapse of a road at Pont Cassé

3. Estimation of Peak Flow

In Engineering Hydrology, it is recognised that peak flood flow estimation for 50 and 100 year return period, based on extreme value probability analysis of stream flow record, is the gold standard. This is because stream flow is the output of a catchment in response to a precipitation input. However, such an analysis requires 20 to 30 years of stream flow data, which is generally not available, especially in developing countries. In the absence of a suitable stream flow record, the appropriate hydrologic method for flood peak flow estimation is the application of an event based rainfall/runoff model such as the Triangular Unit Hydrograph proposed by the Natural Resource Conservation Service (Chow et al., 1988, NRCS, 1986). This however, requires an IDF curve for the catchment in question, and land use and topographic information. When neither of these two hydrologic methods is possible, Global and Regional Frequency Analyses – which are generally used for cross checking the estimates of the previously mentioned two methods—can be applied as a primary method of estimation.

It is against the foregoing background, that this report estimates, as a first approximation, the likely return period (probability of occurrence) of peak flow

which occurred during the breach of the road on the morning of Friday 19th April 2013. It does so by a combination of Global and Regional Flood Frequency Analyses (DHV Consultants, 1998, Meigh et al., 1997). Specifically, Mean Annual Flood (MAF) is estimated first and it is then scaled up for higher return periods. For estimating MAF a regression equation for West Africa ($\leq 8^0$N) is selected, since in the author's experience its hydrology is similar to that in the Caribbean. This perhaps should not be surprising, since Caribbean Weather Systems normally originate off the coast of Africa. The MAF equation includes the catchment area (AREA) as well as the Average Annual Rainfall (AAR), and gives an MAF of approximately 2 m^3s^{-1} for the stream at Pont Cassé (see Figure 4) for an AREA = 0.5 km^2 and AAR of 6,645mm.

Figure 4. The stream at Pont Cassé

Regional correlation with the Global Frequency for the stated region in Africa shows that a 50 year return period peak flood is about two times the MAF and a 100 year peak flood is about three times the MAF. Subsequently, comparison with the hydraulic capacity of the failed culvert indicates a rainstorm of return period ≥ 100 years.

An attempt can also be made, with an accurate map of the catchment and rainfall at Pont Cassé (if belatedly available), to distribute the 24 hour rainfall using Type III Distribution and compute the peak flow using the NRCS method (NRCS, 1986). The visually estimated curve number (about 50) would need to be corrected for antecedent moisture condition (AMC III) in view of about 200mm of rainfall, at Melville Hall, in the preceding two days. This estimate can act as a cross-check of the peak flow estimated earlier. This is an area for further work .

4. Hydraulic Setting

Given that the channel slope downstream of the culvert outlet is much steeper (17%) than the culvert slope of 9%, the possibility of culvert operating under outlet control does not arise. Further, in view of near vertical drop of 5m approximately 14m from the outlet, the possibility of any backwater effect downstream (which would have led to outlet control) is also ruled out.

As stated previously, a mathematical analysis of flow through a culvert under inlet control condition is difficult due to complex physics. Therefore, physical scale models are tested, for critical situations such as culvert spillways going through earth dams or in lock gates, to observe and calibrate its hydraulic characteristics. Nevertheless, an approximate mathematical analysis is possible from first principles (Prashun 1987), from the geometry of the inlet, and the original road cross section (see Figure 5).

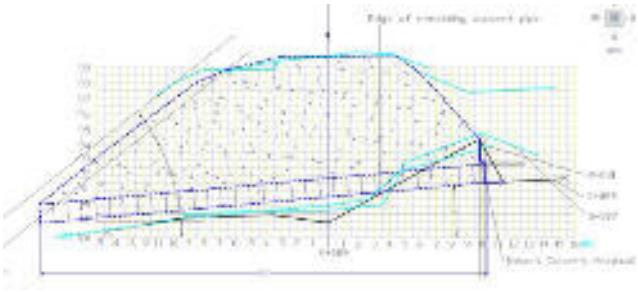

Figure 5. Reconstructed Road Cross Section
Source: Gay (2013)

Hydraulic analyses under inlet control with a headwater depth at the road crest level (i.e. 8m) gave a peak discharge, of the 1.2m diameter culvert, as 11.3m^3s^{-1}, entrance velocity of 13 m/s, an inlet velocity of 10.5 m/s running 95% full, an outlet velocity of 10m/s with culvert flowing full. Such a velocity regime can impart a force (approximately 50 kNm^{-2}), which is about half of the atmospheric pressure at sea level on a dislocated/exposed culvert joint.

5. Failure Mechanism

The mechanism of road failure remains open to question. On one hand, there is a possibility of a peak flow exceeding the culvert capacity. This can cause failure due to combined overflow erosion and progressive jet erosion at culvert joints (through joints dislocated by traffic vibration, slope instability or seismic activity over time) commencing at the outlet (see Figure 6). On the other hand, if the culvert capacity was not exceeded, there is the possibility of failure entirely due to progressive jet erosion of dislocated culvert joints commencing at the outlet. One interim conclusion that can be made from these perspectives is that, irrespective of the failure mechanism the choice of reinforced concrete box culvert (FHWA, 2005) is clearly superior for a replacement structure.

Now some comments on field evidence: to begin with, the presence of gabion baskets at the downstream end (see Figure 7) raises the possibility that there was a downstream slope failure and dislocation of 1m long

culvert pipe segments some time prior to the event. This observation underscores the need for a regular inspection, and preventive maintenance of bridges and culverts. Besides, the inlet structure (see Figure 8) and upstream segments of the culvert remained intact (see Figure 9) and give credence to the argument that an overflow did not take place.

Figure 6. A photo showing dislocated culvert joints

Figure 7. A photo showing gabion baskets at the culvert outlet

Figure 8. A photo showing the culvert inlet

Figure 9. Remains of the culvert at the upstream end

Furthermore, the shape of the three post failure cross sectional profiles (0+087, 0+089 and 0+091) seems to indicate an overflow. It is hoped that a geotechnical analysis/numerical simulation may resolve this contradiction. This then, is another area for further investigative work.

6. Discussion

Failure of culverts and bridges due to scour phenomenon is not uncommon across the world, and often leads to loss of life (Kala, 2014, Murillo, 1987, Polemio and Lollino, 2011). With reference to the Commonwealth Caribbean region, there seem to be four primary causes for such failures. First, uncertainty in estimating the magnitude and intensity of a rainstorm is due to insufficient hydrologic data. Second, equally unpredictable, is a catchment's response to a given rainstorm, underscoring the need for good quality information on land use, topography and geology. Third, there is, frequently, an absence of a code of practice or guidelines for the design of drainage structures, which results in subjective design criteria. Finally, there is the ever present issue of poor maintenance of infrastructure.

7. Conclusions

Admittedly, the hydraulic and hydrologic analyses lack rigour primarily due to unavailability of event specific hydrologic data. In such circumstances, methods of analyses depend more on the data available than on the nature of the problem posed. Nevertheless, it is believed that in due course more information may be obtained which can permit a deeper investigation of the event.

Meanwhile, the following interim conclusions may be made: (a) the scour failure at a culvert crossing at Pont Cassé can be attributed to concurrent occurrence of a storm of a return period in excess of one hundred years and overflow on the road embankment. These circumstances were exacerbated by dislocated joints of concrete culvert segments arising from prior slope instability; (b) there is a need to expand the network of recording rain-gauges and stream-gauges in Dominica. Specifically, Rainfall Intensity-Duration-Frequency and Flood Frequency Curves are needed for optimal design of hydraulic structures; (c) the Caribbean Council of Engineering Organisation should undertake the preparation of a code of practice for the design of hydraulic structures in the islands of the Commonwealth Caribbean; and (d) in these islands, there is a need to regularly inspect, repair and retrofit culvert and bridge crossings.

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Inhibition Efficiency of *Moringa Oleifera* Leaf Extract on the Corrosion of Reinforced Steel Bar in HCl Solution

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Abstract: *The inhibiting effect of Moringa Oleifera leaf extract on the corrosion of a reinforced steel bar in 2M solution of hydrogen chloride (HCl) was studied using gravimetric, gasometric and potentiodynamic polarization techniques. The study revealed that as the concentration of the extract increases, the inhibition efficiency increases in all three investigation scenarios. 1.0 g/l attained the efficiency of 92.31 % after 120 hours exposure during gravimetric measurement. The volume of the hydrogen gas evolved reduces with an increase in the exposure time during the gasometric test. It was noted that the extract slowed down the corrosion rate and the rate at which the hydrogen gas evolved. The formation of an adsorption layer on the surface of the metal reduces the rate at which hydrogen gas is evolved, which is a function of the concentration of the extract. Potentiodynamic polarization results revealed that the Moringa Oleifera leaf extract modifies the mechanism of anodic dissolution and cathodic hydrogen evolution. It was also observed that the corrosion current density decreases with the increase in the concentration of the extract. This decrease in corrosion is due to increased blocking of the metal surface by adsorption of the leaf extract. From the results, it can be concluded that Moringa Oleifera leaf extract can be used as a green inhibitor to slow corrosion of metals in aggressive media.*

Keywords: *Moringa Oleifera leaves, corrosion rate, weight loss, hydrogen evolution, potentiodynamic polarization*

1. Introduction

Corrosion processes are responsible for losses and failures in the industrial sector. It can be viewed as a universal phenomenon. Corrosion occurs in air, water, soil and in every environment and often affects most materials. Other than material loss, corrosion interferes with human safety, disrupts industrial operations and poses danger to the environment. Nations of the world loose a considerable amount of their gross domestic product (GDP) as a result of corrosion, for example the United States and the United Kingdom loose about $70 billion annually, accounting for about 4% of their national GDP (Gerhardus et al., 2002). A developing nation like Nigeria will most likely be spending a huge fortune on corrosion control annually.

Steel is one of the most versatile; least expensive and widely used engineering materials. It has a wide range of mechanical and physical properties that make it suitable for many applications in the industrial sector. The use of metal involves a major setback—corrosion attack (Raja and Sethuraman, 2009). Problems caused by corrosion can be reduced or minimised by many ways, such as conditioning the metal by coating the metal with another, or conditioning of the corrosive environment by the removal of oxygen, or electrochemical treatment of the metal by cathodic protection or the use of corrosion inhibitors (Bradford, 1993).

The use of a corrosion inhibitor had gained wide acceptance as a means of preventing corrosion in industries. Corrosion inhibitors can be defined as a chemical substance that retards corrosion when added to an environment in small concentration without significantly changing the concentration of any other corrosive agent (Bradford, 1993). It is widely accepted that the corrosion inhibition process takes place through physical or chemical adsorption of the inhibitor's molecules on the metal surface (Kairi and Kassim, 2013). In recent times, some industrial corrosion inhibitors are no longer used because they contain highly toxic compounds such as chromate, phosphate and arsenic. Thus, there is a need for a suitable substitute, which will not only be environmentally friendly but is also safe for the operator to use (Odusote and Ajayi, 2013). Green inhibitors contain alkaloids, tannins and flavonoids and other active agents (Chowdhary *et al.,* 2004; El-Etre *et al.,* 2005) which contribute to their inhibitory properties. The major source of green

inhibitors is plants, and they are now being widely studied as a viable replacement for the toxic and harmful synthetic inhibitors being used in most applications.

Several studies have been conducted to examine the use of plant extracts as corrosion inhibitors in various media. Some of these plants include *Tithonia diversifolia* (Alaneme and Olusegun, 2012); *Isertia coccinea* (Lebrini et al., 2011); Rice husk (Alaneme *et al.,* 2015); *Telfaria occidentialis* (Oguzie, 2005); *Nicotiana tabacum* (Olasehinde *et al.,* 2013); *Justicia gendarussa* (Satapathy *et al.,* 2009); *Jatropha Curcas* (Odusote and Ajayi, 2013; Ajayi *et al.,* 2014; Olusegun *et al.,* 2013); *Water hyacinth* (Oloruntoba *et al.,* 2012); *Curcuma Longa* (Kairi and Kassim, 2013); *Phyllanthus amarus* (Okafor *et al.,* 2008); *Carica papaya* (Ebenso and Ekpe, 1996); *Azadirachta indica* (Ekpe *et al.,* 1994), and *Moringa oleifera* (Singh *et al.,* 2011).

Moringa Oleifera (MO) is a perennial plant that grows very fast and flowers within 12 months of planting. It is one of the most widely spread plant species that grows quickly at low altitude in the whole tropical belt, including arid zones. It can grow on sandy or loamy soil having relatively low humidity (Ndabigengesere *et al.,* 1995). All the parts of *Moringa Oleifera* (MO) plant are useful. Oil can be extracted from its seeds to be used as coolants; cosmetics, cooking and soap. The press cakes (i.e. what is left after the oil extraction) are used as soil fertilizer. Pods and leaves are consumed both by humans and animals, as they contain many vitamins. Significantly, the extract from the leaves of the tree is used in engineering as a corrosion inhibitor (Nnanna and Owate, 2014).

Singh *et al.* (2011) studied the effect of the fruit extract of shahjan (*Moringa oleifera*) on the inhibition of the corrosion of mild steel in hydrochloric acid solution using weight loss, electrochemical impedance spectroscopy (EIS), linear polarization, and potentiodynamic polarization techniques (Tafel). The inhibition was found to increase with increasing concentration of the fruit extract in the acid solution. In this study, the inhibiting effect of *Moringa Oleifera* leaf extract on the corrosion of reinforced steel bar in hydrochloric acid solution was evaluated using gravimetric, gasometric and potentiodynamic polarization techniques. This is in continuation of the developmental work on green corrosion inhibitors.

2. Experiment Details

2.1 Preparation of the steel test samples

The reinforced steel bar was obtained from Prism Steel Mill Limited, South West, Nigeria. Its chemical composition was determined using an Optical Emission Spectrometer and the results are presented in Table 1. The steel sample was cut into pieces measuring 12 mm × 6 mm, polished using emery paper, degreased in ethanol, dried in acetone and then stored in desiccators.

Table1. The chemical composition of the reinforced steel bar

Element	Percentage (wt%)	Element	Percentage (wt%)
C	0.2910	**Al**	0.0210
Si	0.1930	**Ti**	0.0080
Mn	0.5790	**Nb**	0.0001
S	0.0420	**B**	0.0020
P	0.0540	**W**	0.0001
Cr	0.2710	**Mo**	0.0001
Ni	0.1050	**V**	0.0001
Cu	0.3080	**Fe**	98.1260

2.2 Preparation of the *MO* leaf extract

The procedure for the preparation of the leaves extract is similar to that reported by Odusote and Ajayi (2013). Fresh green *Moringa Oleifera* leaves were obtained from the surroundings of The University of Ilorin, and then washed, cut into pieces, and air dried before pulverization. 200 grams of the pulverized leaves were soaked in 250 $cm^3$of methanol in a conical flask. The resulting solution was left for 48 hours and then filtered. The filtrate was subjected to evaporation at room temperature to obtain the extract. The inhibition test solutions were prepared from the extract to obtain 0.2 g, 0.4 g, 0.6g, 0.8 g and 1.0 g in 1 litre of 2M hydrogen chloride (HCl).

2.3 Weight loss measurement

The pre-weighed test specimens were immersed in the 2.0 M HCl solution with and without varying concentrations of *Moringa Oleifera* extract. After 24 hours, the test specimens were retrieved, washed with distilled water, rinsed with ethanol, dried with acetone and reweighed using an electronic weighing balance (HX 302T with 0.01 g accuracy). The difference in weight was taken as weight loss. The same procedure was repeated after 48, 72, 96 and 120 hours exposure. From the weight loss data, corrosion rate, inhibition efficiency (IE%) and surface coverage (θ) of the plant extract were calculated using Equations 1, 2 and 3, respectively.

$$CR = \frac{\Delta W}{AT} \quad (1)$$

where *CR* is corrosion rate, *W* is the weight loss (g), *A* is the area of the coupon in cm^2, and T is exposure time (hours).

Inhibition efficiency from weight loss (IE_{wt}) and surface coverage (Θ) were calculated using Equations 2 and 3, respectively.

$$IE_{wt}\% = \left(1 - \frac{CR_{inh}}{CR_{blank}}\right) x\ 100 \quad (2)$$

where CR_{inh} and CR_{blank} correspond to the corrosion rates in the presence and absence of the extract, respectively.

$$Surface\ coverage, \theta = \left(1 - \frac{CR_{inh}}{CR_{blank}}\right) \quad (3)$$

2.4 Hydrogen evolution measurement

The hydrogen evolution measurement was carried out using gasometric assembly. The prepared corrodent (2M HCl) was poured into 100 ml two-necked flask and the initial volume of the air in the 50 ml burette was recorded. Thereafter, the already weighed test specimen was dropped into the HCl solution. The flask was quickly closed to ensure that it was air-tight, preventing the escape of gases. The volume of the hydrogen gas evolved from the corrosion reaction was monitored by the downward displacement of water. The absorption time was noted. The displacement was monitored by the volume change in the level of water in the burette. The displacement was recorded at 20-minute intervals and progressively for 3 hours and 20 minutes. This procedure was repeated for a fresh inhibition test solution of different concentration of *Moringa Oleifera* leaf extract (0.2 g/l, 0.4 g/l, 0.6 g/l, 0.8 g/l and 1.0 g/l).

The inhibition efficiency and the degree of surface coverage from hydrogen evolution measurement were determined using Equations 4 and 5, respectively.

$$IE_{H_2}\% = \frac{V_{H0} - V_{H1}}{V_{H0}} X\ 100 \quad (4)$$

$$Surface\ coverage, \theta = \frac{V_{H0} - V_{H1}}{V_{H0}} \quad (5)$$

where V_{H0} is the volume of hydrogen gas evolved in the blank solution and V_{H1} is the volume of hydrogen gas evolved in the presence of *Moringa Oleifera* leaf extract.

2.5 Potentiodynamic polarization measurement

This involves changing the potential of the working electrode and monitoring the current that is produced as a function of time and potential. This test was carried out using a three-electrode cell assembly at room temperature with the AUTOLAB PGSTAT 204N instrument. The metal samples of area of 1 cm^2 were embedded in resins. The embedded metal sample was used as the working electrode; the platinum electrode was used as the counter electrode and saturated silver/silver chloride as the reference electrode. The electrolyte used for this study was 2M HCl solution with varying concentrations of the extract and without extract.

The working electrode was polished with different grits of emery paper until the surface became smooth. The open circuit corrosion potential was carried out for 30 minutes until a stable potential was attained. The potentiodynamic polarization study was carried out from cathodic potential of -250 mV to an anodic potential of +250 mV with a scan rate of 1.0 mVs^{-1} to determine the current density, corrosion rate and inhibition efficiency (IE%).

The surface coverage (Θ) and inhibitor efficiency (*IE%*) were determined using Equations 6 and 7, respectively.

$$Surface\ coverage, \theta = \frac{I^o_{corr} - I_{corr}}{I^o_{corr}} \quad (6)$$

$$IE\ \% = \frac{I^o_{corr} - I_{corr}}{I^o_{corr}} \times 100 \quad (7)$$

where I_{corr} and I^o_{corr} are corrosion current density in the presence and absence of the extract, respectively.

3. Results and Discussion

3.1 Phytochemical Screening of the *MO* Leaves

The phytochemical screening of the *Moringa Oleifera* leaves was carried out and the results are presented in Table 2. The results show that the extract contains tannins, saponins, alkaloids, cardiac glycosides, anthraquinones, flavonoids, phenol, oxalate, steroid and terpenoid. This result is similar to the experimental results reported by Kasolo *et al.* (2010). Previous results have attributed the inhibitory properties of most green plants to the presence of active agents such as flavonoids, tannins, saponins and alkaloids (Ekpe *et al.*, 1994; Ebenso and Ekpe, 1996; Lebrini *et al.*, 2011; Odusote and Ajayi, 2013; Ajayi *et al.*, 2014 and Alaneme *et al.*, 2015).

Table 2. Phytochemical screening result of the *Moringa Oleifera* leaves

S/N	Constituent	*Moringa Oleifera* leaves
1	Alkaloids	+
2	Cardiac glycosides	++
3	Tannins	+++
4	Saponin	+
5	Anthraquinones	-
6	Flavonoids	+++
7	Terpenoids	+
8	Anthraquinone	++
9	Oxalate	+
10	Phenols	+
11	Trypsin	++

Key: - = absent; + =present in minute amount; ++ =present in moderate amount; +++=present in an appreciable amount.

3.2 Weight loss measurement

Figure 1 shows weight loss with respect to exposure time to *Moringa Oleifera* leaf extract. It can be deduced that there is a significant reduction in the weight loss of test specimens immersed in varying concentrations of the extract in comparison to the blank solution. Additionally, as the concentration of the extract increases, the weight loss reduces. The reduction in the weight loss could be attributed to the adsorption of tannin, alkaloids, and flavonoids, among others. The adsorption of these compounds on the metal surface creates a barrier to the dissolution of the metal in corrosive medium (Oguzie, 2007). The 0.2 g/l recorded a weight loss of 0.19 g after 120 hours of exposure while at the same time for 0.4 g/l recorded 0.07 g, 0.6 g/l recorded 0.07 g, 0.8 g/l recorded 0.06 g and 1.0 g/l recorded 0.04 g as shown as in Figure 1. This indicates

that the weight loss is highly dependent on the concentration of the inhibitor.

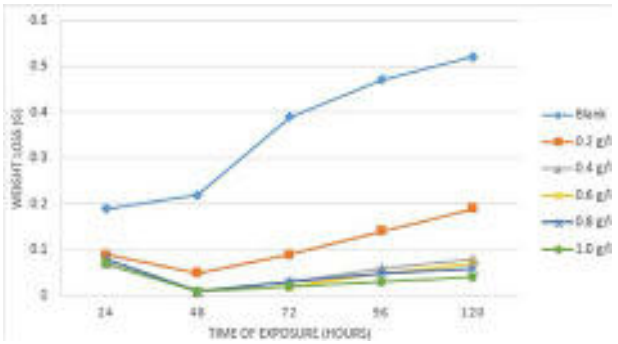

Figure 1. Weight Loss in the steel test sample against time of exposure in acidic medium with and without *Moringa Oleifera* leaf extract

Figure 2 presents the variation of corrosion rate against the exposure time. It is very obvious from Figure 2 that the corrosion rate of the reinforced steel bar in the absence of the plant extract decreases with the increase in concentration of the extract. The result after 24 hours revealed that the values of corrosion rate of the steel bar in 2M HCl decreased with increase in the concentration of *Moringa Oleifera* leaf extract. This suggests that as the concentration of the extract increases, there is an increase in adsorption of the extract constituents on the surface of the steel bar which resulted in the reduction of the corrosion rate (Nnanna and Owate, 2014; Okoronkwo *et al.*, 2015).

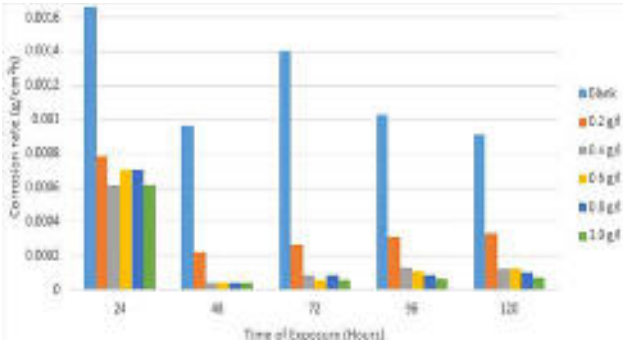

Figure 2. Variation in the corrosion rate of the reinforced steel bar against exposure time with and without *Moringa Oleifera* leaf extract

The stability of inhibitive behavior of the extract was assessed by the trend of the inhibition efficiency as a function of time. The values of inhibition efficiency (IE%) for each concentration of *Moringa Oleifera* leaf extract are recorded in Table 3. It was observed that the inhibition efficiency increases with an increase in inhibitor concentration but this was not consistent with the time of exposure. This is due to the formation of a protective film which is as a result of transition of the metal/solution interface from an active dissolution state to a passive state.

Table 3. Inhibition efficiency of reinforced steel bar for various concentration of *Moringa Oleifera* leaf extract at different time of exposure

Time of exposure (Hours)	Inhibition efficiency (%)					
	Blank	0.2 g/l	0.4 g/l	0.6 g/l	0.8 g/l	1.0 g/l
24.00	-	52.63	63.15	57.89	57.89	63.15
48.00	-	77.27	95.45	95.45	95.45	95.45
72.00	-	76.92	92.31	94.87	92.31	94.87
96.00	-	70.21	87.23	89.36	91.49	93.62
120.00	-	63.46	86.53	86.53	88.46	92.31

Therefore, the extract at this concentration protected the reactive surface of the metal from the aggressive environment of the acidic medium as reported by Ritchie and Bailey (1999). This observation agrees with the results obtained by Singh *et al.*, (2011), which revealed that the inhibition of corrosion of mild steel in hydrochloric acid solution by the fruit extract of shahjan (*Moringa oleifera*) increased with increasing concentration of the extract. They also concluded that the fruit extract of *Moringa oleifera* could serve as a viable inhibitor of the corrosion of mild steel in hydrochloric acid solution. However, there is a little decline in the inhibition efficiency after 72 hours exposure. The reason could be attributed to the adsorptive film of inhibitor that settles during the immersion time. After the formation of adherent and compacted adsorptive film, the effect of the exposure time become less significant because of the presence of barrier between the metal surface and the inhibitor (Faustin *et al.*, 2015, Li *et al.*, 2012).

3.3 Hydrogen evolution measurement

The volumes of hydrogen gas evolved in the presence and absence of *Moringa Oleifera* leaf extract are presented in Table 4. The results showed that the volume of hydrogen gas evolved increases with time but decreases as the concentration of extract increases. This indicates that the rate of the dissolution of the metal was retarded, leading to reduction of H^+. Readings of the lowest and highest volume of hydrogen evolved were noted in the 1.0 g/l and blank solution, respectively. These results conform to the conclusion drawn by Odusote and Ajayi (2013), that the rate of evolution of hydrogen gas decreases as the concentration increases and the least value of hydrogen gas was recorded at the highest concentration. The higher volume of hydrogen gas evolved in the blank solution suggests that there is no adsorption layer to inhibit the reaction of the acid on

the surface of the metal according to Nnanna and Owate, (2014).

It can be deduced from Figure 3 that as the concentration of the extract increases, the inhibition efficiency also increases. This follows the same trend with the weight loss measurement. It can also be observed that there was a re-ordering of the inhibition efficiencies after 80 minutes. The corrosion inhibition of the plant extract on the surface of the steel may be due to the phytochemical constituents present in the leaf extract. It can be observed that the inhibition efficiency becomes more stable as the exposure time increases. This stability in the inhibition efficiency indicates that the extract must have been fully absorbed on the surface of the metal. It can also be observed from the plot that 1.0 g/l possessed the highest value of inhibition efficiency. This also suggests that the surface of the metal was protected against acidic attack at higher concentration as reported by Uwah *et al.* (2013).

Table 4. Volume of Hydrogen gas evolved with time of exposure in the presence and absence of *Moringa Oleifera* leaf extract

Time of Exposure (Minutes)	Volume of Hydrogen gas evolved in the presence and absence of the *Moringa Oleifera leaf* extract (ml)					
	Blank	0.2 g/l	0.4 g/l	0.6 g/l	0.8 g/l	1.0 g/l
0.00	0.03	0.03	0.20	0.20	0.20	0.10
40.00	0.80	0.60	0.60	0.40	0.40	0.50
80.00	2.80	1.10	1.30	0.80	0.70	0.80
120.00	4.00	1.60	1.90	1.30	1.10	1.20
160.00	5.20	2.20	2.20	1.90	1.50	1.30
200.00	6.80	2.90	2.60	2.40	2.00	1.50

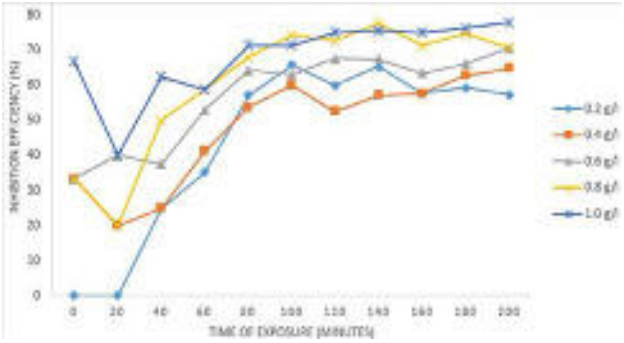

Figure 3. Variation in the inhibition efficiency with time of exposure in the presence and absence of the *Moringa Oleifera leaf* extract

3.4 Tafel polarization

Figure 4 shows the potentiodynamic polarization curves of corrosion inhibition of the mild steel in 2M HCl in the absence and presence of different concentrations of *Moringa Oleifera* leaf extract. It was observed that the polarization resistance (Rp) and inhibition efficiency (IE%) increase as the concentration of the extract increases. The highest inhibition efficiency of 81% was obtained at 1.0 g/l concentration. This also indicates that more inhibitor particles were absorbed on the surface of the metal thus providing a wider surface coverage and the extract acts as an adsorption inhibitor as reported by Mokhtari *et al.,* 2013. It can be observed from Table 5 that the corrosion current density (I_{corr}) decreases with increases in the concentration of the extract which is due to the increase in the blocked fraction of the metal surface by adsorption as reported by Fouda *et al.* (2014).

The shift in the Tafel slopes of both the cathodic reaction (βc) and anodic reaction (βa) as shown in Figure 4 in the presence and absence of the extract suggest that the inhibitor affects both the cathodic and anodic reactions. This also suggests that *Moringa Oleifera* leaf extract is a mixed type of inhibitor. It can also be observed from Figure 4 that as the concentration of the extract increases, there appears to be a shift towards more negative potential indicating that the *Moringa Oleifera* acts as a good corrosion inhibitor.

It can be observed that as the corrosion current density (I_{corr}) decreases, the inhibition efficiency (IE)% increases as the concentration of the extract is increased. This suggests that the extract retards the reactions at both the cathodic and the anodic sites as a result of coverage of these sites by the molecules of the extract as reported by El-Shafei *et al*. (2004).

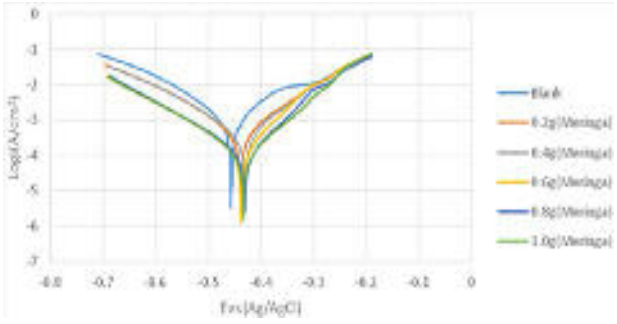

Figure 4. Polarization curves of reinforced steel bar in the presence and absence of different concentration of *Moringa Oleifera* leaf extract

Table 5. Corrosion parameters of the test sample in 2 M HCl in the presence and absence a *Moringa Oleifera* leaf extract

Concentration (g/l)	$-E_{corr}$ (mVvs SCE)	I_{corr} ($mAcm^{-2}$)	Tafel Slope		Rp (Ω)	Θ	IE%
			βa ($mVdec^{-1}$)	βc ($mVdec^{-1}$)			
Blank	458.06	617.53	70.375	72.329	25.085	0.000	---
0.200	438.9	442.52	123.47	99.994	54.223	0.283	28.30
0.400	430.28	413.72	137.63	91.053	57.524	0.330	33.00
0.600	436.60	147.81	121.34	74.798	135.96	0.761	76.06
0.800	431.71	134.17	121.65	87.757	165.02	0.783	78.27
1.000	434.94	113.73	104.44	89.484	184.03	0.816	81.58

The shift in βc and βa values as shown in Table 5 indicates that adsorption of *Moringa Oleifera* leaf extract modifies the mechanism of anodic dissolution and the cathodic hydrogen evolution, this reveals that the inhibition mechanism occurred by simply blocking the available cathodic and anodic sites of the metal surface according to Abdel-Gaber *et al*. (2009).

4. Conclusions

Based on this investigation into the inhibition of the corrosion of reinforced steel bar in hydrochloric acid solution by the leaf extract of *Moringa oleifera* using gravimetric, gasometric and potentiodynamic polarization techniques, the following conclusions can be drawn:

1) The corrosion rate of the steel bar in HCL solution was found to decrease with increasing concentration of the leaf extract of *Moringa Oleifera*.
2) The inhibition efficiency of the leaf extract of *Moringa Oleifera* is dependent on the concentration of the extract, and it increased with increasing concentration of the extract in the acidic medium.
3) As the concentration of the extract increased, the cathodic evolution of hydrogen gas decreased and the least evolution was recorded at the highest concentration.
4) Tafel polarization results showed that the extract acted as a mixed type inhibitor via a simple adsorption of the phytochemicals present in the extract on the mild steel surface in HCl solution.
5) The leaf extract of *Moringa Oleifera* could serve as an effective inhibitor of corrosion of mild steel in hydrochloric acid solution.

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Design of a Special-Effects Wrist-Mounted Flamethrower

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Abstract: *This paper presents the design of a special-effects wrist-mounted flamethrower. The device facilitates the illusion of the user holding a flame in the palm. It is intended as a cost-effective special effects device to be used in the local entertainment industry. This paper covers the main issues that were considered during the development of the flamethrower from inception to the development of the final design concept. With initial tests of the prototype, the potential utility and usability of the device are demonstrated. The potential of the flamethrower as an enabling tool in the Special Effects sector will also be discussed.*

Keywords: *Product design, special-effects, flame thrower, entertainment*

1. Introduction

Computer animation of natural phenomena often poses great challenges for visual effects teams. It is often very difficult to realistically recreate the fluid-like motions of water, wind and, in particular, fire. Fire is one of the elements that is most used in the entertainment industry, and while there have been significant advances in computational simulation, the visual reproduction of the elements has yet to be captured in a realistic form. Additionally, the cost of creating these effects can be very expensive. Given this, filmmakers sometimes opt to have their special effects teams build devices that actually generate fire from controlled explosions and pyrotechnics. This paper shares the design of a flamethrower that can be worn and be triggered with the press of a button.

2. Background

Fire effects are some of the most desirable effects in modern films. However they often pose a challenge: filmmakers and visual effects teams still have difficulty in producing realistic looking animation effects. Nguyen et al. (2003) state that the complexity of the motion exhibited by natural phenomena defies the ability of animators to produce realistic animations by hand. In the era where unrealistic visual effects are being harshly reviewed by the audience and critics alike, there is need for a realistic and safe alternative.

The aim of this project was to design, build and test a wrist mounted flamethrower for use in the entertainment industry. It is intended to add to the special effects industry by creating a flamethrower that is capable of being mounted in such a way that the flamethrower can be worn close to the body and be triggered with the press of a button.

To pursue our objective, it was imperative to examine different types of flamethrowers to get a holistic view of the existing mechanisms and how these could be successfully adapted for use in the special effects industry. The majority of the flamethrower designs outlined are the classic models that are often used in the military or for agricultural purposes. It is extremely difficult to obtain information on flamethrowers that are used for special effects purposes in movies as the creators most often do not make designs available to the general public. One such example is Filmmaker Evan Glodell who built three flamethrowers for his film *Bellflower* (2011), one of which was a regular special effects flamethrower while the other two were fuel-injected exhaust flamethrowers adapted and attached to the back of a muscle car.

Gartrell (1965) describes the ideal portable flamethrower as a weapon that is light, compact, requires little training to operate, has a range of 100 meters or more, and has self-contained pressurisation. Benson (1990, 24-26) describes a simple flamethrower that can be built with everyday materials for a cost of less than 1,000 USD. This includes:

1) A pump to propel the petroleum or other fuel out of the nozzle.
2) An engine, pressure tank or similar to power the pump.
3) A spray nozzle or spray gun to propel and disperse the fuel over a target and away from the body.

4) A lighting mechanism to set alight the fuel as it leaves the spray nozzle.
5) High pressure hoses to circulate the fuel from the storage tank to the pump and then to the spray nozzle.
6) A pressure valve to relieve pressures within the recirculation system. This involves returning the unused fuel to the storage tank.
7) The fuel storage tank.
8) A clutch or engine/pump coupling. This is used as a safety mechanism to engage the clutch only when the spray nozzle trigger is pulled.

A portable flamethrower, developed by Graham (1947) boasts of an improved gas ignition system and a safety trigger that controls the ignition. Graham (1947) decomposes his flamethrower into two main sections: the fuel unit (comprised of the pressure system, part of the fuel system and the carrying pack) and the flame gun (which is comprised of the rest of the fuel system, the electrical ignition system and the ignition gas system).

The operation of this flamethrower starts by opening one of the valves to allow pressured gas from a cylinder to pass through the pressure diffuser to the fuel tanks. From there a second valve is then opened (this is known as the fuel discharge valve) which propels the opening of a third valve. This third valve leads to the emission of the ignition gas from the ignition gas cylinder to the ignition trigger valve that is controlled by a push button. The flame gun is then gripped and the fuel discharge lever is disengaged by sliding the locking lever into a position where the catch disengages and the generation of sparks begins. The operation trigger valve is then released to permit flow of the ignition gas into the pilot vent, where the pilot gas is ignited followed by the ignition of the combustible mixture in the gas burner. Release of the lever then results in the termination of the flame by stopping the flow of the gas.

This flamethrower boasts of improved performance due to the introduction of the pressure diffuser system. The nozzle design is critical as it improves the distance achieved by the flamethrower. Finally, the use of the electrical ignition system is vital as it improves the safety and the reliability of the system. Figure 1 shows the two main parts described for the first section comprised of the fuel unit and the second section with the flame gun. Figure 2 shows a detailed design drawing of the ignition gas cylinder inclusive of the sparking generator housing.

Hayner and Loew (1949) developed the fluid projector to produce a flamethrower that was lightweight and easier to use in tactical situations, where it would be impractical and even cumbersome to use a traditional flamethrower that would be carried on one's back. The fluid projector works on the principle of pressurising a gas within the barrel of the system, thus forcing the fluid out of the container. The pressurised system can use either a solid material to manually force the liquid out or a highly compressed gas or propellant that forces the liquid out. The fluid projector may be operated automatically with the use of a remote or an automatic delay device. This then leads to the ignition of the incendiary agent. Figure 3 shows the main sections of the Fluid Projector developed by Hayner and Loew.

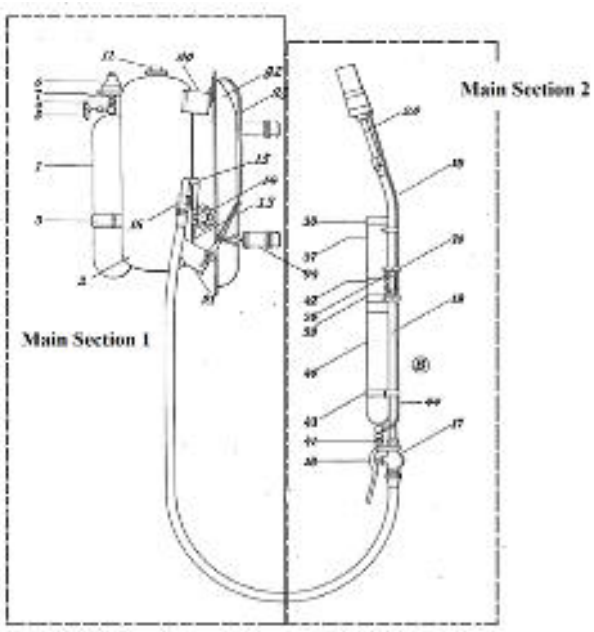

Figure 1. Two Main Sections of the Flamethrower
Source: Adapted from Graham (1947)

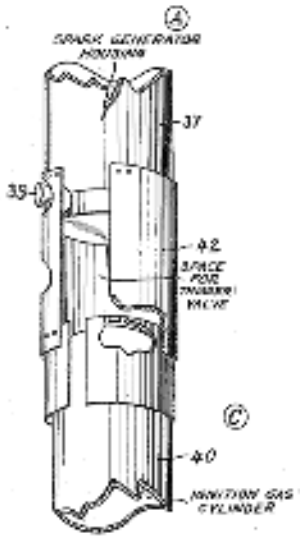

Figure 2. Sparking Generator Housing and the Ignition Gas Cylinder. Source: Adapted from Graham (1947)

Figure 4 shows the flamethrower created by Benson (1990). The system works by first setting up the pump and engine in order to start the circulation system at the storage tank. The pump, engine and storage tank are all double connected using high pressure hoses. As the fuel

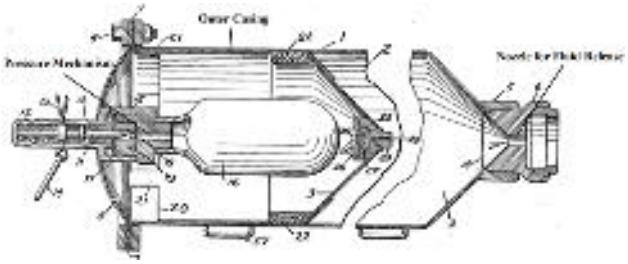

Figure 3. Main Parts of the Fluid Projector: The Pressure Mechanism, Outer Casing and Nozzle. Adapted from Hayner and Loew (1949)

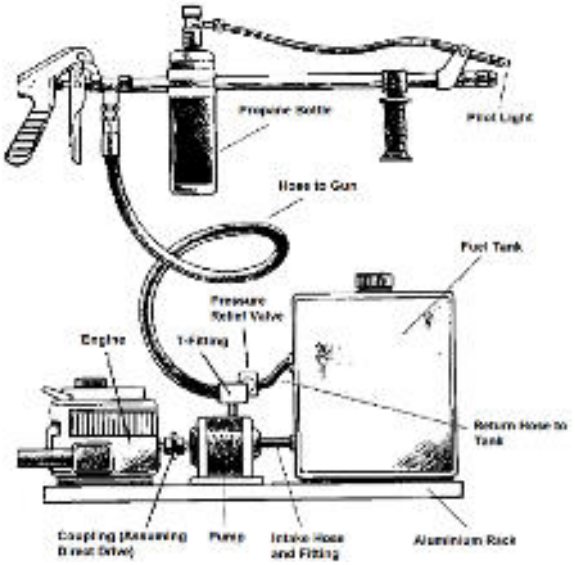

Figure 4. Design of a typical Flamethrower
Source: Adapted from Benson (1990, 26)

is pumped along the system, the trigger is then pulled in order to disperse the fuel. As this is engaged, the lighting mechanism is triggered thus igniting the fuel leaving the spray nozzle. When the trigger is released, the lighting mechanism is disengaged and the pump sends the excess fuel through a pressure valve for depressurisation and then back into the storage tank. The notable features of this design are a separate propane bottle which is used for the lighting and an aluminium rack at the bottom for bolting on the pump, engine and storage tank. The entire system of pump, engine and storage tank can be configured in such a way that it can be either carried on the back or left on the ground depending on how large a flamethrower is needed.

One of the most important aspects of this project was the attention to safety due to potential risk. The safety considerations have been divided into two main categories: 1) The materials and design against fire and 2) safety precautions for flammable or potentially explosive materials. One of the main design concerns is the fuel storage tank. Cooke et al. (1997) extensively discuss the consequences of a vessel containing pressurised liquid gasses being consumed by fire.

Cooke et al. (1997) conducted four liquid propane jet fire impingement trials. There was tank failure when the tanks were unprotected. Jet fire, as defined by the Health and Safety Executive (HSE), "is a turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular direction or directions". This is useful information as propane is often used in modern flamethrowers especially of smaller scaled design. In Cooke et al.'s testing, a standard two tonne tank was consumed by fire and failed within 5 minutes of the jet fire impingement with pressures ranging from 16.5 to 24.4 bar/g and temperatures ranging from 704^{o}C to 870^{o}C. There was longitudinal splitting of the tank, leading to fireballs (the rapid release of the contents after the tank splits) and noise. The test also examined the use of passive fire protection (PFP) materials. PFP materials prevent or slow the spread of fire through protective coating. The two materials tested were a cementitious coating and epoxy intumescent coating with the cementitious coating being the superior material for containing the effects of jet fire impingement.

While the Occupational Safety and Health Administration Act (OSHA 2004) does not expressly provide guidelines for the production and handling of a potentially flammable device, there are general safety guidelines that should be applied when dealing with anything potentially flammable. This is detailed in part 5 section 29 of the act: "In every industrial establishment there shall be provided, maintained and kept readily available for use appropriate fire equipment approved by the fire authority for fighting fire and the occupier shall ensure that a sufficient number of persons trained in using such equipment are available during the working hours and a record of the number of persons trained and the frequency of lectures and fire drills shall be kept and presented on demand for inspection by the fire authority". Therefore when handling the testing of the device all fire safety precautions should be taken into consideration inclusive of both personal protective equipment and fire safety procedures.

Standard safety procedures include the prompt extinguishing of a fire by removing either the fuel source (disconnecting the fuel valve) or the exclusion of oxygen by the use of a blanketing agent such as foam, carbon dioxide, dry chemical or vaporizing liquids. Guidelines for handling of flammable liquids and open flames and sparks include:

1) Using less flammable liquids when possible
2) Storing flammable liquids in closed containers
3) Limiting the amount of flammable liquid in the work area to only the amount that is required at a given time
4) Providing safe disposal of flammable waste

5) Prohibiting smoking, open flames or spark producing devices or equipment in the vicinity of flammable liquids
6) Providing adequate ventilation for all operations involving the use or storage of flammable liquids
7) Encouraging housekeeping to prevent the accumulation of fuels and combustibles in the vicinity of open flames
8) Providing fire extinguishers where open flames are unavoidable
9) Providing adequate clearance between combustibles and open flame
10) Using certified equipment - Personal Protective Equipment inclusive of fire resistant clothing, eye and face protection and safety shoes)

These safety guidelines informed the building, testing, and use of this device.

3. Design Process and Final Design

The design process was customised for the specific problem being considered (Otto and Wood, 2000, Clarkson and Ekert, 2005, Eppinger and Ulrich, 2007). After identification of the need and setting design requirements, an extensive conceptual design process was executed to generate many design alternatives. These alternatives were evaluated and a final conceptual design was produced. A functional prototype was constructed, and various tests were carried out to ensure the device functions as intended. In addition, various safety tests were carried out based on safety guidelines for such equipment.

Given that the success of the flamethrower depends on its usability and safety (Rubin and Chisnell, 2008), these aspects were the focus of user testing in order to demonstrate that the design will work as intended and would be of value to potential users (Otto and Wood, 2000, Eppinger and Ulrich, 2007). The testing methodology and results are presented in the user testing section of the paper. This combination of both functional and user testing provided comprehensive evidence that the new flamethrower design can be a viable competitor in a largely untapped local market.

3.1 Flamethrower Design

The device developed was named The Prometheus after the figure in Greek Mythology best known for his theft of fire for the benefit of mankind. Figure 5 shows detailed drawings of the final concept of the Prometheus. Like many conventional flamethrowers the Prometheus consists of three major working systems. These are: 1) the storage area and propellant system, 2) the spraying mechanism to distribute the fuel and 3) the lighting mechanism. Figure 6 provides a closer look at the Flame Pack. This is used as the storage area for pressurised butane. Figure 7 shows the flame glove system inclusive of the piezoelectric spark generator (the lighting mechanism) and the mounted nozzle (the distribution system).

In order to use the Prometheus, after strapping the system onto the user, the butane tanks are loaded into the flame pack housing and the cover is used to depress the top of the canister before locking it into that position. Two valves located along the tubing are then opened to allow the flow of gas out of the nozzle that is mounted onto the palm of the glove. The piezoelectric spark generator is then used to ignite the gas flowing out of the nozzle thus producing the flame stream. There are then the methods of disengaging the system; these are shown in Figure 8. This is further elaborated on in Section 4.2.1.

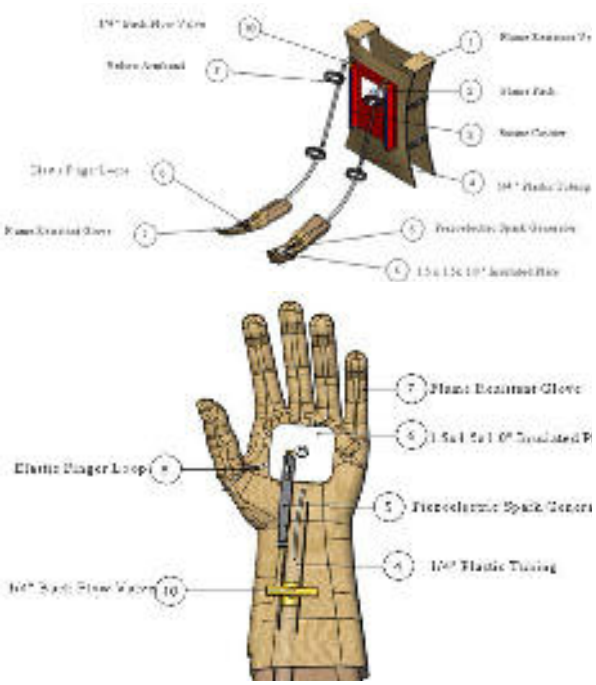

Figure 5. Isometric View (top) and the Flame Glove Control (bottom) for Final Concept

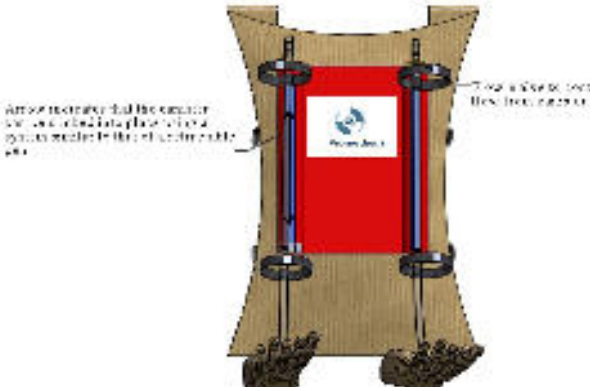

Figure 6. Operation of the System

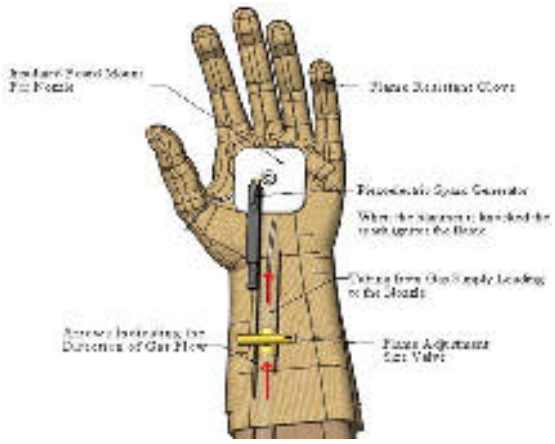

Figure 7. The Flame Glove System Major Components and Operation

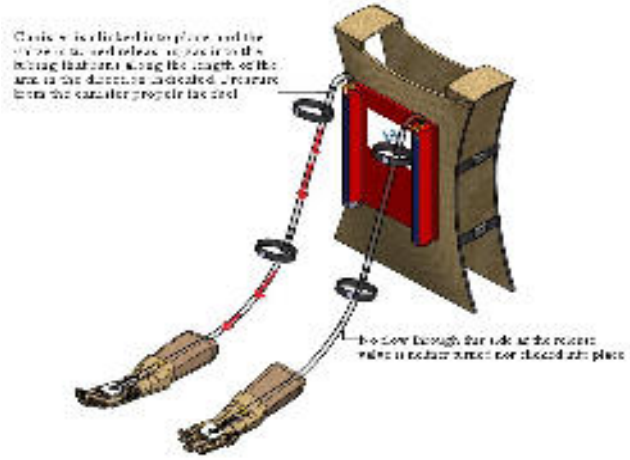

Figure 8. Operation of the Gas Flow System

3.2 Sub-Assemblies within the Prometheus

3.2.1 The Cap for the Canister Holster

The cap for the canister holster doubles as a safety mechanism as well as a method for depressing the top of the butane canister. Figure 9A shows the exploded view of all the components that comprise the canister cap. The canister cap has spring-loaded triggers that when compressed can fit inside of the cap as shown in Figure 9B. This allows the cap to slide along the inside of the canister holster before locking into place and depressing the butane tank top.

When the fuel supply is to be stopped, the triggers are pressed and the spring on the top of the cap cover is released and pushes the cap upward. Figure 10A and 10B are section views of the cap exposing the mechanism working on the inside of the cap.

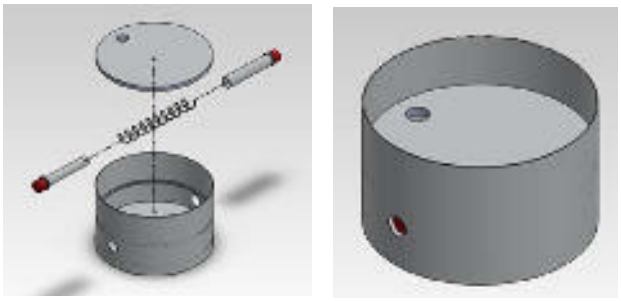

Figure 9. A) Exploded View of Canister Cap (left) B) Collapsed View of the Canister Cap (right)

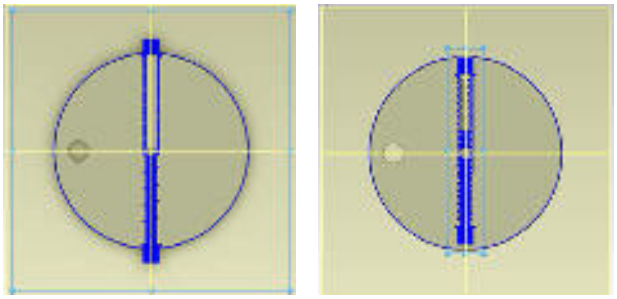

Figure 10. A) Rest State of the Canister Holster Cap (left) B) Canister Cap when Triggers are compressed (right)

3.2.2 Canister Holster Triggering Mechanism on Flame Pack

The flame pack requires safety precautions as this is where the top of the butane canister is depressed thus releasing the gas in the first place. It is therefore the first point for safety mechanisms. It is imperative that the design not only caters for depressing the button at the top, but also for quickly releasing to stop the flow of gas. This is achieved with the use of the specially designed cap for the canister holster. Figure 11 shows the collapsed view of the flame pack as well as the exploded view showing all the components that comprise the flame pack triggering mechanism. Figure 12 shows a cross sectional view of the flame pack, revealing the workings of the flame pack in more detail.

Figure 11. The Major Sub-Components of the Flame Pack in both the Collapsed and Exploded States

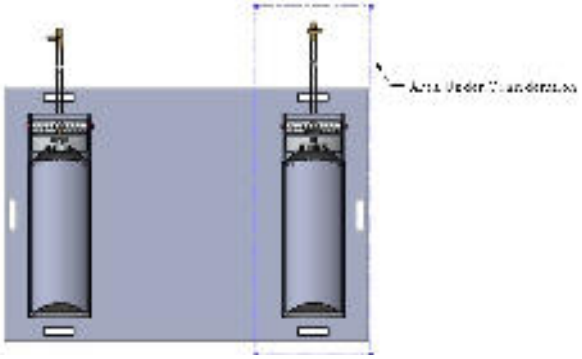

Figure 12. Cross Sectional View of the Flame Pack

When the cap is disengaged, the cap triggers are on top of the canister and the spring is uncompressed (the cap cannot go any higher than the locking collar that is indicated). When it is engaged, the bottom of the cap presses down on both the spring and the trigger of the canister thus allowing the gas to flow into the tubes of the system. This can be seen in the engaged state. Figure 13 shows the inner workings of the flame canister triggering mechanism.

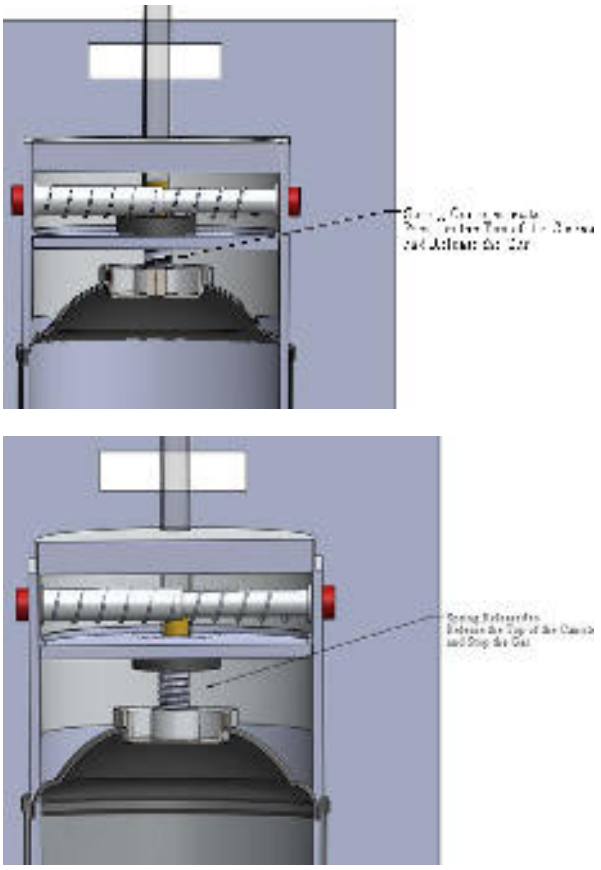

Figure 13. The Inner Workings of the Flame Canister Triggering Mechanism in the Disengaged State and the Engaged State

3.2.3 The Flame Glove Controls

Figure 14 shows the controls of the flame glove. The configuration is simple: it is the nozzle mounted onto a 1.50'' x 1.50''x 0.016'' plastic plate. The piezoelectric spark generator is connected onto the top of the plastic board so that the sparking wires sit just above the top of the nozzle. When the fuel flows through the top of the nozzle, the piezoelectric generator is knocked, creating a spark that ignites the fuel. The back flow valve must be turned on to allow the gas to flow through the system and out of the top of the nozzle. When the valve is turned off, the flow of gas stops and thus the flame stream will stop.

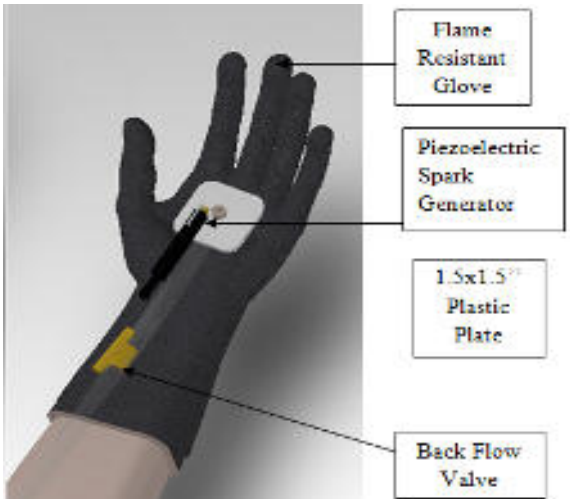

Figure 14. The Flame Glove

3.2.4 Material Selection

The maximum pressure inside the tubing was assumed to be a worst-case pressure of the canister containing the fluid, which was 28 psi. The maximum working pressure of the vinyl tubing selected was 55 psi (The Home Depot, 2015). Therefore the tubing size was safe for this application.

A 26 gauge sheet of aluminium was used to construct the flame pack itself. This material was chosen for its flexibility and lightweight properties. Aluminium is the best material for the flame pack as it allows for the device to be light enough to carry while still being strong enough to support the butane canisters. The flame pack contributes to the bulk weight of the device. Brass release turn valves were used as the main method for releasing or stopping gas flow through the system, in addition to being one of the safety features of the device. This allows the user to easily control gas flow by simply turning the valve on and off like a tap. These were selected as the preferred fixtures as they are most commonly used when dealing with gases which must be cut-off without leaking.

4. Experimental Testing of Prototype

4.1 Safety Testing

4.1.1 Pre-Operation Phase

Due to the nature of the project and its use of highly flammable materials, it was imperative that all precautions necessary be taken to ensure that no physical harm may come to people either testing the device or a casual observer. Therefore several safety experiments were conducted before testing with the butane and spark generator. This ensured the structural and design integrity of the device. Liquid Penetrant Dye Testing and Visual Inspection were conducted.

4.1.2 System Connection and Leak Testing

The System Connection and Leak Testing experiment is a non-destructive testing method, testing for leaks during the operation of the device, while submerged in a tank of water. The presence of air bubbles is noted. Method of testing involved the following steps:

1) The system is set-up for use with the butane canisters replaced by compressed air canisters.
2) The system, shown in the Figure 15, is placed in a small tank filled with water. These are the main areas that must be airtight and thus the essential areas to be tested.
3) While submerged, the hand controls are engaged (it should be noted that the piezoelectric spark generator is not present at this point) and the system is allowed to run as normal.
4) The system is run for a period of 3 minutes with observations made at every 30 seconds.
5) After the 3 minute period, the system is disengaged and removed from the tank.

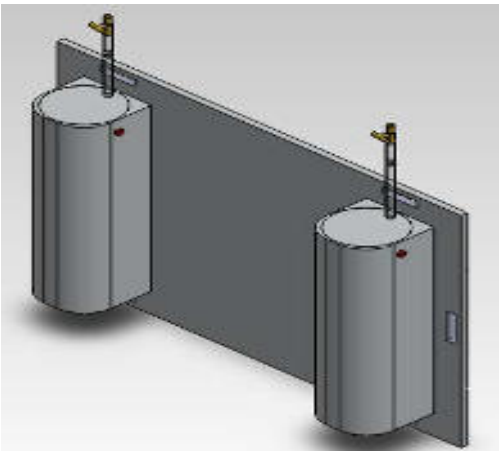

Figure 15. System undergoing the System Connection and Leak Test

Although this test is a good one for checking for leaks there are a few limitations. Though the presence of the air bubbles will indicate the general location of the defect, it is difficult to locate exactly the defect. Additionally it may be difficult to pinpoint the exact location if the air bubbles obscure the tubes from view. These limitations were compensated for, however, by the use of the multiple testing methods such as Visual Inspection and Liquid Penetrant Dye Testing.

4.2 Operational Testing

4.2.1 Safety Mechanism Test

The safety mechanism test is a simple way of checking whether the valves and the trigger can shut off the system independently. The system is engaged and is disengaged using the various mechanisms along the system. The three methods of shutting off the system are:

1) Shut off the wrist-valve
2) Shut off the valve above the flame pack
3) Disengage the canister by releasing the housing trigger.

If the system can be disengaged by any one of the methods, it is awarded a pass and if it requires more than one method to disengage the system is awarded a fail. This is done to ensure that at least 3 safety features are available at all times and are able to work independently to shut off the system.

4.2.2 Flame Height Test

The flame height test is a simple test to determine the highest distance the flame can attain when the canister is fully depressed and all the valves are opened fully. This is accomplished by gradating a board and placing it in the background and filming the tests. This is a crude method used to get the approximate maximum height (a high speed camera is the preferred method for taking this reading), but it gives a fair enough approximation to determine if the objective was achieved. Figure 16 shows an image of the Flame Height Test with a maximum flame height of 3 feet.

Figure 16. Flame Height Test

4.2.3 Sound Test

The sound test is a simple test used during operation to determine whether or not the system is leaking. This is achieved by listening to the system while it is engaged and determining if there is a hissing sound, indicating that there may be gas leaks. If this is the case, the system is to be disengaged immediately and either the soap bubble test is conducted or the pre-operation testing phase is repeated. This is the most common test used to determine the leaks in the system.

4.2.4 Soap Bubble Test

The soap bubble test determines the location of a leak if sound testing indicates a possible gas leak. This is done by pasting soapy water along the region where the leak is assumed to be and looking for the formation of the bubbles in the soap. This would indicate the position of the leak.

4.3 User Testing

A short demonstration was held in an open park. This demonstration included eight people involved in the entertainment industry, mainly in film and photography. The demonstration was done to show the functionality of the flamethrower in addition to the visual effects it is able to produce. After several screen tests and still shots (see Figure 17), participants were allowed to try on the device and operate it for themselves. The footage and stills that were obtained from the demonstration were further distributed to another four individuals involved in The University of the West Indies, St. Augustine Film Programme for their review. After the demonstration was completed, questionnaires were distributed and feedback was recorded (Rubin and Chisnell, 2008).

Figure 17. Still from the Prometheus Flamethrower Demonstration

Of the twelve participants involved in the validation study, 8 were female (67%) and 4 were male (33%). In terms of the age distribution, 8 participants were in the 18-25 age group, 2 participants were in the 26-35 age group, and 2 participants were over 56 years of age. Participants were involved in various activities (with some being involved in multiple activities): 8 working in film and television (66.66%), 3 in photography (25%), 2 in theatre (16.67%) and 1 in musical concerts and performance (8.33%). 3 participants use mechanical effects (25%) in their work, 9 participants use digital effects (75%), 6 participants use live action (50%) and 3 participants use matte painting and stills (25%). Table 1 shows their responses to the more general questions with respect to the device.

From the evaluation of the questionnaires all twelve respondents found the device to be safe to use and easy to incorporate into their respective fields of the industry (filmmaking and photography) with a very short set-up time (inclusive of stunt training required for the operation). Additionally seventy-five percent of the users have indicated that the device was ergonomic. After the demonstration eighty-three percent of the users intimated they would consider using the device in their work for the future. The device received positive reviews overall with one respondent stating, “Excellent minimal/compact design approach to a normally bulky and dangerous device. Can be utilised as expected in a multitude of operations in many operating conditions.” and another stating, “It is light, effective and completely autonomous which gives the user complete control. The flame size can be controlled which is a plus as it takes into account all kinds of performances and visual effects”. These free responses are seen documented in their unedited form in Table 2.

5. Discussion

There are many benefits to a wrist-mounted flamethrower, especially in the entertainment industry. At the start of this project, the device has sparked great interest mainly due to the lack of innovation in this area in general, and particularly in the local context of Trinidad and Tobago. The intention is that such a project will hopefully encourage more innovators to see the opportunities for design and innovation in the local environment.

There are many avenues for future development of the flamethrower. Since this prototype achieved its objectives, in terms of usability, safety and ergonomics, further development can be pursued. Areas for improvement include:

1) The development of the hand-control system in order to achieve independent ignition.
2) Further work on the mechanisms for choking the flame and thus turning off the flame through the use of hand independent controls.
3) Development of the flame pack to further reduce the size of the device (although this is directly proportional to the amount of fuel the device can store as well as the maximum flame height that may be achieved).
4) Experimentation with different gases to achieve different flame colours.

Table 1. Results from Questionnaire

Question	Response	
	Yes	**No**
Do you apply the use of Visual Effects or Special Effects in your work?	66.7%(8/12)	33.3%(4/12)
From the Demonstration do you consider the Prometheus Flamethrower safe to use?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is easy to use?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower a Special Effects Device that would be easy to incorporate into your area of the entertainment industry?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is easy to set-up with little time consumption?	100%(12/12)	0%(0/12)
Do you consider the Prometheus Flamethrower as one that is ergonomic? *(n=8 responders for this question as the remaining four would not be able to discern this from video footage and stills alone).*	75%(6/8)	25%(2/8)
Would you consider using the Prometheus Flamethrower in your future projects?	83.3%(10/12)	16.7%(2/12)

Table 2. Responses to free-response questions

Q: In your own words, describe your initial thoughts and feelings with regards to the Prometheus Special Effects Flamethrower Demonstration.	"Operates as desired, safety hazards have been well reduced to within reason. The model is robust and will not require costly approaches when modifying or adjusting." "I would definitely like to use this in my next project!" "Amazing" "It was easy to use and I felt safe and comfortable." "I especially liked that it was very small, simple to setup, manoeuvrable and could be operated by one person. This can potentially lead to a more efficient workflow on the set (saving on crew and time). To be able to achieve that level of efficiency while still being able to deliver realistic special effects will be the driving points behind this tool." "Having tried it myself, I didn't feel unsafe and felt that it was very simple and got the job done."
Q: Overall, what are your final thoughts on the Prometheus Wrist-Mounted Special Effects Flamethrower?	"Excellent minimal/compact design approach to a normally bulky and dangerous device. Can be utilised as expected in a multitude of operations in many operating conditions." "It's perfect for like stage plays and even carnival events. And if there is someone who wants to play the Human Torch or Pyro or any fictional character with flaming powers the Prometheus Wrist-Mounted Flamethrower can do the job." "It is light, effective and completely autonomous which gives the user complete control. The flame size can be controlled which is a plus as it takes into account all kinds of performances and visual effects." "I think it's something that can definitely enhance the local film industry and the quality of productions that are currently being put out. Hopefully this will also spark more innovations for local filmmakers and the film industry." "It is an easy to use, affordable device."

6. Conclusion

The design for a special effects, wrist-mounted flamethrower was presented. From the results obtained both via the simulation study and the practical prototype test, the device can project flames from the palm of the hand in a manner that is safe for the user while at the same time being visually appealing. Further work on the device involves optimisation, rigorous performance testing, and a more extensive user testing study in an actual stage or carnival performance. It is hoped that the device presented in this paper would contribute to the special effects sector of the entertainment industry.

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Aligning Project Quality and Risks into Business Processes: A Review of Challenges and Strategies

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Abstract: *As organisations seek competitive advantage in a dynamic business/operations environment, projects have become the tool for quickly implementing tasks geared towards adapting and transforming the organisation while the management of these projects has become the instrument and means for change and development. It has therefore become essential that projects be aligned to the organisation's strategic objectives and be integrated into the organisation's day-to-day operations and business processes. This paper explores the literature on managing project risks and quality as they relate to business processes. There has been relatively little research on the alignment of project management practices with business processes, incorporating project risks and quality. A literature search of PM processes was conducted using articles abstracted from two databases, Ebscohost and Emerald Insight, spanning the period from 2000 to 2014. The conceptual links between the PM and business processes are discussed, and the attributes of project risks and quality are identified. The paper concludes by advocating a process paradigm for managing project risks and quality in organisations.*

Keywords: *Project management, business processes, strategy, alignment, quality, risks*

1. Introduction

There has been a growing body of research on the application of projects and their role in modern business (Cicmil 2000, 554). A project is a "temporary endeavour undertaken to create a unique product or service in a workplace" (PMI 2013, 3). Managing projects is a source of competitive advantage for many leading global organisations such as Coca-Cola, BMW and Nike (Zdanyte and Neverauskas 2012, 782). Increasingly, managing projects has become "the preferred or dominant business process" and is widely used within the organisation for strategic and complex change (Olsson 2007, 746). Achieving success in projects is vital in the context of competitive advantage (Mishra et al. 2011, 356). Given the increasing use of projects within organisations, projects must not only be aligned with the strategic objectives and goals of the organisation but must be effectively managed consistently with everyday operations.

Other than the customer, the strategic emphasis of organisations today is on the internal and external processes. While in the past 15 years, there has been a considerable body of literature on project management (PM) processes, one challenge has been the alignment of these processes with business operations in organisations. This paper reviews two (2) core processes of PM, and discusses the challenges and strategic issues in managing project risks and quality from the business/organisational context. It attempts to shed light on the link between these PM processes with business processes and determine the attributes of aligning these processes using a generic process paradigm.

2. Literature Search and Review

In order to identify the determinants that impact the alignment of PM processes with business operations in organisations, a search was made of journal articles in the areas of PM and related areas for the period of 2000-2014. Two online databases, Ebscohost and Emerald Insight, were used. These databases host abstracts, full-text journal articles and reference details of articles in a variety of subject areas. These cover major management disciplines from marketing, human resource management, library and information management, training and education, economics, engineering, and quality, to operations management.

The key term "project management" was first used to search the abstracts. The search was narrowed into sub-categories based on the issues pertaining to this study: "project quality management", "project risk management", "project management practices", "project management challenges", and "project management and organisation strategy". These searches yielded hundreds of articles many of which focused on various aspects of

PM practices and associated processes. The first three searches yielded hundreds of articles but only a few were relevant to the study's objectives.

3. Distribution of Article Statistics

3.1 Distribution of Articles from 2000 to 2014

Table 1 shows the distribution of the articles found in the databases searched from the period 2000 to 2014. The initial search, "project management" yielded thousands of articles related to the discipline in a variety of fields including, information technology, construction, health services, and management. The data show that while the growth was not exponential over the period under consideration, there was a significant increase in the research being carried out in PM over the years. However, there was also no significant difference between the two databases with regard to total number of publications. The statistics show that the discipline gained significant ground in the mid-2000s (and particularly, in 2003-2004 for Ebscohost and in 2005 for Emerald Insight) which indicates its growing relevance.

Table 1. Distribution of PM Publications from 2000-2014

Year	Ebscohost	Emerald Insight
2000	70	126
2001	91	143
2002	83	123
2003	182	163
2004	346	147
2005	269	263
2006	288	264
2007	330	272
2008	374	299
2009	323	291
2010	373	319
2011	317	287
2012	293	324
2013	249	311
2014	77	318
Total	**3,665**	**3,650**

3.2 Distribution of Articles by PM and Related Areas

Building on the previous search summarised in Table 1, the follow-up searches focused on identifying PM related articles, more specifically PM challenges, project quality management (QM), project risk management (RM) and PM and organisational strategy. The searches were carried out probing the databases for key words in the abstracts. Table 2 identifies the distribution of articles based on overall searches carried out in these areas. The data suggest that considerable research has been carried out in these areas. The area of PM and quality has the highest number of articles (1,017 for both databases) which may indicate the growing concern for quality projects and/or project quality. This can be an indication of the increasing need to address issues of customer satisfaction at both the organisational and the project level. The high number of articles in the area of PM challenges (a total of 967 articles found in both databases) indicates that despite studies being conducted and the increased use of PM tools, challenges in PM still exist. This also indicates an increasing need to address these challenges. Of particular interest is the low quantity of research in the areas related to PM and organisation strategy.

Table 3 shows the distribution of articles into six (6) categories based on the type of research conducted in these specific areas. Table 4 gives a total of these categories searched within the two databases for PM and related areas. The preferred method for conducting research in PM was found in the area of case studies for Emerald Insight (with a total of 301 articles across various PM areas) and the least preferred was literature reviews (with some 19 papers found). In Ebscohost, the preferred method of research was the literature review for the PM processes (with a total of 293 articles) and theoretical studies for PM challenges (with 200 articles). Case studies were also popular in each area (with 170 articles) and the least popular were empirical studies (with 28 articles). In general, the overall trend in PM research has been leaning towards case studies across various areas.

Moreover, an attempt was made to determine, from the literature, if strategies were being developed to address some of the challenges identified in the field of PM. The data suggest that strategies were indeed being developed to a fairly high degree (with a total of 556 articles across the two databases). Of particular interest was the last search in the area of "PM" and "Organisation Strategy" where very little research has been carried out in this area in comparison to the other areas searched (with a sum of 82 articles found in both databases).

3.3 Distribution of Articles by Journals

Table 5 shows the list of journals in Emerald Insight with articles on PM and related areas along with the number of articles published within each journal. These journals span a wide range of subject areas, including: business management, engineering, knowledge management, quality, information technology, library and information studies, human resources and production and manufacturing. These articles were published in journals ranging from project management, information systems, manufacturing and production, communication, engineering to human resource management. This indicates a wide use and acceptance of PM across many disciplines as well as the versatility of PM in practice.

The journal with the most publications relating to PM issues is the *International Journal of Managing Projects in Business* (with 202 articles). This is an indication of the shift in the use of PM from the traditional areas of focus in construction industry to other businesses and sectors. This is further supported by the increasing

Table 2. Distribution of Articles in PM Related Areas

PM Related Areas	Ebsohost	Emerald Insight	Total
"Project Management" and "Challenges"	386	581	967
"Project Management" and "Quality"	475	542	1,017
"Project Management" and "Risk"	429	388	817
"Project Management" and "Organisation Strategy"	16	159	175

Table 3. Distribution of Articles by Categories

Categories	Ebsohost		Emerald Insight	
	Number of Articles	Percentage (%)	Number of Articles	Percentage
Project Management Challenges				
Case Studies	60	18.3	109	24.1
Literature Reviews	8	2.4	4	1.0
Empirical Studies	7	2.1	68	15.0
Theoretical Studies	200	61.0	52	11.5
Conceptual Studies	10	3.0	38	8.4
Strategy	43	13.1	181	40.0
TOTAL	**328**	**100**	**452**	**100**
Project Quality Management				
Case Studies	44	15.9	110	29.0
Literature Reviews	154	55.8	4	1.1
Empirical Studies	9	3.3	60	15.8
Theoretical Studies	17	6.2	34	9.0
Conceptual Studies	11	4.0	35	9.23
Strategy	41	14.9	136	35.9
TOTAL	**276**	**100**	**379**	**100**
Project Risk Management				
Case Studies	64	22.1	52	19.8
Literature Reviews	139	48.1	10	3.8
Empirical Studies	11	3.9	41	15.6
Theoretical Studies	17	5.9	26	9.9
Conceptual Studies	11	3.9	26	9.9
Strategy	47	16.3	108	41.1
TOTAL	**289**	**100**	**263**	**100**
Project Management and Organisational Strategy				
Case Studies	2	66.7	30	38.0
Literature Reviews	0	0	1	1.3
Empirical Studies	1	33.3	29	36.7
Theoretical Studies	0	0	11	13.9
Conceptual Studies	0	0	8	10.1
TOTAL	**3**	**100**	**79**	**100**

Table 4. Total Number of Article by Categories

Categories	Ebscohost	Emerald Insight	Total:
Case Studies	170	301	**471**
Literature Reviews	301	19	**320**
Empirical Studies	28	198	**226**
Theoretical Studies	234	123	**357**
Conceptual Studies	32	107	**139**
Strategy	131	425	**556**
TOTAL	**896**	**1,173**	**2,069**

number of journals (i.e., 7 journals accounting for 338 articles) in management with PM articles.

These journals are *Business Process Management Journal, Journal of Management History, Management Decision, Human Resource Management International Digest, International Journal of Operations and Production Management, Strategic Direction*, and *International Journal of Productivity and Performance Management*. The widespread report of PM practices and applications implies a growing acceptance of PM in industry. This also suggests that the focus of the PM discipline which was originally designed to manage projects within the construction industry, has been expanding into other industry sectors and organisations.

4. Managing Project Quality, Risks and Challenges

Despite the increased use of PM within industry in the last 15 years, there have been many organisations facing different kinds of challenges on managing their project success and performance.

Table 5. The Distribution of PM Articles in Selected Journals for Period 2000-2014

Name of Journal (Emerald Insight)	Number of Articles	Percentage
International Journal of Managing Projects in Business	202	14.2
Engineering, Construction and Architectural Management	172	12.1
Facilities	97	6.8
Journal of Knowledge Management	86	6.0
Business Process Management Journal	81	5.7
Construction Innovation	78	5.5
Journal of Management History	66	4.6
Industrial Management and Data Systems	65	4.5
International Journal of Quality and Reliability Management	60	4.2
Management Decision	59	4.1
Journal of Enterprise Information Management	55	3.9
Library Management	54	3.8
Management of Environmental Quality: An International Journal	49	3.4
Human Resource Management International Digest	47	3.3
International Journal of Operations and Production Management	45	3.2
Strategic Direction	43	3.0
The TQM Journal	42	2.9
OCLC Systems and Services	42	2.9
Journal of Manufacturing Technology Management	42	2.9
International Journal of Productivity and Performance Management	42	2.9
Total:	**1,427**	**100**

Many of these challenges relate to managing projects in the areas of information technology, team dynamics, customer satisfaction, communication, and quality. Besides, there has been a growing need for aligning PM with the organisation's strategy and performance improvement. An attempt was made to collate the views, from the literature, on managing project quality, risks and performance in organisations. A total of 69 articles were eventually searched from 28 journals based on research methodology—case studies, literature reviews, empirical studies, and theoretical and conceptual studies.

Tables 6 and 7 present the excerpted views and some exemplified approaches and strategies as advocated by researchers and practitioners on managing project quality in organisations, respectively. Tables 8 and 9 show the excerpted views and exemplified approaches/strategies on managing project risks, whereas Tables 10 and 11 summarise the excerpted views and exemplified approaches/strategies on managing challenges associated with PM practices in organisations.

Table 6: Excerpted Views of Managing Project Quality in Organisations

Study	Comparable Views		Alternative Views	
	Author(s)	**Views**	**Author(s)**	**Study/View**
Role of PM in quality and quality management (QM)	van der Water and de Vries (2006)	Organisations define project in areas of quality and QM as a means to improving their competitive advantage	Orwig and Brennan (2000)	By instituting a formal PM methodology and basic PM techniques, organisations are fulfilling the principles of quality
	Hides and Irani (2000)	Projects are used to adopt total quality principles and PM is required for successful programmes of continuous improvement		
QM theories and practices usage	Barad and Raz (2000)	A holistic approach to implementing QM results in improvements to product quality as compared to a more fractional implementation	Hides and Irani (2000)	Implementing total quality tools on a case by case basis enables companies to identify their specific needs and outline their own processes.
			Henderson and McAdam (2000)	Organisations should select an approach to quality that is most suitable to their varying tasks and specific priorities
Criteria to determining successful project performance	Bryde and Robinson (2007)	Organisations with total quality management (TQM) programmes are more customer-focused in their PM practices than organisations with no TQM programme	Toakley and Marosszeky (2003)	Project quality measures consist of other measures such as flexibility, customer satisfaction, and training and responsiveness

Table 7: Approaches and Strategies of Managing Project Quality

Author(s)	Research and Findings	Approaches and Strategies
Cicmil (2000)	Defining the critical factors for project success criteria and the quality aspects within the project	Project management multiple perspective (PMMP) framework
Henderson and McAdam (2000)	A key to managing quality in organisations	Organisational change as a shared vision
Van der Water and de Vries (2006)	Changing company culture through commitment from all levels of management	
Henderson and McAdam (2000)	Designing quality into the organisation by incorporating it into projects	Self-assessment systems
Orwig and Brennan (2000)	Identifying where improvement are needed such that it becomes the foundation of continuous improvement	
Henderson and McAdam (2000)	Quality approaches selected based on the tasks and priorities as outlined by the strategy of the organisational as opposed to standard approaches to QM	Flexible organisations
Hides and Irani. (2000)	Discussing an international standard which integrates both QM and PM	*BSI 1995*
LePrevost and Mazur (2005)	Tool to managing the project resources and priorities as well as prioritising the internal initiatives based on their benefits	Quality function deployment (QFD)
Chao and Ishii (2004)	Tool to clarify project goals and achieving organisational alignment by analysing the organisations requirements and resources	
Bryde and Robinson (2007)	Improving performance through the implementation of TQM with PM in areas such as process management	Total quality management (TQM)
Orwig and Brennan (2000)	Providing assistance in assessment and facilitating continuous improvement on a long term basis	A document or knowledge management strategy
Orwig and Brennan (2000)	Providing the organisation with means to formalise its PM methodology	A project management office
Neale and Letza, (1996)	Enhancing decision making throughout the organisation	Post-audits

Table 8: Excerpted Views of Managing Project Risks in Organisations

Study Issues	Author(s)	Views
Challenges to managing risk in projects	Kutsch and Hall (2009)	The research focused on developing ways to manage risk with few assessing their effectiveness
	Olsson (2007)	Methodologies of RM were focused exclusively on "*single-project management*"
	Shimizu et al. (2012)	Overall business risks must be minimised through systematic risk management
Linking risk management (RM) to organisational factors	Parker and Mobey (2004), Kutsch and Hall (2009), Olsson (2007)	There should be a link between the strategy for RM and organisational behaviour
	Besner and Hobbs (2012)	The use of PM tools and practices such as RM is influenced by both the project context and the organisational context
The way risk and RM is viewed by the organisation and managers	Olsson (2007)	Managers often acknowledge the relevance of RM but fail to apply them in managing projects
	Besner and Hobbs (2012)	A gap exists between the organisations interest expressed in RM and the allocation of resources
	Shimizu et al., (2012	Project managers focus on lower level risks and senior management focus on higher-level risk
	Parker and Mobey (2004)	RM was *ad hoc* because it was reliant on the experience and expertise of the manager and formal risk analysis was seldom used by managers when making decisions
	Cervone (2006)	Project managers often only carry out minor examination of the risk related issues and then add a "*margin of risk.*"
	Kutsch and Hall (2009)	Project managers only focus on certain risk based on "*the perceived ease of information processing*

Table 9: Approaches and Strategies of Managing Project Risks

Author(s)	Research/Findings	Approaches and Strategies
Besner and Hobbs (2012)	Developing new responses for specific contexts for which it was not primarily developed	Flexible approaches
Cervone (2006)	Adapting and changing plans as new information became available, as the cornerstone on which to build continuous risk assessment	
Jafari et al. (2011)	Storing for future use, in planning and during implementing of projects, the knowledge associated with key issues in RM	RM model of knowledge
Patterson and Neailey (2002)	Documenting information and data collected during project for use in future project RM	Risk register database system
Kohlmeyer and Visser (2004)	Measuring project performance (to measure the effectiveness of risk management in projects) and documenting for future comparisons and evaluation	Key performance indicators and documenting
Shimizu et al. (2012)	Responding to the requirement for an integrated and comprehensive strategic approach to managing risks	Enterprise-wide RM

Table 9: Approaches and Strategies of Managing Project Risks (continued)

Author(s)	Research/Findings	Approaches and Strategies
Parker and Mobey (2004)	Managing information technology infrastructural projects and re-engineering projects	Change management techniques
Kohlmeyer and Visser 2004	Developing a single process, comprising of both the project risk process with the project management life cycle process, that distinguishes it from the existing processes	Risk project life cycle

Table 10. Excerpted Views of Managing Challenges Associated with PM Practices

Author(s)	Views	PM Challenges
Hides and Irani(2000)	Commitment by both management and employees as essential to PM success within the organisation	Management commitment and related factors
Harding (2012)	Commitment of essential resources to the project	
Hides and Irani(2000)	Leadership as critical to project success	Leadership and related factors
Pressman (1998)	Project success is about the person leading the team	
Perkins (2006)	Project managers abilities and their inability to apply their knowledge impact negatively on projects and their management within the organisation	
Harding (2012)	Proper support network comprising PM and subject matter experts that the project manager could contact or call upon to give advice	Team dynamics and related factors
Cicmil (2000)	Choosing appropriate personnel and the compatibility of the members selected for the project	
Hides and Irani (2000)	Training of the team members to generating company-wide employee commitment	
Cerpa and Verner (2009)	Factors that could de-motivate team members	
Hides and Irani (2000)	Six human factors that could affect PM practices in an organisation; training employees in skills to which they are best suited enhances their role or level of competency; competence development; and empowering of employees	Human resource and related factors
Hidesand Irani(2000)	Organisational physiological factors such as structures, functions, performance and human behaviour (group and individual)	Organisational and related factors
Yazici (2009)	Organisational culture impact on the project performance and on the organisation	
Ritter (2008)	Organisational structure, and culture and style also influence the project	
Harding (2012)	Effective communication within the organisation could contribute to PM performance and project success.	
Newell (2004)	Sharing the lessons learned from previous projects with future project team members	
Cerpa and Verner (2009)	Learning from failed projects due to post-mortems not carried out on projects as well as ignoring lessons learned from past projects	
Yazici (2009) and Ritter (2008)	Level of maturity that an organisation has with regard to managing projects impacts on the performance of the project and its management	
Pinto and Mantel (1990)	Identifying and understanding the causes for project failure	Project management and related factors
Cicmil (2000)	Reasons for project failure	

Table 11. Approaches and Strategies of Managing PM Challenges in Organisations

Author(s)	Research and Findings	Approaches and Strategies
Gasik (2011)	Identifying knowledge an important resource for PM and as a basic prerequisite for effective PM	Project knowledge management
Hides and Irani (2000)	Ensuring that the lessons learned from new product development projects could be used to inform future project work to improve successive project performance	
Newell (2004)	Capturing the learning that took place during the project by conducting end of project reviews and the information collected stored on a database which is uploaded for easy access for future or current team members	
Jafari et al. (2011)	Protecting the knowledge gained from projects as it could give the organisation an advantage over their competitors and make PM a foundation of competitive advantage	
Zdanyte and Neverauskas (2012)	Sustaining and driving PM strategies	PM maturity models
Mullaly (2006)	Assessing the capabilities of organisations specifically functional capabilities as well as organisational excellence	
Yazici(2009)	Providing a standardised approach to measurement and benchmarking and serving as a road map for strategic improvement	
Hides and Irani. (2000)	Developing a business strategy to reflect the dynamic of competitive advantage	Strategic management
Kenny (2003)	Viewing projects as a means of implementing strategy and PM as a process applied to manage the implementation of strategy	
Aubry et al. (2007)	Using PM as a means of implementing the organisations strategy	
Henderson and McAdam (2000)	Managing and implementing the proposed strategy while allowing that strategy to evolve in response to the changing business and global environment	Balanced scorecard

5. Discussion and Recommendations

5.1 Aligning PM with Business Strategy

According to Mintzberg and Waters (1985), there are two types of strategy. These are: 1) deliberate strategy which is "*realised as intended*" and can be considered the traditional approach to developing strategy within an organisation, and 2) emergent strategy which are "*patterns or consistencies realised despite, or in the absence of intentions*" (Mintzberg and Waters 1985, 257). Srivannaboon and Milosevic (2006, 499) argued that they found instances where PM elements impacted business strategy. This was as a result of information gained during the management of projects used to adapt the business strategy. This was in line with Mintzberg's concept of emergent strategies. Alsudiri (2012, 601) argues for the need to incorporate portfolio management, strategic planning and emergent approach as steps in the alignment process.

Organisations plan and implement innovative business strategies to attain or maintain a competitive advantage (Srivannaboon and Milosevic 2006, 493). They utilise projects to implement their innovative business strategies and this has resulted in PM being considered an important business process. The need to align strategic priorities across the organisational hierarchy – the corporate, business and functional levels – has also become a dominant concern within the literature on strategic management. Of particular concern is the alignment of the functional level (for instance, R&D, marketing, production, and human resources) with the business level strategies. Project management can be considered a functional strategy because it is a building block of organisational strategy similar to functional strategies and as such could be aligned with the business strategy.

While some research has been undertaken in aligning these two areas, none discuss explicitly the relationship between the areas. Research by Srivannaboon and Milosevic (2006, 495), however, sought to explore the interaction between these two areas by what they refer to as the "*nature of the alignment*" and developed a theoretical framework showing the impact of these two areas on each other (i.e., the PM elements on the business strategy and then the business strategy on the PM elements). Their research was based on Porter's generic strategies (i.e., cost leadership, differentiation and best-cost) using a case study methodology to examine eight case studies that covers nine projects in seven organisations.

Alsudiri et al. (2013, 596) argued that business outcomes could be considered another dimension of project success and it can be achieved through the alignment of the PM process and the business strategy. They reported that misalignment between these two areas results in 30 per cent of project failures. As such, their research looked at the misalignment between PM with business strategy. Based on case study methodology using four case studies in the telecommunications industry, they looked at three types of strategy which were based on the corporate, business and functional levels within a typical business. Alsudiri et al. (2013) developed a conceptual framework which aligns PM with the business strategy and looked at the factors that impact the process of the alignment. Several internal factors (such as, communication, leadership competency, involving the project manager in strategy planning and executive management commitment) and external factors (such as, vendors, contractors, government agencies and the change market) were regarded as important elements in their alignment approach for the telecommunications industry. This framework could be extended to include multi-projects based on more than one business strategy.

Moreover, several benefits could be obtained from aligning PM process with business strategy. For instance, this could 1) help organisations focus on the right projects based on the objectives of the business strategy (Srivannaboon and Milosevic, 2006, 493); 2) ensure the successful overall direction of both strategy and project (Alsudiri 2012, 597), that is, every aspect of the organisation's activities would be integrated and move in the same direction based on achieving the organisations goals; and 3) assist the team to implement the organisation's business strategy through the projects in the correct way (Alsudiri 2012, 600).

5.2 Aligning PM with Operations Strategy

The strategy that was utilised by Alsudiri et al. (2013) was based on the organisation's business strategy. It was a top-down approach to strategic development where top management determines the strategy and the objectives over the long-term for the organisation. An alternative is a bottom-up approach to developing emergent and/or operations strategy. The strategy is developed based on the ideas and input from various employees, at any level of the hierarchy depending on the location of the expertise (Lister, 2014; Sting and Loch 2009).

Operations strategy looks at the strategies of managing resources which produce products and services over the long-term. According to Slack et al. (2010), the traditional view of operations strategy is based on several functional strategies and uses the top-down approach. In this approach, overall business strategy determines the direction of the organisation and the functional areas (such as operations, marketing, and finance) interpreting it in their functional strategies. On the other hand, the bottom-up approach of operations strategy suggests that strategic decisions are based on an accumulation of practical experiences (Slack et al., 2010). Ideas are developed based on experiences with customers, suppliers and even the organisation's own processes. This type of strategy is referred to as the emergent strategy because strategic ideas emerge over

time as the organisation starts to understand the realities of their situation. A strategy that could therefore be used to improve PM practice within organisations could be to align PM with the operations strategy of the organisation based on this emergent strategy perspective.

5.3 Integrating PM Processes with the Business Processes

In organisations today, the strategic emphasis is placed on the customer as well as on both internal and external processes. The process view is built on the belief that the functional areas within an organisation need to work together based on a common goal if the organisation is to run more effectively and efficiently (Sandhu and Gunasekaran, 2004, 673-677).

Processes exist in three (3) different forms within the organisation; formal processes (used by management), best practices (used by consultants who learn real processes from workers and sell back to management) and real processes (used by workers who are doing the work experientially and come up with the ideas) and there is no connection between these three processes (van der Merwe 2002, 408). In many organisations, operations are driven by projects, the benefits of aligning or integrating the project processes and the operational processes would be relevant and advantageous. Sandhu and Gunasekaran (2004, 678) stress three (3) basic processes in organisations. These are 1) the strategic process which is the formulation of the organisations strategy; 2) the functional process which is the procedural and operational requirement within the organisation; and 3) the administrative process which is the overall management including the functional processes.

While van der Merwe (2002, 408) argues that the management of business process is different from the management of scientific processes in that there is "no measurement, no control, no maintenance and no incremental improvement". Orwig and Brennan (2000, 351) maintains that the management of processes in an organisational setting is different from the management of processes in a project setting. The management of processes in an organisational setting is an aspect of operations management where processes are repetitive while the management of processes in a project environment, which is a temporary and unique endeavour, is based on the particular requirements of each project (Orwig and Brennan 2000, 351). Also most processes are 'cross-functional' spanning the various functional areas within the organisation, a factor which van der Merwe (2002, 407) argues is similar to projects and their management.

Research carried out by van der Merwe (2002, 408) shows a link between projects and processes, and contends that "the management of business processes and the management of projects are interrelated" and that "the process team can be directly equated with the project team" because they both work across functions. According to van der Merwe (2002), business processes are governed by three rules, namely: 1) they must have a clear purpose (goal); 2) there must be incremental improvement while seeking to reach the goal; and 3) each incremental improvement must be a project involving people. Based on these rules, it is claimed that "processes are governed by a group of projects that bring about incremental improvement."

Orwig and Brennan (2000, 352) sought to integrate QM with PM to improve business performance in organisations. Since projects are the organisation's basic form of operation, PM can be viewed as an ongoing repetitive operation as is the case with business processes such as QM. Their approach is that integration is possible based on selecting common criteria from the disciplines' fundamental principles, methodologies and techniques. Three (3) principles are considered crucial to business success, namely 1) customer focus, 2) continuous improvement, and 3) teamwork. Orwig and Brennan (2000) argue that these principles are critical to projects as key project deliverables include, for instance, customer satisfaction, team collaborations and continuous improvement.

Moreover, continuous improvement in a PM setting can be facilitated through project debriefings, assessment of project performance against planned results, and the establishment of a Project Management Office (PMO) to serve as a project archive for future project planning (Orwig and Brennan, 2000). While Project Management Institute (PMI) acknowledges that project QM must address both the management of the project and the product of the project, the quality tools and techniques identified in the Project Management Body of Knowledge (PMBOK) are explicitly described in terms of their application to project deliverables and not the management process (Orwig and Brennan 2000, 354). It is therefore possible to integrate the PM processes with the operational processes.

6. A Generic PM Process Model

In responding to the changing nature of projects, the discipline of PM now embraces several of the underlying concepts and assumptions from the various related fields. Based on a project-based strategic management process advocated by Cicmil (2000 p. 558), a generic process model was developed. This model attempts to incorporate various strategies/approaches identified in the literature. Figure 1 is a diagrammatic representation of this generic process model. It shows on-going feedback at each level to facilitate both continuous improvement and organisational learning.

This generic model comprises a series of processes and steps. Figure 2 depicts the process flow chart for this generic model. The first step would begin with the process of developing an organisational strategy. Once this has been agreed upon, the next step would be the

process of operationalising strategies into projects. These projects would be managed through the development of a PM strategy. It is at this PM strategy level that PM is aligned to the organisational/business strategy. At the PM strategy level, it is important to ensure that the projects identified would be aligned to the organisational strategy, mission, vision and strategic direction. At this level, senior management leadership would be reinforced, and performance criteria would be identified to measure the success of the project against the organisation's strategic objectives and goals.

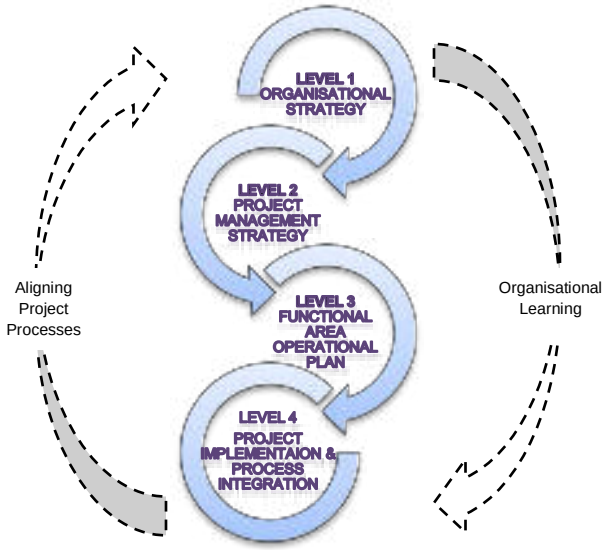

Figure 1: A Generic Process Model of Project-based Strategic Management

Figure 2: A Process Flow Chart for Aligning PM with Business Strategy and Operations

Within this PM strategy, other functional areas (e.g., R&D, marketing, and production) for each project would be identified. It is at this point that a project team should be created. This team should comprise members from each functional area within the organisation that was identified as being required for the project. The team should be trained in PM practices as well as in team dynamics and should be chosen based on their individual skills as deemed necessary for the project and on their compatibility with the rest of the team members. Within each functional area, the operation strategy should seek to include the project resource requirements for the processes that would be impacted. It is at this level of the operation strategy within each functional area that the PM processes are aligned with the operational strategy/business processes and it is at the process management level that the PM processes could be integrated with the operational/business processes.

At the process level, a strategy for integrating the PM processes and the operational/business processes in such areas as managing operations/project quality and risks could be developed and implemented. The integration would be based on the QM and RM principles that are considered crucial to the success of the operations strategy, the business, and the project itself. This integration strategy could be developed as an overall strategy or a case-by-case strategy specific to the varying needs of the project or the changing environment.

Moreover, effective communication could be achieved through formal meetings held on a regular basis or through update reports sent to members of the team. A feedback mechanism should be put in place to enable continuous improvement and facilitate organisational learning. Through the documentation and management of knowledge gained throughout the project, organisational learning could be reinforced. This feedback would be based on the bottom-up approach, where lessons in implementing at the bottom are fed back up through the model to the relevant decision makers. This guarantees that the strategy formulation is based on input from those who actually carry-out the projects. This would ensure organisational-wide acceptance of the strategy. Any refinement would be based on the input from the persons actually implementing the project or working directly with the process.

7. Conclusion

Despite the myriad of information regarding PM issues within the published literature, there are still many challenges related to the successful PM implementation in organisations. Various approaches and strategies advocated in the literature address challenges associated with PM practices in organisations. Analysis of these findings suggests that integrating PM processes with the business processes is worth exploring in relation to incorporating PM practices and managing project risk and quality into the business/organisational context.

This paper explores a variety of determinants that would affect the management of the PM processes, and identifies the common factors affecting PM processes in organisations. It also advocates the need to 1) integrate the PM processes with business processes and 2) incorporate viable approaches, for facilitating improvement in project and organisational performance.

One approach was to align PM with the business strategy of the organisation. Through this alignment, the right projects could be chosen to facilitate the particular needs of the organisation as outlined in its strategic plan. This would ensure the commitments from managers across various departments and ensure that they chose projects based on the objectives of the organisation. Moreover, by aligning PM with the operations strategy, the experience and inputs from various levels of employees could be incorporated into the organisation's strategy at the operations level.

Aligning PM to the strategic focus would enable organisations to remain relevant and attain competitive advantage. There is a need to expand the project-based strategic management process by aligning it to the organisation's strategic objectives and goals. This paper also proposes a generic project model that incorporates the project process in aligning PM with business strategy and operations in organisations. Further research would lead to the identification of other fundamental principles on which to integrate the PM and business processes, thus improving performance of projects and business operations.

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Communicating in the Workplace: Self-Reports by New UWI Electrical and Computer Engineering Graduates

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Abstract: *There is no existing research on communication practices in engineering workplaces in Trinidad and Tobago. The study maps the broad terrain of communicating in local industry by reporting quantitative data gathered by means of a questionnaire. Fifty-eight new hires in the field of Electrical and Computer Engineering were polled on the time spent communicating; common written genres produced; and the importance of communication to job performance and career advancement. The study revealed that in an eight-ten hour workday, new hires spend upward of two hours per day writing and three hours in formal oral communication scenarios. New hires can also expect that with and without substantial support they will be required to produce an array of communication artefacts. Respondents rated proficiency in writing, speaking and teaming as critical to career advancement.*

Keywords: *Workplace Communication; the Engineering Workplace; Electrical and Computer Engineering*

1. Introduction

In chronicling the rise of technical writing instruction, Connors (2004, p4), cited a "series of condemnatory articles about the illiteracy of engineering-school graduates" which began appearing in 1903. More than a century later, those complaints persist. The Institution of Engineering and Technology (IET) (2008, p182) found that while UK employers were "not critical of the engineering knowledge and understanding graduates bring to their first job", they were unhappy about "the lack of key skills that graduates possess": Deficiencies identified were weak interpersonal, teaming, and writing skills. Commenting on Trinidad and Tobago industry, Shrivastava (2004) lamented that there is an "insufficient deepening and broadening of competence", particularly in technical writing and communication skills.

Engineering schools across the globe are responding to this competence gap in a variety of ways (Reave 2004). Russel (2001, p261) has argued that regardless of the curriculum provisions addressing this deficit, it is necessary to understand "where students are headed", so that we may assess "the ways schooling helps [or hinders] them getting there". In this respect, counterparts elsewhere, and in the United States in particular, have a distinct advantage: their curricula can draw on a number of workplace studies that describe the communication contexts in which their graduates will work. This study addresses that research gap by describing, in broad quantitative terms, the communication demands made of novice engineers working in Trinidad and Tobago. Based on these findings, the paper makes recommendations for communication curricula in local undergraduate engineering programmes.

The study was limited to an examination of the work contexts of new graduates, employed in the field of Electrical and Computer Engineering. Recent graduates were chosen as it is likely that their adjustment to the workplace would bring into relief the unfamiliar demands that are being made of them. More significantly though, the focus on entry-level engineers was necessary as the paper makes recommendations for curriculum provisioning: The focus was therefore on the immediate demands that are being made of recent hires—the competences needed to gain employment, and to function effectively at the start of their careers.

The current study, which is a pilot of a larger study, focuses on recent Electrical and Computer Engineering graduates as a matter of convenience, since there was immediate access to this group of alumni from The University of the West Indies, St. Augustine Campus (UWI), Trinidad and Tobago.

2. Literature Review

Engineering education reform is achieved through interventions at three levels: accreditation, programmatic, and course. Relevant to Electrical and Computer Engineering graduates of the UWI, is the UK Standard for Professional Engineering Competence (UK-SPEC 2008), which specifies inter alia that graduates must have the ability to communicate; work with others; use ICTs; and retrieve information. Writing about ABET's programmatic criteria, Passow (2012) found the criteria unhelpful, as they do not indicate the relative importance of the various skills: This in turn impacts curriculum development as the depth of treatment to be accorded to each skill is unstated.

Similarly, UK-Spec provides no such clarification. By examining communication practices in local industry, engineering programmes can focus on what is most useful to our graduates.

Many technical communication specialists (Brinkman and van der Geest 2003; Dannels et al 2003) have made recommendations targeting the programmatic level, where instruction and assessment are threaded throughout the degree, as may be found in Communication across the Curriculum (CXC) approaches. Dannels et al (2003) reported a growing recognition of the "theoretical and pragmatic" value of CXC models to teaching communication. Reave (2004, p452) has claimed that "the most comprehensive preparation" is a CXC approach that offers "concentrated instruction, continual practice, situated learning and individualised feedback".

However, as Craig et al (2008) observed programmatic interventions do not take account of disciplinary idiosyncrasies. They argued that meaningful instruction and assessment must be contextualised by authentic workplace practices.

This study can be regarded as informing all levels of engineering education reform by:

- Localising accreditation specifications, by suggesting which skill-sets gain salience in local industry: The capacity to work with others may perhaps be more important than the ability to retrieve information;
- Advocating for CXC provisioning: The data presented later in the paper indicate that the ability to communicate well is indispensable in the engineering workplace and thus programmes must systematically teach and assess communication skills.
- Identifying focal points for communication courses and or communication-intensive interventions: The data presented identify, for example, target writing genres.

"Workplace communication" and "non-academic communication" are used synonymously (Odell and Goswami 1985; Faigley 1985). Workplace communication distinguishes itself from "academic communication" by:

- Being diverse: Workplace communication draws on overlapping communities of practice.(Faigley 1985).
- Having different stakes: Grades are the primary concern in the academy, while workplace communication can have far reaching legal and professional consequences (Leydens 2008; Shrivastava 2004).
- Having differing foci: Students need to demonstrate learning in their academic writing, while workplace communication serves varied organisational ends (Paradis et al 1985).
- Targeting varying audiences: Workplace communication targets a wide array of audiences, often complex and sometimes unknown, for which the engineer has to assume different writing personae and invent internal representations of the audience (Paradis et al. 1985). Typically, the student's writing persona is singular – they inhabit the role of student, and the audience is well-defined – faculty who assigned the task.

Workplace communication is not synonymous with 'professional communication'. Faber (2002), explained that 'professional communicators' are occupational writers whose primary responsibility is writing, as distinct from 'professionals who write' as part of their occupation. The investigation was confined to studying communication in local industry, where that communication is part of the daily work performed by respondents.

Research into workplace communication practices experienced a groundswell in the late half of the 20th century — Odell and Goswami's (1985) anthology on non-academic writing being a landmark publication in this period. However, there are only a few empirical studies in this large body of work which focus on the engineering workplace and even fewer depended on self-reports from engineers to describe their routine communication practices, as is the case with the present study.

In a survey of 243 Electrical Engineers in the United States, Vest et al (1996) found that engineers regard strong communication skills as critical to both the hiring and the promotion processes. They found that practising Electrical Engineers, regardless of their position within the organisation, spend most of their workdays communicating — 55% of their work time. The authors did not distinguish between time spent writing and speaking. Instead, they accounted for time spent communicating by examining who engineers communicated with — 58% with colleagues working on the same project; 20% with colleagues elsewhere in the organisation; and 22% with external parties.

Kreth (2000) surveyed 162 new graduates from a single, mid-western American university about their co-operative writing experiences. Co-operatives or internships allow students to apprentice for credit toward their degree. Co-operatives therefore provide authentic workplace experience within a programme of study. Although Kreth (2000) claims to have examined both graduates' experience of co-operative writing and their experience as full-time engineers, she only presented data about their co-operative writing experience. This data may have helped explain some of the workplace experiences of this study's respondents, since the respondents may be in the local equivalent of an apprenticeship — graduate-in-training (GITs) programmes. However, this investigation did not differentiate between alumni in GIT programmes from those in tenured engineering positions, because the interest lay in the workplace communication practices of new hires, regardless of their posts.

Sageev and Romanowski (2001) polled 208 graduates from a single university practising in the fields of Mechanical, Industrial, Chemical, and Computer and Electrical Engineering. The authors examined the relationship between the number of technical communication credits taken while at university and the impact on the engineer's career. They found that the "amount of instruction graduates received correlates with the career benefits they gained". Also, Sageev and Romanowski (2001) decomposed time spent on various communication tasks — 32% of the workday on writing; 10% on formal oral presentations and 22% on discussions (including informal, interpersonal communication). In total, the authors concluded that their graduates spent two-thirds of their workday communicating.

The findings from Vest et al (1996) and Sageev and Romanowski (2001)—largely accounts of time spent communicating and the importance of strong communication skills to job performance — were, where appropriate, compared to the data presented in this paper.

3. Method

This research examined the general communication demands made of recent Electrical and Computer Engineering graduates in local industry. Quantitative data were collected by means of a questionnaire. Alumni of the Department of Electrical and Computer Engineering, UWI (DECE), who are employed in local industry, were polled. They were drawn from the three graduating cohorts—2010/2011; 2011/2012; 2012/2013.

The questionnaire was piloted using a test-retest method. The questionnaire was administered twice to five graduates from a cohort other than those investigated, with a one month elapse between administrations. The coefficient of stability was found to be 0.71, which is acceptable according to Frey, Botan and Kreps (2010).

The questionnaire was distributed electronically to all 155 graduates for the 2010/2011; 2011/2012 and 2012/2013 cohorts. The questionnaire was mailed twice, with a three week interval between mailings and posted twice in a closed Facebook group for the DECE.

Seventy-nine (79) graduates completed the survey. Of those completing the questionnaire, seven were unemployed; five were in fields outside of engineering; and nine were working abroad. Therefore, 58 responses (n=58) were usable. The overall usable response rate was 43%.

Since the research investigated new graduates of the DECE there are no claims to generalisability to the larger local population of practising engineers or even practising Electrical and Computer engineers: rather, the paper offers a modest description of the communication demands made of new, Electrical and Computer Engineering graduates of the DECE, by local industry.

4. The Respondents

To every one female respondent there were two males. This is not in keeping with graduation trends of a 3 male: 1 female ratio (see Table 1). This could be as a result of over-representation of women in the sample — that is, comparably more women than men responded. The bulk of the sample — 90%, has been employed three years or less, indicating relative newness to the workplace (see Table 2).

Table 1. Respondents by Sex

	2010/2011	2011/2012	2012/2013
Graduating Cohorts	Male: 40 Female: 13 Male to Female Ratio: 3:1	Male: 31 Female: 7 Male to Female Ratio: 4.1	Male: 48 Female: 16 Male to Female Ratio: 3:1
Respondents	Male: 41 Female: 17 Male to Female Ratio: 2:1		

Table 2. Years of Work Experience

	Male		Female		Total (n=58)	
	count	%	count	%	count	%
Less than 1 year	18	31%	12	21%	30	52%
1 to 3 years	19	33%	3	5%	22	38%
More than 3 years	4	7%	2	3%	6	10%
Total	41	71%	17	29%	58	100%

New engineers working in the fields of control systems and energy systems made up more than half the sample or 55% (See Table 3). Included in the 'other' category were jobs in Acoustics and Standards Development, demonstrating that some graduates gain employment outside mainstream Electrical and Computer Engineering fields.

To determine the areas of specialisation in which graduates were working, respondents were allowed multiple-mode responses. Therefore respondents were allowed to indicate as many of the thematic areas in which they practiced. Thus, while there were 58 respondents, the number of responses for this item was 97.

Notably, 56% of the alumni worked in two or more thematic areas (see Table 4). Thus, the workplace is demanding fairly broad disciplinary competence from the novice. Of the 33 persons who worked in more than one thematic area, the most common pairing was Controls and Energy systems engineering —19 alumni.

Not surprisingly the single largest employer of new engineers is the oil and gas sector (see Figure 1). One encouraging sign, at least by way of suggesting diversity in engineering enterprise, is that a few new engineers were employed in software development and in

entrepreneurial pursuits. Taken together they account for 7% of the sample.

Table 3. Respondents by Thematic Area

	Total (n=97)	
	count	**%**
Communication Systems	15	15%
Control Systems	31	32%
Energy Systems	22	23%
Computer Systems	13	13%
Electronics	8	8%
Other	7	8%

Table 4. Respondents Practising in Several Thematic Areas

	Total (n=58)		
	count	%	
Practising in 1 thematic area	25	43%	
Practising in 2 thematic areas	28	48%	33 or 56% novices practising in more than one thematic area
Practising in 3 thematic areas	2	3%	
Practising in 4 or more thematic areas	3	5%	

5. Communicating in Local Industry

Most novice engineers, 48%, spent 21 – 40% percent of their workday writing (see Table 5), where the workday is eight-ten hours on average. This is comparable to Sageev and Romanowski's (2001) finding that their alumni spent 32% of their day on written communication. Writing time in this study was defined as time spent on official communication artefacts—reports, correspondence, or any item needed by or generated by the organisation's business process. At the minimum, therefore, novice engineers can expect that they may have to write upward of two hours per day.

Table 5. Time spent on Written Communication

% Time Spent writing per day	Number of respondents	% of Sample
Less than 20%	9	16%
21- 40%	28	48%
41-60%	13	22%
Greater than 60%	8	14%

Novices who claimed to write for more than 60% of their day, or more than five hours per day, may be over-estimating. However, when considered with a description of daily work tasks, some new engineers are given demanding, time-consuming writing tasks (see Table 6).

Of those polled, half communicated orally for 41%-60% of their working day and an additional 33% spent more than 60% of their day speaking to others (see Table 7). Oral communication activities were taken to include participating in team meetings and delivering oral presentations, but did not include time spent on informal, and or unplanned discussions. This is higher than Sangeev and Romanowski's (2001) finding that new engineers spent less than 32% of their day communicating orally — a figure which included informal oral communication. That local engineers are spending more time in formal, oral communication situations, may be explained by the ubiquity of

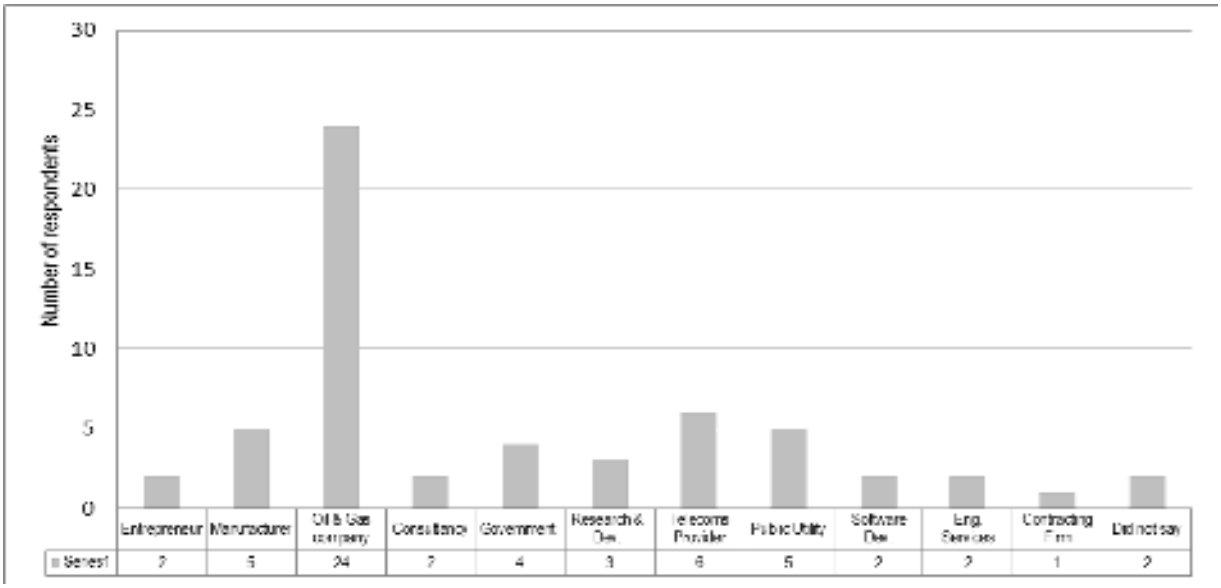

Figure 1. Novice Engineer by Employer Type

Table 6. Novices with Significant Writing Tasks

	Writing tasks (***bold italics***)
Respondent 1 Employed 1-3 years	I'm the only (key post with specialised skills) at (Company name redacted) and my primary responsibility is to administer (critical company installations). These (critical company installations) provide access to (key ICT resources in named Caribbean Territories) and they are used to change configurations, monitor performance and perform troubleshooting. I am also responsible for ensuring the (key company installations) meet a certain quality by doing ***detailed trends analysis, and forecasting.***
Respondent 2 Employed 1-3 years	My job entails engineering and to some extent executing various projects assigned to me. These projects are new changes to the plant requested by various plant personnel. I work directly under another Electrical Engineer, who reviews my engineering reports, etc. I also work along with him on his projects. Aside from these projects, I am also involved in the ***reviewing and revising of our CAPEX [capital expenditure] list of projects as well as aiding with generation of work orders, etc. in our Computerized Maintenance Management System.***
Respondent 3 Employed 1-3 years	Job functions include ***documentation of the software systems*** being designed. My documentation and ***reports also support and determine business activities and guide decisions of upper management***.

engineering teams supplanting the stand-alone engineer. Indeed, Sangeev and Romanowski's (2001) work was published over a decade ago: The engineering workplace has become incredibly complex (power systems using wireless telecommunication systems and advanced control systems for example) and globalisation of the physical workplace has given way to virtual workplaces with teaming on a transnational scale (Nair et al 2009; Spinks et al 2006).

Table 7. Time spent on Oral Communication

% Time Spent Oral Communication per day	Number of respondents	% of Sample
Less than 20%	2	3%
21- 40%	8	14%
41-60%	29	50%
Greater than 60%	19	33%

Table 8 presents data on time spent on communication in relation to the number of thematic areas in which respondents practiced. It is likely that the more areas of knowledge and practice drawn upon, the more complex the communication task and therefore the more time required for completing such tasks. The data does tentatively suggest that this may be the case: generally wider disciplinary practice involved more time on writing, with those practising in more than four thematic areas writing for in excess of 60% of their workday. However, this finding needs probing as many other factors affect time spent on writing — job duties; workplace dynamics; business practices, to name a few.

New graduates practising in just one thematic area communicated orally just as much as those practising in several areas, testifying perhaps once again to the critical role that engineering teams have in the workplace. Thus, regardless of the knowledge and technical skill-sets being drawn upon, a large part of 'engineering work' is accomplished via oral communication.

Novice engineers produced, on their own or through collaboration, a range of technical documents from technical reports to technical manuals: The most common was the technical report, followed by the technical presentation (see Table 9). In this multi-mode item where respondents could have indicated all the responses that applied — technical reports, technical presentations, field reports, technical proposals, and technical manuals — respondents did not list any other writing genres, though the option to do so was provided.

Table 8. Number of Thematic Areas and Time Spent on Communication

	Time spent on writing			Time spent on oral communication		
			Mode			Mode
Practising in 1 thematic area 43 % of Respondents	<20%	5	21-40%	<20%	2	>60%
	21-40%	13		21-40%	4	
	41-60%	6		41-60%	9	
	>60%	1		>60%	10	
Practising in 2 thematic areas 48 % of Respondents	<20%	4	21-40%	<20%	0	41-60%
	21-40%	14		21-40%	4	
	41-60%	7		41-60%	17	
	>60%	3		>60%	7	
Practising in 3 thematic areas 3 % of Respondents	<20%	0	21-40% and >60%	<20%	0	41-60% and >60%
	21-40%	1		21-40%	0	
	41-60%	0		41-60%	1	
	>60%	1		>60%	1	
Practising in 4 or more thematic areas 5 % of Respondents	<20%	0	>60%	<20%	0	41-60%
	21-40%	0		21-40%	0	
	41-60%	0		41-60%	2	
	>60%	3		>60%	1	

Table 9. Most Common Technical Documents

Document Type		Most common to least common →					
	Rank	5	4	3	2	1	Mode
Technical Reports	Count	21	19	18	0	0	5
	% of Sample	36%	33%	31%	0%	0.0%	
Technical Presentations	Count	18	19	7	6	6	4
	% of Sample	31%	33%	12%	10%	10%	
Field Reports	Count	13	6	18	6	15	3
	% of Sample	22%	10%	31%	10%	26%	
Technical Proposals	Count	4	13	12	17	12	2
	% of Sample	7%	22%	21%	29%	21%	
Technical Manuals	Count	2	1	15	18	22	1
	% of Sample	3%	2%	26%	31%	38%	

This finding needs to be treated with scepticism, as other responses indicated that new engineers prepare written artefacts other than those explicitly listed in the questionnaire. Indeed, the self-reports appearing verbatim in Table 6 point to an even wider writing repertoire — capital expenditure reports, work orders, and trend analyses — than respondents claimed for themselves.

The majority of novices received support in their workplace communication (see Figure 2). The most frequently used support is from peers — 67%. And, 40% of respondents received additional training in workplace communication. Of note is the employ of technical writers. Though few in number, as only five respondents indicated that they received this type of assistance, the hiring of technical writers may be indicative of new skill-sets being required by local industry: Hitherto there was no evidence that there is a local market for technical communicators. Table 10 indicates how these technical writers were distributed by employer type.

When asked about the relationship between communication ability and career advancement, new engineers felt that the ability to write, speak and collaborate well is essential to promotion (see Table 11).

Table 10: Workplace with Technical Writers

Employer Type	Number of Workplaces with Technical Writing Personnel
Oil and Gas	2
Public Utility	1
Software Development	1
Research and Development	1

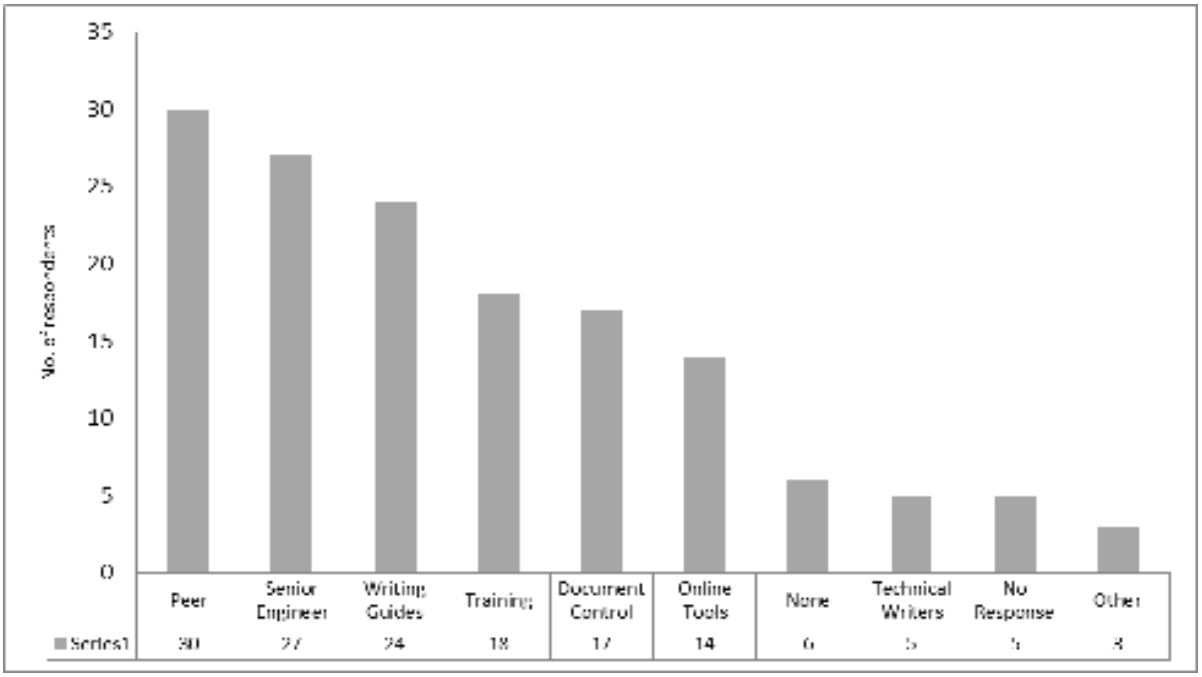

Figure 2. Workplace Support available to the Novice

Table 11. Communication and Career Advancement

Communication Skill	Likert Scale	Critical	Important	Neutral	Somewhat unimportant	Unimportant	mode
Ability to write	Count	34	18	5	1	0	Critical
	% of Sample	59%	31%	9%	2%	0%	
Ability to speak	Count	36	19	0	3	0	Critical
	% of Sample	62%	33%	0%	5%	0%	
Ability to team	Count	37	15	5	1	0	Critical
	% of Sample	64%	26%	9%	2%	0%	

Each skill received a modal ranking of 'critical'. A similar conclusion was drawn by Vest et al. (1996). They report that in the recruitment process, proficiency in technical writing and interpersonal skills are deemed the most valuable: While, all communication skills, and in particular strong presentation skills, are needed for promotion.

6. Discussion

For the new engineer, industry demands broad disciplinary competence, often favouring specialisation in more than one Electrical and Computer Engineering thematic area. This is paired with the need for strong communication skills. The majority of respondents reported that these skills are essential to their daily work and career advancement.

In keeping with trends elsewhere, local novices spend their workday in large part writing and speaking: 50% claimed to spend 41-60% communicating orally, while 48% spent 21-40 % of the day writing. Nominally, engineering graduates entering local industry can expect that five hours of an eight-ten hour workday will be spent communicating.

Novice engineers are expected to have a wide writing repertoire. Other than the technical report and technical presentation, some new engineers were expected to write, on their own or in collaboration with others, field reports, manuals, job orders, and proposals. In these tasks, engineers were supported by their companies through a slew of resources — training, writing guides, and reviews by senior engineers: Novices made overwhelming use of peer support. However, though few in number, some new engineers found themselves without writing support and had to rely on the training received in their degree programme.

7. Conclusion

If local, new hires spend over half of their workday communicating, then there is need to vigorously debunk the idea that engineers do not write nor do they need to write well — the vast body of work which predates this research and the current investigation demonstrate the groundlessness of this belief. Anecdotal evidence testifies to the widely-held, contrived dichotomy between the sciences and the humanities; invariably engineering students believe that "maths" and "language" are two unrelated disciplines and that pursuit of a math-based discipline is the surest escape from writing. It can be argued that for the entry-level engineer the biggest impediment to getting the job done and done well is their uninformed belief that they will not be required to write and speak formally and they therefore are not mentally prepared for these tasks.

If over half of the workday is absorbed by communication tasks, then employers are expending a large part of salaries for the communication artefacts needed for and generated by their business process. The stake that employers have in the communication preparedness of local graduates cannot be gainsaid in this regard. Indeed technical competence is enacted through communication: where communication is weak, the technical soundness is likely questioned or lost to its audience and becomes purposeless.

If local engineering programmes are to meet the needs of the job market then they must have curriculum provisions which substantially treat with communication skills. What specific communication-intensive interventions are needed is beyond the scope of this paper. However, this study does demonstrate that communication curricula need to prepare graduates for writing, with and without support, a range of 'mainstream' artefacts — correspondence, reports, technical reports, and proposals. Also, communication instruction is needed to prepare graduates to meet the rhetorical demands of writing scenarios that lie outside common genres — capital expenditure reports and trend analyses. While it is impossible to anticipate all the genres and emerging genres graduates will have to produce, a strong focus on developing rhetorical awareness will serve graduates well in unique communication situations (Leydens 2008).

Though few in number, some new engineers work in non-traditional enterprise — a trend which should be encouraged, as we seek to diversify our local economies. As more engineers find themselves in start-ups and entrepreneurial enterprise where organisational structures are fluid; resources are thin; and communication is even unpredictable; there is need to consider how communication curricula are meeting these needs.

Like Sageev and Romanowski (2001) and Vest et al (1996), this study treated communication practices as if they were objective fact, which can be described and understood in quantitative terms. This approach was

practical in this instance, as the study sought to describe in simple terms the day-to-day communication demands that are made of entry-level engineers. There is nonetheless a need for mixed-methodology and ethnographic investigations to derive a more nuanced understanding of communication practices in local engineering workplaces. Of immediate interest would be studies that examine:

1) What communication practices are common across a wider array of engineering workplaces — ones which hire civil engineers; mechanical and so on. Also, it would be useful to examine how specialisations and industry type may be making unique communication demands of new engineers. Communication in the field of Electrical and Computer Engineering has in this paper been treated as a monolithic whole. A more exhaustive examination of communication practices in local industry can inform curricula as there may very well be need for differentiation of instruction to meet the varying workplace demands. And since undergraduate programmes cannot cater to the every need of industry, such research may reveal where universities can provide ongoing training for practising engineers.

2) How well engineering graduates are faring in the world of work. There is need to evaluate the extent to which undergraduate programmes have prepared graduates for communicating in the workplace – whether that job is in a more traditional setting, like the oil and gas industry, or emerging enterprise; or whether the graduate is working locally or abroad. This data can inform curriculum reviews and provisioning.

Finally, this study depended entirely on self-reporting, like the studies by Sageev and Romanowski (2001) and Vest et al. (1996). It would have been useful to have external auditors, in this instance senior engineers or employers, comment on the data sets presented. Such auditors could verify the novices' accounts of their communication tasks and add clarifying details. In this regard, there is need not just to engage new hires but all levels of the organisational hierarchy to better understand the communication contexts in industry; to assess the preparedness of locally trained engineers; and to identify skills gaps.

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As a guide, technical/research papers should be between 3,000 and 6,000 words in **length.** Shorter articles (Communications, Discussions, Book Reviews, etc.) should be between 500 and 2,000 words. Please provide the word count on the first page of your paper. A **title** of not more than eight words should be provided. A brief **autobiographical note** should be supplied including full name, affiliation, e-mail address and full international contact details.

Authors must supply a **structured abstract**. Maximum is 250 words in total. In addition provide up to six **keywords** which encapsulate the principal topics of the paper and categorise your paper. **Headings** must be short, and clearly defined. **Notes or Endnotes** should be used only if absolutely necessary and must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.

All **Figures** (charts, diagrams and line drawings) and **Plates** (photographic images) should be submitted in both electronic form and hard copy originals. Figures should be of clear quality, in black and white and numbered consecutively with Arabic numerals.

Figures created in MS Word, MS PowerPoint, MS Excel, Illustrator and Freehand should be saved in their native formats.

Electronic figures created in other applications should be copied from the origination software and pasted into a blank MS Word document or saved and imported into an MS Word document by choosing "Insert" from the menu bar, "Picture" from the drop-down menu and selecting "From File..." to select the graphic to be imported.

For figures which cannot be supplied in MS Word, acceptable standard image formats are: pdf, ai, wmf and eps. If you are unable to supply graphics in these formats then please ensure they are tif, jpeg, or bmp at a resolution of at least 300dpi and at least 10cm wide.

To prepare screen shots, simultaneously press the "Alt" and "Print screen" keys on the keyboard, open a blank Microsoft Word document and simultaneously press "Ctrl" and "V" to paste the image. (Capture all the contents/windows on the computer screen to paste into MS Word, by simultaneously pressing "Ctrl" and "Print screen".)

For photographic images (plates) good quality original photographs should be submitted. If supplied electronically they should be saved as tif or jpeg files at a resolution of at least 300dpi and at least 10cm wide. Digital camera settings should be set at the highest resolution/quality possible.

In the text of the paper the preferred position of all tables, figures and plates should be indicated by typing on a separate line the words "Take in Figure (No.)" or "Take in Plate (No.)". Tables should be typed and included as part of the manuscript. They should not be submitted as graphic elements. Supply succinct and clear captions for all tables, figures and plates. Ensure that tables and figures are complete with necessary superscripts shown, both next to the relevant items and with the corresponding explanations or levels of significance shown as footnotes in the tables and figures.

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